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Agroecology as a Science of Integration for Sustainability in Agriculture

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Abstract

A knowledge contribution is provided in order to understand agroecology as both a scientific discipline and a philosophical paradigm for promoting sustainability in agriculture. The peculiar character of agroecology as an applied science based on the systems paradigm is explored in the fields of research and tuition. As an organisational capability of connecting different hierarchical levels in accordance with the goal of sustainability, integration is shown as an emergent property of the evolution of agriculture as a human activity system.

Key-words: Agroecology, integration, sustainable agriculture.

1. Introduction

Agroecology is the science of ecology applied to agriculture. According to a more detailed definition (Francis et al., 2003), agroecology is the *integrative* study of the ecology of the entire food system, encompassing biophysical, economic and social dimensions. Indeed, its peculiar character is that to be an "integrative" science, i.e. a science that looks for relationships in order to promote more understanding of the agricultural reality and its context. Society as a whole seems to be reactive to agroecological pressure, as it shown at academic, political and practical levels.

At academic level, new curricula in Agroecology and in Organic Farming have already been implemented in Europe (Francis et al., 2003; Caporali, 2004) and are currently under construction in cross-continental university networks, like that promoted in the EU programme "Asia-Link" (Caporali, 2006). At political level, the Rio UN Conference of 1991 on "Sustainable Development" yielded the most important international document or platform for decision making processes (Agenda 21). Many chapters – 7, 8, 10, 14, 15, 16, 28, 31, 32 – have been devoted to directly or indirectly promoting sustainable development in agriculture, in accordance with agroecological principles (FAO, 2002; Caporali, 2006). At practical level, IFOAM (International Federation of Organic Agriculture Movements) has been successfully established since 1972 as a network of farmers and other stakeholders in the agriculture chain in order to promote continued development of organic farming worldwide.

The aim of this contribution is to illustrate the many patterns of the integrative character of agroecology at academic level and their positive implications on theory and practice of agriculture.

2. Agroecology is a science of public utility

Agroecology integrates theory and practice. According to Edwards et al. (1993), agroecology is a relatively new discipline that integrates the techniques and paradigms of ecology with the practices of agricultural sciences for the study of agroecosystems. As an applied science, agroecology focuses both on theoretical principles and on their practical applications in order to inform design and implement solutions to real

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problems. With this attitude, it reflects the most original innovative character of humanism, as expressed earlier in the 15th century by Leonardo da Vinci, who stated that "the most useful science is that more communicable" (Trattato della Pittura, 1490-1519). This ontological link between theory and practice in agroecology is well shown by the following key-word sequence:

Ecology → Agroecology → Sustainable Agriculture → Organic Farming

that unveils how the science of ecology, once applied to agriculture (agroecology), has generated a set of values or paradigm for an ideal model of agriculture (sustainable agriculture) which is currently being implemented (organic farming) in compliance with a practical platform (standards) defined and supported by law (Caporali, 2004). On this base, Gliessman (1998) was right in defining "Agroecology as the application of ecological concepts and principles to the design and management of sustainable agroecosystems".

3. Agroecology is a science based on the systems paradigm

The most relevant scientific character of agroecology is its methodology based on the systems paradigm, which is *the integrative principle* by definition. Indeed, a system is a functional unit in a context made up of parts or components, which are functionally linked and interdependent. When applied to agriculture, the systems paradigm generates a representation model of agriculture or agroecosystem, which is both a scientific and an epistemological tool for enquiry at any spatial and temporal scale. In analogy with the ecosystem concept, the agroecosystem is both an ecosystem modified and used for agricultural purposes as well as the model that represents it. In this sense agroecology exhibits a method that reflects contents, whereby ontology and epistemology coincide (Caporali, 2006). The best general model to represent structure and functioning of an agroecosystem is based on an input/output functional scheme (Fig. 1), where socio-economic and biophysical components are fully integrated in a process of continuos production and consumption that happens at any spatio-temporal scale. The agroecosystem concept is like a lens for focusing on rural reality at different levels of resolution. With this process of enquiry, the four fundamental elements of the systems paradigm – *hierarchy, emergence, communication and control* (Checkland, 1993) – are unveiled.

The systems paradigm is completely reflected in agroecological research and teaching.

