REVIEW ARTICLE

Facilitation of augmentative and conservation biological control during the agroecological transition of agricultural systems

Luis L. Vazquez

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ABSTRACT

The sustainability of biological control in agriculture requires improving the characteristics of agroecosystems as an appropriate habitat for these organisms, whether they are bioproducts used augmentatively or through the conservation of natural enemies that inhabit the systems. Because the agroecological transition of agricultural production leads to the transformation of agricultural lands, ecological functions are facilitated that contribute to building capacities for greater effectiveness of biological control and ecological self-regulation. Experiences on the contribution of the agroecological transition to biological control in Cuban agriculture are systematized in this article.

Key Words: *Biological control; Agroecological transition; Agriculture; Cuba*

INTRODUCTION

Biological control appears today, worldwide, as one of the first challenges that farmers must value to adopt agroecology [1]. In turn, turn, production systems in agroecological transition show the best characteristics as a habitat to facilitate the efficacy of bioproducts and the regulatory activity of natural enemies that inhabit agroecosystems.

Biological control should be considered a much more complex practice than multiplying in mass and introducing into the fields an effective agent for pest control. As a living organism, the characteristics of the cultivation and production system and the area where it will be released or applied must be known and improved [2].

In recent years, the need to pay more attention to the effects of diversity on stability and the occurrence of harmful organisms and their natural enemies in agroecosystems has been widely documented, as well as favoring interactions that contribute to the ecological services of functional biodiversity, including the connections between production systems and natural ecosystems [3-6].

The scaling of biological control in Cuban agriculture has been fundamental in the agroecological transition and greater sovereignty in pest management. In addition, it has contributed to valuing the multifunctions of biodiversity in the design and management of agricultural production systems, thus generating new territorial dynamics and territorial governance [7].

Precisely, the adoption of Agroecological Pest Management (APM) led to an increase in the effectiveness of biological control agents and reduce the number of applications of these, mainly in the most complex farms of traditional peasants and in urban agriculture systems, due to a gradual increase in the ecological self-regulation capacity of these systems [8].

Based on this experience, the objective of this article is to demonstrate the contribution of the agroecological transition of agricultural production to augmentative biological control and the conservation of natural enemies, to make the systems a favorable habitat for ecological self-regulation.

LITERATURE REVIEW

Experiences and results of several projects facilitated in different territories of Cuba were systematized, namely:

- Diagnosis of phytosanitary problems and generation of Agroecological Pest Management programs in different urban agricultural production systems. CITMA. Havana Territorial Program (2002-2004).
- Systematization of scientific results and experiences of specialists, extensionists, and farmers in the validation, adoption, and improvement of agroecological practices for pest management. Agricultural Extension Branch Program. MINAG (2006-2008).
- Strengthening of phytosanitary management in Cuban agricultural systems. INISAV. Innovation Program (2008-2009).
- Participatory diagnosis of the agroecological pest management in the National Polygon of Soil Conservation and Improvement. Soil Conservation and Improvement Program. Soil Institute. MINAG (2010-2012).
- Diagnosis, learning, and innovation for the adoption of practices that contribute to the beneficial interactions of agrobiodiversity on farms in Havana. Territorial Innovation Program for food production. CITMA Havana (2011-2012).
- Results of a participatory process of systematization of experiences in good agroecological practices for pest management. INISAV Innovation Program (2011).

Publications on territorial management of biological control in Cuban agriculture, its adoption by farmers, and integration into pest management were reviewed.

RESULTS AND DISCUSSION

Augmentative biological control

The territorialization of augmentative biological control in Cuba implied the local appropriation of four capacities:

- The massive production of biological control agents in specialized laboratories.
- The consolidation of a delivery service for certified strains and ecotypes, complemented by a production quality control system.
- The learning by the farmers of the characteristics of these products and their differences with chemical pesticides, mainly on: integration with chemical pesticide applications, preparation of the broth, quality parameters of the bioproducts, determination of the field dose, application techniques, mechanism of action, determination of the effectiveness of applications, among other technical aspects.
- The transformation of production systems into a suitable habitat for the use of these bioproducts.

