Scientific Paper

Contribution of the agroecology approach in the functioning and structure of integrated agroecosystems

Katia Bover-Felices *https://orcid.org/0000-0001-5112-9312* and Jesús Suárez-Hernández *https://orcid.org/0000-0002-6232-1251*

Estación Experimental de Pastos y Forrajes Indio Hatuey, Universidad de Matanzas, Ministerio de Educación Superior. Central España Republicana, CP 44280, Matanzas, Cuba. E-mail: katia.bover@ihatuey.cu

Abstract

Objectives: To reflect on the function and importance of agroecology in integrated agroecosystems, and its effect on the structure, functioning and efficient use of the resources of such system.

Materials and Methods: The available literature on the fields of ecology, agricultural sciences and agroecology was consulted and analyzed, in order to establish the scientific bases, definitions and state-of-the-art in the studies and the results related to conventional and integrated (agriculture-animal husbandry) systems and to agroecology.

Results: It was observed that the integration of animals and crops in integrated agriculture-animal husbandry systems generates synergies that enhance the productive capacities of such systems, in addition to allowing the reduction of vulnerability to agricultural pests, decreasing the dependence on external inputs and capital requirements, and increasing the efficiency of land use.

Conclusions: The application of agroecological approaches contributes to the sustainable intensification of food production and to the solution of many problems, related to adverse environmental effects and to the low productivity and efficiency that still prevail in specialized systems.

Keywords: agroecosystem, agroecology, sustainability, efficiency

Introduction

At present there is consensus about the need to reach sustainable agriculture. Nevertheless, the development of the agricultural activity still has noxious effects for the environment. Modern agriculture, commonly called conventional, is consequence of the so-called green revolution, which consisted in pursuing the increase of productivity of agricultural crops, at the expense of the use of high-yield bred seeds, synthetic fertilizers and pesticides (FAO, 2015).

The environmental and socioeconomic crisis that has been caused by this form of agriculture has led to redefining the current agricultural model towards a more sustainable one, and to the emergence of agroecology, as a theoretical and methodological approach that intends to reach agricultural sustainability from the ecological, social and economic perspectives. Agroecology offers the scientific and methodological bases for the strategies of transition towards the construction of a new development paradigm and sustainable agriculture (Queiroz, 2016).

The Cuban agricultural sector has not been exempt from the above-mentioned problems. Through the years several transformations have been experienced, which comprise from the land management form to the productive model *per se*, in a transit towards sustainable holistic approaches. It is known that the industrial model of agriculture, known as green revolution, adopted during the sixties of the 20th century, had very negative environmental and socioeconomic impacts. Among them the specialization of agriculture and animal husbandry, the subsequent loss of the biodiversity of agroecosystems, soil erosion, deforestation and large-scale migration of rural population towards cities, can be cited (Machado *et al*., 2009).

Because of the above-referred motives, as well as the intensification of the economic embargo of the United States against Cuba, in the 1990's, the efforts of research centers and farmers were focused on the search for options that allowed to keep high yields, and at the same time to be viable in environmental terms. It is in this context that the agroecological reconversion of Cuban agroecosystems begins. The importance of integrated systems is then taken up again and a dynamic process of participatory extension work is started, with the intention of introducing this new conception of

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production, based on animal husbandry-agriculture integration (Funes-Monzote, 2009).

At present, in the face of the challenges imposed by the situation of agriculture worldwide, which intends to increase and ensure food production and, in turn, reduce environmental problems, this process of technological reconversion to sustainable systems has higher validity. From this perspective, the integrated agriculture-animal husbandry systems (IAAHS) are taken up as one of the pillars of the new paradigm of agricultural production, because they are considered an efficient design for sustainable agricultural systems, of ecological basis (Stark, 2016). This new paradigm, that is, ecological intensification (Rockström *et al*., 2017), ecoagriculture (Garbach *et al*., 2017), agroecology (Altieri and Nicholls, 2017; Bergez *et al*., 2019) or modernization of ecological agriculture (Pretty *et al*., 2018), has as objective the design and implementation of productive agricultural systems, which require the least possible quantity of external inputs, with the support of interactions and synergies among their biological components. This need of designing and implementing sustainable and productive environment-friendly agroecosystems, which are less input-dependent, has been increasingly expressed in the last decades (Therond *et al*., 2017; Sharma *et al*., 2017; Stark *et al*., 2018).