Table 1. Application of the systems paradigm in agriculture: expression of the hierarchy concept

Agroecosystem's hierarchical level	*Fields of study and management*
Field system	Soil-plant-atmosphere relationships
Cropping system	Relationships between crops in a spatio-temporal scale
Farming system	Relationships between crops, livestock and management
Landscape system	Biodiversity. Land conservation practices and aesthetics
Regional system	Rural activity integration; socio-economic development
National and International system	Globalisation aspects (Market, Economy, Policy and Environment)

3.1 Hierarchy

Hierarchy in agriculture is to be meant as a spatio-temporal continuum or an open, interconnected sequence or stratification of multi-layered agroecosystems, which are isolated only for a necessity of study and management (Tab. 1,

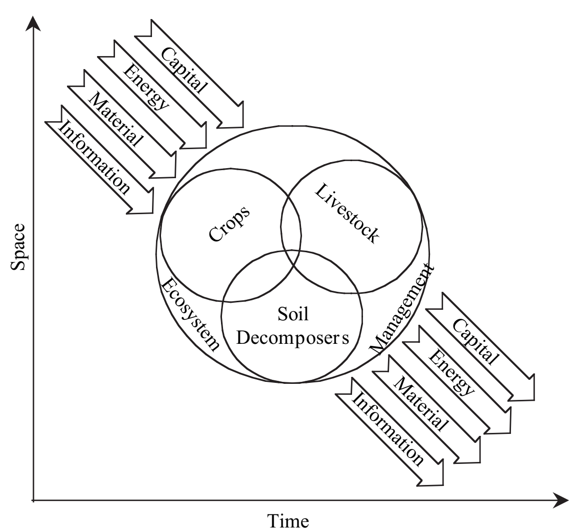

Figure 1. Agroecosystem as an input/output model of agricultural reality.

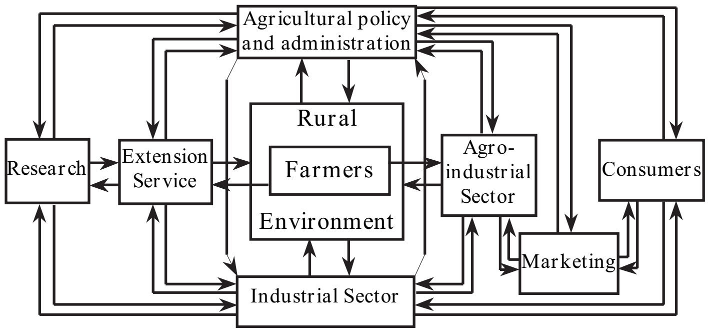

Figure 2. Agriculture as a system of human activities. – Farmers, who are at the heart of the system, organise their activity to interact with other components of the agricultural system. These interactions manifest themselves firstly through information exchanges and secondly in the form of energy-matter exchanges between the agroecosystem and its context. The context is by now globalized and it results from the interaction of the national economies within the international scenario (Caporali, 2004).

Caporali, 2006). The functional characteristics behind this hierarchical representation model of agriculture is the *openness* of each level in the sense that each level is at the same time context of the next lower level and component of the next upper level. Therefore, integration between different levels is an ontological necessity for the existence and the functioning of both each level and the whole system.

For agroecosystem design, planning and implementation according to an ecological perspective, hierarchical organisation of levels of enquiry should be better meant as *hierarchical integration* of levels of enquiry, because there is the need to harmonise all levels of hierarchy for the common goal and good that is sustainability of agriculture. Indeed, integration is a kind of organisation that is purposefully oriented. Due to the ecosystem representation of reality, there is an ontological link (Caporali, 2006) between ecology and sustainability because sustainability is the ultimate property of ecological systems. That means that ecology and sustainability are inherently interconnected and we cannot speak of ecology without meaning sustainability as well as speak of sustainability without meaning ecology.

3.2 Emergence, communication and control

Scaling up hierarchical levels, new properties emerge that are manifestations of more communication and control between levels. Emergence or the appearance of a new component or property at any hierarchical level is an effect of more integration. Usually, an emergence is a more adapted component or a more complex property that stems from the interaction of more components (communication) and is useful for conferring more coherence among components within a hierarchical level and/or more correspondence between different levels (control).

