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On the Use of Life Cycle Assessment to Improve Agronomists' Knowledge and Skills toward Sustainable Agricultural Systems

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Abstract.
Purpose. In agricultural and forestry sciences higher education, environmental sustainability is most often taught through the discussion of examples of green agricultural practices, such as precision farming, and more rarely by taking a more general point of departure in environmental assessment methods, such as Life Cycle Assessment (LCA). Nevertheless, we think that teaching LCA in the agronomists' curriculum might significantly contribute to enhance students' systemic perspective on agricultural sustainability. The purpose of this paper is to highlight which additional knowledge and skills may be given to agronomists thorough the teaching of LCA. *Design/Methodology/Approach.* We designed two short courses focused on LCA to be followed by students at the Bachelor´s degree in Agronomy (University of Turin, Italy) and at the Master´s degree in Sustainability of Agro-food Networks (UNESCO Chair for Sustainable Development, Turin, Italy). After the courses, students filled in a questionnaire about their opinions on the usefulness and value taken from the short courses. *Findings.* From students' answers in the questionnaire and their comments during both teaching sessions, it was possible to point out four key aspects acquired by students during the courses: (I) Complexity of agricultural systems. Application of LCA requires to describe the energy flows and material cycles of the system under study and to decide the allocation of environmental impacts to specific phases of the production. (II) Systemic view of the farms. The need to identify boundaries between technical and natural systems for impact assessment highlights the strong interconnection between the two of them. (III) The problem of efficiency. The application of LCA may highlight that productions that are efficient from an agronomic point of view may not be as efficient from an environmental point of view. (IV) Conceptions about sustainable agriculture. During the group work, students were asked to highlight (if possible) the paradigm of sustainability of the authors of the scientific papers and to discuss it. This way, they were able to reflect on the complexity of the concept on environmental sustainability. *Practical Implications.* Teaching LCA in an interactive course, agronomists discussed pivotal concepts for environmental sustainability, such as system thinking, the problem of efficiency as well as conceptions about sustainable agriculture. All of these aspects reflect positively on the professional life of the agronomists, even if they will not apply any environmental impact methods in their future careers. *Originality/Value.* This paper describes a pioneer research in which LCA is used as a pure educational tool for understanding the environmental efficiency of agricultural systems, but also founding concepts of environmental sustainability in the agricultural sector.
Keywords. Life Cycle Assessment, Sustainable agriculture, System thinking, Crop management, Higher education, Teaching improvements.

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Introduction

Theoretical framework and aims of the research

Environmental sustainability has been included in the curricula of undergraduate and graduate programmes across Europe for more than 10 years (Holmberg et al., 2008; Lozano and Lozano, 2014). In fact, integrating sustainability into diverse academic curricula has been recognised as essential for providing students with the skills and insights which allow them to help societies become more sustainable (Lozano, 2010). This integration is occurring at different levels and rates in relation to the academic area of the Bachelor´s or Master's degree. In particular, there are a number of studies on approaches for embedding sustainability issues into engineering curricula at technical universities (Holmberg et al., 2008; Segalas et al., 2010), but studies about the integration of sustainability issues in other disciplines, such as agronomy (Parr &Trexler, 2011), dentistry (Kinakh, 2015) or information systems, (McGibbon& Van Belle 2015) are rare.

In general terms, sustainability is perceived from two very different points of view: sustainability as practices, such as reducing food miles, buying organic, consuming less meat, etc., or sustainability as metrics, involving the quantification of the environmental performance of a system through the application and comparison of sustainability assessment indicators (Sala et al., 2013). In the agricultural context, the teaching of environmental sustainability is often just exemplified by greener agricultural practices, such as precision farming, but usually, a systemic vision of sustainability in the food production is missing. The agricultural education in Italy (in both high schools and academies) reflects this approach. When sustainability is presented to students, it is usually discussed as practices for lowering the use of chemical products or plastics; rarely, environmental assessment methods are used as tools to give students a more concrete perception of the environmental performance of agricultural systems. In contrast to this traditional approach, some studies have proven that the practice of environmental impact assessment and the application of professional tools can also be efficiently used for educational purposes (Bergeå et al., 2006).

One of the tools commonly used for environmental impact assessment is Life Cycle Assessment (LCA), which includes the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its whole life cycle. In particular, LCA is a well-established and scientifically recognised methodology whose principles and methodological framework have been drawn in several certification schemes focused on environmental profile of products and services, such as ISO 14064:2013, well known as Carbon Footprint (CF), Environmental Product Declarations (EPD), Product Environmental Footprint (PEF), etc. The Life cycle assessment methodology has been standardised by the International Standardisation Organisation (ISO) in the ISO 14040 series (1997-2003) and revised in 2006 (i.e. ISO 14040:2006 and ISO 14044:2006).