Centro Latinoamericano de Investigaciones Agroecologicas (CELIA),Cuba

Correspondence: Luis L. Vazquez, Centro Latinoamericano de Investigaciones Agroecologicas (CELIA), Cuba, e-mail llvazquezmoreno@yahoo.es

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Precisely, from the sixties to the nineties, research was carried out for the generation of new technologies in the fight against pests, which led to Integrated Pest Management (IPM) programs, which began to be introduced in practice at the end of the eighties to contribute to the rational use of chemical pesticides and integrate biological control agents, among other practices in crop management, a system that is managed from territorial stations through crop monitoring [9-11].

In agricultural production, a network of 175 Centers for the Reproduction of Entomophagous and Entomopathogens (CREE) and four microbiological biopesticide industrial plants guarantee the massive production of entomopathogens (*Beauveria bassiana, Metarhizium anisopliae, Lecanicillium lecanii, Bacillus thuringiensis*), entomonematodes (*Heterorhabditis spp.*), entomophagous (*Lixophaga diatraeae, Trichogramma spp.*), among others. Every year microbiological agents are applied to almost 2.5 million hectares of crops.

A contribution of territorial management is the diversification in the use of biological control agents since in the country 30 species of biological controllers are used or have been used for releases or augmentative applications against 175 insect pest-crop combinations, represented mainly by immature parasitoids for the number of species used (46.66%) and entomopathogenic fungi with the total of pests-crops to control (29.7%), being the biological controller with the greatest diversity of use *Bacillus thuringiensis* against 25 insect pest-crops [12].

The decentralization strategy towards the territories of the production of biological control agents led to the appropriation of these technologies by local actors, consolidating a highly self-sufficient system for planning according to the demands of agricultural production, which has been sustained by a system that has favored incremental innovation, mainly since the mid-1990s, facilitated by the network of laboratories and plant health service stations, together with farmers, who have led to greater integration of biological control and pest management to the management of the crop, the production system and the agricultural territory [13,14].

As a result, for the releases of entomophagous and the applications of microbiological biopesticides with augmentative criteria, different techniques have been established that contribute to better integration of biological control in agricultural production (Table 1).

In conventional agricultural production systems, augmentative biological control is generally used according to the characteristics of Integrated Pest Management (IPM) programs. Systematic applications of bioproducts predominate and when the incidence of pests reaches a critical rate, an application of chemical pesticides is carried out and subsequently continues with biological ones. In other cases, the applications of bioproducts are scheduled with a certain frequency and are carried out until the crop begins to bear fruit, tolerating the critical indices.

The substitution of inputs follows the same paradigm of conventional agriculture in which the objective is to overcome the limiting factor, although this time it is done with alternative and non-agrochemical inputs. This type of management ignores the fact that the limiting factor (a pest, a nutritional deficiency, etc.) is nothing more than a symptom that an ecological process does not work properly, and that the addition of what is missing, just recently optimize the irregular process. The substitution of inputs has lost its agroecological potential, as it does not go to the root of the problem but to the symptom [15,16].

In the programs of augmentative biological control, the interactions between entomophagous and entomopathogens are generally considered. However, little attention is given to the interactions with the natural enemies that inhabit the agroecosystems. When the microbiological agents are applied, be they inundative or inoculative, two effects are generally achieved: the direct control of the pest population and their establishment in the agroecosystem to act as a regulator. On the other hand, the use of biological control agents as if they were a product (the focus of substitution of inputs) is not sustainable; instead, they must be used as part of a pest management system to increase the capacity of pest self-regulation [17].

TABLE 1

Innovated augmentation biological control techniques in Cuban territories [15]

Techniques of use	Purpose
Flooding applications or releases	Control of populations of harmful organisms caused by insects, mites, nematodes and phytopathogens
Treatment by immersion of botanical seed and seedlings	Protection against infections of phytopathogenic fungi
Mix with organic fertilizers	Incorporate in the soil to control phytopathogenic fungi and nematodes
Inoculative applications or releases in field sites or crop rows	Establishment of populations in the agroecosystem
Management of strains or ecotypes	Massively multiply local or adapted strains or ecotypes

In this context, the Agroecological Pest Management (APM) system emerged, a transformation process with very specific objectives:

- Optimize the use of chemical pesticides, with the integration of alternative control methods, to reduce the selection pressure of tolerant populations and resistant to these molecules, while reducing the toxic load that affects the natural enemies of pests.
- Make the farming system more complex through agroecological designs and management, which reduce the possibility of establishment and multiplication of harmful organisms, while becoming a higher quality habitat for the regulatory activity of biological control agents, natural enemies, the epiphytic and rhizospheric microbiota.
- Redesign the spatial and structural matrix of the production system, based on the principles of agroecology, to facilitate processes of ecological self-regulation of pests [18].

