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Sustainability of agricultural systems: A comparison between conventional and organic farming

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Declaration

I declare that the Bachelor Thesis"Sustainability of agricultural systems: A comparison between conventional and organic farming" is my own work and all the sources I cites in it are listed in the Bibliography.

Prague, 21/4/2018

Signature

SUMMARY

The aim of this thesis 'Sustainability of agricultural systems: A comparison between conventional and organic farming crop rotation systems' is to compare organic and conventional crop rotation systems by using scientific literature, scientific articles and books. This thesis is composed of four main chapters, each of them describing different aspects of organic and conventional agricultural systems

The first chapter is introductory and describes the current state of agriculture along with its main problems and future challenges. Chapter two is a brief description of the objectives of this paper that explains the significance of sustainability in the modern and future agricultural world and highlights the importance of developing sustainable agricultural systems in the future. Chapter three is the main source of information and constitutes the vast majority of the thesis. Firstly, the main production systems of organic and conventional agriculture are presented by using the same outline. A brief history of each system is followed by a characterization of the modern situation based on the advantages, disadvantages and future challenges of both systems. The comparison is made by identification and investigation of the main sustainability indicators of crop rotation systems in order to conclude on which of the two systems is more sustainable. Since sustainability is a broad and multisided term the overall assessment of all sustainability indicators is quite complicated even for experienced authors. Therefore, the different sustainability indicators are presented and assessed individually based on the life cycle assessment of each report and the results are clearly stated in the end of each related subchapter.

Conclusions are drawn in chapter 4. In this chapter an overall assessment of the thesis is given and results are demonstrated. The results highlight the importance of agricultural crop management practices. Even though conventional systems are superior in terms of yield and efficiency they are not environmentally sustainable. Organic systems can be sustainable and competitive by implementation of the appropriate agricultural management practices concerning rotation system selection and its crop composition. The system should be designed based on these parameters, taking into account the effect of climatic conditions and the economic environment.

Key words: organic agriculture, conventional agriculture, sustainability, crop rotation, life cycle assessment.

Table of contents

1 INTRODUCTION

The continuously increasing population along with the change of consumption patterns occurring worldwide has dragged agricultural production to its limits. On a daily basis, agriculture produces on average 23.7 million tons of food. From this 19.5 include roots, fruits, vegetables, cereals and roots, 2.1 billion liters of milk and 1.1 million tons of meat. Aquaculture and other fisheries harvest about 400 000 tons of fish.In addition, the amount of timber and fuel wood harvested in one day s 9.5 million cubic meters. More specifically, in crop production systems on a daily basis 7.4 trillion liters of water for irrigation is used, along with 300 000 tons of fertilizers. The grand total daily agricultural production is valued about € 5.6 billion(FAO, Building a Common Vision for Sustainable Food and Agriculture: Principles and Approaches, 2014). Furthermore, agriculture is responsible for about one third of the world's employment, providing the necessities of life for 2.3 billion people.

World population is expected to grow by 2.3 billion people until 2050 In addition; the income per capita is expected to be a multiple of today's level. On economic growth level, the economies of developing countries are expected keep growing at today's rate that is significantly faster that the developed ones. ((FAO, Global agriculture towards 2050, 2009)

Energy costs are increasing and available resources are declining (T.L.Fess, 2018).Agriculture has a significant contribution to greenhouse gas emissions and consequently to climate change. About 25% of total GHG are directly linked to agricultural production(IPCC, 2014). Land scarcity, degradation and soil depletion make the need for sustainable practices absolutely necessary to produce the 80% more food required to feed the population by 2050 (FAO,2014). All these facts are related to the topic of sustainability that is the main focus of this thesis. Sustainable development has been defined by the FAO as"the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations."(FAO council, 1989). Since sustainability is a broad term and many think that it is related mainly to the agroecological factors, the paper will provide information based on several sustainabiliity indicators related to crop rotation systems such aseconomical, social and environmental factors. The research on this paper focuses on examination and evaluation of organic and conventional crop rotation systems in order to conclude on which is the most sustainable practice in our modern agricultural world.

2 Objectives of work

In this growing demand world where natural resources start to deplete, it is important to produce food in an efficient way, but also with respect to the environment and without compromising the ability of the next generations to cover their own needs. There is a big debate on whether or not organic agriculture can feed the world or at least make a valuable contribution. Conventional farming is more efficient in terms of yield, as it can utilize land better in terms of yield compared to the organic system. Despite that fact, there is growing concern on the effect of the agronomical practices used in the commercial systems and more particularly at the use of chemical fertilizers and pesticides. The evidence of the damage done to the environment areindisputable but the difference in yield between the two systems constitutes a substantial difficulty in making the transition to organic systems.

