Agroecology: scientific and technological challenges for agriculture in the 21st century in Latin America

Agroecología: retos científicos y tecnológicos para la agricultura del siglo XXI en América Latina

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ABSTRACT

In the first section of this article, an analysis is presented of the evolution of agroecology as a scientific discipline starting with its establishment in the third decade of the twentieth century and with an emphasis on the contributions of the different disciplines as well as the local knowledge and the most significant theoretical developments since its inception. Agroecology as a science has been emerging incrementally through knowledge obtained from disciplinary contributions although it is distinguished from its parent disciplines through the integration of these disciplines and work that occurs across scales. Such research leads to a broader understanding of the associated problems and their solutions, which are characterized by an integrative approach in which disciplinary information is collected and processed to resolve problems on greater scales. The second part of the article starts by establishing five challenges of agriculture in Latin America that can be significantly improved through contributions from agroecological science. These challenges could be achieved by taking into account agroecology as a science, practice and social movement; where the agroecology as a practice will act as a functional interface to the others. To achieve these challenges, five main topics have emerged including the reductionism or holistic research approach, the scale of the planning and analysis unit, concretizing discussions on sustainability, quality management and producers organization strengthening; each of these topics is discussed.

Key words: natural resources, ecological balance, sustainability, socioeconomic development, livelihood diversification, less favoured areas.

RESUMEN

En su primera parte se realiza un análisis de la evolución de la agroecología, como disciplina científica, desde sus inicios en la tercera década del siglo XX; enfatizando los aportes de las diferentes disciplinas así como del conocimiento local y los desarrollos teóricos más importantes desde su misma definición. La ciencia agroecológica ha venido emergiendo paso a paso, nutriéndose de los aportes disciplinarios pero distinguiéndose de sus disciplinas parentales por su integración entre estas disciplinas y a través de escalas, dando lugar a un conocimiento de los problemas y a una oferta de soluciones a los mismos caracterizados por un enfoque integrador, donde la información disciplinaria es colectada y procesada para resolver problemas a más altas escalas. La segunda parte de este artículo establece cinco retos de la agricultura en Latinoamérica que pueden ser mejorados significativamente a través de las contribuciones desde la agroecología como ciencia. Estos retos podrían ser alcanzados tomando en cuenta la agroecología como ciencia, práctica y movimiento social; donde la agroecología como práctica actúa como una interfaz funcional para las otras dos. Para alcanzar los retos mencionados emergen cinco tópicos que incluyen el enfoque reduccionista u holístico en la investigación, la escala de la unidad de planeación y análisis, concretar las discusiones en sostenibilidad, manejo y gestión de la calidad y fortalecimiento organizacional de los productores. Cada uno de los tópicos mencionados es discutido.

Palabras clave: recursos naturales, equilibrio ecológico, sostenibilidad, desarrollo socio-económico, diversificación de medios de vida, zonas en desarrollo.

Introduction

Over the past 50 years, surprising increases in agricultural yields have been achieved because of technological and research. However, the economic, environmental and social costs of conventional production models must be able to manage information related to agriculture to address the complexity of unresolved issues. Such management must also offer alternatives to reconcile human demands with the need for natural equilibrium and fair economic and political systems. Under this type of management, the agricultural producer of the 21st century must be an active subject where decisions are no longer the result of a list of requirements but based on knowledge and empowerment. Technology alone does not guarantee ongoing success, which is reflected in the variable success of a

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given technology depending on the situation. Similarly, agricultural restrictions have changed over time and will continue to change; for example, future harvests will be the product of less land per capita, less available water, and a more diversified genetic foundation and management system than is observed with conventional methods.

This article has two parts. The first part presents an analysis of the evolution of agroecology as a scientific discipline starting with its establishment in the third decade of the twentieth century and emphasizing the contributions of the different disciplines and the most significant theoretical developments since its inception. The second part discusses the five challenges of agriculture that can benefit from the contributions of agroecological science.

Agroecology and its evolution throughout the agricultural sciences

There are some publications that have done deep reviews on agroecology evolution (Hecht, 1991; Dalgaard *et al*., 2003; Wezel and Soldat, 2009; Wezel and Jeauneau, 2011; Koogler, 2015) These publications show that the term agroecology was proposed in the Third decade of the twentieth century, initially as a synonym for the application of ecology within agriculture. According to Dalgaard *et al*. (2003), when the term was first proposed, the ecological approach was still narrow although it had already shown a trend toward a more integrated view of ecosystems. After more than 80 years, agroecology as a science integrates not just the perspective ecology-agriculture at the plot or farm level, but a wider approach involving interactions at the regional and country level. Taking into account this approach, Dalgaard *et al*. (2003) suggested that agroecology will be defined as "the study of the interactions between plants, animals, humans and the environment within agricultural systems".

