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Implementation of biological control of plant diseases in integrated disease-management systems

Santosh Kumar[1], Vivek Singh[2] and Mehi Lal[3]

[1]Jute Research Station, Katihar, Bihar Agriculture University, SABOUR (BIHAR) INDIA
(Email: santosh35433@gmail.com)
[2]Indian Agricultural Research Institute, NEW DELHI (INDIA)
[3]Central Potato Research Institute Campus, Modipuram, MEERUT (U.P.) INDIA

The protection of cultivated crops against pests (insect pests, diseases and weeds) requires the integration of biological control and other ecologically based pest-management practices that also protect the environment and the health of the population, and ensure a satisfactory economic return to farmers. Despite the amount of resources and time invested in this area, biological control is still far from our early expectation that it would play a major role in integrated pest management (IPM).

IPM and biological control: IPM is the use of a combined set of strategies and practices aimed to keep pests at levels under the economic damage threshold. The term IPM, coined by entomologists in the mid-1960s, was developed in order to reduce the risks associated with excessive use of pesticides and to preserve the ecological balance. Biological control may be defined as ‘‘the reduction in the amount of inoculums or disease-producing activity of a pathogen accomplished by or through one or more organisms other than man’’

Theoretical consideration for implementation success: The chance of the success of implementing a biological control measure in IPM is theoretically related to the establishment and growth of the population of a biological control agent. Of the two mechanisms utilized by biological control agents, competing with resources for growth and parasitism, the probabilities of success with implementation are determined by different factors. For the first case, the ability to compete with pathogens, such as *Rhizoctonia* and *Fusarium*, growth is important, and the chance of success is determined by the available resources of a system. For a pathosystem with limited resources, the more competitive the biological control agents are, the more likely they will succeed, as indicated by a low infection level. When resources for growth are unlimited, the use of competitive-type agents in such a system would likely be unsuccessful. The amount of infection in a competitive environment is a function of the amount of available resources. If there is no competition for resources from biological control agents, the pathogen population builds up quickly and, consequently, the infection level increases exponentially. When the competition for resources is strong and the pathogen is not a good competitor with the control agent, the pathogen population will have a reduced growth rate and, consequently, a relative lower inoculum density. Correspondingly, the level of infection increases slowly with the availability of resource, indicating a higher chance of success.

The resource-infection relationship can be further used to determine the relationship between probability of successful implementation and competitiveness of biological control agents. In a pathosystem with limited resources available for population growth, the probability of successfully implementing a biological control agent to reduce disease infection is an exponential relationship. The greater the competitiveness, the higher the disease reduction is likely to be. When the competitiveness reaches a level where the pathogen population can no longer compete for resources to grow, maximum control will be achieved.

Biological control as an implement of IPM: The IPM philosophy embraces sustainability and reduced environmental impact of agricultural production systems. Biological control in many ways is at the center of this philosophy. Some of the disadvantages of biological control like complete control levels and specificity of control, can be overcome by the combination of several other methods. The integration of different disease control methods will prevent or reduce the possibility of disease outbreaks.

The dynamic nature of a pathosystem also predetermines the implementation of biological control measures in an IPM program. For some systems, control measure is effective and sustainable, and for other systems short term inputs may be more effective. In many pathosystems, the frequency of destructive epidemics is low. Systems with a low frequency of pest outbreaks are economically efficient and sustainable if a disease- or pest-management component is the basis for preventative pest control. Management of diseases cannot depend on chemical control due to their unpredictable nature and cannot be justified by low crop price. Resistance has been effectively used as a preventative disease-management component in the pathosystem.

In pathosystems with equilibrium maintained by pest-management components, we can classify those components into two groups: balancers and controllers. The controllers are single factors that have critical and major roles in system dynamics, e.g., an effective disease-resistance gene built in to the host crops. The effects of balancers on equilibrium are collective and secondary, with many balancers interacting through different pathways. Often a group of balancers function collectively to sustain the balance of the system over a longer period of time. Few examples of biological control used for disease management are below this level. However, many biological control agents are naturally effective balancers in agro ecosystems. In a system that has a low disease epidemic frequency; implementation of a biological control measure aimed at developing a built-in preventative component is ecologically feasible and practical. However, because the population of a control agent often cannot be established early enough at a threshold level, as discussed previously, biological control measures would be less likely to play a solo major role, but would rather assume a complementary role in balancing the system.