The aim of this bachelor thesis is to provide a comparative analysis between conventional and organic crop rotation systems in order to assess and compare their sustainability indicators.Crop rotation systems that are the backbone of organic agriculture will be divided in parts in order to examine the sustainability current situation and compare it with the conventional. The breakdown of these indicators will provide a clear picture of what is actually sustainable and which are the realistic goals of a potential transition to organic farming practices.

3 Literature review

3.1 Conventional agriculture

Conventional or industrial agriculture originally started as a modernization project in Europe in the last 30-40 years due to the food shortages that appeared at the time(Tilman, 2002).). The outcome was positive as the productivity and efficiency of the agricultural systems were enhanced leading to an increase in food production. EU's Common Agricultural Policy(CAP) introduced increased use in fertilizers, pesticides and gradual mechanization of many components of the agricultural system such as irrigation and seeding. Subsequently, this fact led to new seed varieties by genetic modification and high intensification of crop and animal production practices.

As state by the CAP(same citation):" The resulting agricultural mode is highly specialized, capital intensive, large-scaled and market-oriented. It operates in a global supply chain, characterized by complexity and concentration of market power in some segments of the supply chain, i.e., in the industries of agricultural input production, food processors and retailers((OECD, 2013).

Industrial farming practices have made a significant contribution in feeding the world's continuing increasing population but they have also a negative impact in the ecosystems and earth s ability to restore itself.

Conventional agriculture.is a production system aiming to maximize production and profits. The whole system was designed with these goals and consequently it did not take into account the long term consequences of the ecological dynamics of agroecosystems. According to Gliessman, (2000) there are six main proctices that form the backbone of modern agriculture are:

- Intensive tillage:
- Monoculure
- Irrigation
- Application of inorganic fertilizer
- Genetic manipulation of crop.plants

The problem with this system is that each of those parameters absolutely needs and depends on the other ones to function.

3.1.1 Problems related to conventional agriculture

These practices compromise the future of agricultural production as they tend to utilize all the attributes of the field without taking into account its future health amd productivity. During the decade of(book was written) all the countries of the green revolution have experienced steady decline in the annual growth rate of their agricultural sector. This fact can be viewed as a clear sign that the factors and parameters affecting and sustaining(both same words) agricultural production are being somewhat(can u use this word) eroded.

Soil degradation can involve erosion, water logging,, compaction, salting, pesticide contamination and in general decline of soil quality parameters such as structure and fertility. Furthermore, many reported problems directly related to conventional agriculture include waste and overuse of water, environmental pollution, loss of genetic diversity, global inequality, loss of control over agricultural production and its future.

3.2 Organic Farming

Until the end of the WWII the majority of agricultural systems worldwide could be considered as organic, since the application of fertilizer and pesticides was limited or non-existent. After the end of the war, due to lack of food resources the application of fertilizers along with the modernization of all parts of agricultural systems led to the most widely accepted system today known as conventional agriculture.

Searching though the web you can find many definitions related to the so called organic farming. These include biodynamic agriculture, which approaches the cultivation based on the power of natural forces and also biological agriculture that started from h.p. Rusch and H.Muller in Switzerland((Gwénaëlle Le Guillou, 2001 . The concept of organic agriculture was widespread in England during the 1940’s.

In the General Assembly of IFOAM - Organics International held on September 2005 in Australia, a motion was passed to establish a Definition of Organic Agriculture. The International Federation of Organic Agriculture Movements (www.IFOAM.org) defines organic agriculture as follows (IFOAM, IFOAM, 2018)"Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."

Firthermore, the four principles of organic farming are defines as the principle of health that refers to the health of soil, plants, animals and humans, the principle of ecology that should emulate and sustain natural ecosystems, the principle of fairness, meaning that all parts of the supply chain should be treated equally and with justice and finally the principle of care that is about using as much natural resources so the earth can have time to regenerate (IFOAM, 2017). All these principles are the backbone of organic agriculture and the way in which the system will move forward and hopefully develop and expand.

Organic agriculture uses several practices to maximize its potential. Incorporation of crop residues in the soil, animal manures, nitrogen fixing crops, green manures, off- farm.organic wastes, biological peat control, mineral rocks and crop rotation systems.(Altirei, 2003)All these practices aim to maintain soil productivity and tilth, are part of a plant protection plan and supply plants with all the necessary nutrients.

Organic systems present wide variability depending on economic needs and envoronmental conditions. For many years people perceived organic agriculture to be a return to pre-industrial practices, but in fact it combines traditional techniques with modern practices and techonological developments. Organic farming now has certified seeds, uses modern harvesting equipment and water conservation practices.

Altieri (1993)defined the most common elements of organic farming system to have the several characteristics. Firstly, they build soil organic matter and avoid the use of chemicals for plant protection and fertilizing purposes. The nutrients, especially nitrogen lacking from the system due to the ban of synthetic fertilizers are replaced by application of natural fertilizers and by inclusion of nitrogen fixing crops such as legumes into the rotation system.