Since the early 1970s, the scientific literature, with an agroecological focus, has expanded significantly. The first volume of the journal "agroecosystems" was published in 1974 and included work by Harper, Spedding, and Fassbender, which was inspired by the school of ecological processes of Tansley (1935) and by the theory of systems analysis of Von Bertalanffy (1969) and stimulated the development of scientific research in agroecosystems. Subsequently, studies from Dalton (1975), Netting (1976) Van Dyne (1969), Spedding (1988) and Cox and Atkins (1979) were published. Special mention should be made of the contributions of Hart (1979), who synthesized the methodological bases for research into agricultural systems in his book *Introduction to Agroecosystems* and provided significant contributions to the conceptualization, modeling, and criteria for the evaluation and validation of such systems. These contributions were definitive at a time when the results of agricultural research at national and international centers were not well adopted, which was primarily because the biophysical and socio-economic conditions of the research centers did not represent the actual conditions of most producers and the producer and traditional production systems were not recognized as useful sources of knowledge and experience for agricultural research. These two elements represented, especially in Latin America, the pillars of the development of two movements within agricultural research that have provided strong contributions to the agroecological science.

Contributions to agroecological science from ecological knowledge and local knowledge

The first of the two movements mentioned above is represented by Gliessman *et al*. (1981), Vandermeer (1981), and Ewel (1986), who focused on designing agroecosystems that would imitate the components and functions of local natural ecosystems. This movement includes ecological knowledge, which incorporates certain elements of local knowledge, including rural production systems, in its management. The authors mentioned above were joined by entomologists who were developing integrated pest management strategies and made valuable contributions to the development of an ecological perspective for the protection of plants. The theory and practice of the biological control of pests is based exclusively on ecological principles (Wilson and Huffaker, 1976). Ecological pest management focuses on approaches that compare the structure and operation of agricultural systems with that of relatively undisturbed natural systems or more complex agricultural systems (Southwood and Way, 1970; Price and Waldbauer 1975; Levins and Wilson, 1980; Risch, 1981; Risch *et al*., 1983). Browning and Frey (1969) had previously argued that approaches to pest management should emphasize the development of agroecosystems that mimic natural succession as closely as possible because these mature systems are often more stable than systems that consist of a simple structure of monocultures.

A number of research centers, government organizations, and non-governmental organizations (NGOs), such as CATIE, in Turrialba, Costa Rica, the International Development Research Center (Centro Internacional de Investigaciones para el Desarrollo - CIID), the Latin American Center for Rural Development (Centro Latinoamericano para el Desarrollo Rural - RIMISP) have focused their efforts on guiding research programs in the tropical areas of

Latin America to improve the design and management of agroecosystems based on rural production systems, or local knowledge, since the 1970s, and their work has coincided with the approach of assessing ecological knowledge and local knowledge with the aim of providing farmers with access to technology according to their resources and needs. These activities encompassed two large topics: research on associated crops and research on agroforestry systems.

In tropical agriculture, the highest expression of the synergy between ecological knowledge and local knowledge is represented by associated crops. This system of agricultural production is governed by a series of natural principles complemented by knowledge that has been accumulated for hundreds of years by local populations. Investigations have shown that compared with monocultures, these systems provide advantages that reduce farm labor needs and machinery usage and they may also decrease soil compaction and erosion and help regulate factors such as wind, humidity, radiation and temperature in productive systems. In addition, these systems improve soil fertility through the continuous addition of organic matter to the soil, increase the exchange of nutrients in a more balanced way and increase the life of the soil. Moreover, associated crop systems help control and prevent certain common problems, such as weeds, pests and diseases because of the greater genetic diversity and they also have the potential to increase sales and improve the quality and variety of food production (Soria *et al*., 1975; Tapia, 2000).

Highlighting the role of the arboreal component of many traditional agricultural production systems, important studies on agroforestry systems and associated crops have been published since the end of the 1970s with the goal of optimizing these systems. Land management techniques are recognized in these systems, which involve combinations of perennial tree or shrub species with crops, domestic animals or both (Combe, 1982).

