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Sustainability of Agricultural Management Options Under a Systems Perspective

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Targeting Sustainability in Agricultural Systems

Analysis of the sustainability of agroecosystem management assesses the productive, economic, environmental, and social performance in terms of selected indicators, as affected by configuration of landscape and farm practices and technologies. Sustainable development of agricultural landscapes has become a primary issue for policy-makers, land managers at different hierarchical levels including farmers, advisors, policy-makers, and scientists. This is also reflected in many of the Sustainable Development Goals (SDGs) identified by the United Nations (UNs) to end poverty, protect the planet, and ensure prosperity for all, as part of a new sustainable development agenda started in 2015.

This focus has developed since the oil crisis of the early 1970s, which revealed in an incontrovertible way the limited nature of world resources. In 1992 the UNs Conference on Environment and Development (UNCED), also known as the Earth Summit was held in Rio de Janeiro, Brazil, and produced Agenda 21, a nonbinding, voluntarily implemented action plan proposed by UNs to promote sustainable development at local, national, and global levels. In 2000 a panel of 1360 experts was called by the UNs Secretary-General Kofi Annan to carry out a global study on the state of the environment, named Millennium Ecosystem Assessment (MA). Initiated in 2001, the objective of the MA was to assess the consequences of ecosystem change for human well-being and to overview the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being. MA experts' findings provided a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide and the options to restore, conserve, or enhance the ecosystems. Modifications imposed by humans to ecosystems resulted in a substantial and largely irreversible loss in the diversity of life on Earth. Although net gains in human well-being and economic development were achieved, these gains have been obtained at growing costs in the form of the degradation of many ecosystem services. This was recently confirmed by the Food and Agriculture Organization of the UNs for what concerns land and water resources as well as regarding the ability of the world ecosystems to adsorb greenhouse gas emissions (FAO, 2011).

From a methodological perspective, one of the major MA achievements was the definition and the classification of ecosystem services based on the assumption that it is difficult to protect and sustainably use what is not definable under the common sense, that is, what do we want to protect or use? Following the MA definition, ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (MA, 2005).

After defining the object of protection/sustainable use, the MA has defined how to protect/use it, which is the ecosystem approach. Following the MA definition, the ecosystem approach is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structure, processes, functions, and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems (MA, 2005).

As stated by Pretty (2008), concerns about sustainability in agricultural systems center on the need to develop technologies and practices that do not have adverse effects on ecosystems services, are accessible to and effective for farmers, and lead to improvements in food productivity.

Pretty claims that the key principles to develop sustainable technologies in the agricultural sector are:

(i) Integrate and balance biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation, and parasitism into food production processes.
(ii) Minimize or avoid the use and concentration of those nonrenewable inputs and artificial substances that accumulate faster than they are degraded in the environment, and therefore cause harm to the environment or to the health of farmers, consumers, and domestic animals.
(iii) Make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs.
(iv) Make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest, and credit management, and aggregated supply of products on the markets.

Farming systems can be designed for sustainable performance using a set of performance indicators and using the appropriate type, frequency, and intensity of technologies and practices. In agriculture the priority is feeding a world of projected 9.1 billion

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people in 2050, without compromising the ability of agroecosystems to persist in the realization of such an objective due to environmental or social harmful side-effects of employed technologies. Then, how to do it?

Agroecosystems Analysis

Comparing alternative potential technologies and assessing relevant results in terms of their implementation on agroecosystems in specific environmental and social contexts is indeed a complex matter. As stated by Marten (1988), "agroecosystems are overwhelmingly complex. The numerous ecological processes that tie people, crops, weeds, animals, microorganisms, soil and water together into a functioning, on-going ecosystem are so intricate that they can never be fully described, nor can they be fully comprehended."

Complexity increases also with increasing demands related to the concept of sustainable development including the needs of future human generations and lately also of animals. Concern for animal welfare is often based on the belief that nonhuman animals are sentient and that consideration should be given to their well-being or suffering, especially when they are under the care of humans. In recent years animal welfare has become an issue of increasing concern, also in several developing countries. The welfare of humans and the welfare of animals are closely linked. In many regions, a secure supply of food for people depends on the health and productivity of animals, and these depend on the care and nutrition that animals receive. The increase in animal production of the last decades has raised a wide range of ethical issues, including concern for animal welfare, which has to be considered alongside environmental sustainability and secure access to food (FAO, 2013).

FAO-OECD Guidance for Responsible Supply Chains strives to "ensure that the 'five freedoms' for animal welfare are implemented, i.e. freedom from hunger, thirst and malnutrition, physical and thermal discomfort, pain, injury and disease, fear and distress, and freedom to express normal patterns of behaviour." All questions concerning animal welfare are directly taken from the five freedoms defined by the UK Farm Animal Welfare Council in 1979. The five freedoms outline five aspects of animal welfare under human control. These freedoms define ideal states rather than standards for acceptable welfare. Instead, standards for acceptable welfare should be identified by fitting animal freedoms in the context of surrounding agroecosystems and management options, which makes things even more complex.

