Front. Agr. Sci. Eng. 2022, 9(1): 161–166 https://doi.org/10.15302/J-FASE-2021426

PERSPECTIVE

SUSTAINABLE PLANT PEST MANAGEMENT THROUGH OPTIMIZATION AND MINIMIZATION

Jingyuan XIA, Alexandre LATCHININSKY (✉), Buyung HADI, Maged ELKAHKY

Plant Production and Protection Division (NSP), Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy.

ABSTRACT

Plant pests and diseases have significant negative impacts on global food security, world trade and rural livelihoods. Climate change exacerbates these impacts in certain parts of the world. Overreliance on pesticides as the primary tool for plant pest management leads to problems such as pesticide resistance and pest resurgence. Environmental and food safety concerns are also associated with overuse of pesticides in crop production. There is clearly a need for a shift in pest management strategies and practices globally. Optimization of structures and functions in crop production agroecosystems through soil conservation practices and cropping diversification can improve pest regulation services provided in the systems. Prioritization of safer alternatives and practices in the IPM pyramid, such as resistant varieties and biopesticides, helps minimize the use of potentially risky agricultural inputs such as synthetic pesticides. Investment is needed to boost the development of innovative green technologies and practices. Production, distribution, use and regulatory capacities need to be strengthened to facilitate large-scale adoption of green technologies and practices. Finally, policy, financial and market instruments should be wielded to provide an enabling environment for the transformation to sustainable plant pest and disease management strategies and practices worldwide.

Received August 25, 2021.

Correspondence: alexandre.latchininsky@fao.org

1 GLOBAL STATUS OF PLANT PESTS

There are about 10,000 species of plant pests and diseases that significantly affect crop yield and threaten food security. Yield loss due to pest and disease epidemics are estimated to be between 30% and 40% annually, costing the global economy about 290 billion USD[1].

Plant pests and diseases cause enormous impacts not only on plant production but also on the livelihoods of people. In 2004, the desert locust (*Schistocerca gregaria*) swarms destroyed over 80% of crops in Burkina Faso, the Republic of Mali, and the Islamic Republic of Mauritania, endangering livelihoods of a rural population of over eight million[2]. Since 2016, fall armyworm (*Spodoptera frugiperda*) has been spreading beyond its native American boundaries, and is now present in over 70 countries in Africa, the Near East, Asia, and the Pacific, resulting in annual yield losses in Africa alone of 11% to 26% (about 9.4 billion USD)[3].

The most infamous example of the high impact disease epidemics is the potato late blight (*Phytophthora infestans*) which triggered famine and large-scale human migration in the mid-nineteenth century in Ireland. Since the 1990s, Banana Fusarium wilt caused by *Fusarium oxysporum* f. sp. *cubense* tropical race 4 has occurred in Africa, Near East, and Asia, and recently in South America. A recent projection concluded that 17% of current banana growing area with an annual production of 36 Mt worth about 10 billion USD at current prices could be lost over the next 20 years due to this devastating disease[4]. Since 2013, olive quick decline syndrome caused by the bacterium, *Xylella fastidiosa*, has spread to more than 715 kha and, by 2017, had severely damaged 6.5 million olive trees in southern Italy, which led to an economic loss of over 1.5 billion USD[5].

2 GLOBAL CHALLENGES IN PLANT PEST MANAGEMENT

Plant pest management has a key role in ensuring food security and nutrition, promoting food quality and safety, protecting the environment and biodiversity, and facilitating safe trade and economic growth. During the recent desert locust upsurge in the greater Horn of Africa and Yemen, about 2.2 Mha were treated with pesticides between March 2020 and July 2021, resulting in a saving 4.3 Mt of cereals which is enough to feed 28.8 million people and saved 1.3 billion USD of income, in addition to saving the livelihood of two million households of pastoralists[6]. Calculations show that despite their seemingly high costs, successful pest control programs have a cost-benefit ratio varying between 18:1 and 29:1[7]. However, we are, currently, facing serious challenges in sustainable plant pest management.