The objective of this work was to reflect on the function and importance of agroecology in integrated agroecosystems, and their effect on the structure, functioning and efficient use of resources in such systems.

The agroecological approach

The contemporary use of the term agroecology dates back to the 1970's; although its science and practice are as ancient as the origins of agriculture, because they have their roots in the analysis and study of natural ecosystems and indigenous agroecosystems (Hecht, 1999).

The term agroecology was first used in two scientific publications by Bensin (1928; 1930). This author suggested it to describe the use of ecological methods in the research of commercial crops (Bensin, 1930). Thus, agroecology would be preliminarily defined as the application of ecology in agriculture, meaning that is still used (Wezel *et al.*, 2009).

According to Wezel *et al.* (2009), four main historical periods are identified in the study of agroecology:

- Emergency (1930's-1960's)
- Expansion (1970's – 1980's)
- Institutionalization and consolidation (1990's)
- New dimensions (2000 - present)

Although agroecology as a science has significantly evolved and concepts have been articulated, there is still a large diversity in the approach of this discipline and its definitions in different countries and regions of the world.

Altieri, one of the founders of this paradigm, defines it as the science that integrates ideas and methods for doing agriculture. According to Altieri and Nicholls (2017), it is the scientific discipline that approaches the study of agriculture from an ecological perspective and considers agricultural ecosystems as the fundamental units of study, where the mineral cycles, energy transformations, biological processes and socioeconomic research are considered and analyzed as a whole.

During ninety years of scientific study this term has been used to make reference to a range of scientific principles, agronomic practices and political positions of social movements.

The United Nations Food and Agriculture Organization (FAO), after regional seminars and global exchange with representatives of Member States, which took place between 2014 and 2018, accepts an internationally accepted definition, describing agroecology as a discipline «based on the application of ecological concepts and principles to optimize the interactions among plants, animals, humans and environment, taking into consideration the social aspects that should be approached to achieve sustainable development and a fair food system». This concept refers mainly to the food production conditions; while the qualifiers of sustainable and fair refer to the socioeconomic relations among the actors of the system (Loconto, 2020).

Thus, agroecology is based on the application of agronomic and ecological sciences to the study, design and management of culturally sensitive and socioeconomically viable sustainable agroecosystems. This approach leads to an analysis and redesign for the management of agricultural diversification, which promotes synergies among all the components and a complex dynamics of socio-ecological processes, restoration and conservation of soil fertility, maintenance of productivity, efficiency and long-term self-sufficiency (Casimiro, 2016; Nicholls *et al*., 2016; 2017).

Agroecology is based, according to Casimiro (2016) and Nicholls *et al*. (2016; 2017), on basic principles that can assume diverse technological practices, depending on the context of a farm, and which can have different effects on its productivity or resilience, depending on the environment and resource availability, which coincides with criteria expressed by Paolini *et al*. (2018).

These principles, approached by Altieri *et al.* (2015) and Gliessman (2016), are mainly based on ecological processes. Nevertheless, Casimiro (2016) equally considers of essential importance the associated social complement (table 1).

Thus, agroecology is focused on ecological relations in the field, and its purpose is to enlighten the shape, dynamics and functions of this relation. As a result, researchers of agricultural sciences and related areas, started to consider the agricultural farm as a special type of ecosystem, as an agroecosystem, and to formalize the analysis of the set of processes and interactions that intervene in this kind of system.