Crop diversification is also an essential part of the system in order to gain stability. The goal of reaching an agro ecosystem similar to a natural one can achieved by inclusion of animals and tree crops in the system. Finally, water from precipitation should be collected and used efficiently in order to avoid wasteful runoff.

3.3 Crop rotation system

Crop rotation is one of the most historical and fundamental agronomical practices((Lawes, 1895), and has played an important role during the British industrial revolution, by enhancing agricultural production((Brunt, 1999).

The roots of crop rotation systems can be found even in the middle ages(early 8th century) and more particular during the rule of Charlemagne, emperor of the Carolingian Empire(H.Bruns, 2012).

During that period crop rotation was widely used in Europe in a form of two-field rotation where a crop was seeded one year and the following was left to fallow. The following season the crops and fields were reversed. In later years, the three field system was introduced, where one field was used for the production of a winter cereal, another for a summer annual legume and a third one was left to fallow (J.Butt, 2002). During the 17th to 18th century the relation between legume crops and soil available nitrogen was discovered. The discovery was made by application of a three year system in which a legume would follow a fallow in ta three-field rotation. The farmers realized that there was a significant increase in livestock fodder and that the land quality was also enhanced.

The crop rotation systems used in modern agriculture are rooted in the evolution of systems used in Norfolk County England around 1730n (Martin, 1976). The Norfolk four year system or 'four-course system emphasized the importance of including fodder crops in the rotation and did not include a fallow year, which was the most substantial difference in comparison to the earlier methods. According to the Encyclopedia Britannica's " Norfolk four-course system", the crop of the first year was wheat, in the second turnips followed by barley, with ryegrass and clover under sown in the third. The last two crops were cut or grazed and the turnips were utilized as animal feed for sheep and cattle in the winter period. This inclusion of animals in the rotation made the difference, as the animal manure from grazing was utilized better, as better fed animals produce higher quality manure and consequently better cereal yields in the next years. This cumulative effect of the Norfolk four-course system was apparent to the farmers and it started to become widely implemented. Furthermore, the system was adopted in a large area of Europe during the 19^{th} century(Britannica).

In the modern world, FAO (2018) term portal, defines crop rotation as ;“Annual alternation of crops in order to maintain healthy soil. Proper crop rotation depends on local conditions, but in the absence of pre-existing information, adequate crop rotation should involve three crops from different families. Nutrient requirements, root depth, water requirements, diseases, and inter-crop relationships should be considered”.

Crop rotation systems benefits makes them ideal for use in organic agriculture. The first advantage is that the soil health parameters such as soil structure and soil fertility are improved. The plant protection measures are implemented by using rotation practices like intercropping that can lead to a decreased amount of used chemical herbicides and pesticides(A.Altieri, Agroecology- The Science of Sustainable Agriculture, 1993). Furthermore, the crop rotation is composed by different types of crops and consequently there is bigger variation of outputs compared to other cropping systems. This fact decreases the risk of losing the whole crop in a growing season and also improves the soil nutrient pool by nutrient cycling(A.Altieri, Agroecology- The Science of Sustainable Agriculture, 1993).

3.4 SUSTAINABILITY

Sustainable development has been defined by FAO as “the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations.

Sustainability in agriculture can be viewed as a version of the concept of sustained yield. - production of a biological resource (such as timber or fish) under management procedures which ensure replacement of the part harvested by regrowth or reproduction before another harvest occurs.(m.webstet-use book-) There is a certain level of uncertainty concerning the definition. The term refers to the future and the parameters affected from the production process cannot be surely determined. However it is possible to predict and classify a practice as unsustainable.

3.4.1 Measure sustainability

Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable”. (FAO, 1989)

FAO (2016) defines the three pillars of sustainability as social, economic and environmental.

The economic sustainability refers to the end value and profits of the product They should be distributed fairly across the stakeholders in the supply chain, depending on the contribution of each. Secondly, environmental sustainability relates to the the processes used in production . They should ensure the preservation of the existing ecosystem and even improve natural resources. Thirdly, social and cultural sustainability means that the cultural heritage and traditions should be enforced along with the sense of local identity.

3.4.2 Assessment methods

Sustainability is a complex term and scholars have not come to an agreement yet about its way of measurement and which indicators to use in order to do so (Hayati, 2010). In this chapter the focus will be given on identifying the main sustainability indicators in order to quantify them for the crop rotation systems. Hayati (2010) makes a thorough investigation and comparison between indicators used by other researchers in order to come to a conclusion about the most suitable ones to measure sustainability.

Wirén-Lehr(2001) in an attempt to assess agricultural sustainability formulated the basic dimensions and their levels. As you can observe in the table 1, he divided the dimensions in normative, spatial and temporal. The normative include economic, ecological and social aspects that are also defined as the three pillars of sustainability by the food and agriculture organization (FAO 2016). In addition, the spatial dimension includes the sustainability scope of vision that can be local, regional and national. Lastly, in the temporal dimension he takes the dimension of time into account dividing it in short-term and long-term.

