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# Land Use Change Impacts of Biofuels: A Methodology to Evaluate Biofuel Sustainability

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Additional information is available at the end of the chapter

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## 1. Introduction

Biofuel is a type of fuel whose energy derives from biological carbon fixation. Biofuels include fuels deriving from biomass conversion, solid biomass, liquid fuels and various biogases.

Despite the intent of biofuels production as an alternative to fossil fuel sources, its sustainability has been often criticized. In this context, land use change is a major issue. Indeed, considering traditional energy crop yields, vast amounts of land and water would be needed to produce enough biomass to significantly reduce fossil fuel dependency. There is also a wide debate on increasing biomass demand for the energy market which could result in a dangerous competition with the food requirements by humankind, as well as in increasing food prices. Second and third generation sources of feedstock, as well as improved sustainable production of biofuels of first generation such those from non-edible crop, are some of the fields or research handled to fight negative impact of biofuels production on land use.

Agronomic management determines which and how crops are grown: it can have far-reaching impacts on soil quality, water quality, climate change, and biodiversity. The importance of the agronomic management may be magnified as farmers, prompted by high energy-crop prices, would attempt to increase productivity of lands, enlarge the total amount of land under cultivation and expand cultivation into less productive lands.

Among biofuels, biodiesel is one of the main alternative energy sources.

In recent years, the authors have been studying innovative solutions for the field phase of feedstock production as well as for the industrial phase of transformation to produce a more sustainable biodiesel. From the agricultural point of view, the study has been focusing on alternative feedstock and good management practices to increase biomass yields keeping a high soil quality or even rescuing soils not suited anymore for edible crops.

In this context more than other, to accurately balance environmental impacts of biofuels production, it is important to consider agricultural practices applied to grow the biomass and their direct and indirect effects on soil quality. The evaluation of biofuels impacts on soil should not consider only the type of land converted, but also the trend of quality of arable land. Currently, this is still a critical aspect of life cycle analysis (LCA) tools to evaluate biofuels impacts on land use change.

Sustainability analysis of oil production for biofuel should assess the different impact on land use of intensive and extensive cultivation, should consider the not linearity in production yield and in generated impacts and should express the complex equilibrium that guarantees the biodiversity conservation. The authors are studying soil quality parameters and how these parameters could be integrated in a unique indicator able to add additional information to evaluate land use change in a LCA perspective.

The development of this innovative approach aims to improve the evaluation of biofuels impact on land use, allowing taking into account the impact of management practices on soil quality.

In particular, the authors are studying agricultural practices and their influence on soil quality related to biomass culture on marginal soils. The study is focused on agricultural practices which influence measurable parameters and which can describe soil quality trends following a biomass production process.

A methodology which can differentiate impacts of different arable land uses could be not only the base for the development of a powerful tool used by farmers to select the suitable crop and the best management practice in relation to soil type, but also a tool to describe the sustainability of different biofuel production processes in the perspective of new politic regulations and economic incentives.

## **2. Sustainable profile of biofuels**

Biofuels offer a potentially attractive solution reducing the carbon intensity of the transport sector and addressing energy security concerns. General concern for pollution and environmental impact of energy consumption based on fossil sources has led to more and more study on the sustainability profile of available energy sources, traditional and alternative ones.

Among alternative sources, biofuels are those whose energy is derived from biological carbon fixation such as biomass, as well as solid biomass, liquid fuels and various biogases. Ac-

According to this classification, also fossil fuels could be included (because of their origin in ancient carbon fixation), but they are not considered biofuels as carbon they contain has been “out” of the carbon cycle for a very long time.

Even if demand for biofuels continues to grow strongly, some biofuels have received considerable criticism as a result of:

- rising food prices;
- relatively low greenhouse gas (GHG) abatement, or even increases in some cases, based on full life-cycle assessments;
- the continuing need for significant government support and subsidies to ensure that biofuels are economically viable;
- direct and indirect impacts on land use change and the related greenhouse gas emissions;

## 2.1. Edible and non-edible raw materials

Biofuels currently available or in development are shared into three, sometimes also four, groups designed as “generations”.

As the term “generation” indicates, biofuels are classified according to their progressive introduction on the market during the last 20-30 years<sup>1</sup>. The final goal will combine higher energy yields, lower requirements for fertilizer and land, and the absence of competition with food together with low production costs offering a truly sustainable alternative for transportation fuels.

### 2.1.1. First generation biofuels

First generation biofuels are based on feedstocks that have traditionally been used as food such as corn or sugar cane for ethanol production and edible vegetable oils and animal fat for biodiesel production. The technology to produce these kinds of biofuels exists and it's quite consolidated. These fuels are currently widespread and considering production cost for feedstocks, first generation biofuels have nearly reached their maximum market share in the fuels market.

Rising of food prices and doubts on greenhouse gases emission saving improvement are some of the hot spots on their sustainability debate.

### 2.1.2. Second generation biofuels

Facing the main concerns in first generation biofuels, advanced technical processes have been developing to obtain biofuels, for example ethanol and, in some cases, related alcohols such as butanol by non-edible feedstocks such as cellulose from cell wall of plant cells (rath-

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<sup>1</sup> The transesterification process of vegetable oil was first tested in 1853 by E. Duffy and J. Patrick. In 1893 Rudolf Diesel's projected the first vehicle biodiesel-powered. Only in 1990's France launched the local production of biodiesel fuel obtained by the transesterification of rapeseed oil.

er than sugar made from corn or sugar cane). Other researches are trying to find non-edible oil crops for biodiesel such as some brassicaceae (e.g., *B. carinata* and *B. juncea*), *Nicotiana tabacum*, *Ricinus communis*, *Cynara cardunculus* [1].

Even if some issues are still challenging, second generation biofuels make wider the feedstock portfolio for biofuels avoiding competition with food. Nevertheless, feedstock costs remain high (not necessarily due to the feedstock retrieval, but almost due to processing) and GHG emission savings still need to be ascertained by properly analysis of possible emission from land use change [2].

### 2.1.3. Third generations biofuels

Third generation biofuels, as well as second generation biofuels, are made from non-edible feedstocks, with the advantage that the resulting fuel represents an equivalent replacement produced from sustainable sources (for example fast-growing algae or bacteria) for gasoline, diesel, and aviation fuel. These alternative biofuels are anyway in developing and several technological and economic challenges still need to be faced to bring them on the market.

### 2.1.4. Fourth generations biofuels

Fourth generation biofuels are those which result in a negative carbon impact in the atmosphere. These fuels will be obtained from genetically engineered crops that release a lesser amount of carbon dioxide during combustion than that absorbed from the atmosphere for their growth [3].

## 2.2. Land use issues

### 2.2.1. Demand for land

Since biofuels are derived from biomass conversion, demand for land for agro-fuel production has increased significantly over the past few years. Growing demand for land is a sensitive point in biofuels sustainability since, directly or indirectly, it influences all the three sustainability pillars: social, economic and environmental<sup>2</sup>.

According to the so called RED directive (Renewable Energy Directive)<sup>3</sup>, European countries have established targets for the mandatory blending of traditional transport fuels with biodiesel and bioethanol. Developing countries searching for new profitable markets, have increasingly invested in biofuel production for both domestic use and export. In general, all countries at a global level are attracted by this big demand and market, so they are targeting vast tracts of land to produce raw materials for biofuels, often with no concern for the conversion of areas of high biodiversity and high carbon stock.

<sup>2</sup> Art.2 and Art.5 from "Treaty Of Amsterdam Amending The Treaty On European Union, The Treaties Establishing The European Communities And Related Acts", Official Journal C 340, 10 November 1997.

<sup>3</sup> Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

On one side first and second generation biofuels are still strictly dependent on a field phase of feedstock production, while on the other side, third and fourth generation biofuels are not ready to replace them as alternative source of energy. These market drivers, in consideration of the recent food crisis [4] and the financial crisis [5] causes great alarm for the growing of biofuels demand bringing to the debate often referred to as the “food or fuel dilemma” (in 2007 and 2008 cereals and protein crop drastically increased their prizes) [6]. In addition, the drought currently recorded in the USA threatens to cause a new global catastrophe driven by a speculator amplified food price bubble [7].

### 2.2.2. Land Use Change (LUC)

Currently land use is a prerogative of first and second generation biofuels so that land use change should always be taken into account in biofuel sustainability evaluation.

Cultivating biomass feedstock needs land, which might cause LUC regard direct effect on the site of the farm or plantation and indirect effects through leakage (i.e. displacement of previous land use to another location where direct LUC could occur).