The origin of LCA can be found in the early 1970s, when large multinational companies started to investigate the life cycles of their products in order to figure out where in the production process they could save resources, primarily for economic purposes (Bauman and Tillman, 2004). In such studies, results were reported as resource and emission profiles, but no quantitative assessment of the associated impacts on the environment was performed (Hauschild and Huijbregts, 2015). In the following years, the LCA approach was developed and formalised to be used in the industrial sector, but it was only in the mid1990s, that its validity was recognised also for the agricultural sector (Audsley et al., 1997). Nowadays, LCA is considered a useful tool to compare alternative food products, processes or services and as a background for environmental product declaration (Schau and Fet, 2008). Notarnicola et al. (2015) describe LCA as one of the most appropriate methods to study the environmental performance of agricultural systems, as it allows the identification of environmental hotspots and the evaluation of different agricultural techniques; in addition, it supplies scientific data to the decision makers both at firm and political level. However, LCA application in the agri-food sector is a complex and challenging endeavour (van der Werf et al., 2014) and is usually performed by highly specialised experts and not considered for the higher education in the agricultural curriculum.

The application of LCA does not evaluate the absolute sustainability of an agricultural system; nevertheless, from an educational perspective, applying LCA to a case study can be considered as a concrete proxy for sustainability, as it enables students to engage with a range of sustainability issues (McGibbon& Van Belle 2015).

The purpose of this research is twofold: (I) to investigate if LCA can be used also as a didactical tool to support the learning of environmental sustainability for agronomists and (II) to evaluate the potential outcomes and benefits of teaching LCA in agricultural higher education. To make this assessment an action–research perspective (Whitehead &McNiff, 2006), we applied it to two case studies. In particular, the following two sections discuss the theoretical background in with the research takes place, including the way in with environmental sustainability is embedded in academic courses. Section 2 presents the method applied to point out key aspects that can be acquired by agronomy students teaching LCA. Section 3 describes the four main competences that can be improved in the agronomist curriculum via the teaching of LCA; finally, section 4 concludes the paper.

The inclusion of environmental sustainability in agronomic programmes

Papers focusing on the embedding of environmental sustainability in academic curricula of agricultural education are rare. Karsten and Connor (2002) developed an interdisciplinary undergraduate course in the science and policy of sustainable agriculture for students from several backgrounds, from political to agricultural sciences. The aim of their work was to highlight interdisciplinary thought and the inclusion of different perspectives. The authors developed specific teaching materials that featured aspects from both natural and social science domains. Wiedenhoeft et al. (2003) organised an experiential course in Agroecosystems Analysis for advanced undergraduate and beginning graduate students. They applied a mixed approach of lectures and farm visits, including interviews with the farmers and their families. The authors remark that, for the students, the multidimensional learning experience was more valuable than other traditional courses at their home campuses. Also, Parr and Trexler (2011) adopted a field approach for teaching sustainable agriculture. In particular, they assessed perceptions and achievements in focus groups composed of students who worked in college farms in several locations in the United States. The experimental learning approach was extremely productive, and the authors stated that specific activities at student farms on a university campus can be good occasions for in-depth embedding of sustainability in agricultural education.

Besides these three positive experiences, a discrepancy can be seen between the number of researches working on developing sustainability assessment methods and the number incorporating such methods into the curricula of university courses. Lozano and Lozano (2014) pointed out that the main reasons for this discrepancy could be: (1) ignorance or lack of awareness about the relevance of sustainability; (2) a lack of proper settings and support to change teaching curricula; (3) insecurity and fear of lacking academic credibility for teachers and professors who teach interdisciplinary courses that are needed for education in sustainable development; (4) over-crowded curricula; and (5) teachers who might prevent or support the diffusion.

Holmberg et al. (2008) defined two problems for embedding environmental sustainability in academic curricula: (1) internal factors, which are typical for the academic and engineering community, such as scepticism, disciplinarity and specialisation, autonomy, the desire to quantify problems and the reluctance to consider the 'soft' sides of problems; and (2) societal-contextual factors, which refer to the scientific system in a country, national values and mainstream political ideas.

In the agricultural teaching community, all of these aspects are relevant, plus one important additional issue: the traditional agricultural approach in the period from the 1980s–1990s was based on the aim of 'increasing production' and, more recently, this aim shifted to 'increasing the quality of food products'. Nevertheless, in order to understand the importance of education on environmental sustainability in this field, a paradigm shift is needed towards the idea of 'increasing the sustainability of food products'. This approach includes the study of the ecosystem services that are provided by agricultural systems and the application of environmental assessment methods to food production systems; however, at least in Italy, few agricultural courses include these topics, mainly because of the traditional academic separation of environmental and agricultural disciplines.