At those levels of complexity, simplification becomes a practical necessity of the analysis. There is a need to sketch simplified representations of the network of relationships among all the elements of the agroecosystem so to isolate those that potentially impact key aspects of sustainability of agricultural technologies such as the ones identified by Pretty (2008) concerning agricultural sustainability.

Conway (1987) drew the fundamentals of agroecosystem analysis and suggested that agroecosystems can be characterized by a limited set of properties (i.e., productivity, stability, sustainability, equitability) that not only describe their essential behavior, but also can be used normatively as criteria of agroecosystem performance and hence can be employed in the design and evaluation of agroecosystems management options. Agroecosystem properties combine large numbers of agroecosystems processes into single, highly aggregated measures of performance that suggest how well an agroecosystem is meeting human objectives (Marten, 1988).

Agroecosystem analysis can be carried out at different hierarchical levels ranging from the individual plant or animal with its immediate microenvironment and the people managing it, to crop/herd, field/paddock, cropping/livestock system, farming system, livelihood system, household, village, watershed, region, nation, economic community, and the world (Conway, 1987).

When dealing with technology adoption and relevant sustainability impact assessment based on performance in terms of agroecosystem properties, the best standpoint of analysis relies at the level of the farm system, because this is ultimately the place where technological and other management decisions are taken. In other words, the farm agroecosystem is the place where management options supplied by the agricultural technology system—to the extent made accessible by the social and environmental contexts—are selected by the prominent decision-maker of the agricultural production chain, that is, the farmer, and then put into practice. Indeed, the farm system under this perspective is considered as the "building block" of the agricultural sector, whose performances can be aggregated upwards to understand system functions and sustainability at different levels.

The fact that this standpoint is privileged for studies on sustainability impact of agricultural technologies does not mean in any way that management impacts can be analyzed solely at the farm system level. Indeed, systems theory holds that the behavior of any system in a hierarchy, for example, the farm system, is not readily discoverable from a study of lower systems, for example, cropping/livestock systems, and vice versa (Checkland, 1981). Instead, behavior of a system is a consequence of the combination of impacts of decisions taken at different levels in the hierarchy. Examples of exogenous decisions, or more generically behaviors, impacting agroecosystems include:

(i) decisions on off-farm employment at the livelihood system level,
(ii) decisions affecting hydrological balances, water availability and accessibility at the watershed level,
(iii) decisions on support measures for farmers within regional rural development programs,
(iv) national norms on pollutants such as the EU directives on nitrates and sustainable use of pesticides,
(v) decisions on prices at the economic community level,
(vi) agreements on tariffs and trade of the World Trade Organization (WTO) at the global level.

Sustainability assessment of the performance of agricultural technology options must focus on the farm agroecosystem and lower levels without disregarding the above-mentioned aspects.

Identifying a specific standpoint for analysis holds also advantages in terms of practical enforcement of the analysis. Indeed, Marten (1988) identified in the multidimensional character of properties a major limitation of agroecosystem analysis, due to (i) differences in the same property at different hierarchical levels of an agroecosystem and (ii) independent measures of agricultural production. To avoid any confusion related to these two aspects, property-based evaluation of agroecosystems must be conducted after having chosen a priority standpoint for analysis, the farm agroecosystem level in our case, and by acknowledging the multidimensional character of the agroecosystem components, which is dealt with in the following section.

A Conceptual Model to Evaluate Sustainability of Agroecosystems

In the following sections a conceptual model to evaluate sustainability of agroecosystems under a systems perspective is presented which is based on dimensions and properties of agroecosystems.

Dimensions of Farm Agroecosystems

Decisions and norms at the various hierarchical levels are taken according to societal demands organized in a more or less explicit value system. According to Abreu and Camarinha-Matos (2006) a value system can be understood as "the ordering and prioritization of a set of values that an actor or society of actors holds." The value system reflects that components of the agroecosystem have a certain value attached based on societal priorities and rules, which can be expressed in a cultural (or socio-ethical) value and an economic or financial value (**Fig. 1**).

Cultural values are shaped by social interactions, historical events, and shared heritage. Together with traditional knowledge on resource use generated during the coevolution of agrarian societies with nature, the cultural aspect includes historical and architectural aspects and therefore both living and manufactured infrastructures that form an essential part of rural landscapes. Marketable goods and services are denoted commodities that have an economic value, and transformations can add value, which can be reflected in monetary terms. The economic value depends on human demand and local availability of products and services.

When doing a sustainability assessment exercise, breaking the system and the problems of the system down in clearly distinctive dimensions (**Fig. 1**) will facilitate the identification of context specific problems. Subsequently these can then be translated into critical properties and relevant indicators in a rather straightforward fashion. In this manner, the evaluation process is more concrete from the start, thereby increasing the opportunities for contributions of and participation by nonscientific stakeholders in assessment projects. This step of distinguishing dimensions to decompose the problem is part of a simplification process as stated by Marten (1988). It is not a departure from the systems perspective, which is maintained by acknowledging importance of different views on the different dimensions and the attached temporal aspects (e.g., short- and long-term changes and the needs of future generations), spatial scales (e.g., biodiversity impact at different hierarchical levels), and societal drivers (cultural and economic).

