European Scientific Journal May 2016 /SPECIAL/ edition ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

Biological Control of Agriculture Insect Pests

Leonard Holmes
Sivanadane Mandjiny
Department of Chemistry and Physics,
The University of North Carolina at Pembroke, Pembroke, USA
Devang Upadhyay
Sartorius Stedim Biotechnology Laboratory,
Biotechnology Research and Training Center,
The University of North Carolina at Pembroke, Pembroke, USA

Abstract

This review summarizes the efficacy, advantages and safety of using biological agents to suppress and control damage done to crops by insects. Biocontrol has been generally shown to be safe to plants, animals, humans and the environment. This is in stark contrast to more widely used chemical insecticides that often results in environmental pollution causing harm to humans and the environment. Biocontrol manufacturers continue to develop new protocols for assessing agent safety, deploying and measuring treatment success. Government and manufacturing organizations are developing regulations to assure the safe and appropriate use of biocontrol. The benefits of biological control systems drive the increasing adoption of the technology. Protection of biodiversity and high benefit to cost ratio are obvious reasons to promote the use of biocontrol platforms. It will require education and awareness of the general public and those involved in agriculture to accept these alternative farming practices.

Keywords: Biocontrol, Integrated Pest Management (IPM), biocontrol agents, pesticides, insecticides

Introduction

Biological control for agricultural systems is not a new idea. During the last century greater than 2,000 non-native (exotic) control agents have been used in at least 200 countries or islands with few documented problems to flora, fauna or environment. Biological control of insect pests is gradually gaining momentum. Biological control is a component of an integrated pest management (IPM) strategy (1). It is really regarded as a “systems approach”

to IPM (2). Biological control is defined as the reduction of pest populations by natural enemies and typically involves an active human role. It includes the control of animals, weeds and disease. Biological control minimizes the use of chemical pesticides (3). A biological control platform reduces, but does not eradicate pests and it is used to suppress populations of pest organisms below levels that would have negative economic impact (4,5). Natural enemies used in biocontrol measures include parasitoids, predators, microbes and beneficial nematodes (6). Before a discussion of biocontrol, it is necessary to mention "natural control" resulting from biotic or abiotic environmental conditions. These are factors such as weather, availability of food, competition, amount and quality of living space and the presence and abundance of natural enemies (7). This short review paper will address the control of arthropod pests, but it should be kept in mind that biocontrol also includes the control of plants (weeds).

There are three general approaches to biocontrol: (A) Classical biocontrol which is the practice of reducing the populations of exotic pests for long periods by the release of imported (exotic) natural enemies of the pest. Successful biological control is nearly irreversible because the agent is permanently established (8). (B) Augmentation biocontrol is the repeated release of natural enemies in periodic applications. Treatments (inoculations) may be small numbers during periods when pest populations are low, or large numbers of control agents may be released (inundative) as a corrective procedure for immediate results (9). Control is usually achieved by released individuals, not the off-spring. Inundative releases of biocontrol species that are not able to establish permanently are safer than classical releases. With augmented control repeated applications or additional methods may be used to maintain control. (C) Conservation control is the use of indigenous natural enemies (10). Table 1 represents the examples of pest control methods.

Table 1: Pest control methods

Methods	Examples
Semiochemicals	• Pheromone (used for detection and monitoring of insect populations and thus important for the efficient use of conventional insecticides) • Allomone (a common form of defense by plant species against insect herbivores or prey species against predators) • Kairomone (plant odors or compounds which help biocontrol agents to locate their host species)
Physical and mechanical techniques	• Habitat manipulation • Creating barriers • Trapping pests • Hand removal • Mulching
Selective chemicals	• Microbial and botanical pesticides • Horticultural soaps and oils • Insects growth regulators (IGRs) • Minerals and metals • Synthetic chemicals

Source: Integrated pest management. Oklahoma state university extension. Oklahoma (11).

