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Review

Tendencies and challenges for the assessment of agricultural sustainability

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ABSTRACT

Given that agriculture is one of the activities with highest anthropic intervention on ecosystems, this paper focuses on the importance of aligning food production toward sustainability and the need to rely on evaluation methodologies that guide decision-making and take into account social metabolism. It is concluded that a holistic evaluation of sustainability is necessary, which implies including the social dimension as well as the economic and the ecological one and surpassing the linearity of the current evaluation methodologies.

1. Introduction

Recent studies (Rockström et al., 2016, 2009; Steffen et al., 2015) show that human pressure on the biosphere and geosphere is significant, manifesting itself in an accelerated extinction of species, acidification of the oceans, climate change, alteration of biogeochemical cycles among others. According to these authors human activities have reached a scale in which an abrupt global change cannot be overlooked, especially after the industrial revolution due to a higher use of fossil fuels and the intensification of industrial agriculture.

According to Pérez (2007), industrial agriculture is characterized by a growing increase in capital created by humans, represented in agricultural machinery, supplies etc., with the aim of substituting or controlling the natural resource (soil, water, seeds) and the work for capital. The latter generates an artificialization of nature, striving for a maximum homogeneous production.

Broad scientific evidence e.g. (Betts et al., 2017; Ehrlich and Ehrlich, 2009; Foley et al., 2011; Kareiva and Marvier, 2011), demonstrates that industrial agriculture and associated food systems: i) transforms and homogenizes the landscape; ii) reduces biodiversity and promotes genetic erosion; iii) contaminates the air and hydric sources; iv) Puts human and animal health at risk due to the chemical residue in the agricultural products; v) Fosters cultural change and puts traditional knowledge at risk as well as the diversity of non-commercial species among others.

Changes in agricultural practices generated an intensification of industrial production due to the global necessity to guarantee access to food on behalf of the growing population as well as the integration of markets, and globalization.

This propensity toward intensification of industrial agriculture corresponds to a trend in which the tropical regions are affected by agroindustrial modernization. This effect changes all the landscapes and their biodiversity to give way to agricultural monoculture, livestock (pastures) and/or forests (plantations), generating inadequate life quality levels to its inhabitants (Toledo, 2003).

Nevertheless, actions are aimed at reaching sustainability on the agricultural production systems. In this sense three basic questions have been object of study in the last few years (Conway, 1994):

- How to evaluate the sustainability of the agricultural production systems?
- What is the impact of a specific agricultural practice on the sustainability of the rural environment?
- What is the appropriate approach to explore economic, environmental and social dimensions?

Sustainability concept is not new, and it has been widely employed since it was presented by United Nations General Assembly (1987). However, making agricultural production sustainable in the agri-food context requires important changes in production, transformation, distribution and food consumption.

An agricultural product can be cultivated under different production models, nonetheless, its pressure over nature will vary in each historic period. The latter in function of the technical level, the economic importance of the crops in the agro-exporter context, the insertion or not of the local production in food chains, and the way natural resources are used by society.

In this sense, the evaluation of different agricultural practices is

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relevant, since it is possible to redesign them with the appropriate information or to improve them or eliminate them if it is convenient. This can generate useful knowledge for decision making and decisive information for the adequate design of more sustainable agricultural practices.

These changes should be based on the framework of a broad discussion on the socio-ecological implications of sustainability, since there are two opposite interpretations (Ayres, 2007). The weak-sustainability that justifies the use and damage of nature to reach economic growth, while the strong-sustainability highlights the importance of a harmony between nature and economic growth (Munda, 1997).

In this context, the present descriptive research, based on bibliographic revision and analysis by the authors, approaches the society-nature relationship in the context of agriculture and describes social metabolism and the socio-metabolic regimes as theoretical elements for evaluating the sustainability of agricultural practices. In the same way, the effects of agricultural practices on environmental degradation are described, as well as the necessity for a sustainable agriculture, calling upon the need of methodologies that integrate the social, ecological and economic dimensions of sustainability and that surpass the linearity of the current methodologies.

2. Social metabolism and socio-metabolic regimes

An important element for the study of agricultural sustainability stems from the recognition of social metabolism. The theoretical proposal of ecological economy recognizes that aside from social formation and the historic moment, human beings appropriate, produce, circulate, transform, consume and excrete products, materials, energy and water, that come from the natural world in a process known as social metabolism (Toledo, 2008).