In a complex human activity system like agriculture (Fig. 2), where socio-economic components interact with biophysical ones, regulations in agriculture are good examples of emergence, communication and control at the same time. Being agriculture appropriately represented as a network of socio-economic relationships nested upon a rural environment, is the hierarchical level of the latter which establishes the kind of outcome brought about by a new regulation in agriculture. Indeed, when a new regulation is issued in agriculture, a re-organisation of its system components is expected, with changes that can be appreciated at any hierarchical level, i.e. field, farm, landscape, region. In essence, a new regulation in agriculture is an emergence in organisation through communication (extension service, training, etc.) and control (incentives, taxes, etc.) that brings about changes in the properties of the whole system and its components. Organic farming regulations recently approved by many countries in the world can be regarded as new emergences in both the national and global agriculture systems – with a peculiar character of communication and control like certification procedures and produce labelling – purposefully devoted by the civil society to re-orienting agriculture towards sustainability. This kind of emergence can be considered as an adaptation process of agriculture, a human activity system culturally driven and operating for the common good.

4. Integration in Research

The field of agroecological enquiry is defined by its epistemological tool, i.e. the concept of agroecosystem. Indeed, the whole range of interest for research in agroecology stretches along the key-word sequence ecosystem between ecology and sustainability → agroecosystem → sustainable agriculture. Of course, agroecological research can be carried out at any level of agriculture hierarchy, but the inherent goal of any kind of research should be the search for sustainability. Because agroecosystem sustainability is an outcome of human behaviour, a strong element of ethics emerges as a fundamental responsibility component of agroecological research. As a consequence, research in agroecology integrates also ethical principles both as efficient and final causes of its process of development. Due to both the general methodology of enquiry of agroecology that represents agriculture as a hierarchy of agroecosystems and the overall goal of agroecology that is sustainability of agriculture, agroecological research is confronted with the challenge to explore and integrate both the socio-economic and the biophysical conditions that can ensure sustainable development of agriculture.

The political recognition of agriculture as a multipurpose activity in society has promoted the need to invest more intellectual and financial resources in research for monitoring and measuring sustainability conditions in agriculture, in order to appropriately inform decision making processes at both institutional and individual levels. The necessity to stress the importance of the decision making process in society is well documented by the chapter 8 of Agenda 21 "Integrating environment and development in decision-making", where it is stated that: a) prevailing systems for decision-making in many countries tend to separate economic, social and environmental factors at the policy, planning and management levels; b) there is the necessity for a better integration among national and local government, industry, science, environmental groups and the public in the process of developing effective approaches to environment and development, c) responsibility for bringing about changes lies with governments in partnership with the private sector and local authorities, and in collaboration with national, regional and international organisations; d) the overall objective is to improve o restructure the decision-making process so that consideration of socio-economic and environmental issues is fully integrated and a broader range of public participation is assured.

Among the activities for improving planning and management systems, data and information collection is crucial; therefore, it is recommended that "countries could develop systems for monitoring and evaluation of progress towards achieving sustainable development by adopting indicators that measure changes across economic, social and environmental dimensions".

In agroecology, the knowledge tools suitable for this task are named Agriculture Sustainability Indicators (ASIs) and their development and use have been largely promoted in research as a necessary instrument for understanding agroecosystems' performances, facilitating judgements and suggesting solutions for improving sustainability in agriculture (Caporali et al., 1989; Tellarini and Caporali, 2000; Caporali et al., 2003; OECD, 1999a, 1999b, 2001). Generally, ASIs are developed on the base of the general input/output model of agroecosystem analysis derived by the systems paradigm (Edwards et al., 1993; Tellarini and Caporali, 2000). With the development and use of ASIs, agroecological research is getting more and more integrated in the structure of civil society, improving its role of scientific service for public utility.

The aim to develop ASIs have both an epistemological and a practical meaning, representing, respectively: a) an efficient instrument of enquiry for studying agroecosystem functioning and performance according to an input/output approach; and b) a relevant knowledge base for both the designing of sustainable agroecosystems and decision-making processes. According to Tellarini and Caporali (2000), ASIs can be subdivided into two large categories: a) structural indicators and b) functional indicators.