Agrecosystems. Types and definitions

A basic foundation of agroecology is the concept of ecosystem, defined by Odum (1971) and Gliessman (1998) as a functional system of complementary relations between living organisms and their environment, delimited by arbitrarily established frontiers in time and space, which seems to maintain a stable, but in turn dynamic, balance status, and which can be considered sustainable. A well-developed and mature ecosystem is, according to Gliessman *et al*. (2007), relatively stable and self-sustainable; recovers from disturbances, becomes adapted to change, and is capable of maintaining its productivity through the utilization of energy inputs that come only from solar radiation.

An agroecosystem is a man-disturbed ecosystem for the development of agricultural exploitation. According to Gliessman *et al.* (2007), an ecosystem is, often, more difficult to study than natural ecosystems, because human intervention alters its structure and normal function. Argüello (2015) refers that when the concept of ecosystem is extended to agriculture, and agricultural systems are considered as agroecosystems, the complex set of interactions (biological, physical, chemical, ecological and cultural) can be appreciated, not only at farm level, but in the region or country, which determine the processes that allow food production.

As stated above, human manipulation of agroecosystems introduces several changes in the structure and function of natural ecosystem. As a result, some of their key qualities are modified, known as emergent properties or system properties, which are manifested once all its components are organized and that, according to Gliessman (1998), can also serve as indicators of its sustainability.

The structure and functioning of agroecosystems can be very simple or very complex, and depend on the number and type of components and the arrangement among them. This is the case of an integrated system, where many species coexist, or of a specialized or conventional monoculture system.

Nevertheless, the functioning of an agroecosystem is not conditioned only by the sum of its components, but by the way in which they are interrelated, which determines its particular properties. Specifically in an agroecosystem, it provides it with its productive characteristics.

The idea of applying the system approach is not new or exclusive to the agricultural sciences. Since the 4th century B.C., Aristotle (384-322 B.C.) acknowledged that «the whole is more than the sum of the parts». Years later, Von Bertalanfly (1968) developed the General Theory of Systems, in which it is recognized that «a system is a set of interrelated elements». Nevertheless, the most widely acknowledged concept of system is the one formulated by Becht (1974), who declares that «a system is an arrangement of physical components, a set or collection of things, joined or related so that they form and act as a unit».

Nowadays, two contrasting productive approaches are known. There is conventional agriculture (high-input intensive-industrial) and, opposed to it, different alternative models are present, such as natural agriculture, agroecology, organic, biodynamic, live, alternative, regenerative, conservation agriculture and permaculture (Vázquez, 2015).

Conventional agricultural production systems, according to Vázquez (2015), exploit one or several plant or animal species in specialized cropping and animal husbandry systems and large extensions, through technologies with predominance of mechanization and chemical inputs, which cause negative externalities. Alternative models constitute a production form based on ecological principles and on cycles adapted to local conditions, without using inputs that have adverse effects, combine tradition, innovation and science to favor the environment and promote fair relations and good quality of life for all their participants.

Agriculture-animal husbandry integration (AAHI), acknowledged as the set of agricultural practices which mobilizes diverse ecological processes, is one of the pillars of this last agricultural production approach

Table 1. Agroecological principles and associated technologies or socioecological processes for the development of agroecological family farms.