International experiences in including environmental sustainability in higher education

Despite the limited research published so far, there is an increasing interest in collecting experiences focused on the inclusion of sustainability as a subject in universities' curricula (Lozano & Lozano, 2014). In this direction, Holmberg et al. (2008) described the efforts of three European universities in the integration of sustainable development into their educational programmes through individual interaction with teachers and other faculty actors. Segalas et al. (2010) presented the results of a five-year research project that analysed how competences in sustainability were introduced into five European technological universities in order to evaluate which pedagogical approach best facilitates the learning of sustainability topics. The authors organised the pedagogical strategies applied in the studied universities in lecturing, project-based learning, case study, problem-based learning, back casting and role play. They found that in the case of sustainability, lecturing is a good method to introduce students to sustainability concepts, but the most efficient approaches are the ones that involve students actively. In particular, both case study and problem-solving approaches can be useful, as students directly face real or ad-hoc situations, are able to discuss how they would have acted and compare professional solutions (as either good or bad examples).

Lozano and Lozano (2014) presented the process of developing a Bachelor's degree curriculum in Engineering for Sustainable Development at the Tecnológico de Monterrey, Mexico. In their work, the authors defined five general approaches for embedding sustainability in academic curricula: (1) introducing the discussion of some environmental issues in an existing module or course; (2) developing a new, specific course on sustainable development; (3) intertwining sustainability as a pivotal perspective in already formalised disciplinary courses, tailored to the nature of each specific course; (4) developing a specialisation path (as a set of courses and laboratories) on sustainable development within the framework of each faculty; and (5) developing a specific, integrated curriculum based on sustainability that targets the demands of professionals with this expertise. This last approach has proven to be more efficient and useful for the professional life of students (Lozano et al., 2014), but at the same time, it is the one that encounters more difficulties and resistance. Indeed, the simple incorporation of teaching materials about sustainability in a regular course may be considered just a starting point for institutions, as such steps alone result in insufficient integration of sustainability principles into students' professional lives (Lozano & Lozano, 2014). This happens because of the interdisciplinary nature of sustainability (Sala et al., 2013), which implies that, in order to be effective, sustainability must become part of their paradigm and way of thinking (Holmberg et al., 2008).

Methods

A quali-quantitative investigation

Measuring the effectiveness and the outcomes of teaching interactive and non-standardised disciplines is not straightforward. Several researches on this issue use the approach of testing student knowledge before and after the pilot course or the didactical intervention (Harun et al., 2015). This approach is even more effective when the survey can reach a high number of students, which enables the application of statistics (Azapagic et al., 2005; Kagawa, 2007). In case the number of students is low, any statistical remark will be poorly supported; nevertheless, interesting information can be achieved adopting an action–research approach (Whitehead &McNiff, 2006). This practice allows for meaningful interconnections between personal ideas, the results of educational research and the first-person educational experience of the participants. The prime objective of data collection is therefore that of using data as feedback to enrich and support the constructive process of restructuring and integration of knowledge.

To assess the usefulness of teaching LCA in agricultural higher education, two courses were specifically designed and took place within the University of Turin, Italy (see next sections for the description of the courses). These two courses were considered as case studies in order to highlight conceptions, ideas and benefits of including the study of LCA as a tool in their curriculum. The two courses were designed with an action-learning perspective (Lund et al., 2014), providing students with an active role in discussing among themselves results of papers that are focused on the application of LCA to food products.

In both case studies, students were asked to fill out a questionnaire, answering specific technical questions and highlighting which aspect of the course they found more interesting and useful for further applications. At the end of every course, data were numerous, but heterogeneous and varied, because they were not collected following a fixed research protocol established *a priori*. However, through the application of qualitative research methodologies, concepts that emerged — directly or indirectly — in students' presentations and feedbacks were collected and classified, obtaining interesting results that are, to a certain extent, statistically significant (Creswell, 1998; Silverman, 2000). The accurate documentation of classroom activities, integrated by the participants' final assignments, provides significant information, which can be generalised to some extent, about preconceptions and prior knowledge and the learning and teaching processes that have been developed about the proposed scientific topics.

Case study 1: Bachelor´s degree in agronomy, University of Turin

At the Department of Agriculture, Forestry and Food Science, University of Turin (Italy), a short course (6 hours) about the application of various environmental impact assessment methods in agriculture took place in 2011 and 2012 in three Master degrees: Agricultural Sciences and Technologies, Food Sciences and Technologies as well as Science and Culture of the Alps. In the three cases, the course was designed as 3 hours of lecture and 3 hours of group work. The lecture was focused on the basics of the LCA approach, including a brief presentation of the LCA framework in order to dedicate more time to the outreaches of the approach, such as ecodesign in agricultural systems and environmental product declarations. The group work was then developed around the discussion of a scientific paper describing a full LCA or one footprint (carbon, water or ecological) for a food product following specific guidelines. In particular, each group was asked to prepare a presentation addressing the following issues: *(I) What were the aims of the research? (II) Which environmental impact assessment method was used? And how was it set up? (III) Which system boundaries were applied and why? (IV) Which functional unit and why? (V) Critical comments of the obtained results. (VI) How can the results be used?* Papers for the group work were selected among the most didactical case studies from the *Journal of Cleaner Production*, *The International Journal of Life Cycle Assessment* and *Agriculture Ecosystems and Environment* in the years 2005–2010. In particular, 40 papers were given to the students in each course. Table 1 briefly describes the main characteristics of the 8 papers chosen by the students at least once per course. The paper of Mila i Canals et al. (2007) was chosen all three times because students were interested in the discussion of sustainability of domestic versus imported food products (the well-known issue of food miles). The other papers were mainly chosen because, as highlighted by the students themselves, the food products investigated in these articles were closer to their personal and professional interests. From their presentations, it was possible to verify what students learned to identify conceptual obstacles and educational outreaches.