Climate change. The global expansion of pest and disease geographic distribution has been greatly facilitated by climate change[8] through an increase in pest population sizes and metabolic rates[9] as well as the number of generations per season[10]. This has resulted in increased risks of new pest and disease introductions across geographic borders and higher annual production loss worldwide. Crop losses from pests due to climate change vary by latitude and are higher in temperate regions due to larger increases in both insect population sizes and metabolic rates than in the tropics[11]. A recent high-level review by the International Plant Protection Convention Secretariat[12] calls for international cooperation and development of harmonized plant protection strategies to help countries successfully adapt their pest risk management measures to climate change.

Environmental pollution and associated problems. Sánchez-Bayo et al.[13] estimated that 64% of global agricultural land is at risk of pesticide pollution by more than one active ingredient, posing serious risks for soil and water biodiversity connected with the land. The overwhelming majority of global biodiversity is insects with up to 1% of the one million described species being pests. Environmental pollution by agricultural chemicals, such as pesticides and fertilizers, are one of the major drivers for the decline of insect fauna worldwide, including pollinators, natural enemies and decomposers[14]. Agricultural pesticide is similarly associated with the decline of other non-target species, such as farmland and grassland birds[15,16]. Use of certain compounds such as metals and antibiotics in crop production have also contributed to the rise of antimicrobial resistance worldwide[16].

Three R problems. As the primary tool for pest management, the global use of pesticides has risen to over 4 $\text{Mt}\cdot\text{yr}^{-1}$[17], forcing us to recall the perils highlighted in Rachel Carson's book, *Silent Spring*[18]. Inappropriate use of pesticides has caused severe negative impacts on sustainable pest management through pesticide resistance, pesticide residues, and pest resurgence (the three R problems).

Since 1910, there was a steady increase in documented insecticide resistance in pests with 7747 accumulative cases by 2010[19] and over 10,000 accumulative cases by 2020[20]. A similar increase has been reported for the number of arthropod species with resistance against at least one insecticidal compound with 553 species reported by 2010[19]. As climate change is predicted to increase the number of arthropod generations per season, this increased voltinism will contribute to pesticide resistance problems in the future.

Contamination of pesticide residue was ranked as one of the top food safety concerns in fresh-food chain together with bacterial pathogens, foodborne viruses and mycotoxins[21]. Indeed, consumption of fresh agricultural produce may form the main route for chronic exposure to pesticides[22]. Pesticide residues in an agricultural commodity may also form a significant trade barrier.

Pest resurgence is another phenomenon associated with the overuse of pesticide. There are two types of pest resurgence, primary and secondary. Primary pest resurgence occurs when "the target arthropod pest population responds to insecticide or acaricide treatment by increasing to a level at least as high or higher than in an untreated control or higher than the level observed before the treatment"[23], such as planthoppers in rice[24], and two-spotted spider mite in various horticultural crops[25,26]. Secondary pest resurgence occurs when a "non-target and injurious pest populations increases in a crop after it is treated with a pesticide to control a primary pest population"[23], such as apple leafhopper in apple[27]. Destruction of natural enemy populations, reduction of competition by other herbivorous arthropods, hormesis and alteration of host plant quality have been documented as possible mechanisms for primary and secondary pest resurgence[23,28].

3 NEED FOR A CHANGE OF PLANT PEST MANAGEMENT STRATEGIES

Plant pest management directly and indirectly contributes to achieving the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda, in particularly food security and nutrition (SDG 2), environment and biodiversity protection (SDG 13 and SDG 15), and safe trade and economic growth (SDG 8 and SDG 17). To fulfill this crucial mission while coping with the increased challenges, a sustainable plant pest management approach should be adopted with two main strategies, optimization and minimization.

Optimization of structures, functions and services of crop production agroecosystems. Like other types of ecosystems, agroecosystems have their inherent structures and functions. There is a plethora of agroecosystem structures and functions across the globe, ranging from large-scale annual crop monocultures to arid-land pastoral systems and species-rich home gardens. Each of these agroecosystems delivers various levels of services that benefit human welfare, such as food, feed and fiber provision, biodiversity conservation, pest control, and carbon sequestration, as well as disservices, such as loss of wildlife habitat, pesticide poisoning and greenhouse gas emission. Both farm and landscape-level management practices affect the structure and function of a given agroecosystem and eventually determine the level of services and disservices associated with the system[29].