Social metabolism, according to González de Molina and Toledo (2014), is related to a series of metabolic processes that start with *appropriation,* when a group of human beings uses products, materials, energy and water from nature (input/entry) and ends with the processes of *excretion,* when waste is deposited, emanations or residues to nature (output/exit).

These authors adduce that there are some interior flows that are related to the processes of: i) *transformation:* implies all the changes produced over the products extracted from nature that are not consumed in their original way. ii) *circulation*: it is present when a human group stops consuming all that it produces and also stops producing what it consumes. This triggers economic exchange; the elements that are extracted from nature begin to circulate, transformed or not. And iii) *consumption*: this process can be understood from the existing relation between human, social and historically determined necessities and the subjects proportioned by the three first processes [appropriation, transformation and circulation] (González de Molina and Toledo, 2014).

Social metabolism is based on an organicist analogy by stating that any social system reproduces itself culturally by communication, as well as biophysically (like population, the built infrastructure, artifacts and livestock) through the continuous energetic and material exchange with its natural environment and eventually, with other social systems (Fischer et al., 2010).

According to Sieferle (2003), in the history of mankind on the planet, regardless of the historic moment and the biogeographic conditions, certain methods of production and human subsistence can be distinguished by some fundamental systemic characteristics, originated in the way human beings use and transform nature.

In the perspective of Singh et al. (2010) when a society interacts with nature, it does so through the exchange (at times involuntary) of matter and energy; and intentionally through the application of certain technologies and labor with the aim of increasing the benefits obtained from nature. This link with nature generates environmental impacts and a reciprocal relation of co-evolution that conduces to a situation in which both systems depend on each other mutually, influence and limit themselves.

For Fischer and Haberl (2007) this reciprocal relationship is maintained thanks to a reciprocal exchange of matter and energy between both systems; an Exchange that according to Singh et al. (2010), generally keeps some typical patterns of biophysical interaction that can remain for long periods in a more or less dynamic balance, which are denominated socio-metabolic regimens.

In the history of humanity, for Singh et al. (2010), the socio-metabolic regimes, correspond to the human methods of subsistence, such as the regime of hunters-harvesters, the agricultural or the industrial regime, each one characterized by practices associated to the use of natural elements and the work and demographic patterns that generate a certain set of environmental impacts.

3. Ecological degradation in food production and the need for new sustainable paradigms in agriculture

From the neolithic period, different human groups have developed agriculture, devising processes for the obtention of seeds, sowing, plantation maintenance, harvest and exchange and commercialization of food. In many cases these activities have altered the dynamic balance of ecosystems, and in the Anthropocene, the agriculture is recognized as a primary driver of global change and as the main contributor to environmental risks (Foley et al., 2011).

The degradation of ecosystems (their structure, dynamic and evolution) for food production can be explained in two ways:

- By the appropriation processes of natural resources and environmental services, where any intervention generates negative impacts on environment;
- By disposing residues to the environment. According to González de Molina and Toledo (2014) these emanations should be analyzed by both the quality as well as the quantity of the materials of the residues, meaning if they are recyclable or not by nature or if they surpass or not the natural recycling capacity.

Nevertheless, when the appropriation of nature is done disregarding the productive vocation of the ecosystems, its capacity to renovate itself and its existence is threatened. This in turn generates certain changes that end up affecting society (Toledo, 2008). For example, a reduction on crops productivity or the use of agrochemicals to attenuate the loss of soil fertility. In these cases the farmer spends a great amount of time recovering the ecosystem, generating additional negative pay offs causing the producer to overexploit its labor to balance the relation.

It could be considered that nature generates penalizations to wrong decisions made by the producer, accumulating in time and space, which could lead to a collapse of the material base and even the disappearance of populations, states or civilizations, requiring sustainable interventions over the ecosystems (González de Molina and Toledo, 2014).

Nonetheless, processes such as the circulation, transformation and specially consumption increase the pressure over nature. According to González de Molina and Toledo (2014) in human history the volumes of materials-products that circulate as well as the distances covered before they are consumed, have increased. Going from the non-merchant and non-monetary trade, to the trade mediated by money, private property and markets. The latter results in a vast network of trades that is intimately linked to the transformations where the old relation, direct and almost immediate between appropriation and consumption gets blurred (González de Molina and Toledo, 2014). These authors argue that at a global level and at the beginning of the XXI century, consumption constitutes a powerful factor that demands incentive and even subordinates the other metabolic processes.