Agroecological principles	Technologies or socioecological processes
Nutrient and organic matter recycling, optimization of availability and balance of nutrient flow.	Non-generation of waste, cycle closing, utilization of opportunities, stimulation to biodiversity beneath the soil and waste treatment. Training and stimulation to participatory action and knowledge management by farmer families and actors implied in agroecology development.
Plant and animal diversification at species or genetic level in time and space.	Polycrops, rotations, animal husbandry-agriculture integration, maximum possible biodiversity and promotion of functional diversity.
Optimization of nutrient and water flow.	Production of organic fertilizers from harvest waste or animal excreta, infiltration trenches, contention barriers, water harvest, minimum tillage, contour rows and integration of crops and animal rearing.
Provision of optimum edaphic conditions for crop growth, with management of organic matter and stimulation of soil biology.	Addition of organic fertilizers, covers, green manures, incorporation of mulch, optimum irrigation and use of biological inputs.
Minimization of losses due to insects, pathogens and weeds through preventive measures and by stimulating the beneficial, antagonist fauna, and allelopathy.	Covers, contention barriers, terraces, windbreaks, stimulation of beneficial fauna and cycle closing.
Exploitation of synergies that emerge from plant-plant, plant-animals and animals-animals interactions.	Polycrops and rotations, incorporation of fruit or forestry trees and animals, use of renewable energy sources. Each element performs diverse functions and each function is based on several elements.
Economic viability	Use of renewable energy sources and appropriate technologies for the maximum possible efficiency, along with innovation, farmer experimentation and knowledge dialogue. Independence from the market of external inputs and optimum use of the available resources. Prices of family productions adjusted to production costs. Development of rustic breeds and crops adapted to the environment and local possibilities, conservation of the autochthonous or adapted seeds, adjustment to the family's preferences and to the local consumers' market. Maximum added value to the productions, articulation of short commercialization channels of the agroecological family productions and development of market policies that favor them.
Social justice	Local articulation of public policies of promotion and support, institutionalization of family agriculture, fair markets, solidary economy, awareness of the importance of consuming healthy food and developing family agriculture, valorization of the quality of agroecological products, "family origin denomination", popular certification and social recognition of the agroecology ethics.

Source: Gliessman (1998, modified by Casimiro, 2016)

(Stark *et al.,* 2018). The combination of crops and livestock has been defined by research, but not in an accorded way.

The European bibliography uses the term «mixed crop and livestock systems» (Moraine *et al*., 2016) to denote an association between crops and livestock under exploitation. In the American specialized literature allusion is made to «integrated cropping systems» (Hendrickson *et al.,* 2008), to make reference to the levels of integration between crop and livestock.

According to Bonny (1994), the concept of integrated production is similar to that of sustainable agriculture. This author establishes that integrated production is an agricultural system characterized by:

- Integrating natural resources and regulating mechanisms in agricultural activities, in order to achieve the maximum suppression of inputs [...]
- Guaranteeing the sustainable production of food and other high quality products through the preferential use of environment-friendly technologies [...]
- Maintaining the farm incomes.

- Eliminating and reducing the current sources of environmental contamination generated by agriculture.
- Supporting the multiple functions of agriculture.

There is a large diversity of definitions of mixed agriculture. Nevertheless, in all cases, the coordination levels are implicit, and make reference to its positive effect on the environmental and economic sustainability of all the areas (Horton *et al*., 2017). If the above-explained facts are considered, the mixed or integrated agriculture-animal husbandry systems (IAAHS) can be defined as production systems, which associate livestock and crops in a coordinated framework, more or less in interaction. These properties of biodiversity and interactions allow the concrete implementation of the principles of agroecology (Funes-Monzote, 2009).

Among the key emergent qualities of ecosystems, which are altered when becoming conventional or integrated agroecosystems, the following can be mentioned:

Energy flows

According to Odum (1971), energy flows through the natural ecosystem, as result of a complex set of trophic interactions, with certain quantities dissipated at different points and moments of the food chain. Finally, in this ecosystem, the highest quantity of energy moves by the waste path.

In agroecosystems, the energy flow is highly disturbed by human interference. Although solar radiation is the largest energy source for agriculture, many of the inputs used in the production process are derived from manmade sources, which are frequently not self-sustainable, such as fertilizers or oil-based fuels. At the same time, a considerable part of the produced energy is directed out of the system in each harvest, as main product or in the form of stem and leaf biomass (Funes-Monzote, 2009).