The first category aims to describe the most relevant components of agroecosystems and, therefore, to illustrate the differences and similarities between agroecosystems, while the second category aims to measure the efficiency of transformation processes in agroecosystems. Indicators can be calculated in terms of energy, materials and monetary values. By relating each type or combination of output to each type or combination of input, it is possible to obtain a considerable amount of information on both the circulation of energy-matter within an agroecosystem and the efficiency with which these resources are used, both at the level of components as well as at the whole agroecosystem level. In this way, it is possible to evaluate the energy-matter dependency of the whole agroecosystem (or of each single component) on the external context and on non-renewable inputs. In other words, the sustainability level of the agricultural activity can be evaluated from a process-oriented assessment.

As a follow up to the Agenda 21, the OECD Council approved in 1991 a Recommendation on Environmental Indicators and Information to further develop sets o reliable, readable, measurable and policy-relevant environmental indicators (OECD, 1999a). The indicators chosen cover the range of primary agriculture's impacts on the environment which are policy relevant and that are practical to measure (OECD, 1999b).

The conceptual model inspiring the search for agri-environmental indicators (AEIs) was defined by OECD as Driving Force- State-Response (DSR) framework.

Driving forces are those elements that cause changes in the state of environment and include: natural environmental processes and factors; biophysical inputs and outputs at the farm level; economic and social driving forces. The concept of driving forces recognises that agricultural activity can both produce beneficial impacts to enhance environmental quality, such as increasing the water storage capacity, and also have harmful impacts, such as pollution.

The state or condition of the environment in agriculture refers to changes in environmental conditions that may arise from various driving forces. The impact of agriculture on the environment can occur both on-farm (internal environment) and off-farm (external environment). The state of the environment includes: state of the natural resources; composition, structure and functioning of the ecosystem; state of human health and environmentally related welfare.

Responses refer to the reaction by groups in society and policy makers to the actual and perceived changes in the state of the environment in agriculture. They include farmers behaviour, consumer's reactions, and responses by the agro-food chain and government actions.

The DSR framework denotes much of its agroecological foundation. It can provide a flexible framework to improve understanding of the complexity of linkages and feedbacks between the causes and effects of agriculture's impact on the environment and the responses of the main stakeholders. While agriculture can affect the state of the environment, changes in environmental conditions can also impact on agricultural production activities. Therefore, analysis of the linkages and feedbacks between driving forces, state and responses is a key element in shedding light on the dynamic functioning of agriculture as a human activity system. The choice of indicators is an evolving process depending on societal pressures and political choices. Some environmental areas are gaining in importance (e.g. soil greenhouse gas sinks), while other are diminishing in the context where some control measure is already running. Due to the importance of understanding the linkages between policies, agricultural production and environmental quality, the interpretation of any one indicator may need to be complemented with other indicators and be seen within the overall context of the set or appropriate sub-set of indicators (OECD, 2001).

4.1 Implementation of sustainable agricultural systems research

The title of this paragraph is the same of that written by Edwards et al. (1993) in a paper devoted to define the role of agroecology for agriculture sustainability. In that article, they were able to define a strategy for successful research based on the integration of available information involving the following steps:

1) description of the target agroecosystem including its goals, boundaries, components, functioning, interactions among components, and interactions across its boundaries;
2) detailed analysis of the agroecosystem to determine factors that limit or could contribute to attainment of productive and social goals;
3) design of interventions and identification of actions to overcome the constraints;
4) on-farm experimental evaluation of interventions;
5) review effectiveness of newly designed systems;
6) redesign as necessary.

All this approach could be defined as *participatory research*, which involves not only researchers but also farmers in the whole process, from planning to implementation and evaluation. All steps should be conducted *on farms* by an interdisciplinary team of agricultural, social and ecological scientists and with full participation of farmers. Understanding the farmer's goals is crucial, as the role of the proposed interventions is to help the farmer attain these goals. In accordance with the systems paradigm, even the farmers' decision making process can be represented according to an input/output model (Caporali, 2004), where actions (output) in favour of sustainability should emerge from a newly constructed decision arising from the interaction of external inputs with the personal farmer's attitudes.