Examples around the world could explain the important role of consumption. For example, a global increase in the levels of meat consumption, is recognized as one of the greatest threats to tropical

Table 1
Proposals for evaluating (un) sustainable.

Evaluation tool/Element evaluated	Fundament or evaluation criteria	Relevant authors/documents
Matter and Energy balances/Matter and Energy	Studies the limits of sustainability of agriculture making a balance between energetic/material inputs for production and the energetic/material outputs it generates (Peréz, 2006). This approach is strong on historical transitions, as well as inclusive through standardization based on existing statistics. The exclusion of processes inside the economy and at different scales simultaneously are the main weaknesses (Gerber and Scheidel, 2018)	Vienna school of social metabolism (Fischer and Haberl, 2007; Haberl et al., 2016)
Rural Metabolism/Energy, Matter and money	It is based on a flows model of the appropriation of nature. The model states that all the units of rural production/extraction correspond to a unit of appropriation (P), which has some ecological exchanges with the surrounding environment and others of economic type with the social environment. The model is built when the environmental units are assembled with the unit P, through diverse types of material exchange that flow between these environments and turns them into parts of the whole or of a system (González and Toledo, 2014). The indicators could quantify the flows in terms of matter, money and energy and establish the direction of flows (González-Acevedo and Toledo, 2016)	(González de Molina and Toledo, 2014; Toledo, 2008)
Virtual Water and hydric footprint/Water	Virtual water is the quantity of water used in the production process of a product. It can be understood as an indicator for water consumption from production and the hydric footprint from consumption (Chapagain and Hoekstra, 2004). According to Pérez (2007), while the ecological footprint represents the area needed to sustain people's lives, the hydric footprint (HF) indicates the annual volume of water needed to sustain the population at that life standard; the HF represents the addition of the volume of water used by an economy in the agricultural, manufacturing and domestic sectors.	(Chapagain and Hoekstra, 2004; Hoekstra and Hung, 2002)
Human Appropriation of Net Primary Production (HANPP)/Biomass	It is an indicator used to know the impact of social metabolism; one of the ecological limits that are present in the expansion and economic growth comes alongside the Net Primary Production (NPP) generated annually by the ecosystems. This is, the production of vegetation once the used in plant respiration is subtracted, and that constitutes the base for maintenance of all heterotroph living beings (consumers and decomposers) (Carpintero, 2007).	(Haberl et al., 2014, 2007; Krausmann et al., 2013)
Geographic Information Systems (GIS) and remote Sensors/Land use and land cover change	The remote sensors have been used to obtain information about the elements present on the earth's surface and the GIS, for the management of great volumes of geo-referenced information in the study of rural landscape and vegetation coverage (Guhl, 2004)	(Aber and Aber, 2017; Kent et al., 1993; Qi et al., 2017)
Balance of soil fertility/Soil	Evaluates the efficiency of the different forms of reposition of the fertility of agriculture in historical perspective (González de Molina et al., 2010). This allows the detection of agronomic processes and in general the environmental impacts associated to the implementation of such techniques, just as the possible risks of contamination by lixiviation of nitrogen, eutrophying of continental waters, chemical degradation of soil, loss of potential production capacity among others (Gonzalez de Molina, 2012).	(Garcia-Ruiz et al., 2012; Gonzalez de Molina, 2012; González de Molina et al., 2010; Vanwalleghem et al., 2017)
Hemeroby/Land use and land cover change	It is a measure to evaluate the anthropogenic influence on the ecosystems considering anthropogenic effects that inhibit the development of the system toward the final state of its dynamic balance (Stoll, 2007). The index of Hemeroby, IH, is based on the percentage of territory that each use occupies/covers and the degree of intervention (or degree of Hemeroby) that is assigned to the different human impacts detected in the place (Steinhardt et al., 1999).	(Jalas, 1955; Steinhardt et al., 1999)
Life cycle analysis and assessment/Matter and energy	It is a methodology that attempts to identify, quantify and characterizes the different potential environmental impacts associated to each of the stages of the life cycle of a product (Levy, 2017). The analysis of the life cycle determines the impact of all the stages of the product quantified in the use of natural resources and energy that have been necessary in each part of the process.	(ISO 14001:2015., 2015; ISO 14040:2006., 2006; Levy, 2017)
Emergy Analysis/Emergy	Researches the system's function of "ecosystem of environmental work" required to guarantee its dynamic, assigning values according to the necessity to conduce a process and products, under the potential restrictions (Brown and Ugliati, 2004). The indexes of sustainability developed by Odum (1971) define the sustainability in relation to the quantity and quality of energy transformed by a particular system of production. It is calculated dividing the contribution of nature to generate processes over the environmental load for this case of the agricultural system over the ecosystem. Values close to 0 indicate the unsustainability and higher values indicate the sustainability of the system.	(Odum, 1996, 1971)