As natural pest regulation is one of the ecosystem services inherent in all agroecosystems, farm and landscape-level practices that optimize this service should be identified to have positive impacts on crop yield, farm income and natural enemies, but negative impacts on plant pests and diseases. Practices such as crop rotation or vegetative diversification of field periphery have been shown to conserve and increase the functionality of natural enemies and thus improve natural pest regulations in various cropping systems[1,30]. Soil conservation practices, such as mulching, no-till and organic amendment, have also been shown to limit pest populations by generally improving plant vigor and conserving natural enemies[31]. The effect of these practices varies with agroecosystems, therefore careful studies are needed to tailor the practices that optimize the ecosystem services in a given agroecosystem[32].

Minimization of crop damage, biodiversity loss and pesticide risk. Minimization of these three key components can be effectively achieved only by adopting an integrated pest management (IPM) as the operational framework of sustainable plant protection into the future (Fig. 1). This IPM framework carefully considers all available pest control techniques before subsequently integrating appropriate measures that discourage the development of pest populations. It combines biological, chemical, physical and crop-specific (cultural) management practices to grow healthy crops and minimize the use of pesticides, thus reducing risks posed by pesticides to human health and the environment.

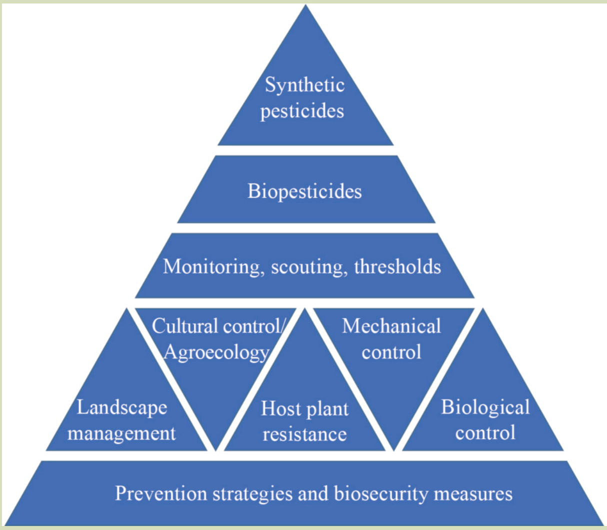

Fig. 1 Integrated Pest Management Framework (modified from Naranjo[33], with permission from Springer Nature).

The IPM framework prioritizes prevention strategies as well as the use of resistant cultivars, cultural control and landscape management before moving on to the use of biopesticides and, as the very last resort, synthetic pesticides. Among those, priority should be given to lower-toxicity options, such as, for example, insect growth regulators. Also, biopesticides can be effective when pests evolve resistance to older, widely-used synthetic pesticides[34]. Careful monitoring, field scouting and the application of scientifically derived economic thresholds must guide the use of pesticides. Additionally, and more importantly, the application of pesticides must take into account environmental and human health considerations.

4 GREEN INNOVATION FOR SUSTAINABLE PLANT PEST MANAGEMENT

Sustainable agriculture calls for sustainable plant pest management, which can be effectively achieved through the green plant protection. The green innovation is the basis for green plant protection through optimization and minimization. The underlying principle for green plant protection is to be less dependent on synthetic pesticides and fertilizers but use more the innate ability of crop plants to resist pests, harsh climates and high salinity. A healthy soil-water-plant ecology should be prompted to improve both productivity and harmony between agriculture and the increasing world population[34]. Thus, management of plant pests should undergo a paradigm shift from reliance on synthetic pesticides to a sustainable and preventive strategy based on optimization and minimization. Such a shift can be ensured only through the following:

(1) Innovation for green technologies

- **Establishing** green agricultural product-based cropping systems, such as green production system for major agricultural crops (e.g., maize, potato and rice), and special agricultural crops (e.g., fiber, fruit and vegetables).

- **Developing** green technical-based pest control systems, such as green technical system for control of brown plant hoppers in rice, fall armyworm in maize, and Colorado potato beetle in potato.