The farm level is the more appropriate one in the hierarchical scale of agroecosystems for doing research and making decisions in favour of sustainability. Indeed, the farm is the management unit of agriculture with a biological base, easily identifiable because of its boundaries, and which represents the meeting point between human interests and the natural environment (Caporali et al., 1989). The most advanced regulations for sustainable agriculture, like those concerning organic farming, provide a framework of legitimisation based on the agreement between the civil society and the farmer. That means that there is an explicit recognition of the farm as the crucial level of organisation of resources, both biophysical and socio-economic. Indeed, the production process at the farm level is able to affect the profile and sustainability of the next upper hierarchical levels of agricultural systems (e.g. landscape and region) as well as the next lower level or field level, where interactions between crop, animals and micro-organisms affect soil fertility, which is the base for agriculture sustainability.

Research based on ASIs at the farm level is therefore of great importance to decision making processes, especially when groups of farms of contrasting management are involved. Organic farming systems are being considered as a long term benchmark for the evaluation of apparently environmentally benign agricultural production systems (OECD, 1999a). Therefore, the aim of some recent research includes the comparison of organic farming systems with conventional ones on the base of appropriate ASIs. (Reganold et al., 2001; Mader et al., 2002; Caporali et al., 2003). Results of this kind of research are easily shown graphically, with the help of a so called sustainability polygon or web, that simultaneously displays scores for different indicators and avoids having to aggregate across different scales.

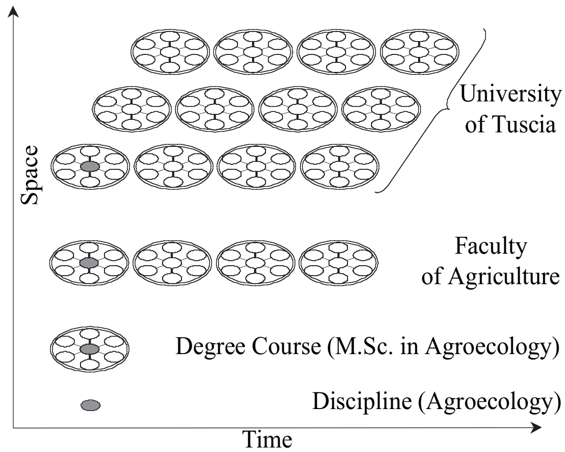

Figure 3. The nested Hierarchy of Agroecology at the University of Tuscia.

5. Integration in curriculum development under the emergent systems paradigm

In the context of educational systems, like University, a nested hierarchy of organisational levels can be detected, starting from single scientific disciplines and their aggregates (e.g. curricula or degree courses), to a Faculty and a whole University. In the current academic organisation, agroecology can occupy two different levels of organisation, the discipline level and the degree course level, like in the case of the University of Tuscia (Fig. 3). This double dimension denotes that agroecology is a scientific discipline but its transdisciplinary method (systems paradigm) and its main goal (agriculture sustainability) are so strong and pervasive as to provide a framework within which interdisciplinary activities can occur. This happens as a shared platform of contents for teaching and research at any degree course level in Agroecology.

At the discipline level, aspects of integration refer to the capacity to see also a single discipline as an educational system (Fig. 4), where teaching and learning are linked in their context and represent a process in becoming with reciprocal interactions between all human com-

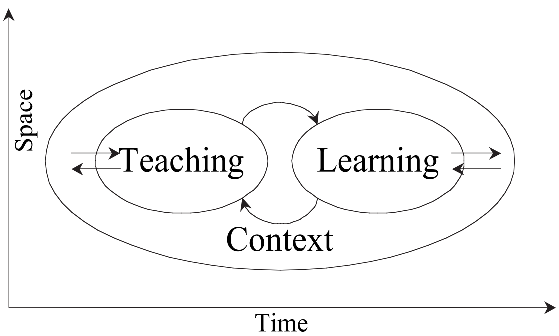

Figure 4. A discipline as an educational system.

ponents – teachers, students and other stakeholders in their context. For agroecology, context is a complex of agriculture, nature, people, human artifacts and institutions as relationships between people. The contents of agroecology as a scientific discipline depend on its method of enquiry (systems paradigm) and have been already discussed (paragraph 3). A detailed description of agroecological contents can be also found in Altieri and Francis (1992) and in Caporali (1991, 2004).

At the curriculum level, integration is a more complex issue in that it has to do with harmonisation of relationships with both the other disciplines of the curriculum and the external context components, whereby *coherence* and *correspondence* need to be established with the other disciplines of the curriculum and the driving forces of the external environment, respectively (Fig. 5).