(*continued on next page*)

Table 1 (*continued*)

Evaluation tool/Element evaluated	Fundament or evaluation criteria	Relevant authors/documents
Evaluation of Management Systems Incorporating Sustainability Indicators (MESMIS)/Water, soil, resilience, adaptability, self-dependency	Values the sustainability from the seven general attributes of the ecosystems: productivity, stability, reliability, resilience, adaptability, equity and self-dependence (Massera et al., 1999). This method allows to value in what measure the alternative systems are more sustainable and identifying the critical points that prevent reaching sustainability. It is based on a battery of indicators that are designed by the researcher to measure each attribute; in the agricultural systems indicators such as productivity, income/outcome, diversity of cultures, sales price, mechanisms of decision making among others. The MESMIS is not a statistic method but it pretends quantifying the evolution of sustainability of a period A and a period B.	(López-Ridaura et al., 2002; Massera et al., 1999)
Land-time Budget Analysis (LTBA)/Alterations of time and soil employed in agricultural production	Allows the estimation and representation of the quantity of time the household members dedicate to food production for subsistence, remunerated and non-remunerated work, and social and domestic activities, among others, like the land dedicated to production of foods for subsistence, of products for the market and for conservation (Pastore et al., 1999)	(Pastore et al., 1999; Singh et al., 2010)
Multi-Scale Integrated Analysis of Societal & Ecosystem Metabolism (MuSIASEM)/Matter, energy, time and soil	It is based on three aspects: i) metabolism endo and exosomatic in relation to the flow of diagrams; ii) The dissipative cycles of applied bio-economy to the ecosystems; and iii) The re-assignation of human time and the patterns of land use in different sectors (Giampietro, 2004; Giampietro et al., 2009). This approach is strong on the analysis of processes inside the economy, as well as able to integrate different scales. However, relies on data not always easy to get and can have an ahistorical perspective (Gerber and Scheidel, 2018)	(Giampietro, 2004; Giampietro et al., 2009).
Agrarian Metabolism/Energy	The objective of this approach is to ascertain if a given agroecosystem is capable of maintaining its biomass production and ecosystem services. As well as ascertain their degradation, and if the agroecosystem requires increasing amounts of external energy in order to compensate for the loss only partially (Guzmán and González de Molina, 2015).	(Guzmán and González de Molina, 2017, 2015; Guzmán et al., 2017; Tello et al., 2016)

ecosystems and biodiversity (Machovina and Feeley, 2014). Livestock production accounts for up to 75% of all agricultural lands (Foley et al., 2011), so that a rise in the consumption of meat products increases the demand for animal feed and consequently changes the land uses with the associated negative environmental impact on ecosystems and biodiversity. Also, it is known that agri-food systems in which higher calories are consumed by humans stem from animal products that have a higher total calorie throughput (Mayer et al., 2015).

Likewise, another interesting example is related to commerce between northern and southern countries. After the XX century, the consumption in northern countries and the international commerce with southern countries has been a factor that has promoted the expansion of agricultural border and has contributed to intensifying the exploitation of the soil in southern countries. This represented an increase in volumes of foods and produced agricultural raw materials, as well as in increased productivity by having higher yields per hectare (Pérez, 2006); with associated environmental costs and natural heritage exhaustion.

According to Pérez (2006) the increases on productivity are very important in economic terms, but these have associated environmental implications a: i) The ecological footprint caused by the intensive introduction of energetic inputs based on non-renewable resources produce energetically deficient agriculture that is of low ecological sustainable value; and, ii) absolute increments on the use of other natural resources such as water, since the dynamic on the use of the soil has a relation of correspondence in the dynamic of the use of hydric resources for agricultural activity.

The strong pressure over nature by conventional agriculture, and also the permanent demand of food by the increasing human population, implies the necessity of new paradigms for an agricultural production in the frame of productive tendency of ecosystems. In relation to this Leff proposes: The environmental crisis takes us to rethink reality, to understand its tracks of complexity and the linking of the complexity of the being and of the thinking process, of reason and passion, of sensitivity and intelligibility, so that from there, open new roads of knowledge and new existential senses for the reconstruction of the world and the reappropriation of nature (Leff, 2006).