Within the environmental dimensions of the system, the physical and ecological dimensions are, although highly interactive, fundamentally different by nature (living vs. nonliving). These dimensions pose different problems and provide strongly

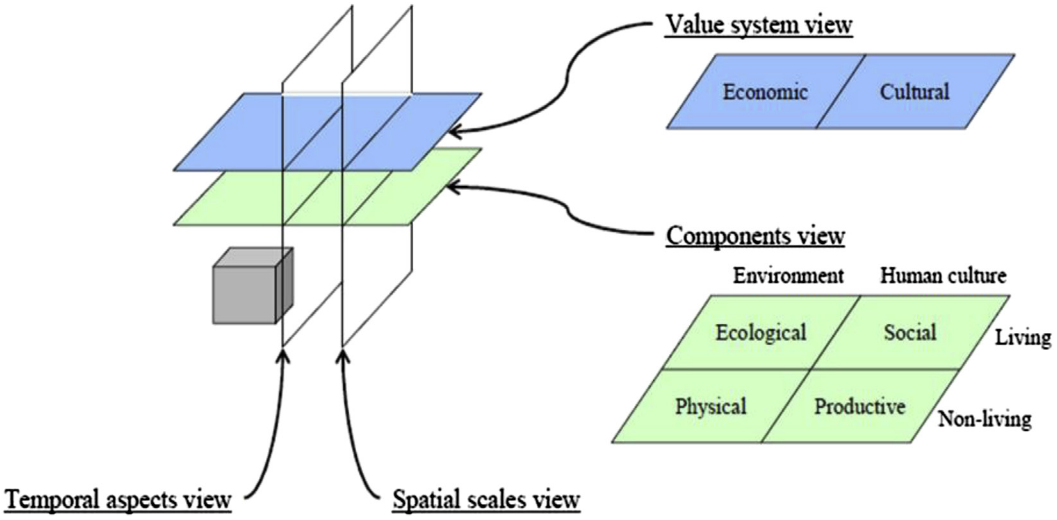


Fig. 1 Views on an agroecosystem (*grey* box): the value system view (*blue*) consists of two dimensions and the component view (*green*) comprises four dimensions. The value system reflects that components of the agroecosystem have a certain value attached based on societal priorities and rules, which can be expressed in an economic and a cultural value. Temporal aspects are included to take into consideration supposed preferences, short- and long-term changes, and the needs of future generations. Spatial scales are included to acknowledge importance to potentially heterogeneous impacts of management options at different hierarchical levels.

contrasting environmental services. In the physical or pedoclimatic dimension, problems of nutrient and biocide pollution of water, soil degradation and erosion are relevant to agricultural systems. The ecological or biotic dimension entails all biological processes in the system, including the growth and production of agricultural crops and animals, until they are being harvested. Problems encountered in the ecological dimension include reduction of the biomass production capacity and gene, species, and ecosystems diversity, posing a threat to the corresponding services supplied, such as food and fiber production, supply of genetic resources for, for example, crop resistance to pathogens, maintenance of habitats, bioremediation capacity, soil retention and regeneration, pollination, and biological pest control.

The productive dimension includes not only products harvested from ecological systems, but also artifacts from industrial or human cultivation processes that use both ecological and physical resources. These products can be transformed into other products (milk into cheese; engines, dashboards, and other components into tractors). The social dimension is the fourth and last and it is based on the human presence and the interrelations between people (either informal or institutionalized) within or outside the system. The social aspect reflects the current state of affairs in terms of human capital and participation in activities in the form of labor and social structures, for example, local interest groups and institutional arrangements.

Although the dimensions are conceptually independent, a myriad of interactions exists among them. For example, a decrease in the total biomass productivity of a market crop in the ecological dimension (e.g., due to depletion of clean water resources in the physical dimension) has a direct impact on the productive dimension as well via a reduction of harvested products and financial revenues associated with specific farm activities. In the long run this can reduce the labor investment into the cropping system with cascading effects of unemployment and migration from rural areas, all in the social dimension (for the purpose of demonstrating the overall principle the feedback loops were omitted in this example). As another illustration, production of crops results in disturbances of the physical and ecological dimensions, which can be observed as lower species abundance and diversity, and decline of soil organic matter content rendering soils more prone to erosion. The resulting negative effects on the physical dimension include soil degradation and compromised water and nutrient retention along with a reduction in soil purification capacity. These examples stress that to assess the interactions between the dimensions and to estimate the impacts of adjustments in management practices for agroecosystems a multidisciplinary approach is indispensable.

Properties of Farm Agroecosystems

Different sets of properties have been proposed for system characterization. Despite some overlap between these sets (for instance the productivity, stability, resilience properties are commonly used), considerable divergence has occurred, resulting in long lists of candidate properties. The arguments for selection of properties are not always insightful and the usefulness of many properties can be questioned from either a theoretical viewpoint (what is the relevance of the property for agroecosystem sustainability or health?) or for pragmatic reasons (e.g., which indicators can be used to quantify the property in empirical studies?) (Xu and Mage, 2001).