- **Setting up** green agricultural input-based pest control systems, such as *Trichogramma* control of corn borer throughout the corn-growing season, sex pheromone control of cabbage caterpillars throughout the cabbage-growing season and light trapping control of stem borer throughout the rice-growing season.

- **Promoting** adoption and implementation of most advanced technologies for green plant protection, such as modern biotechnology and new material technology, for example, RNA-based active ingredients aim to achieve selectivity and sustainability in future crop protection agents[35], nanotechnology ensures targeted pesticide release[36], and the use of drones to facilitate locust monitoring and control[37].

(2) Green innovation for dissemination and capacity strengthening

- **Strengthening** farmer field schools as a participatory approach to improve farmer capacity to understand agroecosystems dynamics and to attract and maintain natural enemies on their farms and produce their own biopesticides and botanicals[38].

- **Establishing** green-technology transformation platform through digital extension to organize a series of activities for integration, demonstration, validation and dissemination of green protection technologies to the field, and also showcase green protection technologies through extension conferences, field days and exhibitions[39].

- **Adopting** modern information and digital technology to enhance dissemination and extension of green protection technologies, for example, remote sensing combined with precision agriculture facilitate detection and management of crop diseases[40];

- **Exploring** transformation mechanism to promote green plant protection, such as farmers plus farmer association, and farmers plus farmer association plus multi-stakeholders (agricultural research and education and agribusiness)[41].

(3) Green innovation for institutional interventions

- **Strengthening** relevant policies through improving pesticide regulatory systems[42], in particular to facilitate biocontrol registration and quality control[43].

- **Improving** commercial availability of biopesticides at low cost by developing local biocontrol industry (financial and technical capacity)[44].

- **Scaling up** sustainable pesticide management through voluntary sustainability standards to offer more remunerative prices or beneficial market conditions, reward the exclusion of the most hazardous pesticides and help share the risk (or perceived risk) of adoption with consumers[45].

- **Providing** access to financial instruments (e.g., loans/credits, direct subsidies to farmers, and insurance) to help farmers overcome the first hurdles to adopt green protection technologies (e.g., UNCTAD[46]).

- **Promoting** institutional, national, regional international cooperation by establishing relevant mechanisms for information sharing, data collection, early warning, capacity building and development of strategic/contingency plans for sustainable plant protection[47].