Cultural practices: Numerous cultural practices have been described as having a positive impact on the reduction of disease levels in different crops and production systems. Combined use of biocontrol agents and cultural practices that enhance the overall health of the plants and favour growth of natural enemies will increase the efficacy of the biopesticides. The implementation of these methods in a production system may result in healthier crops and a less polluted environment.

Habitat stability: It has long been recognized that perennial cropping systems such as orchards are more favourable to natural enemies and biological control because of the habitat stability they provide. Habitat stability can also be provided in situations where crop cycles overlap throughout the year in a substantial portion of the landscape so that individual fields are not too far apart for enemies to move between them.

Crop rotation: Crop rotation is a foundation for pest management in some cropping systems, dissociating pest populations from continued food supply from one year to the next. Placement of rotated crops in relation to prevailing wind direction and previous year's crops may influence the ability of microorganisms to locate and colonize the new crop.

Resistant varieties: This is a built-in component of an IPM system; the best way to control a pest is through the use of resistant or tolerant cultivars. Resistant cultivars not only contribute less pollution to the ecosystem, they do it at a very low cost. Traditional breeding programs have produced a number of cultivars that express different levels of resistance to a number of plant pathogens, but with the aid of molecular techniques, new avenues for production of resistant materials have opened. Identification of resistance genes with the aid of linked molecular markers is currently underway in a number of crops. Transgenic cultivars with pathogen-derived resistance, like the papaya cultivars SunUp and UH Rainbow, which have the gene encoding for production of coat protein from PRSV, are being released. New varieties with enhanced ability to foster general or selective microbial colonization of its roots, or phylloplane, will also be available in the future. The combined use of selected cultivars and biocontrol agents can provide better disease control than the use of any of them alone.

Chemicals: Fungicide resistance is now considered a desired characteristic for a biological control agent, and therefore incompatibility with fungicides will no longer be a limitation for the adoption of biocontrol agents in the future. At the same time, improved activity has been observed when certain biopesticides are used in combination with paraffin oil. The use of bacterial strains in seed treatments provides another avenue to circumvent the fungicide incompatibility issue.

Systems approach for IMPM implementation: The approach is a powerful tool for the implementation of biological control in integrated pest management because this approach was used to develop the theoretical basis of IPM framework. The systems approach originated from the study of the dynamics of large, complicated systems. The approach allows an understanding of such systems, which were traditionally incomprehensible quantitatively with conventional approaches. In a complicated IPM system, this predictive power is very useful in understanding the function of individual biological control measures/agents. With this approach, we can address the following questions quantitatively: how a biological control agent interacts with the host plant, how the agent interacts with plant pathogens, and how parameters of the agent (competitiveness or dose-response) determine the probability of implementation success. We can also explore the effects of important environmental variables such as temperature, moisture, and soil pH on control efficacy. Such study enables us to predict the future development of and increase the success of implementing a control measure into IPM.

Like any ecosystem, a pathosystem is an open system consisting of numerous interacting components. Epidemiologists have used a systems approach to develop simulation disease models and used them to evaluate disease-control strategies in different IPM systems. In disease management, the function of a resistant host as one component in a pathosystem has been evaluated using this approach. Similarly, other modeling approaches can be applied to study the control efficacy of a biological control agent and how the control agent being one component interacts with many biotic and abiotic components in a complicated system. With this approach, we can address the following questions quantitatively: (1) how a biological control agent interacts with the host plant, (2) how the agent interacts with plant pathogens, and (3) how parameters of the agent (competitiveness or dose-response) determine the probability of implementation success. We can also explore the effects of important environmental variables such as temperature, moisture, and soil pH on control efficacy. Such study enables us to predict the future development of and increase the success of implementing a control measure into IPM.

Sustainability of control agents, defined here as the ability to maintain the population level of the control agent, is a key factor in the efficacy of biological controls in IPM implementation. In a natural unperturbed ecosystem, the population equilibrium of a biological control agent is a function of survival and growth. The sustainability of the control agent in a pathosystem is a function of the following multifactors: the growth and survival rates of the agent and the environmental conditions in which the specific biological control is implemented.

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