Table 1. List of all papers chosen by students in the three courses of case study 1. Considered indicators are Life Cycle Assessment (LCA); Ecological Footprint Analysis (EFA) and Emergy Analysis (EM). Country category considers the area of the study and not necessarily the origin of the research group. In boundaries, different kinds of limitations of the system are considered; cradle-to-gate* refers to a cradle-to-gate scenario, but considers the final product at the gate (e.g. palm oil); cradle-to-market (int) considers a cradle-to-market scenario with an international market. Other information about the fields include: cg = capital goods, n = nursery, p = plantation of the orchard.

Times chosen	***Article***	***Product***	***Country***	***Aim of the research***	***Method***	***Reference flow***	***Boundaries***
3	Mila i Canals et al. (2007)	Apple	UK, New Zealand	Domestic versus imported	LCA	Mass-based (FU = 1 kg)	Cradle-to-market (int)
2	La Rosa et al. (2008)	Orange	Italy	Comparison agro-techniques	EM	Mass-based (seJ/g)	Cradle-to-gate
2	Niccolucci et al. (2008)	Grape	Italy	Comparison agro-techniques	EFA	Mass-based (gha/t); land-based (gha/ha)	Cradle-to-market (p, cg)
2	Yusoff& Hansen (2007)	Palm oil	Malaysia	Regional/national profile	LCA	Mass-based (FU = 1 t final product)	Cradle-to-gate* (n)
1	Coltro&Mourad (2009)	Orange	Brazil	Regional/national profile	LCA	Mass-based (FU = 1 t)	Cradle-to-gate
1	Liu et al. (2010)	Pear	China	Comparison agro-techniques	CF	Mass-based (FU = 1 t)	Cradle-to-market
1	Mila i Canals et al. (2006)	Apple	New Zealand	Regional/National profile	LCA	Mass-based (FU = 1 t)	Cradle-to-market (int)(cg)
1	Mouron et al. (2006)	Apple	Swiss	Methodological issues	LCA	Land-based (FU = 1 ha); receipt-based (FU = 1 $)	Cradle-to-gate (cg)

Case study 2: Master´s degree in Sustainability of Agro-food Networks, UNESCO Chair for Sustainable Development

Since 2013, the UNESCO Chair for Sustainable Development of Turin has been hosting the Master's degree in Sustainability of Agro-food Networks. Students are graduated in several disciplines, mainly agricultural sciences and biology, but also economy, marketing and social sciences. In the degree, several courses touch on the concept of sustainability, and in the years 2013/2014 and 2014/2015, a specific course on environmental impact assessment methods was offered. The course was structured in 20 hours of lecture and 4 hours of group work. In the lecture, environmental assessment methods applied to food networks were discussed, including an extensive presentation of the LCA method, ecological footprint analysis, the water footprint, emergy analysis, the urban metabolism approach to food distribution systems and the most updated framework for environmental product declaration for food products in Italy. The focus of the course was to provide students with the conceptual tools to understand environmental assessment methods in order to be able to approach them critically and to make the best of the results of environmental reports.

As for the experience described in Karsten and Connor (2002), teachers of the course faced challenges in connection with the interdisciplinary nature of the course material and the diverse backgrounds of the students. Therefore, as suggested by Karsten and Connor (2002), different teaching practices were applied, such as the focus on crucial concepts rather than specific disciplinary details and the adoption of frequent short questions and written activities in order to check the acquisition of pivotal concepts.

The group work followed the same structure as the course offered at the Department of Agriculture. Students were divided into groups and asked to choose a scientific paper and prepare a presentation addressing the following issues: *(I) What were the aims of the research? (II) Which environmental impact assessment method was used? And how was it set up? (III) Which system boundaries where applied and why? (IV) Which functional unit and why? (V) Critical comments of the obtained results. (VI) How can the results be used?* In contrast to the previous course, students were asked to choose a paper from the proceedings of the scientific congresses of the Italian LCA Network from 2009 to 2014. The following papers were selected: Arrigoni et al. (2014), Neri et al. (2012), Pirilli et al. (2012), Patrizi et al. (2012), Recanati et al. (2014), Ruini & Marino (2009), Secchi et al. (2013), Vitali et al. (2013) and Zamagni et al. (2013). Table 2 briefly describes the main characteristics of the chosen papers. Also in this case, from their presentations, it was possible to verify what students learned to identifyas conceptual obstacles and educational outreaches.