An important prerequisite for effective identification of relevant properties is the definition and conceptualization of the system. For the purpose of the discussion here a system is defined as a collection of components that can be characterized by state variables that represent a certain quantity (stock) or value at a given moment or integrated over a given period such as a growing season or a year. Changes in the state variables represent flows between the external environment and the system, or among system components. Examples of state variables typical for the four dimensions are amounts of available water and nutrients (physical); herbage biomass and mass of animals (ecological); harvested crop and milk produced (productive); number of family members (social). The level of aggregation per state (e.g., total herbage biomass vs. biomass per plant species) should be determined for each specific case, and depends on the scale of analysis and the issue at stake (Grimm et al., 1992). The state variables are dynamic, subject to change through time due to flows of matter, energy, money, and information between the system components, and between the system and its surroundings. Possible approaches for representation and quantitative analysis of such a system and interactions with the environment outside the system include use of a network perspective (Gattie et al., 2007) or a flow analysis (Hannon et al., 1991).

Properties of agroecosystems can be classified into two main categories of structural and functional properties (**Fig. 2**). The structural properties of diversity, coherence, and connectedness express the composition of an agroecosystem in terms of components and processes and their interrelations or the relations with the environment outside the boundaries of the system under analysis. Structural properties determine the functional responses of the system (like the engine of a car), and are particularly relevant to understand the mechanisms that govern agroecosystem performance (Ives and Carpenter, 2007), and to identify possible changes in the system to improve its sustainability. Diversity is related to the number of different components and processes present and their relative abundance, whereas coherence provides measures of the numbers and strengths of the connections among components and processes within the system. In some instances diversity and coherence have been combined in a term referred to as "complexity" (Okey, 1996). Connectedness is similar to coherence, but concerns the connections with entities outside the system. Coherence and connectedness can typically be quantified using network and flow analyses. Monitoring of the flows within the system and thus coherence through time in relation to disturbances can be used to determine the capability of the system for adaptation, self-organization and for maintaining its integrity. From an analysis of connectedness, self-dependence and efficiency of the system could be determined, which refers to the degree to which the inputs or resources native to the system contribute to its functioning and maintenance of the structure (Xu and Mage, 2001). An agroecosystem with a higher degree of self-dependence is less dependent on external inputs, such as artificial fertilizers, animal feeds, or contract labor.

Structural properties

Diversity is given by the number of different components and processes present in the system and their relative abundance. It includes among others biodiversity of genes, species and ecosystems, as well as the diversity of income sources and knowledge, traditional and scientific.

Coherence provides measures of the numbers and strengths of the connections and flows among components and processes within the system. It considers ecological balance, economic integration and household labour, and seeks to minimize trade-offs and maximize synergies.

Connectedness is similar to coherence, but concerns the connections with components outside the agroecosystem. It includes, among others, trans-boundary pollution and the production system connectivity with external waterways and habitats; integration of farm business in the supply chain and independence from exogenous factors; and the participation of producers in social networks and institutions.

Functional properties

Capacity is the average performance level of a state variable in the system, e.g. the quantity of production of foods, biofuels, fibres, timber and other ecosystem goods and services that can be obtained from a unit of inputs (water, land, biodiversity, energy, nutrients and labour).

Stability is the capability of the system to remain close to stable states of equilibrium when facing 'normal' variations, and is reflected in the frequency and amplitude of fluctuations in the state variables.

Resilience refers to the aptitude of the system to maintain its performance defined by capacity and stability after a disturbance or long-term or permanent changes in its environment or internal conditions, including both environmental and macro-economic risks.

Fig. 2 Agroecosystem properties of the conceptual framework for sustainability assessment of land use options. Modified from El-Hage Scialabba, N., Pacini, C. and Moller, S. (2014). *Smallholder ecologies*. Rome, Italy: FAO.

The functional properties of capacity, stability, and resilience describe the performance of the system in terms of variations and continuance of the state variables. Stability and resilience are similar and represent the capability of the system to remain close to stable states of equilibrium when facing normal variations or disturbances/long-term changes, respectively (Conway, 1987; Holling, 1973). Functional properties can be translated into corresponding indicators that are merely descriptive (e.g., like dashboard display in a car). Indicators of functional properties can be used for monitoring of the sustainability of the agroecosystem, but they are not useful to explain the underlying mechanisms or to design targeted adjustments aiming to improve the performance of the system and to innovate (redesign) it.

Thus, from the structural properties that are defined here many other properties can be derived, such as efficiency, self-dependence, adaptability, self-organization, and integrity. These derived properties can also have a more normative value, designating an importance or desirability from a human utility perspective. For example equity signifies the equality (here: lack of diversity) in the distribution of assets in the productive dimension of agroecosystems, which is considered desirable based on the notion of fairness, but is not necessarily crucial for the sustainability of the agroecosystem as such. The often proposed productivity property (Conway, 1987; Marten, 1988; Okey, 1996) can be represented in evaluative frameworks by the functional properties of the ecological and productive dimensions.

Sustainability Assessment of Technology and Agroecosystems

In **Fig. 3** a generic conceptual diagram for diagnosis and design based on properties of agroecosystems is reported, and an illustration of its application is provided.