Safety concerns related to biological control

There are two main areas of safety issues that must be considered when implementing a biological control program. The first question that must be answered is will the introduction of the biocontrol agent have adverse effects on non-target organisms? The second concern is the strength and duration of the biocontrol agent on the environment (12). Accessing the safety of biocontrol continues to be a challenge because of varying environmental applications. Also, the regulations and registration for biocontrol agents varies from country to country. For example, in the United Kingdom, non-indigenous species introduction is regulated by the Wildlife and Countryside Act of 1982 (13). While across Europe, the Organization for Economic Cooperation and Development (OECD) has proposed guidelines to control the importation of natural enemies, such as arthropods and nematodes (14). These guidelines are meant to help prevent damage caused by the release of exotic biocontrol agents. Specific concerns are: (a) importation; (b) taxonomy; (c) release of relevant permits; (d) shipment into another country; (e) quarantine procedures; (f) release testing and protocols; (g) documentation requirements (12-14).

There are very good reasons to adopt stringent safety and regulatory policies and to demand regulation of specific biocontrol agents. Biocontrol agents are broadly defined as pesticides and in general, pesticides and users must be approved before they are imported, marketed and applied (15). Related to this understanding is the mandate to keep ineffective pesticides off the market. Also the public must be educated and understand the danger of exotic agents to human health and the environment. Quality assurance and quality control of biological control agents is important (16).

The International Standards for Phytosanitary Measures (ISPM) as part of the Food and Agricultural Organization (FAO) of the United Nations have supplied guidance documents written for risk management of biocontrol agents capable of self-replication (17). Table 2 shows the different species of organisms which are used as biological control agents.

Table 2: Different types of biological control agents

Biocontrol Agents	Examples
Predators	Ladybugs, dragonflies, lacewings, pirate bugs, rove and ground beetles, aphid midge, centipedes
Parasitoids	Ichneumonid wasps, braconid wasps, chalcid wasps, tachinid flies
Nematodes	*Heterorhabditidae* spp. (Figure 1), *Mermithidae* spp., *Rhabditidae* spp., *Steinernematidae* spp.
Bacteria	*Bacillus thuringiensis, Bacillus popillae*
Viruses	Cytoplasmic polyhedrosis (CPV), granulosis (GV), and entomopox viruses (EPN)
Fungi	*Metarhizium anisopliae, Beauveria bassiana, Trichoderma viride*

Source: Biological pest control. In: New World Encyclopedia (18).

Figure 1: Bright-field micrograph of the beneficial nematode *H. bacteriophora* (19)

ISPM directs responsible authorities to follow accepted protocols related to export, import, quarantine, dispersal and documentation (20).

Industry viewpoints of biocontrol

Balancing the public caution are viewpoints of biocontrol producers. The industry does accept the need for regulation of exotics. However, the industry is concerned that overly stringent regulations will have huge negative impact on the production, expense and development of effective agents (21). Over-regulation will drive costs up and even make some effective, safe products unavailable. These agents should be regulated only if a potential problem is known. There are very few examples of adverse effect due to the deployment of exotic arthropods or microorganisms. Biocontrol agents have been employed for decades with no documented dangers or harms. The industry promotes common sense. Compared with the damage done by accidently introduced invasive alien species, negative biocontrol impacts have been negligible.

It is a fact that the biocontrol producer industry has guidelines in place to facilitate self-regulation (22). The International Biocontrol Manufacturers Association (IBMA) has cooperatively established a code of conduct. There is general agreement that new products should be tested (23,24). However, as more information is gathered, there is concern that additional testing will be required and may become an unnecessary burden. The question arises that who should pay for additional safety and efficacy testing? Currently, the cost of much testing lies on expenses to buyers. Companies, research organizations and universities do most safety and efficacy testing. The marketing of ineffective biocontrol agents is controlled by the market. The biocontrol industry points out that approved chemical insecticides may continue to be sold and used even after they show increasing signs of ineffectiveness due to resistance buildup of target pests (25).

The International Organization for Biological Control (IOBC) has published its conclusions about cost of developing effective biological agents (26). IOBC encourages biological control development and its application in

integrated pest management programs through collection, evaluation and dissemination of information about biological control agents. IOBC sponsors national and international research as well as promoting public awareness of biological control's economic and social importance. IOBC also sponsors training of personnel and coordination of large-scale applications (26). Table 3 represents the general summary of IOBC.