Table 2. List of all chosen papers in the three years of case study 1. Indicators considered are Life Cycle Assessment (LCA); Ecological Footprint Analysis (EFA), Emergy Analysis (EM) and Water Footprint (WF). In boundaries, different kinds of limitations of the system are considered; cradle-to-gate* refers to a cradle-to-gate scenario but considers the final product at the gate (e.g. olive oil or milk).

Article	***Product***	***Aim of the research***	***Method***	***Reference flow***	***Boundaries***
Arrigoni et al. (2014)	Hemp as insulation for buildings	Comparison of products	LCA	Mass (FU = 1 kg of product)	Cradle-to-gate*
Neri et al. (2012)	Wine, olive oil	Comparison of agro-techniques Comparison of methods	LCA, EM	Mass (FU = 1 l wine) Mass (FU = 1 kg oil)	Cradle-to-gate*
Pirilli et al. (2012)	Clementine	Comparison of agro-techniques	LCA	Mass-based (FU = 1 t); land-based (FU = 1 ha)	Cradle-to-gate

Patrizi et al. (2012)	Vertical garden	Background study for EPD	LCA	Product-based (FU = 10-product module)	Cradle-to-user
Recanati et al. (2014)	Average farm in Gaza	Regional/national profile	WF	Time-based (FU = 1 year) nutrient-based (FU = 1 kg of protein)	Cradle-to-gate
Ruini& Marino (2009)	Pasta	Background study for EPD	LCA	Mass (FU = 0.5 g)	Cradle-to-market
Secchi et al. (2013)	Cosmetic ingredient	Comparison of products	LCA	Mass (FU = 1 kg final product)	Cradle-to-gate*
Vitali et al. (2013)	Milk	Background study for EPD	LCA, WF	Mass (FU = 1 l milk)	Cradle-to-gate*
Zamagni et al. (2013)	Sugar	Background study for EPD	CF	Mass (FU = 1 kg sugar packed)	Cradle-to-market

Educational outreaches

In contrast to Segalas et al. (2010), who reported that students at technical universities perceive environmental sustainability as mainly related to technology, this aspect was just slightly present in the courses at the agricultural department (case 1, with just future agronomists) and absent in the course in the UNESCO Master's degree (case 2, with students from several backgrounds). In this second case study, environmental sustainability was perceived more as a social issue in terms of a motivation for behaviours and consumption practices.

From the feedback received in all activities, students demonstrated to have understood the basics of the LCA approach, as well as other annexed concepts related to environmental sustainability. Categorising the different feedback collected from the students, it is possible to summarise that the most interesting aspect in teaching LCA to agronomists is the development of the so-called integrative assets (Viegas et al., 2016), which are considered to be those that lay behind, between and beyond the other environmental sustainability attributes in sustainable higher education. In particular, in the two experiences, it emerged that students understood the importance of complexity and system thinking in agriculture. Furthermore, two important knowledge assets were successfully acquired from the practical activities: the problem of efficiency and the conception of sustainable agriculture. In this case, such assets were not directly taught as such, but they emerged from their own remarks and were deeply discussed.

To highlight the positive outreaches of these four assets for the agronomical curriculum, such concepts are discussed in detail.

Complexity

There are several definitions of complexity. In biology and ecology, complexity refers to systems whose components interact in multiple ways and follow local rules, with the effect of producing a high number of scenarios and effects (Carroll, 2005). Complexity can also be referred to behaviours in social sciences and in economy; nevertheless, besides the different definitions, the capability of incorporated complexity in an analytical approach is considered a funding concept for sustainability education (Dale & Newman, 2005).

The application of an environmental assessment method requires studying the 'personal history' of the product and not just the use phase. Therefore, investigating the life cycle of products, it is possible to understand the energy flows and material cycles of the production system. As a consequence, students are forced to visualise the different direct and indirect components of the agricultural systems and their internal and external links.

In the two case studies, it emerged that students were used to thinking of each part of the agricultural system as a stand-alone component and not focusing on the relations. For example, the choice of a crop variety is usually considered for the yield that can be achieved in a given pedo-climatic site, but it influences the field design, management practices, farm structures and machineries that are needed to support the production, leading to more or less consumption of agricultural inputs such as fertilisers, pesticides and water (Cerutti et al., 2013). This lack of inclusion of complexity in the agronomists' view is in contrast to the idea that academic education should provide conceptual structures and tools for dealing with complexity (Sibbel, 2009).

It is interesting to note that standardisation is somehow the opposite of complexity and, although the LCA approach uses several levels of standardisation, the need for modelling the investigated system requires an understanding of the connections and complexity of the case. An example of visualisation of a part of the complexity of a production system is the modelling of an orchard for the application of the emergy analysis (Figure 1), in which the relations among the components of the systems are accounted in terms of energy flows (La Rosa et al., 2008).