The properties represented in the diagram by set of corresponding sustainability indicators can be used to run two types of assessment (Marten, 1988): (1) *general*, referring to a theoretical or generic agricultural technology system as it occurs over a range of environmental and social conditions in a particular region or (2) *specific*, referring to a specific agroecosystem at a particular location. *General* evaluations tend to be based on rapid assessments through interviews and visual observations, while *specific* evaluations are based on quantitative measurements of indicators.

In **Fig. 4** and **Table 1** examples of diagrams for general evaluations used for comparing agriculture, forestry, and fisheries management options in two FAO global studies are reported (El-Hage Scialabba et al., 2012, 2014). The aim of the conceptual framework based on structural and functional properties used in these documents was to support a common ground for shared sustainability visions and assessments and to help decision-makers in finding their own way to analyze the reality of food systems and guide their perceptions of related impacts. The conceptual framework was applied to support proactive assessments of food systems under an ecosystem approach perspective.

Fig. 4 illustrates the functional and structural properties of selected agroecosystems and lists some generic, aggregated indicators that could guide the analysis of the different agriculture, forestry, and fisheries management options. Indicators included under each property are indicative of the type of information to be researched, but for reasons of brevity, reporting is not exhaustive in terms of

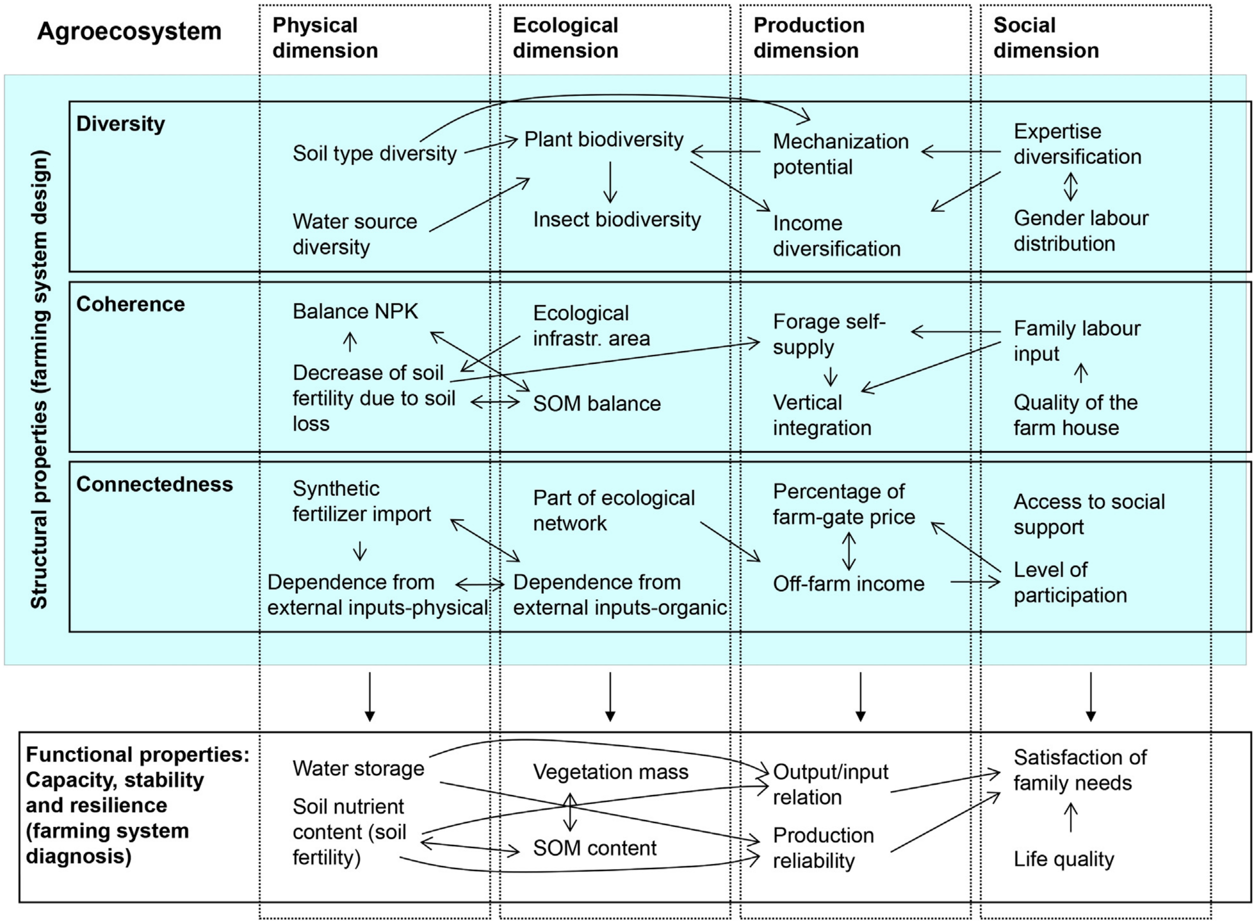


Fig. 3 Generic conceptual diagram for sustainability assessment of technology and agroecosystems. Note that the functional properties are combined in one row.

covering all possible performances related to corresponding properties. For an example of how these generic, aggregated indicators can be deployed into a series of detailed indicators of performance of agroecosystems management options, reference is made to El-Hage Scialabba et al. (2014).