REFERENCES

1. Food and Agriculture Organization of the United Nations (FAO). Save and Grow. A policymaker's guide to the sustainable intensification of smallholder crop production. Rome: *FAO*, 2011
2. Brader L, Djibo H, Faye F G, Ghaout S, Lazar M, Luzietoso P M, Ould Babah M A. Towards a more effective response to desert locusts and their impacts on food security, livelihoods and poverty. Multilateral evaluation of the 2003–2005 Desert Locust campaign. Rome: *FAO*, 2006
3. Eschen R, Beale T, Bonnin J M, Constantine K L, Duah S, Finch E A, Makale F, Nunda W, Ogunmodede A, Pratt C F, Thompson E, Williams F, Witt A, Taylor B. Towards estimating the economic cost of invasive alien species to African crop and livestock production. *CABI Agriculture and Bioscience*, 2021, **2**(1): 18
4. Scheerer L, Pemsl D E, Dita M, Perez Vicente L, Staver C. A quantified approach to projecting losses caused by *Fusarium wil*t tropical race 4. *Acta Horticulturae*, 2018, **1196**(1196): 211–218
5. Schneider K, van der Werf W, Cendoya M, Mourits M, Navas-Cortés J A, Vicent A, Oude Lansink A. Impact of *Xylella fastidiosa* subspecies *pauca* in European olives. *Proceedings of the National Academy of Sciences of the United States of America*, 2020, **117**(17): 9250–9259
6. Food and Agriculture Organization of the United Nations (FAO). Desert Locust upsurge. Mitigating the worst case scenario through anticipatory action. Discussion paper (unpublished). Rome: *FAO*, 2020, 9
7. Zhang L, Lecoq M, Latchininsky A, Hunter D. Locust and grasshopper management. *Annual Review of Entomology*, 2019, **64**(1): 15–34
8. Bebber D P, Ramotowski M A T, Gurr S J. Crop pests and pathogens move polewards in a warming world. *Nature Climate Change*, 2013, **3**(11): 985–988
9. Deutsch C A, Tewksbury J J, Tigchelaar M, Battisti D S, Merrill S C, Huey R B, Naylor R L. Increase in crop losses to insect pests in a warming climate. *Science*, 2018, **361**(6405): 916–919
10. Ziter C, Robinson E A, Newman J A. Climate change and voltinism in Californian insect pest species: sensitivity to location, scenario and climate model choice. *Global Change Biology*, 2012, **18**(9): 2771–2780
11. International Plant Protection Convention (IPPC) Secretariat. Scientific review of the impact of climate change on plant pests—a global challenge to prevent and mitigate plant pest risks in agriculture, forestry and ecosystems. Rome: *FAO on behalf of the IPPC Secretariat*, 2021
12. Tang F H M, Lenzen M, McBratney A, Maggi F. Risk of pesticide pollution at the global scale. *Nature Geoscience*, 2021, **14**(4): 206–210
13. Sánchez-Bayo F, Wyckhuys K A G. Worldwide decline of the entomofauna: a review of its drivers. *Biological Conservation*, 2019, **232**: 8–27
14. Stanton R L, Morrissey C A, Clark R G. Analysis of trends and agricultural drivers of farmland bird declines in North America: a review. *Agriculture, Ecosystems & Environment*, 2018, **254**: 244–254
15. Mullié W C. Don't kill your allies. The impact of chemical and biological locust and grasshopper control on birds. Dissertation for the Doctoral Degree. Wageningen: *Wageningen University & Research*, 2021, 170
16. Holmes A H, Moore L S, Sundsfjord A, Steinbakk M, Regmi S, Karkey A, Guerin P J, Piddock L J V. Understanding the mechanisms and drivers of antimicrobial resistance. *Lancet*, 2016, **387**(10014): 176–187
17. Food and Agriculture Organization of the United Nations (FAO). FAOSTAT statistical database. Rome: *FAO*, 2021. Available at FAO website on September 1, 2021
18. Carson R. Silent spring. Cambridge, USA: *Houghton Mifflin Company*, 1962
19. Gould F, Brown Z S, Kuzma J. Wicked evolution: can we address the sociobiological dilemma of pesticide resistance? *Science*, 2018, **360**(6390): 728–732
20. Sparks T C, Bryant R J. Crop protection compounds—trends and perspective. *Pest Management Science*, 2021, **77**(8): 3608–3616
21. Van Boxstael S, Habib I, Jacxsens L, de Vocht M, Baert L, van de Perre E, Rajkovic A, Lopez-Galvez F, Sampers I, Spanoghe P, de Meulenaer B, Uyttendaele M. Food safety issues in fresh produce: bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. *Food Control*, 2013, **32**(1): 190–197
22. Sandoval-Insausti H, Chiu Y H, Lee D H, Wang S, Hart J E, Mínguez-Alarcón L, Laden F, Ardisson Korat A V, Birmann B, Heather Eliassen A, Willett W C, Chavarro J E. Intake of fruits and vegetables by pesticide residue status in relation to cancer risk. *Environment International*, 2021, **156**: 106744
23. Dutcher J D. A review of resurgence and replacement causing pest outbreaks in IPM. In: Ciancio A, Mukerji K G, eds. General concepts in Integrated Pest and Disease Management. Berlin: *Springer*, 2007, 27–43
24. Wu J, Ge L, Liu F, Song Q, Stanley D. Pesticide-induced planthopper population resurgence in rice cropping systems. *Annual Review of Entomology*, 2020, **65**(1): 409–429
25. Patil C, Udikeri S S, Karabhantanal S S. A note on pesticide induced resurgence of two spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae) on grape. *Persian Journal of Acarology*, 2018, **7**(1): 75–84
26. Wang S Y, Qi Y F, Desneux N, Shi X Y, Biondi A, Gao X W. Sublethal and transgenerational effects of short-term and chronic exposures to the neonicotinoid nitenpyram on the cotton aphid *Aphis gossypii*. *Journal of Pest Science*, 2017, **90**(1): 389–396