Table 3: IOBC general summary

1	A risk assessment procedure is necessary
2	As a general approach, no risk assessments or regulations should be required for native biological control agents
3	The concept of "ecological regions" (eco-types) should be adopted. This would facilitate a positive list for exotics and reduce the expense of further testing for types of ecological regions in other countries
4	Funding of risk assessment research, design and implementation should be partially public funded

Source: International Organization for Biological Control (26).

General information required to safely deploy a biocontrol plan

To fully understand the impact a biocontrol agent has on the environment, certain types of information must be known. Assessment science is not yet well comprehended or applied in many cases. However, there is consensus that four major types of information is important (27).

1. A clear host range assessment must be undertaken to determine if the agent can be successful on the target species. A sound knowledge of the biological agent and the host(s) must be available. These types of studies are not often relevant to the laboratory and must be determined within the host range (28).
2. Abiotic and biotic factors should be determined and especially an understanding of the similarities between region of bioagent collection and the region of planned release. It may also be vital to have knowledge about the synchronization of development of the host and its natural enemies (29).
3. Knowledge of effective dispersal mechanisms of biocontrol agents can provide important data. Dispersal protocols of the biological agent may be affected by geography and behavioral traits such as ranging and host foraging (30). Types of dispersal mechanisms of biocontrol are mentioned in Table 4.
4. Potential direct or indirect effects on non-target organisms should be understood as completely as possible (32).

Table 4: Types of dispersal mechanisms of biocontrol

Dispersal Mechanisms	Examples (Techniques)
Ground Sprayers for Liquids	Airblast sprayers, boom sprayers, hand-held sprayers, backpack sprayer, aerial sprayers
Solid Formulations Applicators	Granular spreader, dust applicators
Fumigation	Soil fumigation, space fumigation
Fogging Equipment	Mist blowers, Thermal foggers, Ultra low volume or ultra-low dosage (ULV/ULD) equipment, Electrostatic equipment
Chemigation	Mixing of chemicals, such as pesticides and fertilizers, to crops through an irrigation system (e.g., sprinkler, flood, furrow, drip or trickle)

Source: Pesticide application methods and areas of use. 2013. Health Canada, Canada (31).

Ten main benefits of biocontrol

There are many benefits to agriculture using biocontrol methods (33):

1. Insect or weed pest repression to manageable levels and reduces potential legal hazard of chemical use. Chemical pesticides can cause a wide range of human health problems such as nerve, skin, and eye irritation.
2. Chemical pesticides can spoil agricultural land by affecting beneficial insect species, soil microorganisms, and worms responsible for soil health. Chemicals also disturb plant root and immune systems, and thus reduce concentrations of nitrogen and phosphorous in soil which are essential plant nutrients.
3. Reduces acute and long-term impact of chemical pesticides on human, animals, non-target organisms and the environment. Biocontrol agents are usually very specific and present less danger to environment and water.
4. There is no resistance buildup making treatment increasingly less effective.
5. Protection of biodiversity and restoring natural ecosystems.
6. Chemical residue-free products from farms and natural systems.
7. Potential to be permanent reductions of pest organisms.
8. There are usually no phytotoxic effects on young plants (abortion of flowers).
9. The use of biological agents in agriculture has a high benefit to cost ratio.
10. The public is more accepting of biological control than chemical agents.

Conclusion

Perhaps the biggest barrier to effective biocontrol is the necessity of educated management and planning. For optimum benefit the user must understand the biology of both the target pests and their natural enemies. The

risks associated with biocontrol to human/animal health are very low. There have been a few reported cases of worker mild allergenic reactions in production facilities. Biological controls are sometime producing airborne hairs or scales which are potential allergens (34). This risk can be mitigated by sanitary protocols (35). It may also be possible that bites from introduced agents can occur. Plants may also be a secondary food for biological control organisms. Parasitoids and predators might sometimes supplement their diets with certain plant juices or pollen. There is no known example where introduced natural enemies of pests inflicted significant damage on crops or native plants. Environmental risks and non-target effects have not been satisfactorily assessed (36).