In this new perspective, the modern world crisis must be considered, especially in the rural sector, as a consequence of the transgression of the biophysical limits of the planet for food production. For Toledo et al. (2009), the way to approach the crisis is through the improvement of the reduced ways in which traditional models as well as the modern ones articulate each other and with nature. Thus, bringing about the concept of sustainable development, which allows perceiving an alternate modernity that is really the adoption of a new method of appropriation of nature.

In this sense, sustainable agriculture can be understood as the management and use of agroecosystems in a way that the biological diversity, productivity, regeneration capacity, vitality and functioning capacity are maintained. So that important biological, economic and social functions at a local, national and international level can be met (today and in the future) without damaging other ecosystems (Lewandowski et al., 1999).

Sustainability can be reached through agricultural practices based on the adequate and profound knowledge of ecological processes in production units and their context. Therefore, agreeing with Gliessman a greater comprehension and evaluation of the current productive processes is required to focus agricultural production toward social and economic changes that promote sustainability (Gliessman, 1998).

4. The biophysical indicators and the evaluation of sustainability

The footprint and the visible patterns of biophysical interaction with social metabolism, and the recognition of the concept of *strong sustainability,* have led to the development of multiple indicators or physical indexes of (un) sustainability.

The biophysical indicators allow identifying the degree of exhaustion and depletion of natural resources, since in practice, the sustainability will depend on the size the economy occupies in the biosphere (Giljum, 2003). A good way to measure the size or "scale" in physical terms that occupy the economic activities in the biosphere, is to quantify the amount of natural resources that an economic activity requires, which allows having indicators that help to interrelate the economic subsystem with the biosphere (Peréz, 2006).

Different researchers have dealt with the topic by attempting to build a theoretical framework, thus, there are diverse proposals for the evaluation of (un)sustainability (IISD, 2006) (See Table 1), that constitute an important advance for the construction of agricultural productive systems which are more sustainable. However, a critical evaluation is required of these methodologies and results, since a great uncertainty is associated to their construction process.

The evaluation of sustainability of the agricultural production systems, as it was mentioned in the introduction has brought up three basic questions that have been object of study in the last few years: How to evaluate sustainability of the agricultural production systems?, What is the impact of a determined agricultural practice on the sustainability of the rural environment? And, what is the appropriate approach to explore its economic, environmental and social dimensions?

There are some limitations despite the fact that these questions have been involved in more than 600 Projects (IISD, 2006) and the existence of multiple proposals of evaluation of agricultural sustainability described in Table 1.

One of the main limitations of the methodologies described on Table 1, can be that not all of them are easily understood or useful to guide the formulation of politics and decision making, so new proposals are required (Graymore et al., 2009).

Some methodologies listed on Table 1, lack including the thermodynamic laws and principles in the analysis of agrifood systems, which is a limited approach to understanding and suggesting changes in terms of sustainability. Some of these methodologies are: Matter and energy balances, rural metabolism, virtual water and hydric footprint, HANPP, GIS and remote sensors, balance of the fertility of soil, hemeroby, life cycle analysis and assessment, MESMIS and LTBA.

The thermodynamic laws and its basic principles are important since they dominate the economic process and impose restrictions on unlimited economic growth. Without the thermodynamics laws, we could constantly burn a piece of coal repeatedly to get energy indefinitely and turn it into work in an endless process (Georgescu-Roegen, 1971).

Some methodologies described on Table 1 acknowledge social metabolism as an approach that recognizes the metabolic processes of appropriation, circulation, transformation, consumption and excretion. This is the case in Matter and Energy Balances, Rural Metabolism, HANPP, MuSIASEM and Agrarian Metabolism. However, the concept of Found and Flows by Georgescu-Roegen (1971) has been less considered by these methodologies. As explained by Guzmán and González de Molina:

> *Flows involve the energy and materials consumed or dissipated by the metabolic process—for example, raw materials or fossil fuel. Their purpose is to configure and supply the "funds" constructed by societies to generate goods and services, and to compensate for the law of entropy by generating order.* (Guzmán and González de Molina, 2017:11)

In this regard, only the agroecological EROIs and the MUSIASEM take into account the fund-flow concept. This is a useful and promising approach, since it acknowledges the thermodynamic laws and its basic principles.