Methodological tools inspired by the systems paradigm can be helpful in bettering connections between a curriculum as a whole and its context (external tools) and among the curriculum components themselves (internal tools). The external context is made up by all kinds of information inputs that can come from international, national and local levels. This external input forms a general framework of reference for decision making. Different feelings and prospects of those involved in the development of a degree originally fuel the initiative and create an internal context also in response to internal inputs, coming from the University, the Faculty, the Departments and the personal attitudes of the people involved.

External methodological tools help introduce a broad concept of faculty and action-based learning. Integrating the expertise of farmers, business owners, government specialists, and non-profit- groups can enrich the educational process by offering different perspectives and ways of knowing (Francis et al., 2001). Case studies, interview and survey techniques, time-series measurements, and activity calen-

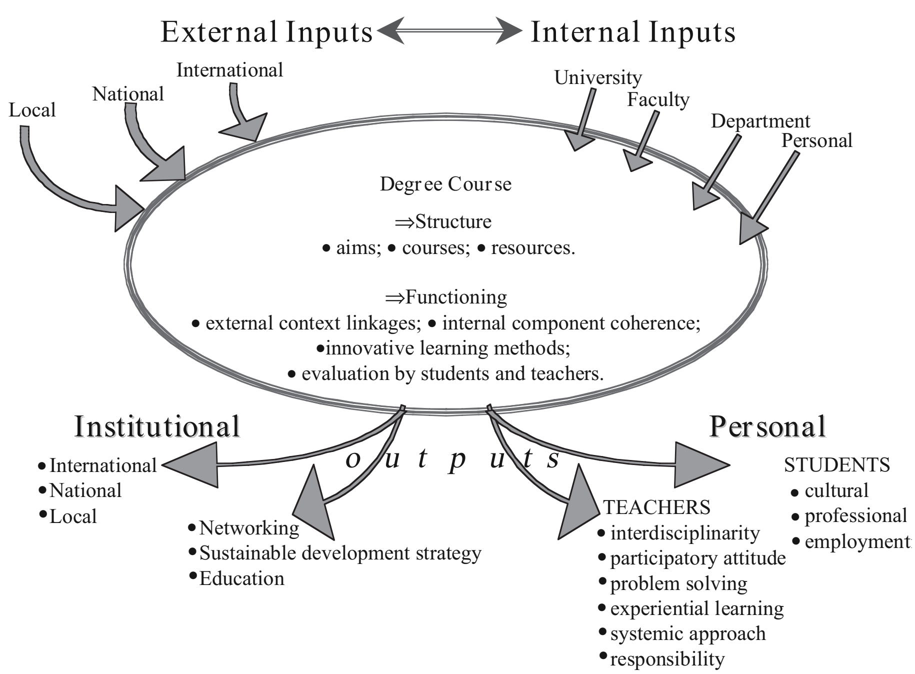

Figure 5. A degree course as an input/output decision making process.

dars can be taught and applied to answer questions about integration within the whole agroecosystem hierarchy (cropping systems – farming systems – regional systems – global systems). These approaches require several changes in attitude and organisation. Faculty members, administrators and others must invest time and money to establish research and learning institutional networks. New sources of funding and revised systems of administering research funds will be required to promote this approach successfully (Stark, 1995).

Tools are also needed in order to give more internal coherence to a curriculum; this concerns more integration among the disciplines that belong to it. Thus, all levels of approaches to integration (multidisciplinarity, interdisciplinarity and transdisciplinarity) are probably needed. Multidisciplinarity generally means bringing separate theories, skills, data and idea to bear on a common problem, while interdisciplinarity involves bringing together people and ideas from different disciplines, to jointly frame a problem, agree on a methodological approach, and analyse the data (Golde and Gallagher, 1999; Hammer and Soderqvist, 2001). Finally, transdisciplinarity implies full interaction between disciplines from a problem-based perspective. According to Hammer and Soderqvist (2001), integrative approaches could be addressed in course programmes by, for example, the following efforts:

1) inviting external lecturers from other disciplines;
2) having seminar exercises and discussions with invited lectures from other disciplines;
3) mixing students from ongoing disciplinary courses for joint exercises;
4) giving full transdisciplinary courses and programmes.