The use of energy from other sources will depend on the selected management systems and agriculture styles. Thus in conventional or specialized systems, it can be huge; while in IAAHS, the biomass that represents accumulated energy remains in the system to contribute to the functioning of important internal processes. Thus, the organic waste returned to the soil can serve as source of energy for microorganisms which are essential for more efficient nutrient recycling, and allow to decrease the use of agrochemical inputs. In these productive systems, biomass is used as fuel for the essential trophic interactions, in order to maintain other functions of the agroecosystem.

Nutrient recycling

In a natural ecosystem, the nutrients enter continuously in small quantities through several hydrogeochemical processes. Through complex interconnected cycles, these nutrients circulate in the ecosystem, where most of the times they are part of the living biomass or organic matter of the soil (Borman and Likens, 1967). In this process, the biological components of each system become very important to determine how to move efficiently these nutrients, and ensure minimum losses. In a mature ecosystem, these small losses are replaced by local inputs, maintaining the adequate nutrient balance.

In an agroecosystem, nutrient recycling can be minimal, and even null, losing considerable quantities of nutrients with the harvest or as result of lixiviation or erosion. This is explained by the constant reduction in the permanent levels of biomass kept in the system.

In the IAAHS, the mechanisms that allow nutrient recycling are favored and enhanced, because the outputs of one activity are used as inputs for another. This can also contribute to reduce the adverse effects for the environment and decrease the dependence on external resources.

Likewise, mixed agriculture improves soil fertility, because the addition of manure to the soil increases its nutrient content, its water holding capacity, and improves its structure. In addition, if rotations of diverse cops and forage legumes are used, the soil nutrients are replaced and erosion is reduced. In this sense, integrated systems have the advantage of allowing the diversification of species and recycling of harvest residues. Thus, nutrient losses are avoided and value is added to the crops and agricultural products (Alves *et al.,* 2017).

Mechanisms of population regulation

In natural ecosystems a natural control is established in the population levels of the different organisms by a complex combination of biotic interactions and limits imposed by the availability of present physical resources. The presence of organisms in a complex but interacting organization, and the environmental conditions under which they are developed, allow the establishment of diverse trophic interactions and niche diversification (Gliessman *et al.,* 2007).

In agroecosystems, the genetic selection and domestication conducted by humans, generally lead to their simplification, which causes the loss of biological diversity and reduction of trophic interactions.

The populations of plants and animals cultivated are very rarely self-regulated, especially agricultural pests. By decreasing biological diversity, the natural systems of pest control are reduced and interrupted, because many niches and habitats become unoccupied and, consequently, the danger of epidemics or pests is increased.

On the contrary, in mixed systems, which have higher agrobiodiversity (genetic, horizontal and temporary), the biotic regulation process is favored and, consequently, the pest incidence is lower. In these systems, the presence of alternative habits for natural enemies is higher, and there is lower concentration of food for pests, lower possibility that certain weeds become dominant population, besides the fact that rotations can promote the activity of pest or disease controlling organisms of the next crop (Vázquez, 2015).

In IAAHS, there is increase of the vegetation strata (vertical diversity), increase of the beneficial entomofauna (specific diversity) and activation of the soil biology. In this case, the ecological processes of biotic regulation and nutrient recycling are favored (functional diversity).

Dynamic balance

The system stability is not synonym of a stationary status, but rather of a dynamic and highly fluctuating status, which allows the ecosystem to recover after a disturbance. This promotes the establishment of a dynamic ecological balance, which functions based on the sustainable use of resources, which can maintain the ecosystem for a long term, or adapt when the environment changes. In mature ecosystems, the richness of species allows high degree of resistance to environmental disturbances; they even have high resilience to truly harmful disturbances, such as hurricanes (Connell, 1978).

The resilience of agroecosystems is closely related to their diversification level in terms of management practices and plant and animal species. In conventional agricultural systems, the excessive emphasis on maximizing the harvest disturbs the above-mentioned balance in natural ecosystems, so that productivity can only be maintained if external interference through inputs continues, importing energy and nutrients (Gliessman *et al.,* 2007). Meanwhile, in IAAHS, biodiversity management offers efficient support to buffer the effects of extreme climate events on productivity and incomes.