The efficiency of agricultural systems can be measured when there is comprehension of how energy flows through the system, it is in this manner that agricultural systems that are highly dependent on fossil fuels tend to run out, bringing along higher prices and the unsustainability of the production system (Pimentel et al., 2005). For the evaluation of sustainability of the agricultural production systems the flows of matter and energy have been studied by methodologies such as the life cycle analysis, HANPP and Matter and Energy balances. These methodologies have an interesting input–output approach that computes the energy return or matter obtained from the agricultural system to the inputs invested from outside. However, the input–output approach is limited, as it conceals the internal agroecological functioning of farm systems into a black box, without unveiling how it works or its structure (Tello et al., 2016).

The majority of methodologies are centered on a dimension of sustainability, whether it is on social, economic or biophysical aspects; without proposals that integrate the three dimensions adequately. For example, virtual water and hydric footprint, GIS and remote sensors, balance of the fertility of soil and hemeroby are centered on a biophysical perspective. Other methodologies like HANPP, rural metabolism, MuSIASEM and agrarian metabolism integrate social, economic or biophysical aspects.

As it has been mentioned, there are approaches that are dominant focused on the study of physical or material aspects of sustainability which is necessary but uncompleted. A weakness in these methodologies is the non-consideration of the immaterial component of the appropriation of nature for its valuation; meaning the set of multiple beliefs, imaginary, knowledge and perceptions through which human beings articulate themselves with nature.

The rural metabolism is the only methodology that considers the immaterial aspects in the evaluation of the sustainability of use and transformation of nature. Another advantage of rural metabolism is that it recognizes some relationships of economic type and others of ecological type that can be approached in function of the spatial scale, temporality and the dimension or metabolic processes analyzed (González de Molina and Toledo, 2014).

Nevertheless, a weakness of rural metabolism is that it does not quantify the amount of the environmental impact on ecosystems and that in non-commercial or traditional agriculture it is difficult to collect the requested information for the construction of indicators. Similarly, the valuation of the energy flows as well as matter is not done in an integral manner with a quantification of environmental impacts.

The low availability of data or its aggregation at a regional and/or national scale is also a limitation for several methods like virtual water and hydric footprint, HANPP, GIS and remote Sensors, balance of the fertility of soil, LTBA, MuSIASEM and agrarian metabolism. For example, for the balance of soil fertility some historical measurements of soil nutrients are required, but in many cases the information is not available (Gonzalez de Molina, 2012). The same is the case for GIS, remote Sensors and Emeroby, since their use requires updated cartography and remote sensor images from several different years in order to establish the changes.

Also, other methods like virtual water and hydric footprint or the agrarian metabolism, are based on statistics and therefore require a great amount of data to extract patterns and tendencies that are reliable, so their application is restricted to dominant cultures, where there is a lot of available data and new ones are constantly generated. Moreover, some methodologies have little sensitivity to detecting subtle changes in the analysis variables. For example virtual water and hydric footprint require fathoming the relation between improvements in the crop yields and the water requirements by surface unit, among others.

In the development of indicators or indexes such as Mesmis, there are limitations for the joint interpretation of multiple indicators and the linearity of the sinthetization and weighing methods. The linearity of methods like the balances of matter and energy that do not recognize the stochastic or other non-linear forms that allow analysis beyond entries and exits. In the same way, the lack of standardization of scales to define the sustainability from different methods makes it difficult for the researcher to do an integral diagnose or comparison. For example, the GIS, remote Sensors and Hemeroby use normally a landscape scale to assets changes in land use and land cover, but LTBA can be used to generate useful and complementary information at farm level on land use.

5. Challenges for integral evaluation of agricultural sustainability

At a global level a growing concern is perceived to ensure social, ecological and economic viability of the rural systems. Making emphasis on the necessity to look for sustainability, in the design process, adoption and diffusion of the productive systems and in the strategies for the management of natural elements (Frame and Brown, 2008; Jan Stobbelaar and van Mansvelt, 2000).

Also, it is recognized that the development of methodological tools should include an agroecological approach that can contribute to a better understanding of agroecosystems, its energy functioning and improve their sustainability (Guzmán et al., 2017).

However, to overcome the limitations exposed in Section 4, and to be able to analyze in terms of sustainability different models of agricultural development, it is recommendable to adopt the social metabolism approach, and the recognition of the fund-flow concept and the thermodynamic laws and its basic principles.