Table 1 illustrates a summary of impacts of agroecological management options on agroecosystem properties, and their current importance to global food supply, livelihoods, and the environment. Such information can be used to take decisions at regional level regarding the best land use options to be implemented, for example, in rural development programs (El-Hage Scialabba et al., 2014).

In **Fig. 5** a diagram for specific evaluation of a soil-crop system is reported. The functional properties are combined in one row to assess the performance of the agroecosystem. This is an example of how the conceptual model was applied to systematize and select performance indicators in a project (i.e., the "Fertility Building Management Measures in Organic Cropping Systems" project, FertilCrop, http://www.fertilcrop.net/fc-home-news.html) promoting the adoption of reduced tillage and green manuring technologies in a number of EU organic farming case studies (Fontana et al., 2015; Madsen et al., 2016).

At the beginning of the FerilCrop project, 27 indicators were considered for analyses (**Fig. 5**, indicators in standard letter format). The application of the framework to FertilCrop case studies highlighted a suboptimal coverage by FertilCrop indicators of main structural properties (diversity and coherence) and functional properties concerning the physical (or abiotic) and ecological (or biotic) dimensions. Indicators of crop productivity were also highly considered. However, the application also highlighted opportunities for further improvement of the indicator set toward a properly holistic assessment of soil quality in soil-crop systems, which might be the subject of future research.

In particular, no indicator was selected in the initial phases of FertilCrop to describe social aspects that might have an impact on soil fertility management, such as soil and agroecosystems expertise potential, farmers' knowledge of soil fertility, farmer-to-farmer learning or labor availability. No indicator was selected concerning the structural property of connectedness, meaning that relationships with components outside the agroecosystem were disregarded, including, for example, the ability of ecosystems to supply important ecosystems services such as provision of beneficial insects and plants. This latter aspect was disregarded also within agroecosystems, where no information was included on ecological infrastructure areas. Regarding the production dimension of

AVAILABILITY
System's **capacity** to produce food

FUNCTIONAL PROPERTIES

EFFICIENCY
of resource use assessed under **normal** conditions in terms of:
- Physical yield per unit of input (productivity)
- Commercial yield per unit of input
- Life quality of producers and consumers

RESILIENCE
to environmental and macro-economic risk assessed under **disturbed** conditions in terms of:
- Physical yield per unit of input (productivity)
- Commercial yield per unit of input
- Life quality of producers and consumers

STRUCTURAL PROPERTIES

CONNECTEDNESS
Assessed in terms of:
- Transboundary pollution and environmental connectedness
- Financial and input dependency
- Participation and social integration

COHERENCE
Assessed in terms of:
- Ecological balance (water, soil, habitat, nutrient, energy)
- Economic integration
- Household labour

DIVERSITY
Assessed in terms of:
- Biodiversity
- Income diversification
- Knowledge

Fig. 4 Agroecosystems' functional and structural properties and indicators (El-Hage Scialabba et al., 2012). Note that the functional property "capacity" as indicated in the generic conceptual diagram is here named "efficiency" and that the property "stability" is embodied within "resilience."

structural properties, it has to be noticed that it was poorly represented (only one indicator, that is, mechanization potential for reduced tillage), while it was widely considered with concern to functional properties.

After this first diagnosis of the project set of indicators, researchers applied the conceptual framework also to improve the set and overall, 39 additional, potentially useful indicators were proposed by Fertilcrop partners while building and applying the conceptual diagrams of corresponding case studies (Fig. 5, indicators in italic letter format). A complete methodological example of the procedure of indicator selection and systematization for sustainability assessment of alternative land use options is reported in Pacini et al. (2016). This example can show how research and development projects can benefit from the application of a systems perspective in the course of sustainability assessment of technologies and agroecosystems. By applying a systems perspective to guide indicator selection, the indicator set of the FertilCrop project evolved and was integrated with information necessary for a truly holistic assessment.

Besides the above-mentioned applications, a system based on the principles of agroecosystems analysis and backed by strong theoretical assumptions can also be used to select indicators and design the auditing procedures of third-party certification of agricultural operations as a means for farmers to document compliance with generally accepted sustainability practices. Third-party certification systems exist for a number of production sectors and are commonly applied to check organic production rules, eco-management audit schemes, biodiversity conservation measures, hazard analysis critical control point and integrated production rules, nongenetically modified, sustainably grown and safe quality food products, good agricultural practices, and the sustainable use of pesticides, among others. Indeed, in all of these cases, it is vital to select indicators in an objective, transparent and holistic way.