Dimensions	Levels
Normative	Ecological aspects
	Economic aspects
	Social aspects
Spatial	Local
	Regional
	National
Temporal	Long-term
	Short-term

Table 1: Basic dimensions and conforming levels to assess agricultural sustainability, Von Wiren-Lehr 2001

3.4.3 Life Cycle Assessment

The complexity and broadness of the term sustainability is a driver to create tools in order to measure the term's different parameters. These tools provide an opportunity to quantify and compare different systems based on parameters such as environmental impact. Such a tool is the life cycle assessment (LCA). It breaks down a product's life in many different parts, from raw materials to end product and provides an analysis and measurement of the resources used along with the environmental impacts they have((Sonnemann, 2003). The LCA approach will be mentioned in several chapter in this thesis as most of the sustainability indicator reports are analysed and assessed by using this tool.

Since then, the definition had evolved until today and now the LCA is used to compare and assess the sustainability indicator of agricultural production systems. Different methodologies have been created over the years in order to approach the assessment.

Brankatschk et Finkbeiner, 2014(Gerhard Brankatschk, 2014) recognized that there were limited information to include several sustainability indicators in the LCA and suggested a methodology that included the following steps.

1. Identifyand specify the structure of the crop rotation system.
2. Identify the crop rotation life cycle and do a quantification of all the agronomic inputs such as diesel fuel, fertilisers, agrochemicals and energy.
3. Take into account the outputs of the agricultural system.
4. Use Cereal Unit as your unit of measurement and convert all the metric tons accordingly.
5. Use the cereal unit to do allocation of all factors that are calculated for all agricultural outputs of the whole crop rotation.
6. The sum of all agricultural output is then allocated between all outputs separately.

7. Using the allocation shares, calculated in step five, the sum of agricultural input (seed, diesel fuel, energy, agrochemicals, fertilizer, etc.) is allocated between all individual agricultural outputs.

Using this methodology, the LCA obtains more data on indicators that would otherwise be really complex to include in the calculation of the LCA. This type of methodologies are used by many researchers to conduct a comparative analysis between two systems. Some of the reports mentioned later in this paper at the sustainability indicators comparison chapter have implemented this kind type of life cycle assessment.

3.4.4 Sustainability indicators

This subchapter aims to inform about the indicators and systems on how to approach sustainability and which factors to quantify and measure. Since there are many authors who use different indicators, once again the need for further research in the crop rotation system is highlighted.

Based on the FAO's three pillars of sustainability, Zhen and Routray(2003), identified some operational indicators aiming to measure agricultural sustainability.(FIFURE X) The economic aspect of sustainability was covered by using crop productivity, net farm income, benefit cost ratio of production along with per capita food grain production. These indicators are used by other referred researches in this document, in some cases they are only structured differently.

The social factors include food self-sufficiency, equality in income and food distribution and access to resources and support services. This way of viewing the social aspect of agricultural sustainability pays a lot of attention in the farmer. The farmer has to be educated and aware of how to conserve his resources and also about ecological aspects.

The ecological indicators of sustainability include the amount of water and fertilizers used for the production and the effect of it in the soil health parameters such as nutrient content and cycling. The main focus of Zhen and Routray(2003), is the effect of the agricultural system in water efficiency and groundwater. The need for measuring parameters as nitrate and depth of groundwater are highlighted.