27. Howitt A J. Common tree fruit pests. North Central Regional Extension Publication No. 63. East Lansing: *Michigan State University*, 1993, 252
28. Hardin M R, Benrey B, Coll M, Lamp W O, Roderick G K, Barbosa P. Arthropod pest resurgence: an overview of potential mechanisms. *Crop Protection*, 1995, **14**(1): 3–18
29. Heeb L, Jenner E, Cock M J W. Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science*, 2019, **92**(3): 951–969
30. He H M, Liu L N, Munir S, Bashir N H, Wang Y, Yang J, Li C Y. Crop diversity and pest management in sustainable agriculture. *Journal of Integrative Agriculture*, 2019, **18**(9): 1945–1952
31. Alyokhin A, Nault B, Brown B. Soil conservation practices for insect pest management in highly disturbed agroecosystems—a review. *Entomologia Experimentalis et Applicata*, 2020, **168**(1): 7–27
32. Ratnadass A, Fernandes P, Avelino J, Habib R. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. *Agronomy for Sustainable Development*, 2012, **32**(1): 273–303
33. Naranjo S E. Impacts of Bt transgenic cotton on integrated pest management. *Journal of Agricultural and Food Chemistry*, 2011, **59**(11): 5842–5851
34. Song B, Seiber J N, Duke S O, Li Q X. Green plant protection innovation: challenges and perspectives. *Engineering*, 2020, **6**(5): 483–484
35. Bramlett M, Plaetinck G, Maienfisch P. RNA-based biocontrols—a new paradigm in crop protection. *Engineering*, 2020, **6**(5): 522–527
36. Huang B, Chen F, Shen Y, Qian K, Wang Y, Sun C, Zhao X, Cui B, Gao F, Zeng Z, Cui H. Advances in targeted pesticides with environmentally responsive controlled release by nanotechnology. *Nanomaterials*, 2018, **8**(2): 102
37. Matthews G A. New Technology for Desert Locust Control. *Agronomy*, 2021, **11**(6): 1052
38. Food and Agriculture Organization of the United Nations (FAO). Farmers taking the lead—thirty years of Farmer Field Schools. Rome: *FAO*, 2019. Available at FAO website on September 1, 2021
39. Naika M B N, Kudari M, Devi M S, Sadhu D S, Sunagar S. Digital extension service: quick way to deliver agricultural information to the farmers. In: Galanakis C M, ed. Food Technology Disruptions. *Academic Press*, 2021: 285–323
40. Yang C. Remote sensing and precision agriculture technologies for crop disease detection and management with a practical application example. *Engineering*, 2020, **6**(5): 528–532
41. Organisation for Economic Co-operation and Development (OECD). Farm management practices to foster green growth. Paris: *OECD Publishing*, 2016
42. Lee R, den Uyl R, Runhaar H. Assessment of policy instruments for pesticide use reduction in Europe; learning from a systematic literature review. *Crop Protection*, 2019, **126**: 104929
43. Handford C E, Elliott C T, Campbell K. A review of the global pesticide legislation and the scale of challenge in reaching the global harmonization of food safety standards. *Integrated Environmental Assessment and Management*, 2015, **11**(4): 525–536
44. Fenibo E O, Ijomat G N, Matambo T. Biopesticides in sustainable agriculture: a critical sustainable development driver governed by green chemistry principles. *Frontiers in Sustainable Food Systems*, 2021, **5**: 619058
45. Food and Agriculture Organization of the United Nations (FAO). Q & A on pests and pesticide management. Rome: *FAO*, 2021. Available at FAO website on September 1, 2021
46. United Nations Conference on Trade and Development (UNCTAD). Financing organic agriculture in Africa. Mapping the issues. *UNCTAD*, 2016. Avaiable at UNCTAD website on September 1, 2021
47. Carvajal-Yepes M, Cardwell K, Nelson A, Garrett K A, Giovani B, Saunders D G O, Kamoun S, Legg J P, Verdier V, Lessel J, Neher R A, Day R, Pardey P, Gullino M L, Records A R, Bextine B, Leach J E, Staiger S, Tohme J. A global surveillance system for crop diseases. *Science*, 2019, **364**(6447): 1237–1239