Concluding Remarks

UN Sustainable Development Goal "Life on land" (SDG 15) fosters the ideas, among others, of protecting, restoring, and promoting the sustainable use of terrestrial ecosystems, while halting and reversing land degradation and halting biodiversity loss. As it happens many times, launching new goals for a better, future world is a challenging, visionary, and exciting experience. However, as we learnt from Marten (1988), agroecosystems are overwhelmingly complex and achieving SDG 15 seem to be an even more complex matter, especially considering the extremely diversified attitude of human populations to issues of social, economic, and environmental development.

Table 1 Summary of impacts of agroecological management options on ecosystem properties, and their current importance to global food supply, livelihoods, and the environment. When not specified in notes, figures were retrieved from FAOSTAT, SOLAWs and other FAOs databases (El-Hage Scialabba et al., 2014)

Management option	*Potential impact on agroecosystem properties*					*Current relevance*			
	Diversity (++/−−)	Coherence (++/−−)	Connectedness (++/−−)	Efficiency (++/−−)	Resilience (++/−−)	Area (Mha)	World food supply	Labor[a]	ES[b]
Conservation agriculture	+	+/−	+/−	++	+	117	n.a.	Less labor	P, R (soil)
Mixed rice-fish systems	+	+	+	+	++	~2	n.a.	10%–234% more labor	P, R
Mixed crop-livestock systems	++	+	++	+	++	2600 (200 irrigated)[c]	70% ruminants; 90% milk; 1/3 pig and poultry	More labor	P, R
Organic agriculture	++	++	++	+	++	37	2% of global food retails	~30% more labor	P, R, C
Grasslands and forage crops	++	++	++	+	++	3930	23% meat; 27% milk	200 millions of workers	P, R, C
Traditional polycultures	++	++	++	+/−	++	80% land W Africa; unspecified amount LA and SE Asia[d]	20% (estimates to be investigated)	More labor	P, R, C
Agroforestry systems	++	++	++	+/−	++	1000[e]	Agroforestry systems are used by 1200 millions		P , R, C
Perennial grain polycultures	++	++	++	+/−	++	Negligible	Negligible	Less labor	P, R
Permaculture	++	++	++	+/−	++	Negligible	Negligible	More labor	P, R
Biodynamic agriculture	++	++	++	+/−	++	0.14	Negligible	More labor	P, R, C

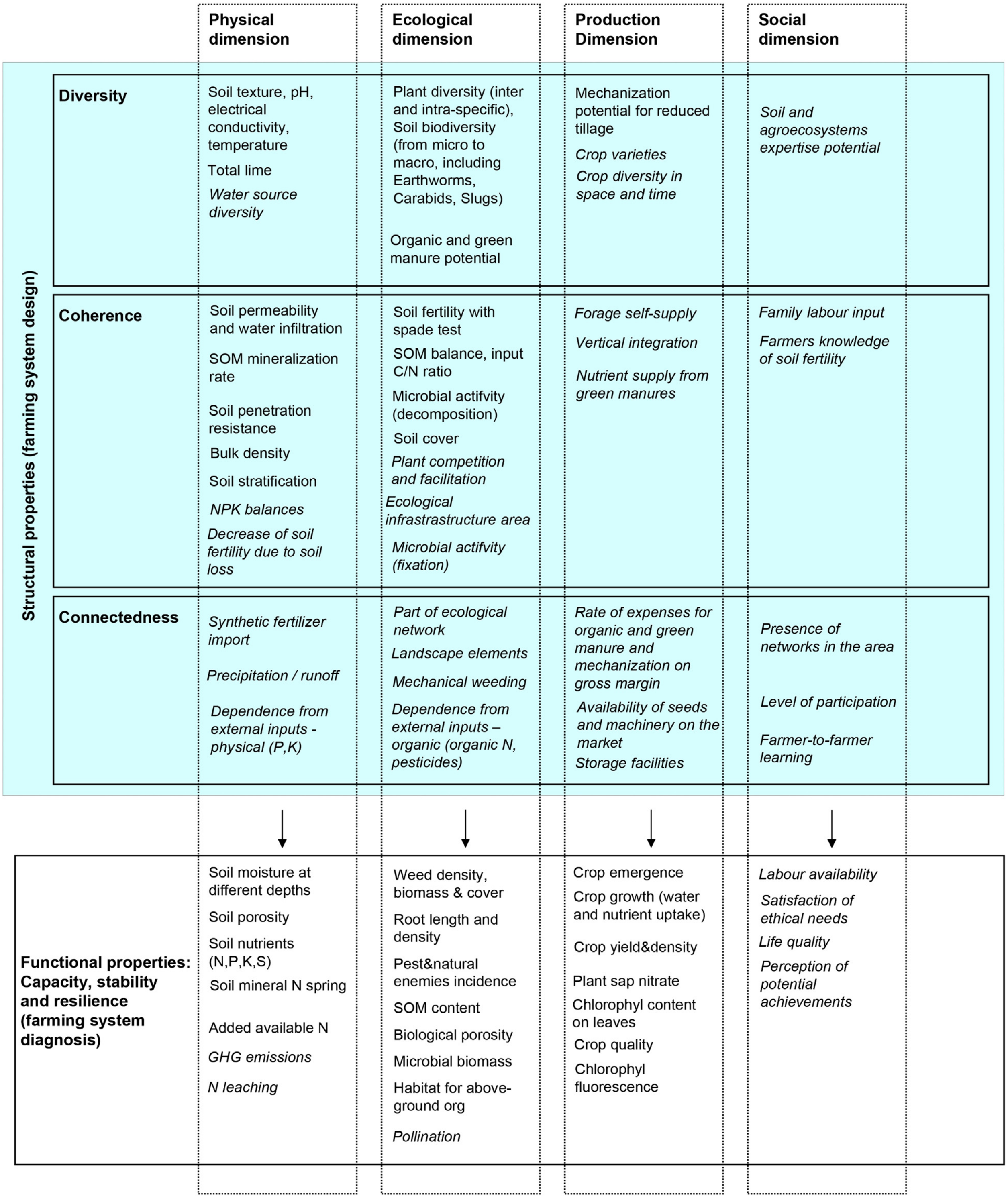
[a] Including employment and family labor: less/more labor is considered as compared to standard conventional techniques.