Two kind of land use change are usually described: direct land use change (dLUC) and indirect land use change (iLUC). The definition of dLUC is straightforward: direct land use change is the conversion of land, which was not used for crop production before, into land used for a particular biofuel feedstock production. The emissions caused by the conversion process can be directly linked to the biofuel load and thus be allocated to the specific carbon balance of that biofuel.

iLUC is a market effect that occurs when biofuel feedstocks are increasingly planted on areas already used for agricultural products. This causes a reduction of the area available for food and feed production and therefore leads to a reduction of food and feed supply on the world market. If the demand for food remains on the same level and does not decline, prices for food rise due to the reduced supply. These higher prices create an incentive to convert formerly unused areas for food production since the conversion of these areas becomes profitable at higher prices. This is the iLUC effect of the biofuel feedstock production. The iLUC effect of biofuels happens only through the price mechanism of the global or regional food market. Therefore iLUC in this context is always direct land use change (dLUC) for food production incentivised by the cross-price effects of an increased production of biofuel feedstocks which then translates into an additional demand for so far unused land areas [8].

From a global perspective which takes into account all land use from all production sectors of biomass, increasing biomass feedstock production has only direct LUC effect, as all interaction of markets, changes of production patterns and the respective conversion of land from one (or none) use to another will be accounted for. Thus it's a problem of scope, when the system boundaries for an analysis are reduced, “blindness” to possible impact outside of the scope is the consequence [9].

The primary risk for indirect land use change is that the use of crops for biofuels might displace other agricultural production activities onto land with high natural carbon stocks like forests, resulting in significant greenhouse gas emissions from land conversion.

The environmental profile of biofuels has to take into account the GHG emissions balance from land use. Indeed most prior studies claimed biofuels environmental benefits mainly on the base of the carbon sequestration that occurs through the growth of agronomic raw materials. These findings missed to consider in the GHG balance, the emissions that could derive from indiscriminate land use change (direct and indirect) from of high value lands to land for biofuels feedstocks production.

Currently most authors are evaluating this “carbon debt” also to calculate the so called “payback period”, the time required for biofuels to overcome their carbon debt depending on the specific ecosystem involved in the land use change event [10, 11].

### *2.2.3. Land Use impact assessment for agronomic system*

In relation to biofuels, land use translates not only into land occupation for a certain time, but also in possible perturbation of soil quality trend. The concept of soil quality is linked to the ability of soil to function effectively in a variety of roles. The primary measures of this effectiveness supply information on biological productivity, environmental quality, and human and animal health.

Because of its consequences on human health and environment quality, degradation of soil quality as consequence of intensive agronomic system is a major global concern. So this factor needs to be properly evaluated in the environmental assessment of agro-forestry systems involved in production of raw material for biofuels.

First methodologies for land use impact assessment in LCA don't respond to the perturbation on soil quality, giving an indication about land use impact in terms of hectare or hectare per year. Currently new methods in LCA studies and furthers indicators need to be developed to describe the aspects typical of land use impacts of agricultural systems, among these: soil quality status and its trend following to the use change, application of different types of managements, non-linear output of production [12].

## **2.3. Legislation on environment and renewable energy**

Acid rain, air pollution, global warming, ozone depletion, smog, water pollution, and forest destruction are just some of the environmental problems that we currently have to face globally and which require long-term potential actions for sustainable development to achieve solutions.

### *2.3.1. Global agreements*

To face the global environment issue, in 1979 the first World Climate Conference (WCC) took place although, only in 1992, countries joined for the first time an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC), to cooperatively consider what they could do to limit average global temperature increases and the resulting climate change, and to cope with whatever impacts were, by then, inevitable. Since 1995, annually, the Conference of the Parties (COP) takes place and in 1997, with the occasion, the

Kyoto Protocol was formally adopted. In 2005, due to a complex ratification process, Kyoto Protocol entered into force introducing the operational provisions agreed by the countries to stabilize and then reduce GHG emissions [13]. The targets cover emissions of the six main greenhouse gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF<sub>6</sub>).

Commitments of countries are based, since 1990, on the scientific contribution of the Intergovernmental Panel on Climate Change (IPCC) which periodically publish the Assessment Reports (AR) of the state of the knowledge on climate change <sup>4</sup> [14].

### 2.3.2. European legislation

Reduction of pollution of the atmosphere, water and soil, as well as the quantities of waste arising from industrial and agricultural installations are issues faced by the European Union (EU) in the "IPPC directive" (Integrated pollution prevention and control)<sup>5</sup>. This Directive defines the obligations with which industrial and agricultural activities, with a high pollution potential, must comply. It establishes a procedure for authorizing these activities and sets minimum requirements to be included in all permits, particularly in terms of pollutants released, to ensure a high level of environmental protection.

The IPPC directive requires industrial and agricultural activities with a high pollution potential to have a permit. This permit can only be issued if certain environmental conditions are met, so that the companies themselves bear responsibility for preventing and reducing any pollution they may cause.

Briefly the following are the basic obligations:

- use all appropriate pollution-prevention measures, namely the best available techniques (which produce the least waste, use less hazardous substances, enable the substances generated to be recovered and recycled, etc.);
- prevent all large-scale pollution;
- prevent, recycle or dispose of waste in the least polluting way possible;
- use energy efficiently;
- ensure accident prevention and damage limitation;
- return sites to their original state when the activity is over.

In addition, the decision to issue a permit must contain a number of specific requirements, including:

- emission limit values for polluting substances (with the exception of greenhouse gases if the emission trading scheme applies);

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<sup>4</sup> Four Assessment Reports have been completed in 1990, 1995, 2001 and 2007. All completed Assessment Reports are available on IPCC website: The IPCC Fifth Assessment Report (AR5) is scheduled for completion in 2013/14.

<sup>5</sup> IPPC Directive (Directive 96/61/EC) recently been codified by Directive 2008/1/EC.



- any soil, water and air protection measures required;
- waste management measures;
- measures to be taken in exceptional circumstances (leaks, malfunctions, temporary or permanent stoppages, etc.);
- minimization of long-distance or transboundary pollution;
- release monitoring;
- all other appropriate measures.

In regard of IPPC themes, renewable energy resources appear to be the one of the most efficient and effective solutions. That is why there is an intimate connection between renewable energy and sustainable development, synergistically approached by energy scientists, engineers and policy makers [15].

The European Union recently updated issues on renewable energy and sustainable developments, which comprises biofuels matter, enacting the Directive 2009/28/EC on renewable energy (RED: Renewable Energy Directive). The ambitious aim of this directive is the EU reaching a 20% share of energy from renewable sources by 2020 and a 10% share of renewable energy specifically in the transport sector. National action plans have to establish pathways for the development of renewable energy sources, create cooperation mechanisms to help achieving the targets cost effectively and establish the sustainability criteria for biofuels<sup>6</sup>. The RED requires that all biofuels supplied to the EU market comply with the sustainability criteria. The Directive 2009/28/EC sets out sustainability criteria for biofuels in its articles 17, 18 and 19. These criteria are related to greenhouse gas savings, land with high biodiversity value, land with high carbon stock and agro-environmental practices. In order to receive government support, this compliance has to be ensured by the economic operators selling fuel on the market. Even if third countries that play a significant role in providing feedstock for EU consumed biofuels are not required to implement the requirements of the RED, the compliance with the biofuel sustainability requirements must be guaranteed by the EU Member States who count imported biofuels towards their national renewable energy targets, where such fuels are counted towards renewable energy obligations and where they receive financial support. For this situation voluntary schemes may be used as a proof of compliance with the EU sustainability criteria<sup>7</sup> [16].

### **3. Soil quality and agronomic management practices in biofuels production**

The authors are involved in a three years study about the feasibility of sustainable biodiesel production in Italy<sup>8</sup>. This phase aims at the characterization of an innovative agronomic sol-

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<sup>6</sup> Art. 4 to the Directive 2009/28/EC.

<sup>7</sup> EC decision 19 July 201.

ution that may positively affect the energy and GHG balance, achieving a high level of sustainability in the oilseeds production.

One of the relevant points in the evaluation of sustainability is land use impact assessment. The authors made a preliminary research on issues related to land use impact assessment such as soil quality, management practices and land use change indicators suitable to describe the agronomic solutions proposed and their impact on land use especially in terms of soil quality trend.

### 3.1. Soil quality

The terms “Soil Quality” and “Soil Science” were first introduced in the 1970s when it was established that the concept of soil quality should encompass the following points [17]:

- Land resources are being evaluated for different uses;
- Multiple stakeholder groups are concerned about resources;
- Priorities of society and the demands on land resources are changing;
- Soil resources and land use decisions are made in a human or institutional context.

From a pragmatic point of view anyway the most concise definitions express soil quality as “fitness for use” [18] or as “the capacity of a soil to function” [19] or rather “the ability of the soil to perform the functions necessary for its intended use”.