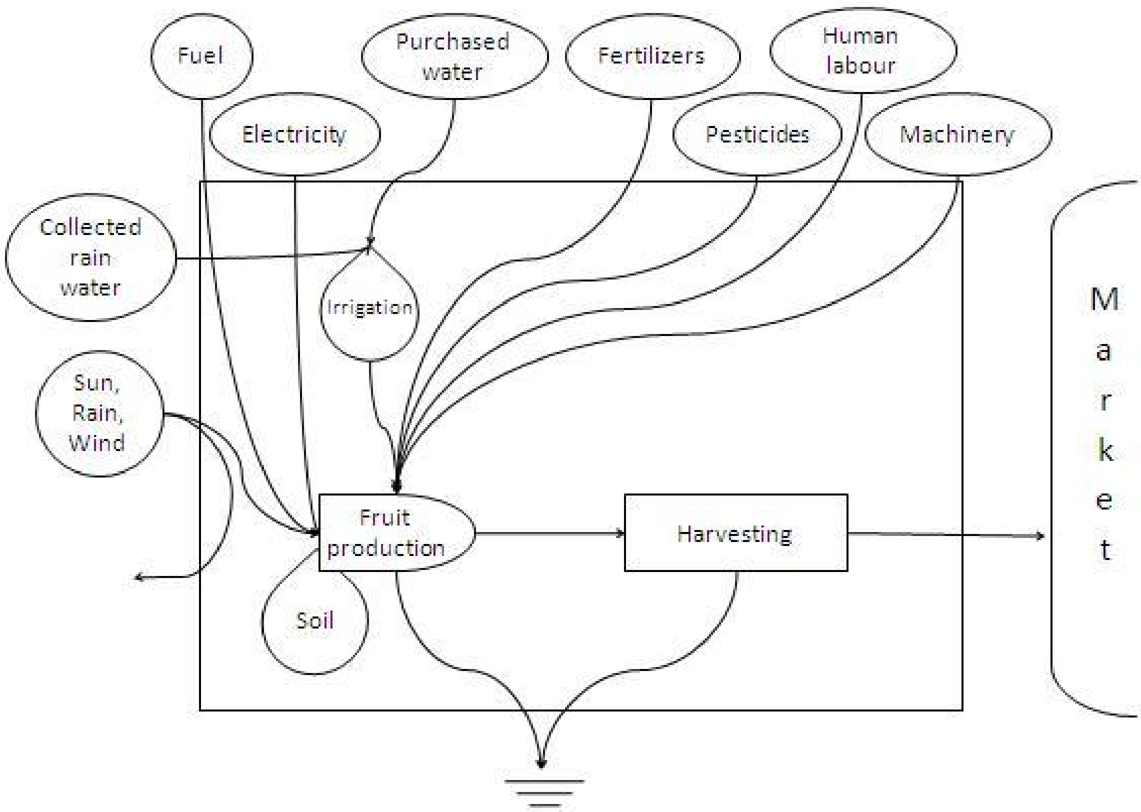

Figure 1. General energy system diagram of an orchard. This diagram is commonly used for emergy analysis and represents the fruit production system from a thermodynamic point of view.

In addition, applying LCA enables students to visualise the breakdown of environmental impacts for each phase of the production system. This process allows the student to visualise that different improvements in the production process might have different effects on the environmental performance. In fact, the most common visualisation of a production system according to LCA is using a diagram flow (Figure 2) in which each life stage of the system is visualised and can be accounted for potential environmental impacts.

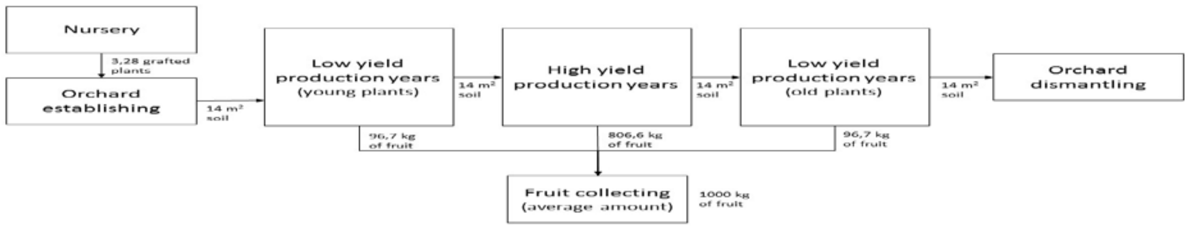

Figure 2. Flow Diagram according to LCA rules, based on a real case study in order to calculate the potential environmental impacts related to the production of 1 ton of apples (modified from Cerutti et al., 2014.)

Systemic view of agricultural fields

System thinking can be defined as the awareness of complexities involved in real-life practices (Viegas et al., 2016). It is considered an important asset in sustainability education because the ability to think systemically can facilitate industrial and societal transitions to sustainable production and consumption patterns (Padovan et al., 2015). Nevertheless, several researchers (Wells et al., 2009) highlight that it is very difficult to achieve system thinking in higher education because teachers are used to giving and taking back from students' disciplinary knowledge as they consider that this kind of knowledge better meets the professional requirements of students.