More internal coherence also means more integration between teachers and students, which are the basic components of a learning system such as a curriculum. Creating a truly integrated curriculum entails that the two groups become reciprocal members of a shared, mutually self-critical learning community. This can be achieved through:

a) creating a community that generates conversation – including such techniques as having members talk in turn – where knowledge is a process of continual negotiation and transformation;
b) creating a team-teaching context. Team-teaching is an excellent way to move away from the individualistic and disciplinary mode of scholarship and research. In teams composed of faculty from different disciplines, those involved find their intellectual life much-enriched (Manley and Ware, 1990). A team-taught course can be a vastly rewarding experience for both students and instructors; if properly conducted, it can represent the ultimate interdisciplinary experience. The key to successful interdisciplinary teaching is really very simple: it is the mastery of significant scholarship that is outside the area of specialization and the assimilation of that learning into one's area of teaching (Mc Farland and Taggie, 1990). A team-teaching context facilitates the transfer of knowledge among the learning community members;
c) implementing intensive programmes or courses allocated in a time space not longer than two weeks (6 ECTS). They can function as more flexible didactic tools for approaching different contextual experiences, provided points a) and b) are met.

The outputs of a degree course can be described in terms of achievements to be pursued at a personal and an institutional level. Key factors and conditions that deserve continuous attention, monitoring and evaluation include: personal educational achievement; professional skills and job opportunities of students and graduates; personal and institutional achievements in terms of improving attitude towards interdisciplinarity, participatory initiatives, problem solving, experiential learning and systemic learning; academic staff responsibility; more general societal benefits for public and private institutions derived from improved networking, local sustainable development strategies, education at local, regional, national and international levels.

In the case of the MSc in Agroecology at the University of Tuscia, its model of representation according to the input/output scheme is shown in Figure 6.

6. Conclusions

Among the human activity systems, agriculture is the most integrated one, since combines bio-

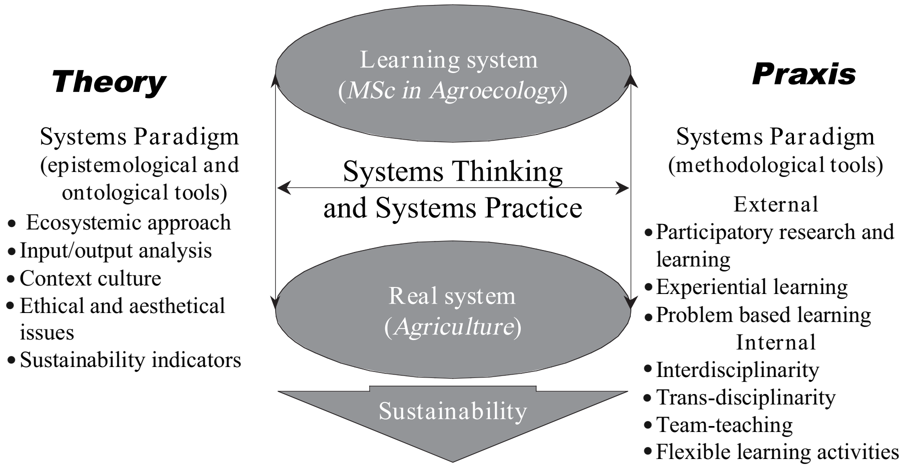

Figure 6. MSc in Agroecology at the University of Tuscia under the emergent systems paradigm.

physical and socio-economic components from both natural and anthropogenic sources into organised agroecosystems at different hierarchical levels. A sustainable integration is demanded today in agriculture at any hierarchical level, from the field to the regional and global level, and the concept of integrated rural development has been created to revitalise rural environment and economy. Agroecology, both as a scientific discipline and a philosophical and organisational paradigm, has potential for constructing more integrated academic curricula as well as promoting more integrated research. University has a role to play in society to prepare a culture and professionals in agriculture to meet the current expectations. New epistemological, ontological and methodological tools based on the systems paradigm, like that professed by agroecology, are needed to university to successfully address the challenge of establishing new culture and praxis for a sustainable development in agriculture and society. But also society as a whole must find the right way of supporting university in this task with effective institutional connections and investments, helping accomplishing its expected role as a learning society.

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