In the beginning, soil quality was only discussed to control soil erosion and minimizing the effects of soil loss on productivity [20]. Only in 1990s, in addition to the productivity factor, some authors began to think in terms of soil quality dependency to management practices and proposed a quantitative formula for assessing soil quality [21, 22]. Indeed soil condition, response to management, or resistance to stress imposed by natural forces or human uses, began to be taken into account as factors able to describe soil quality [23, 24].

#### 3.1.1. Soil functions

According to the most pragmatic definitions, soil quality depends on its intended uses. Although soils cover a wide range of needs, the following are here summarized as general capabilities of soils [19]:

1. sustaining biological activity, diversity, and productivity;
2. regulating and partitioning water and solute flow;
3. filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including agricultural, industrial and municipal by-products and atmospheric deposition;

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8 SUSBIOFUEL project (“Studio di fattibilità per la produzione di biocarburanti da semi oleosi di nuove specie e da sottoprodotti o materiali di scarto” – D.M. 27800/7303/09), financially supported by the Ministry of Agricultural, Food and Forestry Policies – Italy.

4. storing and cycling nutrients and other elements within the biosphere;
5. providing support of socioeconomic structures and protection for archaeological treasures associated with human habitation.

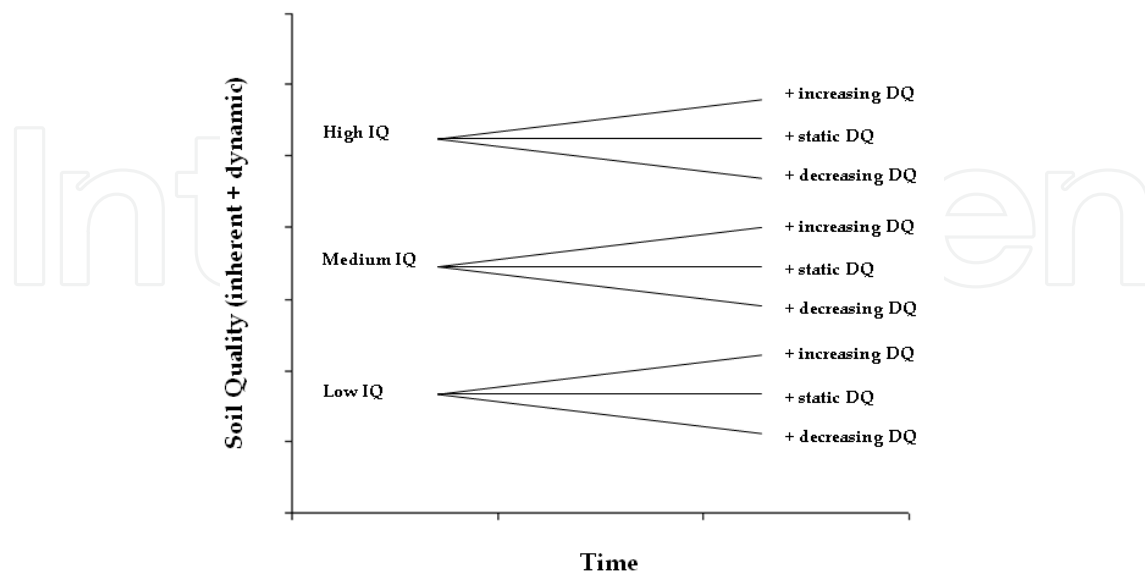
### 3.1.2. Soil indicators

Soil quality can be viewed in two ways: as inherent soil quality, which is regulated by the soil's inherent properties as determined by the five soil-forming factors, and as dynamic soil quality, which involves changes in soil properties influenced by human use and management.

These qualities together determine the capability of soil to function.

Inherent soil quality is independent (or slightly influenced) by land use or management practices so that is described by use-invariant properties rather linked to the soil's genesis over millennia and remain constant during the time (Figure 1). These properties include soil texture, depth to bedrock, type of clay, CEC, drainage class, and depend on the five soil-forming factors [25]:

- climate (precipitation and temperature),
- topography (shape of the land),
- biota (native vegetation, animals, and microbes),
- parent material (geologic and organic precursors to the soil),
- time (time that parent material is subject to soil formation processes).



**Figure 1.** Trends of soil quality according to inherent properties and possible changes in dynamic properties. IQ: inherent quality; DQ: dynamic quality.

Dynamic soil quality depend on land use and management practices and it's also described through use-dependent properties among which organic matter, soil structure, infiltration rate, bulk density, water and nutrient holding capacity, biological factors (micro and macro organisms). Land management practices together with inherent soil quality characterize the trend of soil quality (Figure 1).

Soil quality is a complex matter, with inherent and dynamic properties of soil networking to determine the quality profile of a soil depending of the intended use to be evaluated. So, in order to evaluate the quality, considering the difficulty in measuring functions directly, soil properties are considered indicators to characterize soil quality and to plan the best management practices in order to avoid degradation of soils. Soil properties are usually classified as chemical, physical, and biological characteristics even if stringent classification of many indicators would not be advisable since a soil property can be ascribed to multiple categories:

- Biological indicators give a measurement of the biological activity of the soil. Soil micro-organisms and macro organisms such as fungi, bacteria, earthworms and aggregation of them such as mycorrhizae, influence nutrient cycling by decomposing soil organic matter. Their movements into the soil and the results of their biological activity (e.g., cast, mucilage and hyphae growth) also influence the physical status of soil improving aggregation of soil particles, increasing water infiltration and plant root penetration;
- Physical indicators can be inherent (e.g., texture) or dynamic properties able to respond to different management practices. These indicators rely on plant roots, water and air movements into the soil;
- Chemical indicators include mineral solubility, nutrient availability, soil reaction (pH), cation exchange capacity, and buffering action. Chemical properties are determined by the amounts include and types of soil colloids (clays and organic matter).

In Table 1 a list of the main soil quality indicators is presented.

<b>Indicator:</b>			
<b>Category</b>	<b>Name</b>	<b>Description</b>	<b>Influence on:</b>
	aggregate stability	ability of aggregates to resist disintegration when disruptive forces associated with tillage and water or wind erosion are applied	organic matter infiltration root growth resistance to water and wind erosion
Physical	available water capacity	maximum amount of available water for plant uptake. The difference between the Field Capacity and the Permanent Wilting Point	organic matter water storage runoff and nutrient leaching

**Indicator:**

Category	Name	Description	Influence on:
	bulk density	refers to soil compaction and indicate the dry weight of soil divided by its volume (g/cm <sup>3</sup> )	organic matter structural support water, solute movement aeration
	infiltration	refers to the rate of water infiltration, the velocity at which water enters the soil (space/time)	organic matter water, solute movement and storage
	slaking	refers to the breakdown of large, air-dry soil aggregates (>2-5 mm) into smaller sized microaggregates (<0.25 mm) when they are suddenly immersed in water	organic matter stability of soil aggregates resistance to erosion water, solute and air movement in wet condition
	soil crusts	thin, dense, somewhat continuous layers of non-aggregated soil particles on the surface of tilled and exposed soils.	organic matter water, solute and air movement and storage salt content of soil
	soil structures and macropores	refers to the manner in which primary soil particles are aggregated. Pores exist between aggregates (macropores are larger >0.08 mm)	organic matter biological productivity water, solute and air movement and storage
	electrical conductivity	gives a measurement of soil salinity. It indicates the ability of a solution to be conductive.	organic matter water availability
Chemical	soil nitrate	indicates the nutrients direct available for plant roots uptake.	organic matter nutrient cycling pollution potential
	soil reaction (pH)	refers to the degree of soil acidity or alkalinity.	biological activity and productivity
Biological	earthworms	population of earthworms are measured by counting the number of earthworms/m <sup>2</sup>	organic matter physical structure of soil plant residue depletion water, solute and air movement cycling and distribution in to the soil
	respiration	refers to carbon dioxide (CO <sub>2</sub> ) release from the soil surface	organic matter biological activity and productivity

Indicator:			
Category	Name	Description	Influence on:
	soil enzymes	from viable cells or stabilized soil complexes, increase the reaction rate at which plant residues decompose and release plant available nutrients.	organic matter nutrient cycling
	total organic carbon	the carbon stored in soil organic matter expressed as percentage of carbon per 100 g of soil	organic matter nutrient cycling

**Table 1.** Soil quality indicators. Principal source: USDA.

### 3.1.3. Agricultural management practices: The starting point to improve soil quality

The RED criteria basically determine only the types of ecosystems allowed for conversion into biofuel feedstock production and do not set any requirements on how the feedstock is produced. However, to pursue the sustainability of renewable energy production, especially for biofuels, agricultural choices have a significant effect in short, medium and long term on soil quality, influencing dynamic properties of soil and so modifying the trend of soil quality indicators.