One of the ideas that stand at the base of the LCA approach is the emission (impacts) from the technical system to the natural system (Baumann & Tillman, 2004). The need to identify boundaries between technical and natural systems for impact assessment highlights the strong interconnection between the two of them. In particular, in order to model a farm, three main systems have to be considered: the natural, the technical and the orchard itself. The natural system can be simplified as the biotic and abiotic components of the environment in which the orchard is embedded. The interfaces between natural and orchard systems are mainly soil, air and water (as local parts of pedosphere, atmosphere and hydrosphere). Furthermore, the farm is dependent on several ecosystem processes provided by biotic components. As system theory suggests, all systems are in fact components of still larger systems, and all components of systems are in fact systems made up of still smaller components (Ikerd, 1993). For example, fruit trees are at the same time components of the orchard system and systems themselves (Figure 3).

More precisely, the fruit tree subsystem is the core of the orchard system, because effects of natural and technical systems can be seen mostly at the plant level (Page, 2009). As a consequence, applying a systemic view to a farm allows highlighting connections with related systems and becoming conscious of environmental boundaries that have to be considered for an environmental sustainability assessment.

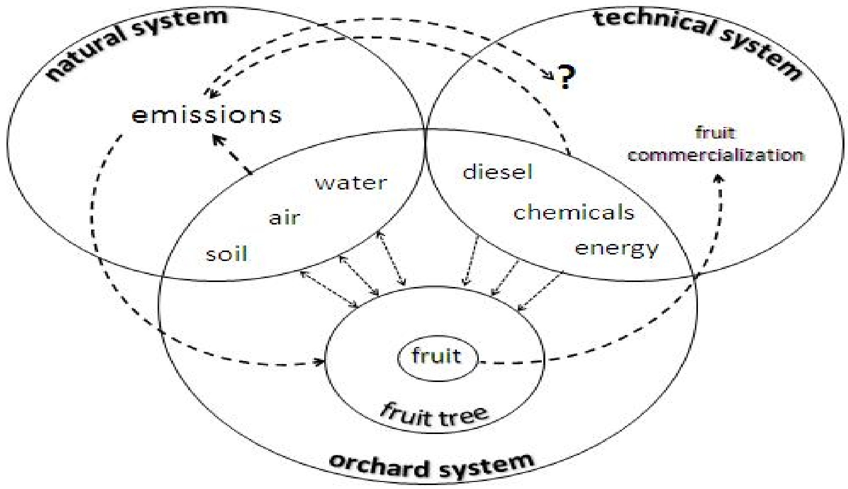

Figure 3. One of the possible representations of the orchard from a systemic point of view modified and generalised from Page (2009). Orchards are at the same time part of the natural system and part of the technical system, but they are also a system themselves with subsystems (e.g. fruit trees). Interface components of the three systems are represented with common areas of the three cycles; arrows represent interactions between components.

The problem of efficiency

In general terms, efficiency is considered to be synonymous with environmental sustainability. For example, in the energy context, the adoption of measures of efficiency allows to save energy; nevertheless, studies on the rebound effect demonstrate that money saved can be used for assessing even more impacting practices (Binswanger, 2001). In the agricultural sector, this effect is less evident and connected to the problem of land use change; however, the problem of the theoretical overlapping of efficiency and environmental sustainability is strongly present in the agronomist's mind. In fact, from the agronomical point of view, the food production systems that are more efficient in terms of input use per unit of product should be more sustainable. But the application of some assessment methods highlights that productions that are efficient from an agronomic point of view may not perform well from an environmental point of view. The LCA helps to understand this issue through the application of multiple functional units in the same case study. As highlighted in several studies (Cerutti et al., 2013; Masset et al., 2015; Van der Werf & Salou, 2015), the choice of the function unit might have a relevant effect on the quantification of the environmental performance. For food products, typical functional units are mass-based (e.g. 1 t of product at the farm gate or 1 kg of final product), yet a land-based functional unit (1 ha of field) often leads to complementary results. Indeed, when considering only impacts per mass unit, high input/high output systems are the favourite, but the total amount of impacts (such as emissions) of a given territory might increase. On the contrary, when considering only impacts per unit area, low input/output systems will have a better ranking in terms of decreased impacts at a regional level, but may create a need for more land use elsewhere, giving rise to additional impacts.