[b] ES, ecosystem services (according to Millennium Ecosystems Assessment): P = provisioning services (i.e., food, fresh water, fuel wood, fiber, biochemicals, genetic resources); R = regulating services (i.e., climate regulation, disease regulation, water regulation, water purification); C = cultural services (i.e., spiritual and religious, recreation and ecotourism, esthetic, inspirational, educational, sense of place, cultural heritage).

[c] This amount of land partly overlaps with grassland (~1200 Mha) and partly with land of other food production systems.

[d] West Africa, Latin America, and South East Asia.

[e] Land with tree cover of more than 10%.



		Physical dimension	Ecological dimension	Production Dimension	Social dimension
Structural properties (farming system design)	**Diversity**	Soil texture, pH, electrical conductivity, temperature Total lime *Water source diversity*	Plant diversity (inter and intra-specific), Soil biodiversity (from micro to macro, including Earthworms, Carabids, Slugs) Organic and green manure potential	Mechanization potential for reduced tillage *Crop varieties* *Crop diversity in space and time*	*Soil and agroecosystems expertise potential*
	Coherence	Soil permeability and water infiltration SOM mineralization rate Soil penetration resistance Bulk density Soil stratification *NPK balances* *Decrease of soil fertility due to soil loss*	Soil fertility with spade test SOM balance, input C/N ratio Microbial actifvity (decomposition) Soil cover *Plant competition and facilitation* *Ecological infrastracture area* *Microbial actifvity (fixation)*	*Forage self-supply* *Vertical integration* *Nutrient supply from green manures*	*Family labour input* *Farmers knowledge of soil fertility*
	Connectedness	*Synthetic fertilizer import* *Precipitation / runoff* *Dependence from external inputs - physical (P,K)*	*Part of ecological network* *Landscape elements* *Mechanical weeding* *Dependence from external inputs – organic (organic N, pesticides)*	*Rate of expenses for organic and green manure and mechanization on gross margin* *Availability of seeds and machinery on the market* *Storage facilities*	*Presence of networks in the area* *Level of participation* *Farmer-to-farmer learning*
Functional properties: Capacity, stability and resilience (farming system diagnosis)		Soil moisture at different depths Soil porosity Soil nutrients (N,P,K,S) Soil mineral N spring Added available N *GHG emissions* *N leaching*	Weed density, biomass & cover Root length and density Pest&natural enemies incidence SOM content Biological porosity Microbial biomass Habitat for above-ground org *Pollination*	Crop emergence Crop growth (water and nutrient uptake) Crop yield&density Plant sap nitrate Chlorophyl content on leaves Crop quality Chlorophyl fluorescence	*Labour availability* *Satisfaction of ethical needs* *Life quality* *Perception of potential achievements*

Fig. 5 Conceptual diagram for sustainability assessment of technology adoption in selected EU organic agroecosystems. Note that the functional properties are combined in one row. Standard letter format, initial set of Fertilcrop indicators; italic letter format, additional indicators added by using the conceptual framework.

Looking at the history of sustainability science of the last decades, we can notice a quite clear trend of development. In the 1970s for the first time humanity took consciousness of the limited nature of environmental resources, which gave rise in the following decade to the elaboration of new visions on economic growth patterns and the definition of sustainable development. 1990s were featured by the Rio Earth Summit and relevant efforts to put in place an agenda for transition to sustainability at local, national, and global levels. In the last decade the focus was on defining what to protect and sustainably use and the strategies to do that, that is, the ecosystems approach. Now the time has come to put all these efforts into practice.

There is not a one-size-fits-all solution to sustainability issues in the agricultural sector; rather, solutions need to be searched for based on a case-by-case approach, trying to optimize the potential of agroecosystems in terms of production of goods and services under different pedoclimatic and production constraints and considering different stakeholder perspectives.

While this article reports on only some conceptual tools to put sustainability into practice, we believe that its intrinsic message holds general validity. Indeed, past efforts have made theoretical propositions, definitions, and strategy principles available; integrating all of them in one unique conceptual framework is possible, as well as necessary, if we want to assure a true transition toward sustainability of agricultural systems.

See also: Environmental Management from a Systems Perspective.

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