Farmers' production strategy is a key point in sustainable agriculture, since interactions among possible crops, soil types and land uses are complex and strictly dependent on the situation, resulting in a variable response of soil quality to the same agronomic practice.

Table 1 shows that most indicators of soil quality are, in some way (directly or indirectly), correlated to the organic matter content of soil. A positive trend in organic substance results in an improvement of soil structure, an enhanced water and nutrient holding capacity, protection of soil from erosion and compaction, and a good biodiversity of soil organisms. As a consequence, complex relationships which describe soil quality and how it can be improved or at least maintained, could be simplified through the analysis of agronomic practices that influence organic matter.

Tillage has been reported to reduce organic matter concentrations and increase organic matter turnover rates to a variable extent [26]. The negative effect of tillage on soil organic matter originally depends on the fact that organic matter can be physically stabilized, or protected from decomposition, through microaggregation [27]. The periodical perturbation of soil structure by tillage may be the major factor increasing organic matter decomposition rates by exposing the organic matter, otherwise physically protected in microaggregates, to biodegradation [28, 29]. In addition, other tillage dependent factors contribute to reduce the organic matter content (e.g., increase in soil erosion, perturbation of helpful organisms' habitat, soil compaction).

Pest management, in some cases, could have a negative effect on soil quality due to soil organic matter deterioration. Chemical strategy of defence has an undoubted useful effect on

agricultural productions, anyway plant protection products need to be efficiently managed in order to avoid adverse effects on non-target organisms (pollute water and air). Indeed, soil organic matter dynamics are governed largely by the decomposition activity of soil born organisms which include the decomposition of organic materials, mineralization of nutrients, nitrogen fixation, as well as suppression of crop pests and protection of roots. Chemical strategy should be limited, whenever possible, promoting the introduction of non-chemical approaches (e.g., crop rotations, cover crops, and manure management).

Nutrient management, as described above for pest management, if mismanaged can influence soil quality through adverse effect on soil biodiversity with consequence on organic matter.

Compaction has been reported to cause serious implications for the quality of the soil and the environment. Soil compaction leads to soil degradation enhancing harmful physical, chemical and biological changes in soil properties [30]. First of all, compaction reduces the amount of air, water, and space available to roots and soil organisms. Since deep compaction by heavy agricultural equipment is difficult or impossible to remedy, prevention results strategic.

Uncovered ground leads to increased wind and water erosion, drying and crusting and impoverishment of soil carbon. So crop residues and cover crops play a dual role maintaining resource quality by providing ground cover to prevent wind and water erosion and carbon input to enhance soil quality [31]. A good management of residues and cover crops should prevent delayed soil warming in spring, diseases, and excessive build-up of phosphorus at the surface.

Diversify cropping systems means diversifying cultural practices with the possibility to minimize unavoidable negative practices and maximize virtuous management practices. Different crops provide soil with different root sizes and types, contributing to improved soil structure, varied diet for soil beneficial organisms, improved pest control and organic matter.

In summary the following good agricultural practices, directly related to physical, chemical and biological soil properties (improving or stabilizing them), represent a simple but powerful handbook:

1. Avoid excessive tillage to loosen surface soil, prepare the seedbed, and control weeds and pests.
2. Use an integrated pest management approach (chemical and non-chemical), accompanied by the monitoring of pest, by the respect of application threshold and by the sustainable use of chemicals according to plant protection product labels.
3. Avoid unnecessary use of chemical fertilizers, and use properly organic ones.
4. Prevent soil compaction by repeated traffic, heavy traffic, or traveling on wet soil. Minimize soil disturbance when soil is wet.
5. Keep the ground covered through a good management of crop residues or cover crops.

- Promote biodiversity across the landscape using buffer strips, small fields, or contour strip cropping. Promote biodiversity over time by using long crop rotations.

#### **4. Biofuels sustainability evaluation: An overview on land use impact assessment**

Biofuels are often considered the best solution to face problems connected to the growing use of fossil fuels like global warming or raw material depletion, although currently there is not yet a unique and recommended methodology to assess their environmental sustainability.

An example of a simple method to roughly evaluate a process, mostly from an economic point of view, is to calculate the Net Energy Balance (NEB) that measures the difference between the amount of energy available after the transformation process and the total energy used to produce the fuel. This method provides a quick and simple result that can give useful information about the process, but it can't be considered exhaustive to describe it. It is also used to evaluate the variation in performance of a process in a temporal horizon [32].

To have a more comprehensive and accurate result the most used methodology is the Life Cycle Assessment (LCA).

Thanks to its standardized methodology (ISO14040 and ISO14044) and the increase in quality and number of database available, LCA has recently grown in importance as one of the most complete and reliable methodology to environmental sustainability of biofuels.

Defining the goal and scope of the study, its system boundary and the functional unit (FU) to which all the study refers, LCA allows to report all input, from raw materials to energy, and output, for example emissions and wastes, related to a process.

Furthermore LCA, considering the entire life cycle, the so called "Cradle to Grave" approach, avoids problems related to the shifting of impacts from a phase to another.

Methods more and more reliable have been developed and offer a vast and diversified range of indicators capable to fully defy impacts both on the environment and on the ecological and human dimensions making LCA a good instrument for decision makers to compare different solutions. Indicators of social and economic impacts have also been developed with the aim to give a result responding to the three pillars of sustainability.

LCA has more and more frequently been used to analyse production and use of biofuels giving indications, recognizing strengths and weaknesses, allowing a continuous improving of the system. Anyway some major challenges for applying LCA on biofuels have been identified in a recent work of McKone et al. (2011) [33]. First of all, there are uncertainties related for example to the large number and type of input used to produce biofuel. This variability is not only linked to the chosen crop but also to the site, to the agricultural practices, the



yield, not forgetting the weather. Standardize such a complicated system requires a huge amount of data and parameters can vary seasonally. Another problem is connected to the composition of biofuel that can deeply vary considering different crops, the treatments applied, the technology used to produce biofuel (in addition new technologies and practices to produce biofuel are still under revision and possible improving in the final yield is not yet predictable), such that many effects on the environment and on the human health are not yet well defined. Lastly, but likewise important, the problem strictly connected to the agricultural phase. The use of land to produce crop for biofuel can have multiple involvements, by a side it could led to a change in the use of the soil, for example from forestry to crop, or the use of the harvest could change from food to raw material for biofuel. All these factors can cause emission to air and to water, soil depletion, or an increase in the agricultural areas to face the growing demand of biomass.

Even in cases in which land use aspects are considered extremely important such as in biofuels production, these aspects are not generally assessed in LCA [34].

Many approaches exist, providing suggestions for indicators, which are suitable to model land use impacts in LCA, but few of them provide detailed instructions on how to calculate quantified indicators. The most interesting approaches can be divided in land use quantification using biodiversity and land use quantification using soil functionality. Even if some promising studies on biodiversity within land use have been proposed (see for instance [35, 36]), the functionality approach seems to show more links towards an application in practice. However, biodiversity is an important issue and should be part of the land use impact assessment.

The first Life Cycle Impact Assessment methodologies assessed the use of land by recording the amount of land used (ha or ha\* year) as an indication of the impacts [37].

It was common practice especially in LCA of agronomic system to evaluate land use as  $m^2$ /year, meaning that less impact is linked to less use of land. This approach doesn't consider several aspects in soil quality and it doesn't allow differentiating different impacts due to same occupation but with different intensities (i.e. extensive or intensive cultivation).

However today is acknowledged that changes in the quality of land should also be assessed in LCA.

Land use and associated factors such as ecosystem services and biodiversity are likely either not be addressed or captured only by a crude measure of area. Even when considered, these measures typically reported provide no practical help in our environmental management efforts; nothing that usefully informs about choices and decisions in product development or supply chain management. This leaves a gaping hole in the supposedly holistic picture by a life cycle approach. However it is still not common practice to include land use impacts in LCA studies and an agreed coherent and consistent method has yet to be defined, in the last years some interesting approaches have been proposed.

To date the ILCD Handbook identified (see Table 2) three midpoint methods and underlying models for land use and suggested the use of the one based on Soil Organic Matter (SOM) developed by Milà i Canals. Also five endpoint methods are selected, but all of them are considered too immature by the ILCD Handbook to be recommended.