Conservation of natural enemies

The strategy for the conservation of natural enemies includes practices that protect, favor the development, and manage these organisms in the agroecosystem, be they parasitoids, parasites, or pathogens, to increase the regulatory activity of the most efficient species or achieve higher rates of regulation as a result of the joint action of the different species that cohabit, including biological control agents that are released or applied in augmentative programs [2].

As a biological control strategy, it has been more evident in production systems in agroecological transition, because they are generally systems with the following characteristics:

- Diversified production.
- Diversity of types of farming systems.
- Design the fields or plots as polycultures.
- Integrate auxiliary vegetation structures (groves, live fences, live barriers, semi-natural environments).
- They have greater spatial and temporal crop dynamics (multifunctional rotation).
- Integrate organic fertilizers and biofertilizers, among others.

In these systems, biological control achieves synergies between the conservation of natural enemies and augmentative applications or releases; the latter can be inundative or inoculative, combining control with the establishment, depending on the characteristics of the pests and the cultivation system, as well as the rest of the production system.

The quality of the agroecosystem as a habitat must facilitate functions of refuge, multiplication, dispersion, and regulatory activity of populations of natural enemies that inhabit the soil and the aerial part of the plants. The innovative techniques to facilitate these functions have been diverse, mainly the following [19]:

- Establishment of reservoir plants of natural enemies in appropriate places of the agroecosystem.
- Collection of populations of natural enemies from cultivated plants and auxiliary vegetation, for transfer to fields infested by insect pests.
- Collection, multiplication, and release of entomophagous insects, through rustic insectaries on the farm itself.
- Design of mixed farming systems (associated and intercropped), to facilitate the activity of applied or released biological control agents and natural enemies that inhabit the agroecosystem.
- A mosaic design of crops with the management of the boundary that favors the flow of populations of natural enemies.

- Design of perimeter and internal live fences for the establishment, refuge, and ecological corridor of biological control agents and natural enemies that inhabit the agroecosystem.
- Integration of live perimeter barriers for the establishment, refuge, and ecological corridor of biological control agents and natural enemies that inhabit the agroecosystem.
- Integration of living covers in crop fields that facilitate the activity of biological control agents and natural enemies.
- Tolerance of non-competitive weeds in crop fields, as reservoir of natural enemies.

Regarding mixed or polyculture farming systems, a study of 24 polyculture designs carried out by farmers, determined the highest functional coefficient for the design that integrates cassava-maize-beans (86.7%); They are followed by sweet potato-corn and cassava-corn designs (76.7%), bananas-cassava (73.3%), beans-corn, banana-beans-corn (70%) and avocado-mamey-coffee (66.7%) [20].

The complexity of the designs of systems of mixed cultivations (polycultures, polyfruits, others) and the integration of auxiliary vegetation structures (ecological corridors, alive barriers, among others) in the matrix of the production systems, among other practices of biological control for conservation, are facilitating the dispersion of natural enemies [21].

Polycultures that integrate corn have been shown to perform the following functions:

- Contribute to the microclimate of the field, mainly because it attenuates surface air currents, retains moisture, and reduces the direct incidence of solar radiation on the surface of the soil, conditions that have effects on the biodiversity associated with the crop.
- It acts efficiently as a physical barrier for immigrant populations of adult insects.
- It is a place of refuge for beneficial insects from the effects of pesticides, cultural practices, air currents, and solar radiation.
- It is a reservoir of populations of natural enemies in different hosts that inhabit corn, mainly in the heart of the plant, which is considered to be one of the main reservoirs of entomophagous.
- Contributes to the development of ant populations in the soil.
- Contributes to the ecological management of weeds [22].