In the early 1980s, a movement involving scientists, professionals and students from different areas was developed with a focus on recognizing and incorporating ecological and local knowledge on the design and management of these burgeoning agricultural production systems. This movement has maintained an open criticism of the technological model known as the green revolution and, as a response to this model, the movement has proposed different production systems that are collectively known as alternative agriculture. The ideological basis of this movement is political ecology based on environmentalism, which presents powerful criticism against economism and the technological optimism of the powerful and wealthy; thus, rural farmers can be considered as the main subject of this environmentalist movement (Martínez, 1990). According to Toledo (1990), "research and interpretation of the natural and social reality eventually become valuable tools of specific political projects and cease to be academic exercises or acts of creativity without direct relationships with their historical-social times and spaces… The rural issue not only does not escape this phenomenon, but… given its peculiarities, makes up precisely one of the key areas of reality that calls for a comprehensive or multidisciplinary approach, and whose study requires a political vision and commitment".

A well known practitioner of political ecology is Altieri (1999), who underlines that the scientific basis of alternative agriculture is agroecology, which started from the practices of groups of producers such as small farmers from underdeveloped countries (especially in Latin America) and organic farmers that were emerging in Europe and the United States. These producers inadvertently challenged the dominant position currently occupied by chemical and mechanized agriculture in such a way that their production systems became the basis for the design of agroecosystems that include principles of stability and productivity. Toledo (1990) suggested an interdependent relationship between the production of rural systems and the production of sustaining natural systems in such a way that the destruction of rural forms of production almost always corresponds to ecological destruction, and vice versa. This conclusion applied to any process of modernization emphasizes the importance of understanding the rural methods of using nature that according to Toledo (1990) is the only method of constructing new rural development schemes, new technologies, and new civilization schemes.

Discussion: challenges of agriculture approaches and the role of agroecology in the 21st century as an integrative discipline

The agricultural systems of the 21st century in Latin America will be faced with a number of challenges, including the issues listed below.

1. Strengthening our understanding of the interactions between various subsystems at different hierarchical levels in agricultural systems and providing alternative solutions that may help overcome the limitations of traditional disciplinary research.
2. Incorporating quality management as a desirable but necessary reference in response to the inherent

ethics involved in the relationship between agriculture, consumers and the environment. A model should be developed that incorporates planning, administration and management to effectively take advantage of the knowledge and understanding of agricultural systems and their relationships with society.

3. Developing technologies that take advantage of the sustainable use of local supplies over external supplies; facilitate the conservation of natural resources and the use of renewable sources of energy; promote the management of phytosanitary and nutritional issues rather than just controlling them; use strategies to adapt genetic materials to environmental supplies; and understanding the role of local biodiversity in the balance and productivity of ecosystems to incorporate these functions into agroecosystems.

4. Improving extension programs by linking the technical production developments to organizational development, institutional articulation, commercial development and local, regional and national policy coordination.

5. Rehabilitating the cultural diversity reflected in traditional productive systems whose products have guaranteed food security and fostered cultural and social relationships that typify the identity of Latin American people.

For almost a hundred years, scientific research results have been published from the most diverse components of agricultural production systems. These studies tend to explore the complexity of the system and address issues that we currently understand as important for building integrative proposals that exceed the limitations of scientific disciplines working in isolation. Agroecology as a science has been emerging incrementally through knowledge obtained from disciplinary contributions, although it is distinguished from its parent disciplines through the integration of these disciplines and work that occurs across scales. Such research leads to a broader understanding of the associated problems and their solutions, which are characterized by an integrative approach in which disciplinary information is collected and processed to resolve problems on greater scales.

In the early 21st century, extreme conceptual tendencies are being reconsidered; there are no winners and no losers and this trend extends to agroecological science. As described in this study, the construction of agroecological concepts includes a variety of approaches and perceptions that must be considered together, regardless of any desires for them to remain mutually exclusive. The challenges listed at the beginning of this chapter will be achieved taking into account agroecology as a science, practice and movement; where the agroecology as a practice will act as an interface to the others. To achieve those challenges, five main topics have emerged including the reductionism or holistic research approach, the scale of the planning unit, concretizing discussions on sustainability, quality management and organization strengthening.

Reductionist and holistic approaches

The central problem that separates reductionist and holistic research is the definition of limits. Bland and Bell (2009) proposed that the two perspectives may be reconciled if fundamental aspects are properly identified as the subject of study. These authors proposed the concept of "holon" for agroecological science. For these authors, the "holon" is something that is simultaneously the whole and part. The notion of the agricultural producer, which may be a multinational corporation or a mother with a family who owns a small plot in Bangladesh, should be central to agroecological sciences. This concept holds if we understand agriculture as planning and human action to develop livelihoods through raising plants and animals (Bland and Bell, 2009), in which the appreciation of the human being as the lead and main actor is evident. This approach helps to reconcile the intentionality of the producer and the notions of agriculture as a system.