Midpoint method	Underlying model	Reference
ReCiPe	Not based on a specific model	De Schryver and Goedkoop (2009)
Milà Canals	Based on Soil Organic Matter	Milà Canals(2007)
Baitz	Based on seven quality indicators	Baitz (2002); Bos, Wittstock (2008)
Endpoint method	Underlying model	Reference
EPS 2000	Base on species diversity loss and production of wood	Jarvinen and Miettinen (1987)
Ecoindicator 99	Based on species diversity loss	Koller (2000), Goedkoop and Spriensma (2000)
ReCiPe	Based on species diversity loss	De Schryver, Goedkoop (2009)
LIME	Based on species diversity loss and production of wood	Itsubo et al (2008)
Swiss Ecoscarcity	Based on species diversity loss	Koller (2001), Koller and Scholz (2008)

**Table 2.** Selected midpoints and endpoints methods. Source: ILCD Handbook [38].

ReCiPe: it takes into account the surface area occupied or transformed without any further characterization. In that sense, ReCiPe is not a characterization model but rather a selection of LCI parameters.

Baitz (2002): based on the method proposed by Baitz and further developed by Bos and Wittstock. This method describes the impacts related to land occupation and transformation using an inventory of seven indicators:

- erosion stability
- filter buffer and transformation function for water
- groundwater availability and protection
- net primary production
- water permeability and absorption capacity
- emission filtering absorption and protection
- ecosystem stability and biodiversity.

All indicators are calculated as elementary flows and until now, the different indicators cannot be combined or weighted at the midpoint level.

Milà i Canals (2007): this method considers Soil Organic Matter (SOM) as a soil quality indicator. SOM is qualified as a keystone soil quality indicator, especially for assessing the impact on the fertile land use. It influences properties like buffer capacity, soil structure and fertility. Evaluation of change in one indicator is interrelated to changes in other indicators: the loss of organic matter reduces soil fertility and degrades soil structure.

The LCA practitioners is expected to know the location, the timeframe and the SOM values before and after the land occupation, the SOM value of the reference land system, the relaxation rate and associated SOM values. Based in this, the LCA practitioners are expected to calculate the characterisation factor for the foreground system.

The choice of the method developed by Milà i Canals is based on general scientific criteria and on stakeholder acceptance and applicability to LCI datasets.

The scientific criteria used in the ILCD Handbook are: completeness of scope, environmental relevance, scientific robustness and certainty, transparency, reproducibility and applicability. Degree of stakeholder acceptance and suitability for communication in a business and policy contexts has been also evaluated. Each criterion has been specified through a number of sub criteria.

According to these criteria the method of Milà i Canals resulted the best one but it reached the level III that means the method is recommended but should be applied with caution (level I: recommended and satisfactory; level II: recommended but in need of some improvement).

The method developed by Milà i Canals takes into account both occupation and transformation process of land as function of the area used, the time (duration of occupation and transformation process) and the quality of land before, during and after the land use. Occupation process refers to the use of a land for a certain purpose, assuming no intended transformation of the land properties during this use. In contrast, a transformation process implies the change quality of a land area according to the requirements of a given new type of occupation process. SOM is the indicator for quality definition of a land, but this methodology is easily adjustable to express impact of land occupation and transformation using different quality indicators.

The method defines formulas for occupation and transformation impact and also data sources for SOM and a calculation model to obtain SOM from Soil Organic Carbon (SOC) measurement. The authors provide also considerations about the reference to measure occupation and transformation impact differentiating between attributional and consequential LCA studies. If the LCA is aiming at describing the system's impacts (attributional approach), the study should focus on determining all the impacts caused by the studied activity relative to a situation where this activity is not undertaken. Thus the adequate reference situation for attributional LCA studies is natural relaxation (natural recover of the land quality). On the other hand, if the study aims at evaluating the consequences of changes in land use (consequential LCA), only the changes in land use impacts directly due to the studied system respect an alternative system are considered. Therefore the alternative system be-

comes the reference. This reference situation should be derived from statistical time series for land use [39].

Milà i Canals method to evaluate land use impact is suitable to be used and improved measuring land quality with different indicators.

For instance, adapting the method of Biatz (2002) to the framework on land use impact assessment set up by Milà i Canals et al.(2007), at the Department for Life Cycle Engineering of Fraunhofer Institute in Germany a tool called LANCA<sup>®</sup> has been developed to calculate land use indicator values based on ecosystem functions.

The PE-Gabi database (2011) includes several land quality parameters as inventory flows based on this approach.

The LANCA<sup>®</sup> method requires the user determine five soil quality parameters based on an extensive amount of site-specific soil parameters in order to calculate land quality in different time steps [40].

Quality alteration is defined to be the change in quantifiable land characteristics. Occupation [ $m^2 \cdot y$ ] is defined as the occupation of the area during the time of its use. Transformation [ $m^2$ ] is the irreversibly affected area of a land use [41].

To represent land quality and their calculation some of the parameters proposed by Baitz (2002) are used:

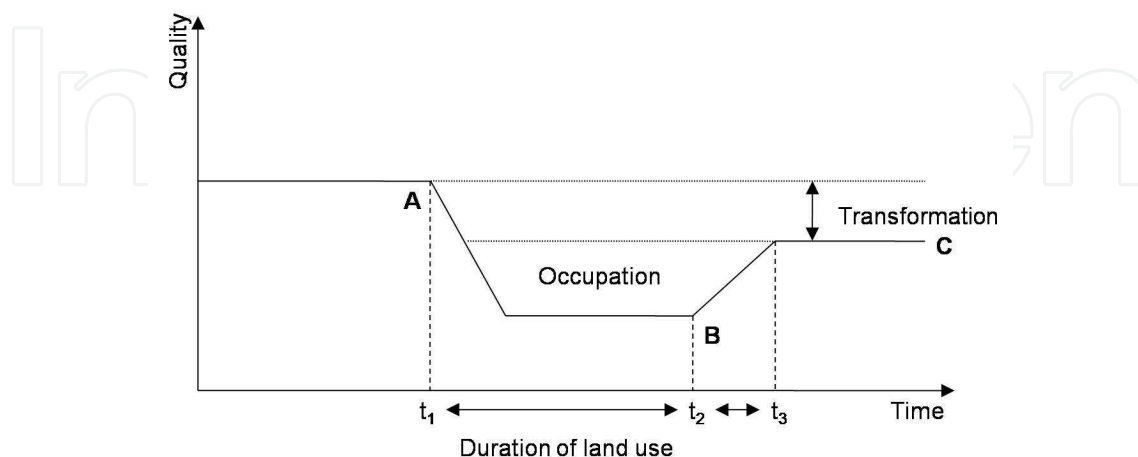
- *Erosion resistance*: input data required are soil texture, declination, summer precipitation, type of land use, skeletal content humus content, kind of surface.
- *Mechanical filtration*: inputs needed are soil texture, distance surface to groundwater.
- *Physicochemical filtration*: for its calculation the effective cation exchange capacity and the type of land use are needed.
- *Ground water replenishment*: input data required are soil texture, type of land use, precipitation, evapotranspiration, distance surface to groundwater and declination
- *Biotic production*: depends on declination, soil texture, skeleton content, nutrient supply, water supply, mean annual temperature and erosion sensibility.

An example from LANCA<sup>®</sup> method report follows. Figure 2 shows a possible quality alteration due to a defined land use: starting at a quality A in  $t_1$ , an hypothetical land use change leads to a quality deterioration represented by the situation B in  $t_2$ . During use, it is assumed, that the quality is constant. After the end of the use, the land quality can recover until reaching the situation C in  $t_3$ .

After the use the land is able to increase its quality via renaturation or succession from B to C. Accordingly C displays the land quality after regeneration and is thus the reference situation for the calculation of occupation. Transformation is the quality difference of the land after use (C) and before the use (A).

These quality values are inventory flows for the Life Cycle Assessment. To characterize the inventory flows and to adapt them to the characterization of emission-based impact catego-

ries, their absolute values are multiplied by the characterization factor  $c=1,-1$  respectively accordingly to display the difference between negative and positive effects of the increase of the land quality parameters values.



**Figure 2.** Land occupation and transformation. Source: LANCA<sup>®</sup> method report figure 2-1.

As a conclusion, to identify land use impacts LANCA<sup>®</sup> quantifies changes of different aspects of land quality using the influence of the land use on different ecosystem functions.

Same as in all LCIA methods, simplifications of established methods had to be made for being able to adapt them to LCA requirements. For instance differentiations between land use types such as conventional and organic farming are not possible yet.

## 5. SUSBIOFUEL project: A case-study

In relation to land use change and soil quality the authors present here preliminary results of a three year study “SUSBIOFUEL” (2010-2013) about the feasibility of using new oilseed species for biodiesel production in Italy [42]. The intent is to propose an innovative agronomic solution that may affect the energy and the GHG emission balance in order to achieve a high level of sustainability in the oilseeds production.

As previously discussed in paragraph 2.2, beside GHG emission saving, land use is a critical point in biofuels sustainability evaluation. To set up an agronomic proposal in compliance with the project objectives and the current needs of sustainability in this field, the authors studied a feedstock sustainable production plan facing the issues which follow:

1. WHERE to produce the feedstock for biodiesel?
2. WHAT are we going to produce?
3. HOW are we going to produce?

4. Which soil tillage?
5. Which pest management?
6. Which nutrient management?
7. Which irrigation management?
8. Which cropping system?
9. HOW can we evaluate the sustainability of the biodiesel?