In their coevolutionary process with their guests or prey, mainly in their area of origin, biological control agents reach different trophic relation degrees. These relationships involve crops, weeds growing in fields and surrounding areas, phytophagous insects that can be hosts or prey, soil and climatic characteristics, crop technology, and production system management. Thus, there is a complex system and the biological characteristics of the natural enemies that determines its regulatory activity [19].

There are similarities among these kinds of species that are related to each other in different ways, giving rise to complex networks of interaction. Networks may occur depending on the type of interaction, competing, trophic, mutualists, and facilitation, among others. The structure of ecological networks determines many of the ecosystem functions they represent. Therefore, when the architecture of these networks is lost, many other functions are changed [23-25].

Although natural enemies vary widely in response to crop distribution, density, and culture dispersion, evidence indicates that certain agroecosystem structural attributes (plant diversity, entry levels, etc.) strongly influence the dynamics and predators and parasitoids diversity. Most of these attributes relate to biodiversity and are management subjects, such as crop rotation and associations, the presence of weed blooms, and genetic diversity, among others [26, 27].

Introducing as a criterion the functions performed by productive plants integrated into the designs of complex crop systems that are obtained because of the design and spatial-temporal management interactions reinforces the hypothesis that it is not enough to achieve complexity in agroecological designs but that multifunctionality is required. As expressed polycultures are systems in which two or more cultures are, at the same time, established and close enough to produce interspecific competition or complementarity [2, 28].

The purpose of the agroecological projects of the cropping systems and the whole production system is to achieve several functional attributes that, besides contributing to the productive efficiency and soil conservation, also reduce the arrival, establishment, and increase of pest populations. In turn, the occurrence of natural enemies is favored, contributing to their ability to self-regulation of pests [29].

Thus, several studies related to the conservation of natural enemies' study or the introduction of biological control agents and their integration into pests' management recommend certain conditions or characteristics. They are desired in the crop and production systems, to contribute to a better efficacy in the regulatory capacity of these organisms, mailing:

- Provide hosts or prey.
- Adult feeding of entomophagous.
- Shelter for adverse factors and time factor.
- Up and down connectivity.
- Populations reservoir.
- Microclimate regulation.
- Reduce physical and chemical effects [2].

Facilitation of biological control by the agroecological transition

The collapse of conventional agriculture in Cuba in the early 1990s led to the beginning of the agroecological transition, a process in which biological control increased and agroecological pest management emerged, contributing to synergies between augmentative biological control and conservation of natural enemies and the capacity for ecological self-regulation in agroecosystems (Figure 1).

During the first years, there was some experience in the rational use of chemical pesticides and the substitution of applications with microbiological biopesticides or entomophagous releases, which had begun in the mid-1980s as a result of the biological control program increase and the rise of Integrated Pest Management (IPM), a system that is managed by a network of Territorial Plant Protection stations (ETPP), created since the mid-seventies as a service to conventional agricultural production in large specialized companies [30].

Precisely since the beginning of the 1990s, when large companies were divided into basic Units Of Cooperative Production (UBPC), as well as the emergence of urban agriculture, subsequently reinforced since 2009 with the extension of urban agriculture to suburban areas and new processes of delivery of idle lands in usufruct, the creation of new types of production systems was promoted, the diversification of crops and the design of polycultures increased. As a result, at the end of 2016, the exploitation of agricultural land in the country shows a very contrasting distribution with that of the 1960s and the end of the 1980s, because the cooperative sector as a whole, where the agroecological transition has begun, occupies around 70% of cultivated agricultural areas, which represent 3.5 million hectares [31].

These structural transformations in agricultural production contributed to a gradual complexification of the matrix of territories, landscapes and production systems, which in synergy with the combined effects of the reduction of agrochemicals and the increase of bioproducts, led to cumulative multi-effects for the benefit of the recovery of biodiversity functions, which was evident in the increase in the diversity and activity of natural enemies of pests and the reduction in the rates of some pests [14].