The proposal of Bland and Bell may not be initially understood, especially because of the implicit inequities in economic-financial processes and the market, which has established large differences between the types of farmers in Latin America. However, all producers, whether large or small or rich or poor, are important in agricultural research, and given their highly complex characteristics, most of the technological problems in agriculture will be resolved through agroecological science.

Compared with research from 10 or 20 years ago, current agricultural research often includes researchers working in interdisciplinary groups. In these work environments, disciplinary distances are less important and complementary efforts are more evident, which suggests that in practice, a large part of the scientific community has overcome issues that once made open communication and open understanding impossible between disciplines, including more systemic views of the complexity of the problems surrounding agriculture.

Complementarity between the approaches of agroecosystems, with farms and landscapes as the planning units

The agroecosystem is understood as a coherent spatial and functional unit of agricultural activity that includes living and non-living components as well as their interactions and it has been assumed as the unit of study in agroecological science (Gliessman *et al.*, 2004). Many studies, however, have focused on the internal components of the agroecosystem and completely ignored its external relationships, including basic relationships, such as ecological and environmental impacts, socio-economic viability and cultural effects. For Hart (1979), the integrative approach must recognize the hierarchy of the subsystems in relation to the central subsystem of study. The agroecosystem has inputs and outputs that relate it to higher and lower hierarchical levels. Moreover, the domain of recommendations or the range over which a single hierarchical level can be extended have impacted the description of behavior at higher hierarchical levels because processes may be involved that depend on the scale at one or more hierarchical levels (Checkland, 1999; Dalgaard *et al.*, 2003). Thus, agroecological science is called upon to improve the quality of the decision-making process, an aspect that Giampietro *et al.* (2009) indicated has not been considered by scientists in the past because they have been searching for the best solution. In this context, studies that do not integrate this minimum requirement can hardly be valued as agroecological studies.

At the farm level, it may be desirable to integrate various agroecosystems where the outputs from one can be the inputs for another; thus, in the context of sustainability, farms must be integrated into management units in which activities beyond agricultural production are involved. From this perspective, an agroecological trend called ecoagriculture has emerged (McNeely and Scherr, 2001; Scherr *et al.*, 2008). Ecoagriculture integrates the diversity of agricultural systems with an assortment of land uses, including forests, human settlements, watersheds and coastal areas. According to Buck *et al.* (2006), it is critical to consider the natural and semi-natural systems that interact with agricultural systems to identify synergies between production and conservation. For example, a nature preserve can benefit neighboring farms by providing clean water and agricultural pest control, whereas the high and sustained levels of agricultural production of the farms can decrease the pressure for agricultural expansion into the preserve.

Concretizing discussions on sustainability: minimal dependence on external inputs and the design and management of agroecosystems that exceed critical factors for conventional agriculture

Sustainable production systems must meet four basic criteria: ecological sustainability, social justice, economic viability and cultural acceptability.

Ecological sustainability refers to the proper use of natural resources (soil, water, air, biodiversity) so that they remain intact and functional over time. Social justice refers to recognizing the rights of society as a whole, especially the rights of rural inhabitants and ethnic groups in terms of their land, resources and knowledge as well as their basic rights for social security and work. Economic viability is often considered from different perspectives: for economists, it is usually measured by cost-benefit relationships or internal rates of return related to the cash flow across a production cycle, whereas for environmentalists, it often introduces externalities that demonstrate how other players that are dismissed in classical economics impact cash flow. However, neither of these perspectives considers the rationality of the production systems of rural inhabitants or indigenous populations, which have remained despite the economic crisis, while many modern agricultural enterprises have collapsed. Cultural acceptability refers to an empathetic relationship between a production system and the traditions and culture of the local people that demonstrates respect for the social fabric that communities have built (Argüello, 2004).

The sustainability of the production systems of rural inhabitants is addressed to avoid risk. The word risk often summarizes the perception rural producers have of economic viability and cultural acceptability. Risk is well perceived by the small producer who is reluctant to join technology-transfer programs, not because of a lack of understanding of the new technologies but because the new technologies may convert his production systems into systems that are dependent on technological procedures that he may not be able to afford in the long run, with these procedures including credit, fertilizers, pesticides, fungicides and herbicides. The farmer is aware of situations in which his neighbors have faced seizures or have had to sell their land because they were not able to pay the price of making a bad decision. For a farmer, a bad decision may affect not only his production system but also his family and his cultural identity if he becomes displaced to a city, which may not support the social fabric that once guaranteed his wellbeing (Argüello, 2004; Borras, 2009).