### 5.1. Agronomical aspects

The agronomic issues listed above were faced and for each of them the authors proposed a solution taking into account that the aim is to produce biodiesel, in Italy, and according to all the sustainability pillars.

#### 5.1.1. Land choice

Marginal lands have received an increased attention by the bioenergy industry as an alternative to cropland for feedstock supply that could help to address the food *versus* fuel debate challenging the industry's further development [43].

The marginality of soils could be ascribed to several different factors so that the term "Marginal land" expresses a wide variety of soil constituting a concept with faint boundaries rather than a definition. For example, a production oriented definition establishes that a soil is considered marginal when the ratio of agricultural production to the inputs required to achieve that is low. According to this definition, the combination crop/land needs to be evaluated in order to decide if a soil should or not be considered marginal for a specific crop.

In the context of SUSBIOFUEL project, as well as crop/land peculiarities, the authors evaluated the agronomic management to assess the oilseeds productivity potential of a promising energy non-edible crop.

The authors identified soils rendered marginal by nematode high pest pressure as a good candidate for sustainable production of feedstock for biodiesel market. Using these lands to grow energy crops, even though the lands are less productive, can provide some additional environmental benefits, including restoration of degraded land and carbon sequestration.

#### 5.1.2. Oil crop choice

To face the ethical and economic problem of using edible crops for biodiesel production purposes, the authors made a selection of the most promising crops to be introduced in the Mediterranean zone among the non-edible ones, taking into account that currently the Mediterranean basin comprises also slightly-arid lands [1].

A promising non-edible energy crop seems to be the tobacco (*Nicotiana tabacum*), which currently exists both in the non-GMO and GMO version for improved oilseed yield and resistance factors against herbicides and insects [44]. In addition, from the climatic point of view its taproot system, widely branched, make it able to survive also in arid condition with limited water needing. Considering all these characteristics, its high oil yield makes it very competitive in front of mainstream oil crops as rapeseed, sunflower and soybean.

The remaining meal revealed to be relevant for combustion or to be used as a protein source for livestock. In addition, the presence of consolidate agricultural practices and know-how make clear the advantage of using a well-known species as tobacco as alternative feedstock for biodiesel. The research on “Energy Tobacco” has also found new economies for the agromanagement and practices which currently are under development [45].

### 5.1.3. Crop rotation system

The large biodiversity of Brassicaceae reveal incipient species, among which *Brassica juncea* and *Brassica carinata*. Besides the potential as raw material for biodiesel, their high content of glucosinolates (GSL) make them able to recover soils made marginal by soil-borne pests as nematodes (e.g. galling nematodes from the *Meloidogyne* genus and cyst nematodes from *Heterodera* and *Globodera* genera) [46, 47]. Many researchers also report weed-suppressive effects of Brassicaceae [48, 49] as well as filtering-buffering effects against heavy metals pollution [50].

Considering the characteristics of tobacco, about high adaptability to hard pedo-climatic conditions, the authors tested the possibility to produce tobacco oilseeds for the biodiesel market on marginal soils. According to a sustainable agriculture approach, the harvest should be achieved in full compliance and in an attempt to restore the soil quality. The authors set up a crop rotation between a cover crop with naturally biocidal effects (*B. juncea* or *B. carinata*) and the tobacco oilseed crop. The cultivation and green manuring of the Brassicaceae is expected to improve soil quality, providing soil pest control and organic matter to land. This crop rotation would substitute chemical approaches with highly toxic products (e.g. methyl bromide fumigation<sup>9</sup>; 1,3-dichloropropane) yet under the regulation of law which restrict their uses<sup>10</sup>.

Thanks to this practice the soil could be rapidly good enough to produce oilseeds with satisfying yields for industrial destination. Furthermore a reduction in inputs of fertilizers is also expected due to preservation of organic matter content of soil. This practice offers the possibility to rescue soils availability for food production. Indeed, after some cycles of this rota-

<sup>9</sup> Methyl bromide is readily photolyzed in the atmosphere to release elemental bromine which contributes to stratospheric ozone depletion. Due to this highly toxic effect, this substance is subject to phase-out requirements of the 1987 Montreal Protocol on Ozone Depleting Substances.

<sup>10</sup> COMMISSION DECISION of 20 September 2007 concerning the non-inclusion of 1,3-dichloropropene in Annex I to Council Directive 91/414/EEC and the withdrawal of authorisations for plant protection products containing that substance, Official Journal of the European Union, 25 September 2007.

tion, the pest control and the progressive increase of organic matter should make the soil eligible again for quality productions.

#### 5.1.4. Tillage

Besides the energetic and economic point of view, conventional tillage is reported to have negative long term influence on soil quality. In relation to some *B. napus* cultivars, some studies showed that although the amount of yield was the highest at conventional tillage, it may be more agronomically sustainable to plant under no-tillage or minimum tillage [51].

Considering the crop rotation between a Brassicaceae (*B. juncea* or *B. carinata*) and tobacco to produce tobacco oilseeds, the authors decided to follow a minimum tillage approach. For the Brassicaceae, as pre-sowing land operation, the authors choose to apply only one low input tillage technique among those suggested by published official local specifications for integrated production. At Brassicaceae flowering time, the green manuring of this crop was tested to evaluate the possibility of exploiting this operation to also prepare the soil surface for successive transplant of tobacco plantlets.

#### 5.1.5. Pest management

Soil born pest, and nematode in particular, are the main issues of marginal soils chosen for the agronomic system to be tested by the authors. Nematodes are worm-like invertebrates known since a long time but the development of plant protection products effective against these parasites is still a challenge of research and development for agrochemical industries. From one side the agrochemicals dedicate low budget for this field of research compared to other sectors such as insecticides and fungicides, but from the other side, researchers have to face some hot pointspeculiar to nematicides development which can be summarized as follow [52]:

1. they live confined to soil or within plant roots, so that the delivery of a chemical to the immediate surroundings is difficult,
2. the outer surface of nematodes is a poor biochemical target and is impermeable to many organic molecules,
3. the delivery of a toxic compound by an oral route is nearly impossible because most phytoparasitic species ingest material only when feeding on plant roots.

For all these reasons, nematicides have tended to be broad-spectrum toxicants possessing high volatility, resulting in highly toxic compounds for the environment (e.g. ozone depletion) and biodiversity subjected to progressive withdrawal of authorizations worldwide.

Some selectivity improvement is being achieved by using agrochemicals with a less wide spectrum, for example fungicides against nematodes but anyway currently the management of plant-parasitic nematodes through alternative strategies seems to become more and more pressing. Among the non-chemical alternatives, biofumigation and solarization are outstanding, and so are crop rotation, use of resistant varieties, and grafting, which are effective



means of control when included in an integrated crop management system. According to this school of thought, the authors tested the possibility to halt the marginalization of contaminated soils introducing a crop rotation system between a Brassicaceae, able to fight nematodes and improving soil organic matter at the same time, and a promising oilseeds non-edible crop, the tobacco plant.

#### 5.1.6. Nutrient and irrigation management

Soil fertility can be improved by managing nutrient stocks and flows. A range of intervention strategies are available to farmers. Land users tend to purchase and use fertilizer nutrients in areas with good market access and higher agricultural potential. Combining manures with inorganic fertilizers can result in significant synergy and increased nutrient and water use efficiencies [53].

The authors decided to exploit the green manure as partial source of nutrients, complementing the nutrient needs of the successive oilseeds crop with organic poultry manure. To optimize the agronomic system (crop/soil/management) from the nutrient point of view, the authors also tested the possibility to apply inorganic fertilizer, sharing the total dose rate of application on the two crops: half on the oilseed crop (the crop which bring the harvest) and the other half on the Brassicaceae aiming at increasing its biomass production to maximize the biofumigant effect of the crop.

The Brassicaceae/tobacco crop rotation, taking into consideration the climate of the Mediterranean basin and in particular those of experimental trial sites chosen by the authors, should not need high input of water. This characteristic depends on the peculiarities of crops involved in the crop rotation and it is in favour of a sustainable agronomic management. Indeed, the Brassicaceae take advantage of the water naturally supplied by the winter season of growing, while the tobacco plant due to its taproot system, widely branched, is able to survive also in arid condition with limited water needing. The authors tested the production supplying only emergency irrigation for the tobacco crop.