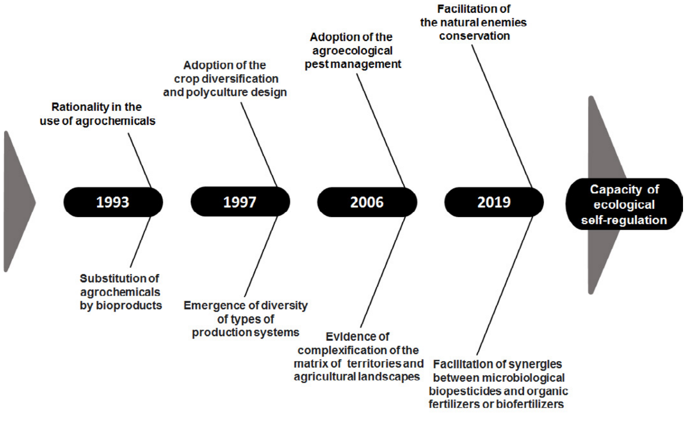

Figure 1) *Components of the agroecological transition that facilitated biological control and ecological self-regulation capabilities in Cuban agroecosystems*

The procedures performed in agroecosystems (crop rotation, new harvests, mechanized works, and chemical product applications, among others) and the simplicity of established designs, especially in conventional farming systems, can cause a dynamic and multicausal fragmentation of biodiversity interactions. This fact affects the natural enemy species that inhabit or those introduced as agents of biological control, as well as interactions with their natural enemies, prey, or hosts and the plants where they cohabit. The foregoing requires research to study and propose the functional integration of seminatural vegetative structures [2].

Habitat management is a way of conserving the biodiversity of agroecosystems, substantially improving the interactions at the different trophic levels and an ecological tactic that favors and increases the activity of entomophagous in agricultural systems, due to the availability of alternative foods, nectar, and pollen, favor shelter and a moderate microclimate, protecting said natural enemies from extreme environmental factors, interspecific competition and the presence of other organisms (hyperparasites, predators, etc.) and pesticides; also fostering habitat for their prey and alternative hosts [32,33].

Agroecology is a science that studies the agroecosystem as a whole (holistically) and considers it as a complex system, achieving a comprehensive approach to the processes that occur in it and in this way, overcoming the approximation simplistic view of industrial agriculture [34,35]. A complex system can be described as a system composed of multiple elements that interact in multiple ways, in which many properties depend on these interactions and are known as emergent properties, of which the stability (homeostasis) of an agroecosystem is a classic example and it does not depend solely on the identity of the components of biodiversity [36].

Farm redesign attempts to transform the structure and function of the agroecosystem by promoting diversified designs that optimize key processes. The promotion of biodiversity in agroecosystems is the key strategy in farm re-design, as research has shown that:

- Greater diversity in the agricultural system leads to a greater diversity of associated biota.
- Biodiversity ensures better pollination and greater regulation of pests, diseases, and weeds.
- Biodiversity enhances the recycling of nutrients and energy.
- Complex and multispecific systems tend to have higher total productivity [37].

The innovation processes carried out since the mid-1990s, facilitated by the network of laboratories and plant health service stations, together with farmers, led to greater integration of biological control and pest management, into crop management. , the production system and the agricultural territory, as evidenced by a systematization carried out in 12 provinces of the country, in which 439 Agroecological Pest Management practices-procedures adopted in agricultural production were identified, of which 7.52% correspond to the agricultural system management component (territory); 23.9% to the management of the production system (farm or others); 8% to comprehensive soil management; 15.3% to the integral management of the cultivation system and 45.3% are ecological control methods; of the latter, 69.8%% correspond to biological control [14].

The transition and staggering of the MAP, which was achieved as part of the emergence of agroecology in the country, was adopted in around 70%-75% of agricultural production [14]. Several factors are contributing to the territorial scope of the MAP system, among others, the experience accumulated since the creation of the network of Territorial Plant Protection Stations (ETPP) in 1974-1975, the regulations on the use of chemical pesticides, the biological control since 1988 and the implementation of IPM since 1989 [18].

CONCLUSION

Chemical pesticides and augmentative biological control with microbiological biopesticides are used, under Integrated Pest Management (IPM) programs, in approximately 25%-30% of the cultivated area; instead, microbiological biopesticides, entomophagous, botanical pesticides, and other methods are integrated under Agroecological Pest Management in 70%-75% of the surface (CNSV 2016).

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