Acknowledgement

This review was made possible through generous funds from Farm Bureau Robeson. Additional support was provided by the University of North Carolina at Pembroke (UNCP) Department of Chemistry and Physics and special thanks to Dr. Sivanadane Mandjiny for his consulation throughout this review article.

References:

Hoffmann, M.P. and Frodsham, A.C. (1993) Natural Enemies of Vegetable Insect Pests. Cooperative Extension, Cornell University, Ithaca, NY, pp 63.

Jean-Christophe, C., Damien, J., Guy, T., Banpot, N. (1999). A systems approach to understanding obstacles to effective implementation of IPM in Thailand: key issues for the cotton industry.Agriculture. Ecosystems and Environment, 72: 17-34.

Integrated pest management. In: Private pesticides applicator training manual, 19th edition. Pesticide safety and environmental education program. University of Minnesota Extension, Chapter 1, pp 1-34.

Bale, J. S., Lenteren J. C. and Bigler, F. (2008). Biological control and sustainable food production. Phil. Trans. R. Soc. B. 363: 761–776.

Dively, G. Integrated pest management overview. University of Delaware's cooperative extension. Newark, DE. http://www.udel.edu/IPM/cca/ipmoverview.html

Mahr, D., Whitaker, P. and Rigdway N. (2008). Biological control of insects and mites: An introduction to beneficial natural enemies and their use in pest management. Cooperative extension publishing, Madison, WI. ISBN: 978-09801401-1-8.

http://learningstore.uwex.edu/assets/pdfs/A3842.pdf

Mahr, D. (2011). Understanding biological control and its potential for managing insect pests on cranberry in Wisconsin. UW Extension Fruit Team. Wisconsin. http://fruit.wisc.edu/wp-content/uploads/2011/05/Understanding-

Biological-Control-and-its-Potential-for-Managing-Insect-Pests-on-Cranberry-in-Wisconsin.pdf
Tu, M., Hurd, C. and Randall J. (2001). Biological control. In: Weed Control Methods Handbook, The Nature Conservancy. U.S. government documents (Utah regional depository). pp:29-52.
http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1532&context=govdocs
Sloderbeck, P., Nechols, J. and Greene, G. (1996). Biological control of insect pests on field crops in Kansas. Cooperative Extension Service, Kansas State University, Manhattan. http://entomology.k-state.edu/doc/misc.-extension-document/mf2222.pdf
Natural Enemis. Pest horeca. Pest control study. http://www.pesthoreca.com/natural-enemis/
Integrated pest management. Oklahoma state university extension. Oklahoma.
http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-8893/L-429.pdf
Pal, KK. and Gardener BM. (2006). Biological Control of Plant Pathogens. The PlantHealth Instructor. DOI: 10.1094/PHI-A-2006-1117-02.
http://www.apsnet.org/edcenter/advanced/topics/Documents/PHI-BiologicalControl.pdf
Shaw, R. and Seiger, L. (2002). Japanese Knotweed. In: Van Driesche, R., et al., 2002, Biological Control of Invasive Plants in the Eastern United States, USDA Forest Service Publication FHTET-2002-04, 413 p.
Activities to Reduce Pesticide Risks in OECD and Selected FAO Countries. Part II: Survey Responses. Environment Directorate. Organisation for Economic Co-operation and Development Paris 1996.
http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(96)122&docLanguage=En
Hoeschle-Zeledon, I., Neuenschwander, P. and Kumar, L. (2013). Regulatory challenges for biological control. The CGIAR Systemwide Program on Integrated Pest Management.
http://www.spipm.cgiar.org/c/document_library/get_file?uuid=3509eb45-64eb-47ac-a933-&groupId=17812
ASEAN Guidelines on the Regulation, Use, and Trade of Biological Control Agents (BCA). 2014. Implementing Biological Control Agents in the ASEAN Region: Guidelines for Policy Makers and Practitioners. http://asean-agrifood.org/?wpfb_dl=57
International standards for phytosanitary measures 1 to 24 (2005 edition). The Secretariat of the International Plant Protection Convention. Food and agriculture organization of the United Nations. http://www.fao.org/3/a-a0450e.pdf