Unlike conventional systems, agriculture-animal husbandry integration, when applying agroecological principles, strengthens the links among the different biophysical components, and offers opportunities for its multi-functionality.

Integrated systems are characterized by a null or minimum dependence on agrochemicals, fossil fuels or energy subsidies. These agricultural systems, capable of subsidizing their own fertility and productivity, are the most viable choice for agricultural production in the face of the currently existing energy, climate and financial limitations (Nicholls and Altieri, 2019).

The benefits of agriculture-animal husbandry integration, mainly through agroecological processes, have been described in scientific literature. Regarding the environmental performance, integration is important for the preservation of biodiversity (Kronberg and Ryschawy, 2019; Rosa-Schleich *et al.,* 2019) and for carbon capture (Smith and Lampkin, 2019). Regarding economic performance, the complementarity between agricultural and animal productions allows the reduction of costs and increase of economic efficiency (Thornton *et al.,* 2018; Rose *et al.,* 2019).

IAAHS have as one of their main objectives the development of strong interactions among their components and, when these interactions are adequate, they are more efficient in the use of natural resources (Thornton *et al.,* 2018), promote nutrient recycling and soil amelioration (Stark*,* 2016; Stark *et al.,* 2018), reduce production costs (Ryschawy *et al*., 2017), maintain high productivity levels and generate diverse ecosystemic services (Kronberg and Ryschawy, 2019). Among other advantages of IAAHS, risk diversification, more efficient use of labor and added value of crops and agricultural products, are included (Alves *et al.,* 2017; Koppelmäki *et al*., 2019).

The above-presented analysis allows to recognize the importance of understanding the structure and function of an agroecosystem based on the knowledge provided by ecology. Nevertheless, it should not be forgotten that the structure and function of an agroecosystem is also the result of a social fabric that exerts a strong influence, for which farmers' decisions will have repercussions on its design and management too (Gliessman *et al.,* 2007).

Agriculture-animal husbandry integration is considered an adequate alternative to face the current environmental, economic and social restrictions of sustainable development (Nath *et al.,* 2016; Gil *et al.,* 2017), because these agroproductive systems, which combine crops, livestock and trees, offer remarkable opportunities for sustainable intensification and efficiency in the use of resources.

For these reasons, the international scientific community is interested in studying their possible potentialities, based on the animal/crops interrelation, in order to increase the production, efficiency and stability levels (Tully and Ryals, 2017; Rosa-Schleich *et al.,* 2019; Walia *et al.,* 2019).

On spite of the above-explained facts, there are still limitations for the development of IAAHS or mixed systems. Among them the great need of labor force during the establishment stage, lack of capital for their implementation (Rosa-Schleich *et al.,* 2019; Walia *et al.,* 2019) and the priority that is still given to conventional agriculture and its specialized infrastructure. It is also necessary to know in higher detail how IAAHS work, as well as to disseminate the knowledge to achieve an adequate design for each context (Chandra *et al*., 2017; Doherty *et al.,* 2019; Magne *et al.,* 2019).

Innovative approaches are needed, which allow to study, implement and disseminate agricultural systems, integrated at higher scale and with different complexity levels.

Final considerations

The integration of animals and crops generates synergies that enhance the productive capacities of agroecosystems. It is also known that the vulnerability to agricultural pests, dependence on external inputs and capital requirements, are reduced, along with higher efficiency in land use.

The application of agroecological approaches contributes to the sustainable intensification of food production and to the solution of many problems, relative to the adverse environmental effects and to the low productivity and efficiency that still prevail in specialized systems.

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Authors' contribution

- Katia Bover-Felices. Contributed to the conception and design of the paper, wrote and revised its content.
- Jesús Suárez-Hernández. Contributed to the conception and design of the paper, wrote and revised its content.

Conflict of interests

The authors declare that there is no conflict of interests between them.

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