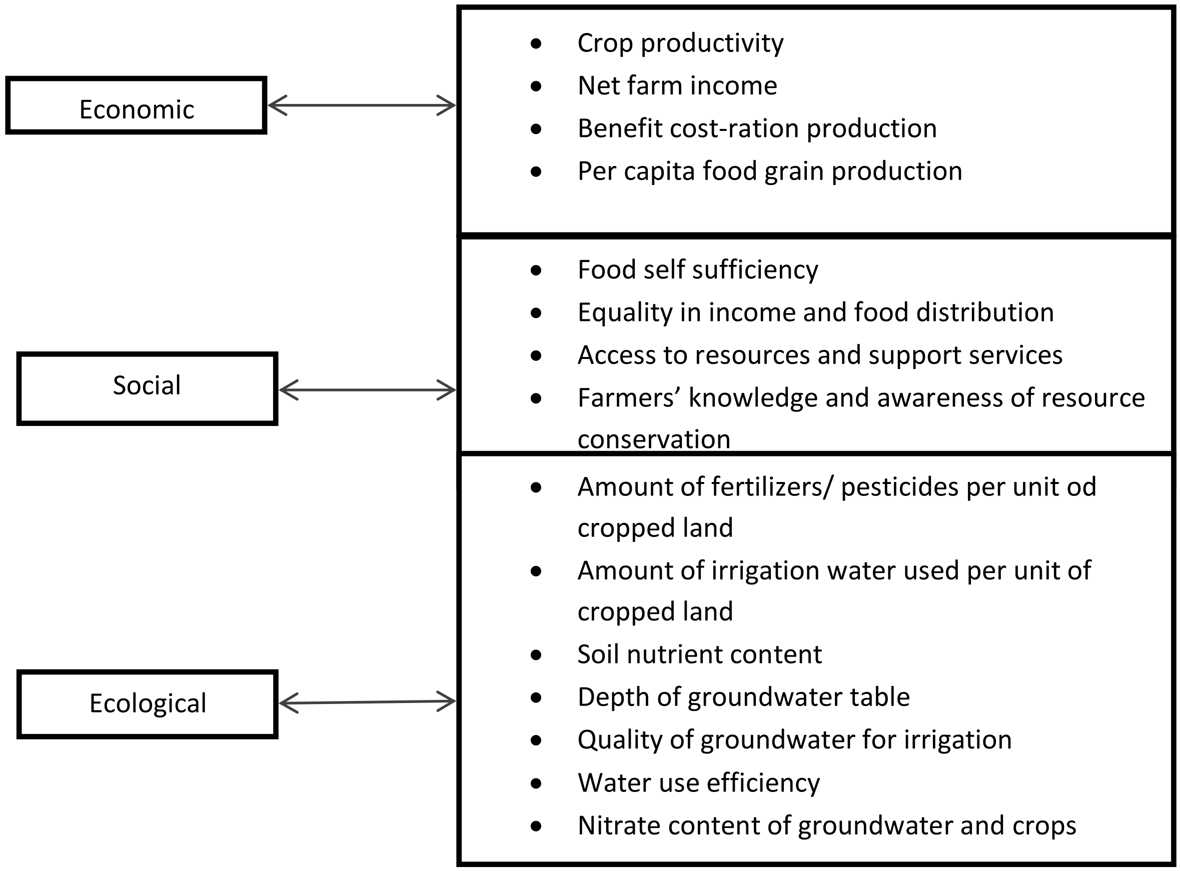

Table 2: Operational indicators fot measuring agricultural sustainability in developing countries, Fzhen et al. (2003)

3.5Comparative analysis

Several researchers have conducted long term experiments to compare conventional and organic production systems. On a study that lasted 21 years in Europe,(Maeder P. et al, 2002) reported that the yield in organic farming was in total 20% lower. This number might seem not promising enough in our effort to feed an increasing world population in a sustainable manner, but there are other indicators to take into account. Maeder also reported that the energy costs were 53% lower, the use of pesticides and fertilizers decreased by 97% and 34% respectively. Reganold et,(1987)(Reaganol J.P, 1987), conducted a report after 40 years of comparing organic and conventional systems and concluded that the several parameters related to soil quality, such as soil organic matter and polysaccharide content were higher in organic systems. Furthermore, organic agriculture presented greater top soil depth and less soil erosion. Another report by (M. S. Clark, 1998) concerning crop rotation systems of organic and conventional methods presented the same type of results. Clark, 1998,observed that organic and low-input systems result in small increases in soil organic C content and amount of stored nutrient pools in soil. The increase of 2% might seem insignificant, but it is of vital importance in agriculture as they play a critical role in long-term soil fertility.

The comparative analysis goal is to investigate whether or not organic agriculture can have a major contribution in feeding the world. (Tomek de Ponti, 2012), complied and analyzed a meta-dataset of 362 published comparative analysis focused on yield indicators. The results were quite surprising as the organic yield was in a really close gap compared to the respective conventional, reaching the yield of 80% of the conventional yield on average. Note that this number is an average and it differs between crops and regions. Furthermore, it was discovered that the yield gap between the two system increases as the conventional yield increases, a fact that suggests that the increase of field's scale will increase the yield gap (Tomek de Ponti, 2012). The above highlight the importance of further research on nutrient availability on regional and farm level. Furthermore, another study carried out by Berkeley university researchers L.Ponision and C.Kremen 2011 (Lauren C. Ponisio, 2014)supports the findings of T.Ponti 2012 report. In this paper, new meta-dataset of 115 studies containing more than 1000 observations was used. The result was that the yields of organic agriculture were 19.2%(±3.7%) lower than conventional yields. The study also investigates different management practices in order to find the effects of them in the final yield. The results suggest that management practices in organic farming practices such as multi-cropping and crop rotations can reduce the yield dramatically (to 9 ±4% and 8±5%, respectively). In addition, another report carried out by (P.Barbieri, 2017), published at nature magazine comes to further support the importance of crop rotations in the effort to mitigate the yield gap between organic and conventional farming. This report takes into account different sustainability indicators of crop rotation systems such as crop composition-diversity.