Also, it can be useful to use some biophysical spatial indicators in the same geographic scale to establish the pressure over natural elements. Considering a temporary scale that includes various historical periods in order to compare the degree of sustainability of the productive strategies, current or past, trying to establish as suggested by Quintero-Angel (2015) which productive practices have been more or less sustainable in the same space.

Assuming a historical perspective is important since as suggested by González and Guzmán (2006) there is not a balance of nature but instead many balances and the ecosystems vary from one balance to the other. These authors adduce that the rejection of the existence of one original state of balance of ecosystems forces the denial of only one and objective sustainable state, so that sustainability is a goal, not a normative definition. Therefore, what needs to be analyzed is the degree of sustainability in the methods of management and organization of each socio-metabolic regime trying to establish a higher or lower degree of sustainability between them, in order to guide decision making toward production patterns and consumption that are less impacting on nature.

Additionally, the ecological, social, economic and cultural advantages and disadvantages related to the different strategies and systems of management must be taken into account, integrating them into a framework of common analysis that provides clear and coherent lineament, with the aim of making the management of natural resources more sustainable (Altieri, 2010; Jan Stobbelaar and van Mansvelt, 2000; León-Sicard, 2010; López-Ridaura et al., 2002; Sánchez-Fernández, 2009).

An interesting field of research could be the integration of the results of different methodologies. The latter could facilitate decision making and offers the researcher a unique and concise answer when comparing different systems of agricultural production. An interesting example is the Aggregate index of Sustainability (AIS) (Gónzalez-Acevedo, 2015) that synthetizes the sustainability evaluation from the calculations given by other indexes like Emergy, Mesmis and Rural Metabolism.

In the development of methodologies of evaluation of sustainability, the analysis of the biophysical limitations that nature imposes should not only be integrated, but it should also consider the environmental conflicts and the socio-economic limitations. In relation to that, it would be useful to consider perspectives or research levels proposed by (Sevilla Guzmán, 2006):

i) Ecological-productive level (distributive): in this perspective, the functioning of the agro-ecosystems is analyzed in a similar way or equivalent to the wild ecosystems, selecting between techniques and adopted technologies that do not significantly degrade natural resources and without losing focus on scientific products that do not generate exploitation ways that degrade society.
ii) Socio-economic level (structural): That analyzes social organization and the exchanges between productive units and with consumers.
iii) Socio-political level (dialectic): that questions the concept and the type of development, the direction of humanity, the manipulation of knowledge and the technological advances as tools of domination and accumulation.

In the same manner, the development of methodologies and evaluation of sustainability, should consider different levels of analysis or scales, as proposed by the multi-scale perspective of rural metabolism (González de Molina and Toledo, 2014), or the MuSIASEM (Giampietro et al., 2009). Both methods integrate different spatial scales into the analysis. Among them the farm or property, local community, local society or watershed; and the greater society, meaning the region, province or nation-state.

In the same way the methodologies of evaluation should assert the analytical triangulation, that according to Ramos (2003) consists on using more than one source of data, the analysis of data with different theories or models, or the use of different hierarchical levels, at the same time, with the aim of getting solidity in the analysis and giving more credibility to the scientific analysis. This will bring redundancies that are very positive, since they will reinforce the argument or the regularities that can be found.

Likewise, taking into account the human pressure on nature for food production, it is necessary to proceed to adjust the food systems based on the principle of precaution (Riechmann and Tickner, 2002), which suppose an ethical position to face technological civilization, something that is close to the strong-sustainability principles (Quintero-Angel et al., 2018). This approach of sustainability states that natural capital cannot be replaced by manufactured capital (Costanza and Daly, 1992).

In this manner, to analyze different models of agricultural production, it is very convenient to approach the attributes of sustainability: productivity, stability, resilience, equity and autonomy, that are

Table 2
The author enumerates 8 operative criteria from which the sustainability of the agricultural systems can be analyzed.
Source: Based on Gliessman 1990, cited in Guzmán et al. (2000).