Biological pest control. In: New World Encyclopedia.
http://www.newworldencyclopedia.org/entry/Biological_pest_control#Predators
Kooliyottil. R, Upadhyay, D., Inman, III F., Mandjiny, S. and Holmes, L.D. (2013) A Comparative Analysis of Entomoparasitic Nematodes *Heterorhabditis bacteriophora* and *Steinernema carpocapsae*. Open Journal of Animal Science, 3(4): 326-333.
Export Program Manual. Second edition. (2010). United States department of agriculture.
https://www.aphis.usda.gov/import_export/plants/manuals/domestic/downloads/xpm.pdf
Animal Health Protection and Disease Control. (2009). National Association of State Departments of Agriculture. Policy Statements. http://www.nasda.org/File.aspx?ID=3224
Wittenberg, R. and Cock, M. (2001). Invasive Alien Species: A Toolkit of Best Prevention. Global Invasive Species Programme (GSIP). Published by: CAB International, Wallingford, Oxon, UK.
Report 6th FAO/WHO joint meeting on pesticide management and 8th session of the FAO panel of experts on pesticide management. 2012. World Health Organization. Rome.
http://www.who.int/whopes/recommendations/Sixth_FAO_WHO_jmpm_2013.pdf
The International Code of Conduct on Pesticide Management. 2014. World Health Organization Food and Agriculture Organization of the United Nations. World Health Organization, Rome. ISBN 978-92-5-108548-6.
http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/CODE_2014Sep_ENG.pdf
Sexton, S., Lei, Z. and Zilberman, D. (2007). The economics of pesticides and pest control. International Review of Environmental and Resource Economics, 1: 271–326.
International Organization for Biological Control (IOBC).
http://www.iobc-global.org/about_iobc.html
Bale, JS., Lenteren, JC. and Bigler, F. (2008). Biological control and sustainable food production. Phil. Trans. R. Soc. B. 363: 761–776.
McClay, A. (1996). Host range, specificity and recruitment: synthesis of session 2. 11th International symposium on biological control of weeds. pp 105-112. V.C. Moran and J.H. Hoffmann (eds.), 19-26, 1996, Stellenbosch, South Africa.
Uniyal, M. (2015). Integrated Pest Management. In: SATNET Asia Training Manual. CAPSA-ESCAP. ISBN: 978-979-9317-79-7
http://www.satnetasia.org/sites/default/files/SATNET-TM-Integrated%20Pest%20Management-resized.pdf

Louda, S., Pemberton, R., Johnson, M. and Follett, P. (2003) Nontarget effects - the Achilles' heel of biological control? retrospective analyses to reduce risk associated with biocontrol introductions. Annu. Rev. Entomol. 48: 365–96.

Pesticide application methods and areas of use. 2013. Health Canada, Canada.
http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_fact-fiche/application/index-eng.php

Pesticide application problems. In: Pesticide application and safety training for applicators of public health pesticides.
http://westnile.ca.gov/special/category_a/?page=Chapter9.htm

Gerdes, E., Upadhyay, D., Mandjiny, S., Bullard- Dillard, R., Storms, M., Menefee, M. and Holmes, L. (2015). *Photorhabdus Luminescens*: Virulent Properties and Agricultural Applications. *American Journal of Agriculture and Forestry.* 3(5): 171-177.

Delfosse, E. (2005). Risk and ethics in biological control. Publications from USDA-ARS / UNL Faculty. Paper 411. http://digitalcommons.unl.edu/usdaarsacpub/411

Tomberlin, J. (2003). Biological control and invasive species management in the United States. American entomologist. pp: 238-249.

Hagler, J. (2000). Biological Control of Insects. In: Insect pest management: techniques for environmental protection. CRC Press LLC.