3.6 Sustainability indicators

Since sustainability indicators vary amongst scholars, a selection has been made on the ones that are more relevant for the goal of this report. These main indicators refer to economic return, crop yield and agricultural management practices. Other parameters such as soil quality and agricultural nutrient balance will be excluded and only mentioned briefly as part of the three main indicators. This is because of lack of sufficient and concrete quantification of these indicators in a crop rotation system.

Nambiar et al. (2001) recognized sustainability indicators of chemical, biophysical and socio-economic nature. By using those, he offered a regional index of agricultural sustainability that includes eight categories. Firstly, the agricultural nutrient balance that refers to the input/output ration along with the gross nutrient balance. Secondly, the crop yield that provides data on the biological production capacity of the agricultural site and its ability to sustain resource production. Thirdly, parameters concerning water and fertilizer efficiency (%) are examined in the agricultural management practices indicator category. Furthermore, agri environmental quality measures soil erosion (soil/km2) and soil salinity(mg/kg). Soil is a crucial subject and thus other parameters of it are examined such as clay content, depth pH, CEC,OM and permeability. Another important indicator is agricultural biodiversity that measures the number and variety of organisms around the specific field area.

The next sustainability indicator is the economic and social viability. It measures the worker's salary and the real net output per unit of area. Finally, the energy required for all inputs and outputs is summed up in the net energy balance category.

Note that since the information on crop rotation systems are limited for some of the indicators, the focus will be given on crop yield, economic return, agricultural management practices and environmental indicators, more particularly carbon emissions.

Explaining the need for monitoring and measuring of agricultural sustainability

Academic, scientific and policy-making communities have focused their attention in recent years on the concepts of the "sustainable environment" and "sustainable development" (Zhen and

Routray, 2003; and others). This has been accompanied by attempts to develop practical systems for measuring sustainability in the different systems of farming, cropping and livestock raising on which humanity depends for subsistence. Zhen and Routray (2003) urge agricultural researchers to: i) recognize the importance of sustainability in agricultural systems; ii) devise ways of measuring sustainability; and iii) examine empirically the sustainability of some well-defined cropping or farming systems and develop methods to measure it.

Since there are not concrete data based on a particular crop rotation system that includes all the sustainability indicators of the system, the focus will be given on each indicator individually, by providing scientific data from different research papers based on different crop rotation systems. The aim of this is to provide an overview of the way a comparative analysis between organic and conventional crop rotation systems is conducted and to sum up the results in order to conclude on which indicators require improvement and provide a realistic assumption on the sustainability of the two systems.

A noticeable realization about crop rotation systems is that the results of a comparative analysis between organic and conventional will have great variability based on the scope of the research.

Barbieri(2017) analyzed crop rotation system on a global scale and formulated some interesting assumptions.

- Organic rotations are more diversified than their conventional counterparts
- At the global scale, organic rotations have fewer cereals and more temporary fodders
- Organic rotations have more nitrogen-fixing crops
- These differences vary among global regions

The focus of the chosen indicators, except the crop yield will be given mainly in a local level which as it will be observed will provide different types of results compared to a global scale analysis.

3.6.1 Crop yield Indicator

The comparative analysis goal is to investigate whether or not organic agriculture can have a major contribution in feeding the world. Ponti et al.(2012) complied and analyzed a meta-dataset of 362 published comparative analysis focused on yield indicators. The results were quite surprising as the organic yield was in a really close gap compared to the respective conventional, reaching the yield of 80% of the conventional yield on average. Note that this number is an average and it differs between crops and regions. Furthermore, it was discovered that the yield gap between the two system increases as the conventional yield increases, a fact that suggests that the increase of field's scale will increase the yield gap (Tomek de Ponti, 2012). The above highlight the importance of further research on nutrient availability on regional and farm level.

Again, it has to be noticed that this report highlights the importance of further research in the organic sector. Examples of countries pioneers in organic agriculture research as Denmark and the Netherlands should be followed. Furthermore, another study carried out by Berkeley university researchers L.Ponision and C.Kremen (2014) supports the findings of T.Ponti 2012 report. In this paper, new meta-dataset of 115 studies containing more than 1000 observations was used. The result was that the yields of organic agriculture were 19.2%(±3.7%) lower than conventional yields. The study also investigates different management practices in order to find the effects of them in the final yield. The results suggest that management practices in organic farming practices such as multi-cropping and crop rotations can reduce the yield dramatically (to 9 ±4% and 8±5%, respectively). In addition, another report carried out by (P.Barbieri, 2017), published at nature magazine comes to further support the importance of crop rotations in the effort to mitigate the yield gap between organic and conventional farming. This report takes into account different sustainability indicators of crop rotation systems such as crop composition-diversity.

The gap between organic and conventional crop rotation systems might not seem like substantial(± 20%), but the reality is quite different. The systems yield gap increases in the more agriculturally developed countries and decreases in the developing ones. This suggests that in the current situation it is more beneficial to use organic crop rotations in the developing countries where the gap is smaller and choose carefully the composition of crops in the system. In many cases, organic rotations are relatively more productive in drought periods (Dobbs et al. 1996, Hanson et al. 1997). The need for more research and more similar discoveries can help to build a more sustainable agricultural world. The selection of area and composition of the rotation systems must be further investigated and researched.