#### 5.1.7. Experimental details of field trials

The agronomic rotation Brassicaceae/tobacco was tested under a wide range of situations. Three field trial allocations were chosen for seasons 2010 and 2011, taking into account Italy's wide latitudinal distribution (two locations in the north and one location in the south)<sup>11</sup>. After two years of experimentation, the author decided to maintain two of these locations, in order to concentrate the attention on the most representative sites<sup>12</sup>. Experimental design was thought to produce oilseeds from *N. tabacum* and from traditional oilseed crops (sunflower, soybean, rapeseed in 2010-2011 and soybean in 2012), used as comparison to validate the methodology. For the third year of experimentation, the authors decided to dedicate more land to the tobacco, limiting the space available for the traditional oilseed crops. They

<sup>11</sup> Altedo (BO), Vaccolino (FE) and Santa Margherita di Savoia (FG).

<sup>12</sup> Altedo (BO), Santa Margherita di Savoia (FG).

chose to compare tobacco only with soybean, since physic-chemical characteristics of its oil is the most comparable. Each field was divided into two parts and the Brassicaceae (*B. Juncea* in 2010 or *B. carinata* in 2012-2012, depending on the sowing time) were sown only in one half of the field. To maximize the biofumigant effect, green manuring of the Brassicaceae biomass was carried out when the crop reached flowering. After this, sowing of soybeans as well as the transplant of tobacco plantlets took place in both parts of the field. In order to make the proposal as flexible as possible, four different fertilization treatments on the oilseed crops were used in 2010-2011: low input (30 kg/ha of chemical fertilizer<sup>13</sup>), medium input (90 kg/ha of chemical fertilizer), high input (140 kg/ha of chemical fertilizer) or organic input (10000 kg/ha of poultry manure). In 2012, to test the possibility of increase the biofumigant effect of the Brassicaceae, the author decided to split the total amount of fertilization dosage on both crops in rotation: a half on the Brassicaceae and the other half on the oilseed crop (tobacco or soybean). In all the field trials, untreated plots were set up as control. All field tests were conducted under Good Experimental Practices (GEP).

Yet in the first year of experimentation the authors assured that the green manure of Brassicaceae do not increase the sulphur content of the successive crop and its oil [1], which is therefore suitable for biodiesel production<sup>14</sup>. To evaluate the effect of the green manure of Brassicaceae on nematode infection, countings of *Meloidogyne* spp. were carried out on soil samples taken from both sides of the field while effects on yield of crops grown in succession were monitored recording the fresh weight per hectare of plant biomass from both sides of the field (or when possible the seed yield). The authors also checked the weed-suppressive effects of Brassicaceae.

#### 5.1.8. Results and discussion on agronomical aspects

Research on alternative biofuel faces the increasing demand for energy requirements by means of a more sustainable energy supply. From this point of view, greenhouse gases saving are expected from biofuels.

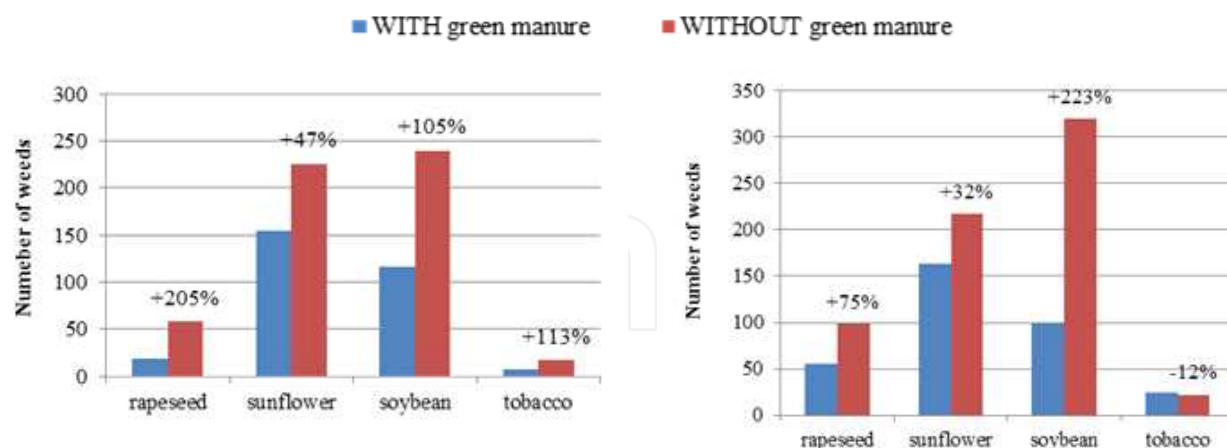
The first year of experimentation showed that the use of *B. juncea* as green manure does not influence the sulphur content in sunflower seeds and oil, suggesting no sulphur accumulation occurs in succeeding crops. The plants grown in succession of *B. juncea* resulted in higher biomass. This could be due either to the increase in the organic matter content or to the pest control. Indeed, counting of nematodes revealed a strong effect of the green manure of *B. juncea* on nematode control. These data trends were confirmed in the second year also for *B. carinata*: the authors observed that the positive effects on biomass correspond to a similar effect on seed yields. In addition the weed suppressive effect of the green manure with *B. carinata* was also observed and reported in Figure 3.

The third year of experimentation will end in 2013, so data from this season are not available.

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<sup>13</sup> NPK fertilizer was composed of 46% urea; 48% P<sub>2</sub>O<sub>5</sub>; 50% K.

<sup>14</sup> The contents of this element in the final product must be under 10 ppm (UNI EN 14214 - Automotive fuels. Fatty acid methyl esters (FAME) for diesel engines. Requirements and test methods).



**Figure 3.** Field trials carried out in Altedo (BO) on the left and in Vaccolino (FE) on the right. Assessment of weeds.

## 5.2. Evaluation of sustainability aspects

In the SUSBIOFUEL project LCA has been chosen as sustainability evaluation and decision making tool.

Several scenarios have been evaluated to assess the environmental burdens related to different feedstock and agronomic management system.

In this chapter, two main scenarios have been selected to compare the production of biofuel using two different crops. Furthermore the possible improving in soil quality due to the agronomic practices proposed will be evaluated.

Both scenarios consider a crop rotation between a cover crop with naturally biocidal effects (*B. juncea* or *B. carinata*) and the oilseed crop, soybean or tobacco. For tobacco crop, a preliminary greenhouse phase was considered. Authors choose to set tillage, nutrient and irrigation management at the lowest level suggested by the good agricultural practices as explained in paragraph 5.1. The use of the rotation with brassica has been considered sufficient and no other pesticides were added in the model.

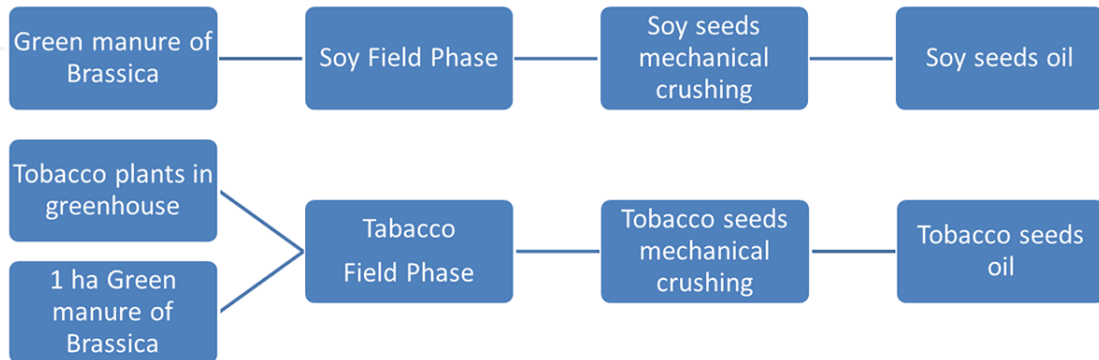
The functional unit is 1 litre of oilseed, system boundaries goes from the seed preservation to the oil production.

Data used in this study are both collected directly on the experimental fields and from good agricultural practices (GAP) vade mecum [54], data from Ecoinvent Database were also used.

The method chosen to evaluate the potential impacts of the system is the CML 2001 (updated in November 2009) using GaBi LCA software. The following impact categories have been assessed:

- Abiotic Depletion (ADP), expressed in kg Sb-Equiv

- Acidification Potential (AP), expressed in kg SO<sub>2</sub>-Equiv.
- Eutrophication Potential (EP) expressed in kg Phosphate-Equiv.
- Global Warming Potential (GWP 100 years), expressed in kg CO<sub>2</sub>-Equiv.
- Ozone Layer Depletion Potential (ODP, steady state), expressed in kg R11-Equiv.
- Photochem. Ozone Creation Potential (POCP), expressed in kg Ethene-Equiv.



**Figure 4.** Flowcharts of soy and tobacco field phase of production.

In order to observe the holistic aim of Life Cycle Assessment, the authors did a special effort trying to include considerations about Land Use impact in their analysis aware of the capital environmental importance of this issue in biofuels sustainability evaluation.