A didactical example used to understand this issue is the case reported in Cerutti et al. (2013). Until the 1950s, hundreds of different varieties of apple (*Malus domestica*Borkh.) were grown in Italy, as in many other fruit-producing countries. However, in the 1960s, with the proliferation of commercial varieties and orchard specialisation, the local germplasm lost importance and began to be forgotten by growers and consumers. Many ancient varieties were gradually replaced by commercial ones, and the Italian fruit-growing scene underwent significant change. Nowadays, more than 70% of orchards grow only Golden Delicious, although the ancient apple germplasm of the Piedmont region (Northern Italy) currently consists of about 350 varieties. Cerutti et al. (2013) calculated the environmental performance of three representative ancient apple varieties from Torino and Cuneo provinces, namely Grigia di Torriana, Magnana and Runsé, using an LCA methodology. In particular, the environmental impacts of the varieties were compared to those of the commercial varieties of Golden Delicious, according to three functional units: a mass-based functional unit (1 t of fruit), a land-based functional unit (1 ha of orchard) and a currency-based functional unit (1,000 € earned). The impacts for the category global warming potential of the four varieties are summarised in Table 3, according to the functional unit used. Considering impacts for 1 t of product, the Golden Delicious varieties showed the best environmental performance; in particular, the ancient varieties showed on average 17% higher emission in relation to Golden Delicious. However, the results were the opposite considering the impacts for 1 ha and 1,000 € income. According to these functional units, the ancient varieties had the best environmental performance, and the impacts for Golden Delicious production per ha of orchard were on average 24% higher in global warming potential in relation to the ancient varieties. A lower difference can be found by applying the economic value-based functional unit; in this case, ancient varieties had on average 9% lower emissions in relation to Golden Delicious.

Table 3. Global warming potential of the four apple varieties according to the functional units considered in the study (elaboration from: Cerutti et al., 2013).

Functional unit	**Dimension considered**	**Varieties**			
		Golden Delicious	**Grigia T.**	**Magnana**	**Runsè**
Mass-based	kg CO_2-eq/t of fruit	163.9	203.9	192.9	196.5
Land-based	kg CO_2-eq/ha of orchard	6,555.3	5,554.8	4,775.9	4,540.8
Economic value-based	kg CO_2-eq/1000€ earned	327.8	305.2	293.9	291.1

Conceptions about sustainable agriculture

Sustainability is a broad concept that is sometimes considered ambiguous because it means different things to different people at different periods of time. As a consequence, many definitions of sustainable agriculture can be found, but most of them are connected to the three pillars of sustainability: society, economy and environment. For example, Reganold et al. (2001) summarised this concept as follows: ‘To be sustainable, a farm must produce adequate yields of high quality, be profitable, protect the environment, conserve resources and be socially responsible in the long term’ (pag. 927). Nevertheless, although it is generally accepted that sustainable agriculture is achieved when the economic, social and environmental conditions are fulfilled, the emphasis given to each of these components varies greatly across individuals, organisations and governments. One aspect that inevitably influences the choice of the way of seeing sustainable agriculture is the scholarly background of the researcher.

Furthermore, two distinct perspectives exist: weak and strong sustainability (Ayres et al., 2001). In general terms, weak sustainability allows for the near complete substitution of natural capital with other kinds of capital, whilst strong sustainability means no substitution ofnatural capital with other kinds of capital. A consequence of the adoption of a strong sustainability perspective is the acquisition of an eco-centric vision in which the three pillars are not at the same level and environmental sustainability is considered as a prerequisite for socioeconomic sustainability; therefore, it has priority over other aspects. In this vision, the use of metrics for environmental sustainability is seen as necessary in order to give scientific-based information to support polices and stakeholders. natural capital with other kinds of capital. A consequence of the adoption of a strong sustainability perspective is the acquisition of an eco-centric vision in which the three pillars are not at the same level and environmental sustainability is considered as a prerequisite for socioeconomic sustainability; therefore, it has priority over other aspects. In this vision, the use of metrics for environmental sustainability is seen as necessary in order to give scientific-based information to support polices and stakeholders.

Several papers, technical documents and policy guidelines that support sustainable food production and consumption take into account environmental criteria based not on threshold values of the environmental impact indicators, but on qualitative judgements of practices, such as the seasonality of products, harvesting practices, minimisation of waste and professionalisation of operators (Cerutti et al., 2016). However, if sustainability practices are not associated with a specific evaluation of an environmental indicator (such as emissions of climate-changing gasses, water depletion or soil consumption), they do not allow quantification of the actual environmental savings (Cerutti et al., 2016). During the discussions in both the lectures and group work, several reflections on the concept of sustainable agriculture emerged. One clear feedback was that through the study of LCA, students changed their personal understanding of sustainability from a vague set of practices to environmental metrics. Despite the complexity that stands behind the ‘measurability’ of sustainability, it became clear to students that in order to be defined as sustainable, a production or a production system has to quantify an environmental performance. Furthermore, a deep discussion occurred on the concept of strong sustainability (Goodland & Daly, 1996), in which maintaining ecosystem services is more important than production.

Concluding remarks

Life Cycle Assessment is one of the most applied tools for environmental impact assessment of food products (Notarnicola et al., 2015), but the feedback received from students highlighted that it can be much more. Focusing on the right questions, LCA can be transformed into a powerful didactical tool for education in sustainable development.

The knowledge and integrative assets achieved by learning and discussing the LCA approach positively reflect in the professional life of the agronomists, even if they will not apply any environmental impact method in their activities.

Further studies should focus on developing specific activities, possibly using educational versions of LCA software, to enable students to put into practice abstract concepts of sustainable development and to understand the importance of metrics in accounting for environmental sustainability.

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