Degree of dependence on external “inputs” (energy, materials or information)	A lower dependence and greater self-sufficiency, greater autonomy of the agroecosystem
Use of renewable resources (locally accessible)	The external dependence is reduced and the renewability ensures a greater diversity and perdurability of the favorable conditions of production
Local environmental Conditions	Acceptance, tolerance and adaptation to environmental conditions facilitate sustainability. This decreases on agro-ecosystems under intense modifications
Productive Capacity	Sustainability of an ecosystem is a function of this parameter (considered ecologically)
Heterogeneity	Sustainability increases on heterogeneous landscapes and where synergism and temporary complementarities are exploited.
Biological and cultural Diversity	Sustainability increases with greater biological and cultural diversity
Local Knowledge	A greater use of knowledge by the farmers means higher sustainability
Product availability	Sufficiency for the local internal provision and for economic trade
Criteria	Description

described on Table 2, and that allow an integral valuation of agricultural sustainability. However, for each of these attributes a series of variables or indicators is required through which they are measured, that should be selected according to the reality studied. This means, to consider which are the most important factors that condition sustainability of the agro-ecosystem (Aristide, 2009).

The attributes for sustainability described on Table 2, allow overcoming the limited evaluation of the yields of the agricultural productive systems, through productivity and profit variables, that belittle different crops to the main crop. These other crops provide options to the producer for food security, ecosystemic services, and recognize tradition and culture that are not valued in the intensive productive systems.

The graphic representation of analyzed data is another interesting challenge to the improvement and development of methodologies of evaluation of sustainability. This graphic representation should consider changes during time, multiple scales of analysis and suggest stakeholders the uncertainty associated to its construction.

A graphic representation of several indicators aggregated is useful to get a simplified characterization of the analyzed problem, so that it is easy to handle, but also implies the loss of useful information in the final graphical output which corresponds to a loss of the holistic view (Gomiero and Giampietro, 2005).

Additionally, to overcome the linearity of the indicators and its valuation of importance, it is considered that artificial intelligence can be useful, taking into account that it is a technology that allows the study of systems that possess stochastic and changing characteristics, like the environmental systems can be.

For the aforementioned, there have been tools used such as neuronal networks, diffuse systems, data mining methods and extraction of knowledge and the hybrid systems and case-based reasoning, which have demonstrated great efficiency in the treatment of data and generation of forecasts and diagnosis (Fajardo Toro, 2008). In the agricultural context artificial intelligence has been used for selecting characteristics of climate, soils, productivity predictions, etc, and it is considered a new field (Mucherino et al., 2009).

6. Conclusions

Although, sustainability is recognized as an essential element to guarantee the socio-cultural, ecological and economic viability of the systems of agricultural production, its implementation requires evaluation of methodologies, that provide useful information about the current state of the interventions over the ecosystems, the intensity and the direction of the possible changes of each production system.

When understanding sustainability as a goal to reach throughout time, it is necessary to consider a historical perspective to analyze the degree of sustainability of the ways of management and organization of the agricultural productive systems, trying to establish the higher or lower degree of sustainability among them, to guide decision making toward production patterns and consumption that is less impacting on nature, because it is the changes on social metabolism that can make a system more sustainable in time.

For the evaluation of agricultural sustainability, balances of matter and energy, the hemeroby, rural metabolism, the balance of nutrients and human appropriation of the net primary production, have been used, among others that should be employed with a critical vision, since its construction process is associated to a great uncertainty. Each methodology of evaluation analyzes different aspects (energy, money, materials, and resources) it is for that reason that it suggests the analytical triangulation to consider various methods of analysis.

It is recognized that the methodologies described, are an important step toward the construction of more sustainable agricultural production. However, more integral methodologies are required that deal with the social, ecological and economic dimension of sustainability and that reduce the linearity of the current ones.

The recognition of the social metabolism approach, the fund-flow concept and the thermodynamic laws and its basic principles is a necessary and interesting challenge for the improvement and development of methodologies of evaluation of sustainability.

To overcome exposed limitations and be able to analyze different models of agricultural production in terms of sustainability, it is more convenient to deal with the attributes of sustainability: productivity, stability, resilience, equity and autonomy that allow an integral valuation of agricultural sustainability.

It is perceived that the evaluation of sustainability does not only respond to quantitative criteria, but also to qualitative criteria, and in this sense, the statistic techniques of the majority of methods, are limited to a holistic evaluation of sustainability.

However, these methods could be improved to evaluate sustainability in an integral way, if their procedures are built over a model of aggregation of qualitative information as well as quantitative.

In this sense the study of other techniques and mathematical and computational tools should be impelled for the analysis of information, such as the neuronal networks and diffused logic which integrate the qualitative and quantitative analysis that reduce linearity and subjectivity to the evaluation of sustainable agricultural practices.

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