Currently, society demands the availability of abundant, inexpensive and healthy food. However, this trend shows that, although food is abundant, it is increasingly expensive and may carry different types of contaminants that could pose serious risks to the population and the environment (Daniel, 2008).

The sustainability of the conventional agriculture is limited by its dependence on external inputs. Agricultural production has become a big business for companies that produce agricultural inputs, although not always for the producer. Agricultural business strategies have always been characterized by having to convince producers of the need to use more synthetic inputs every day. The inputs include fertilizer as well as seeds, which are susceptible to pests and diseases; thus, pesticides are also included as inputs. However, the failure of these technologies has led to requirements dictating the use of transgenic seeds for all producers worldwide. These strategies are designed to generate a greater and greater degree of dependence.

The contributions of agroecological science have shown for some time that abundant, inexpensive, and healthy food can be produced. However, Rosset and Altieri (1997) suggested that the problem goes far beyond simply replacing inputs and resolutions require changes in the planning and design of agroecosystems to transform the key forces that have caused issues in conventional agricultural systems, such as extensive use of monocultures, excessive use of machinery, control of inputs by producing companies, dependencies on fossil fuels, and high requirements for capital.

Quality management

The intense worldwide development of the non-conventional agriculture sector, such as organic farming, must be understood as a consequence of increased awareness by consumers who want food that is safe and has a high nutritional value. Thus, compared with global products that present an unnatural homogenous appearance, foods associated with a particular environment and that represent local raw materials are perceived as more natural and of greater quality (Nygard and Storstad, 1998). The societal sensitivity towards environmental deterioration, consumer desire for natural products and regulations that establish a fair relationship with rural workers to guarantee access to social security and minimal occupational hazards must be considered in the agricultural production of the 21st century, especially in agroecological proposals. Similarly, the management of agro-ecological processes must consider not only the stages of production but also the entire production chain according to new rural perspectives.

Producer organizational strengthening

Agroecology, as a social movement, could help to strength rural inhabitants and indigenous organizations. Besides the weaknesses of technology for production at the farm level, the hardest barriers for rural producers are commercialization and production costs. Often, rural producers have no union recognition and its greater disadvantage lies in the lack of collective action. Among the goals of a transition to agroecology are increased autonomy from input markets, putting peasant families in control of their own production systems, restoring degraded soils, living in harmony with Mother Earth, producing healthy food, improving the economic viability of rural agriculture, and building food sovereignty up from the level of rural families to the national level (Rosset *et al*., 2010).

Strengthening member organizations is a critical priority. The experience of the "campesino a campesino (CAC)" in Cuba shows that the tasks of internal strengthening and the promotion of CAC can be mutually supportive in terms of developing grass root leadership cadre and credibility inside organizations (Rosset *et al*., 2011). At the same time, these efforts could contribute to an autonomous community based extension programs that could overcome the limitations of the national institutional extension services and keep and strength cultural and social relationships.

Conclusions

An important number of publications show the evolution of agroecology as a science for the last 90 years. The scientific literature has contributed to the conceptualize and integration of knowledge from diverse disciplines into the agroecology core, mainly based on the application of components and functions of local ecosystems to design agroecosystems -ecological knowledge- addressed to develop making decisions capacities to solve concrete problems. However, complementary knowledge, from rural inhabitants and indigenous production systems or local knowledge, has transcendental significance to not just theoretical but to solve gaps for agroecology as a practice. This contribution is the basis for the alternative agriculture movement in Latin America.

Challenges of agriculture approaches and the role of agroecology in the 21st century include overcoming the limitations of traditional disciplinary research on agricultural systems; incorporating planning administration and quality to take advantage of the knowledge and understanding of agricultural systems and their relationships with society, which wants healthy food produced without negative environmental impacts; developing technologies that minimize external dependence and taking advantage of the sustainable use of local suppliers far beyond simply replacing inputs; improving the autonomous community based extension programs based on community organization strengthening that, besides its capacity to overcome limitations on commercialization and production costs, could keep and strength cultural and social relationships.

Agroecology, as a practice, will be an interface among agroecology as a science and a social movement. An integration of these three approaches is necessary, taking into account the complexity of agricultural systems. The solutions to the Peasants and indigenous people need to integrate efforts and agroecology could be a useful platform.

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