3.6.2 Economic yield indicator

Economic returns are of vital importance in the agriculture business world. Farmers worldwide, struggle to gain sufficient and steady income in order to ensure the viability of their business. With that in mind, economic yield can be viewed as a social sustainability indicator as it can be economic.

As mentioned in the sustainability chapter, the three main pillars are the three P's, that are people, planet, profit. Profit as part of economic sustainability will be investigated based on a an economic comparison of organic and conventional grain crops in a long-term agroecological research (LTAR) site in Iowa. The research was conducted by Delate et al,(2003)et al of the Iowa state university. Delate et al., (2003) compared the yields and economic return of organic and conventional grain crops. Their results indicate that the organic Corn Soybean rotation can be competitive with the conventional given the experiment's conditions of on farm labor and management. The organic rotations have an economic advantage if the cost of compostdoes not exceed $20/T. In the case that the cost increases from 20 to 40$/T, the need to change the rotation system is necessary. The organic C-S rotation should be modified, adding alfalfa(C-S-O-A) in the mix, in order to maintain its competitiveness. Another major production cost, labor was studied thoroughly in this study. The outcome suggests that even if the labor cost increase from 10 hr^{-1} to \$50 hr^{-1} the effect on the return of the rotations was minor. These results differ from other studies and are valid given certain parameters that were applied in the organic system. There was an on time pest andweed control-management, adequate soil fertility in the rotation and the organic C-S rotation had higher seeding rate, to compensate for loses caused by weed management(rotary hoeing).

In the table3you can observe the economic comparison between conventional and organic

U.S. State	Year	Crops	Yields	Economics
South Dakota (Dobbs and Smolik, 1996)	1985-92	Corn (Zea mays L.)	No statistical difference between conventional and organic; Higher in organic in drought years	Cost of production (C.O.P.) similar to conventional; organic premiums were not calculated
South Dakota (Dobbs and Smolik, 1996)	1985-92	Soybean (Glycine max L.)	No statistical difference between conventional and organic	C.O.P. similar to conventional; organic premiums were not calculated
Pennsylvania (Hanson et al., 1997)	1981-95	Soybean	No statistical difference between conventional and organic after 3 yr. rotation; higher in organic in drought years	C.O.P. 12% lower in organic across all rotations; organic premiums were not calculated
California (Clark et al., 1999)	1989-96	Tomatoes (Lycopersicon esculentum Mill.)	No statistical difference between conventional and organic	C.O.P. 5% higher in organic, but with organic premiums, superior economics with organic
New Jersey (Brumfield et al., 2000)	1991-1993	Tomatoes, pumpkin (Cucurbita pepo L.), sweet corn (Zea mays L. var. saccharada)	Higher average in conventional (statistics not shown)	C.O.P. higher in organic when previous crop costs (cover crops) and additional management over conventional (staking) included; net return per unit 5-16% higher in organic with organic premiums

Table 3: Yield and economic comparison of conventional and organic farming systems, Delate(2003)

farming systems in several studies from 1985 to 2000. Dobbsand Smolik, 1996 concluded that the cost of production in the two studied crops, corn(Zea mcs L.), soybean(Glycine max L.) did not present significant differences. Note that for both crops, organic premiums were not used in the calculation. On another study conducted by Hanson et al., 1997 in Pennsylvania, USA, using Soybean as a main crop, the results were slightly different. The cost of production was 12% lower in the organic rotations, with the organic premiums being again excluded from the calculations. An important result between these two studies was that during drought years, the organic rotation systems had higher yields from the conventional ones. Clark et al, 1999 used tomatoes(Lycopersicon esculentum Mill.) to make the same analysis. The result were different, as the cost of production of organic was about 5% higher, with the difference being that organic premiums were taken into account. Finally, Bruumfield et al, 2000 used Tomatoes, pumpkin(Cucurbita pepo L.),sweet corn (Zeamays L. var. saccharada) in their research. They claimed that the cost of production was higher in the organic system, when additional organic crop costs are included in the calculation. These are cover crops and additional management costs of the organic system. The end result was that the net return of the organic was 5-16% higher, including organic premiums.

Organic products have a much higher value in the market and with the aid of governmental subsidies the farmers can consider of making a transition to this system. The main disadvantage is plant protection. Without the use of chemical pesticides, insecticides and fertilizers you run the risk of having low yield or even lose the whole crop in one growing season. A multi cropping system such as crop rotation can prevent such a disaster as it is composed of several crops that are harvested in different time periods. Overall,, the cost of production between the two systems is about the same with main difference being the products end value in the market where organic products are much superior.