The method of Milà i Canals has been considered as the most consistent with the scope of the study. The ultimate goal of the project is the sustainable production of biodiesel with a contemporary rescue of marginal soils. The Soil Organic Matter indicator chosen by Milà i Canals constitutes a trade-off between an easy to measure and a representative indicator of soil quality.

This indicator could confirm the expected increase in SOM in marginal soils after the crop rotation and management system defined in the SUSBIOFUEL project. SOM evaluation could help also in GHG emission assessment (biofumigant green manure practice already showed important saving in CO<sub>eq</sub> emissions, calculated with a simplified LCA approach [55]).

Measures of SOM in the marginal soil before the crop rotation for each scenario represent the reference situation for the land use indicator, while measures of SOM during and after the SUSBIOFUEL tests constitutes the quality value needed for occupation and transformation impacts calculations.

In order to have information useful for decision making between different project options, the authors recurred to the Soil Conditioning Index.

The Soil Conditioning Index (SCI) is a Windows-Excel based model developed by NRSC (Natural Resource Conservation Service) US Department of Agriculture to estimate soil car-

bon trends. This tool can predict the consequences of cropping system and tillage practices on the status of soil organic matter in a field[56]. SCI estimates the combined effect of three variables on trends in organic matter, as a simple weighted average.

The soil conditioning index formula is:

$$SCI = (OM \times 0.4) + (FO \times 0.4) + (RF \times 0.2) \quad (1)$$

Where OM accounts for organic material returned to the soil (as a function of biomass produced), FO represents tillage and field operation effects and ER is the sorting and removal of surface soil material by sheet, rill and wind erosion.

Controlling erosion and building organic matter do not guarantee good soil quality, but in most cropping situations they are prerequisites to improving and protecting soil quality and productivity. The SCI is a quick way to characterize the organic matter dynamics of a farming system and can help assess good soil management. The following information is needed about the field to calculate the SCI:

- Soil texture
- Climate data
- All crops in the crop rotation
- Typical yield for each crop
- Additional applications of organic matter or removals of organic matter
- All field operations (tillage, fertilizer and manure application, harvest)
- Rates of erosion

The SCI can predict if a particular management system will have a positive or negative trend in SOM. If the SCI value is negative, soil organic matter is predicted to be declining under a given production system, and corrective measures should be planned. If the SCI value is zero or positive, soil organic matter is predicted to be stable or increasing.

The Soil Conditioning Index represents a support to plan and design conservation crop rotation and residue management practices when low organic matter, surface crusting or erosion are identified as concerns and it helps producers in changes in SOM monitoring or prediction.

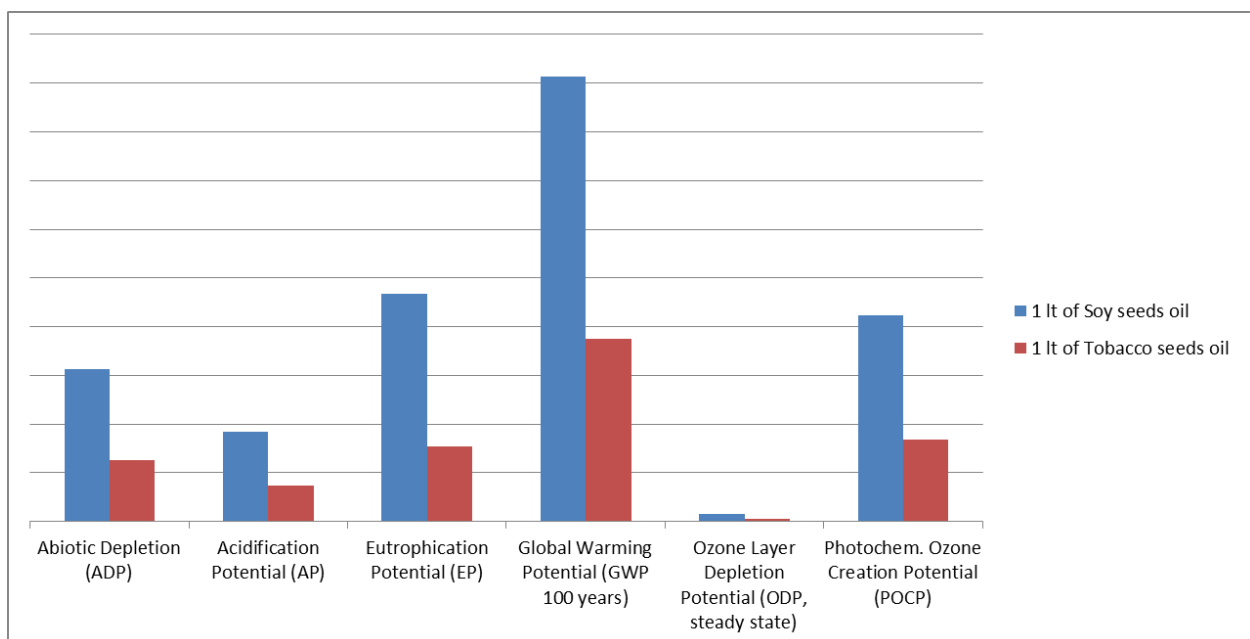
The use of this semi-quantitative tool allows running several what-if scenarios which results could be useful to drive decisions taken in the project.

Understanding processes that affect soil quality can guide in management decisions and practices that will maintain or improve the soil resource.

Appropriate management strategies can significantly reduce the payback period and enhance greenhouse gas benefits associated with biofuel production system.

### 5.2.1. Results and discussion on sustainability evaluation

Results obtained represent the comparison between the two scenarios which don't include yet land use impact category, since further researches are needed on this topic. As shown in Figure 5 for all impact categories selected the tobacco oil production, despite the greenhouse phase, generate less than 30% of potential impacts in comparison with soya oil. Results have been normalized to find which impact categories are the more important. Figure 5 shows that these processes have a great effect on global warming potential, nevertheless, the other impact categories, apart from Ozone Layer Depletion Potential, have anyhow to be considered.



**Figure 5.** Scenario results normalization<sup>15</sup>.

Even if these results have to be considered preliminary, they give the indication about the validity of the use of tobacco as non-edible oilseed crop.

## 6. Conclusion

The use of oilseeds derived from non-edible crops represents a first step in order to increase the sustainable profile of biodiesel production.

Beyond the use of non-edible crops, to face the land use change (one of the main criticisms about biodiesel sustainability) the authors propose to set up the non-edible system of pro-

<sup>15</sup> For confidentiality reasons, unit of measures and numerical results are detailed on SUSBIOFUEL internal report.

duction on marginal soils. According to the state of the art on soil quality properties and indicators, soil organic matter is outstanding, so each phase of production was thought to respect, and if possible improve, this property of the soil. In this scenario the aim of the production is not only the oilseeds harvest, but also the maintenance and if possible the rescue of the full soil functionality. Taking into account these considerations, the authors analysed which oilseed crop would have been the most suitable, which kind of marginal soil, which the best agronomic practices to follow in this particular situation. In this publication the authors present a case study which contributes significantly to a wider portfolio of land-use strategy. Tobacco was individuated as the most promising non-edible oilseed crop and the possibility to produce tobacco oilseeds from soils rendered marginal by nematode infestation was analysed.

The authors verified that the green manure of *B. juncea* or *B. carinata* (depending on the sowing period) resulted in nematode infestation drastically decreasing and improved soil quality reflected in higher seeds yield of crops in agronomic succession. In addition weed-suppressive effect of this agronomic practice was shown, avoiding chemical herbicide applications for this agronomic system. The restoring of soil fertility avoiding the fumigant usage, and in the meantime the generation of income from non-edible vegetable oils, assure the ethical, economic and environmental sustainability of the solution. It should be also considered that food production from marginal soils would worsen soil depletion and nematodes infestation.

Preliminary results, according to the traditional LCA, confirmed that tobacco is a promising non-edible oilseed crop according to the agronomic practices applied, for those soils rendered marginal by nematode infestation.

This study reports the impact of cover crops and their green manures on the density and damage of root-knot and lesion nematodes to oilseed crops, as well as those of tillage, soil amendments, crop rotation, and cover crops on oilseeds yield and root rot severity. The incidence and severity of root diseases is an indirect assessment of soil health for specific commodity/soil use [57]. In order to evaluate the sustainability of this scenario through the LCA methodology, it would be relevant to estimate the benefits on soil quality of the agronomic system proposed. For this reason the authors are studying how to complete the information supplied by the traditional land use indicator.

Policy strategies will be needed to increasingly shift abandoned or low biodiversity value marginal lands to this kind of ecologically-friendly practices.

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