3.6.3 Agricultural Management Practices

P.Barbieri, 2017, compared crop rotations between organic and conventional farming in a global level. The findings of the report highlighted some differences between the two systems, such as that organic rotations are more diversified than their conventional counterparts .Worldwide, organic crop rotations last 4.5 years $\pm$ 1.7 years, a difference of about 15% more than conventional agriculture. Furthermore, organic crop rotations include 48% more crop categories, a fact that makes them more diversified both in terms of space and time. However, the fact that organic systems require more space makes them unsustainable. As (Barbieri, 2017)

Barbieri, 2017compared many differentcompositions of rotations and found out that there are significant differences differed between farming systems. On average,, organic rotations are mainly composed by primary cereals(i.e. maize, wheat, rice) that account for 29 ± 2% of the total length of the rotation. Secondary cereals(i.e. barley, spelt, triticale, rye, pseudo cereals, millet and sorghum) account for about 17% $\pm 2\%$, pulses ($15 \pm 2\%$), temporary fodders ($24 \pm 2\%$),) and the rest 15% is divided among root crops, oilseeds, industrial crops and vegetables.

Organic rotations are composed of primary cereals (i.e. wheat, maize and rice; 29of the rotation length), secondary cereals (i.e. spelt, barley, rye, triticale, oat, sorghum, millet and pseudocereals; $17 \pm 2\%$), pulses ($15 \pm 2\%$) and temporary fodders (whereas the remaining 15% is shared among oilseeds, root crops, industrial crops and vegetables".

Organic systems use more crops on average as diversification is a vital management tool for weed, pest and disease control. Since synthetic pesticides and herbicides are not allowed in organic farming, the use of these crops is important as they create biotic barriers and discontinue the biotic cycle of pests and diseases(Adrien Rusch, 2013).

Organic crop rotations need to diversify in order to compete with the conventional systems. This diversification offer many advantages such as protection for the farmer from losing the whole crop, by growing many different ones into the system. The cycling of nutrient between the crops and growing seasons are of vital importance for social, economic and ecological factors.

3.6.4 Ecological indicators-CO2 footprint

Many organic agricultural systems present high dependency from animal manure that mainly derives from conventional agriculture systems(Knudsen, 2014). This fact underlines the connection of the two systems analyzed in this paper. Organic agriculture is perceived to be climate friendly, but the yield difference between the two production methods raises questions on the validity of this perception. The choice of the main research paper to study the environmental CO_2 footprint was made based on the results and parameters examined by Knudsen et al, 2014. In their paper, they examine the carbon footprint both in $C0_2$ emissions per kilogram and per hectare.

In this study, carbon footprints of crops from organic and conventional arable crop rotations are compared using life cycle assessment as a tool. In this study, M.Knudsen et al made a comparative analysis between four different crop rotation systems. The crops have different N supply sources the data are derived from long-term field experiments in three different locations in Denmark.

In the figure 1you can observe the detailed rotation system description. Three different organic systems are compared to a conventional and a 'no input' that are used as reference with the main goal of measuring the carbon footprint in all cases.

Three main cash crops are used in the systems; potatoes (Solanum tuberosum L.), spring barley (Hordeum vulgare L.) and winter wheat (Triticum aestivum L.) . Then the last one can be either grass-clover for green manure or faba beans (Vicia faba L.) used as cash crop.

The 'slurry' organic rotation scenario refers to mainly pig slurry imported from pig farms and all the crops of the rotation can be sold as cash crops. In the 'no input' there is no use of organic fertilizer and again all the crops can be used as cash crops. In order to maintain soil fertility the researchers used catch (cover) crops. In the 'Mulching' scenario the soil fertility is maintained by a green manure crop(grass-clover). This replacement leaves the system to function with only three cash crops. Finally, the 'biogas'scenario) uses a green manure crop in a different way. It is not incorporated into the soil, but utilized for gas production. In that way gas production residues are returned to the field.

Finally, the'conventional' system usesmineral fertilizers and pesticides and has a structure similar to the 'Slurry' rotation.

Carbon footprints at farm gate from the full crop rotations 2006–8 per hectare or per kg DM cash crop. The values are means over three years (2006–8) and two replications.

	Carbon footprint (kg CO_2 eq. ha^{-1} $year^{-1}$)			Carbon footprint (g CO_2 eq. kg^{-1})		
	Jyndevad	Foulum	Flakkebjerg	Jyndevad	Foulum	Flakkebjerg
Mulching	1394	1014	693	713	305	261
Biogas	166	46	−476	42	25	−144
No input	1453	1223	897	695	348	379
Slurry	2038	1797	1437	540	382	397
Conventional	2599	2558	2032	481	443	350

Table 4: Carbon footprins ar farm gate from the full crop rotations 2006- per hectare or per kg DM cash crop. The values are means of three years(2006-8) and two replication, Knudsen et al, 2014

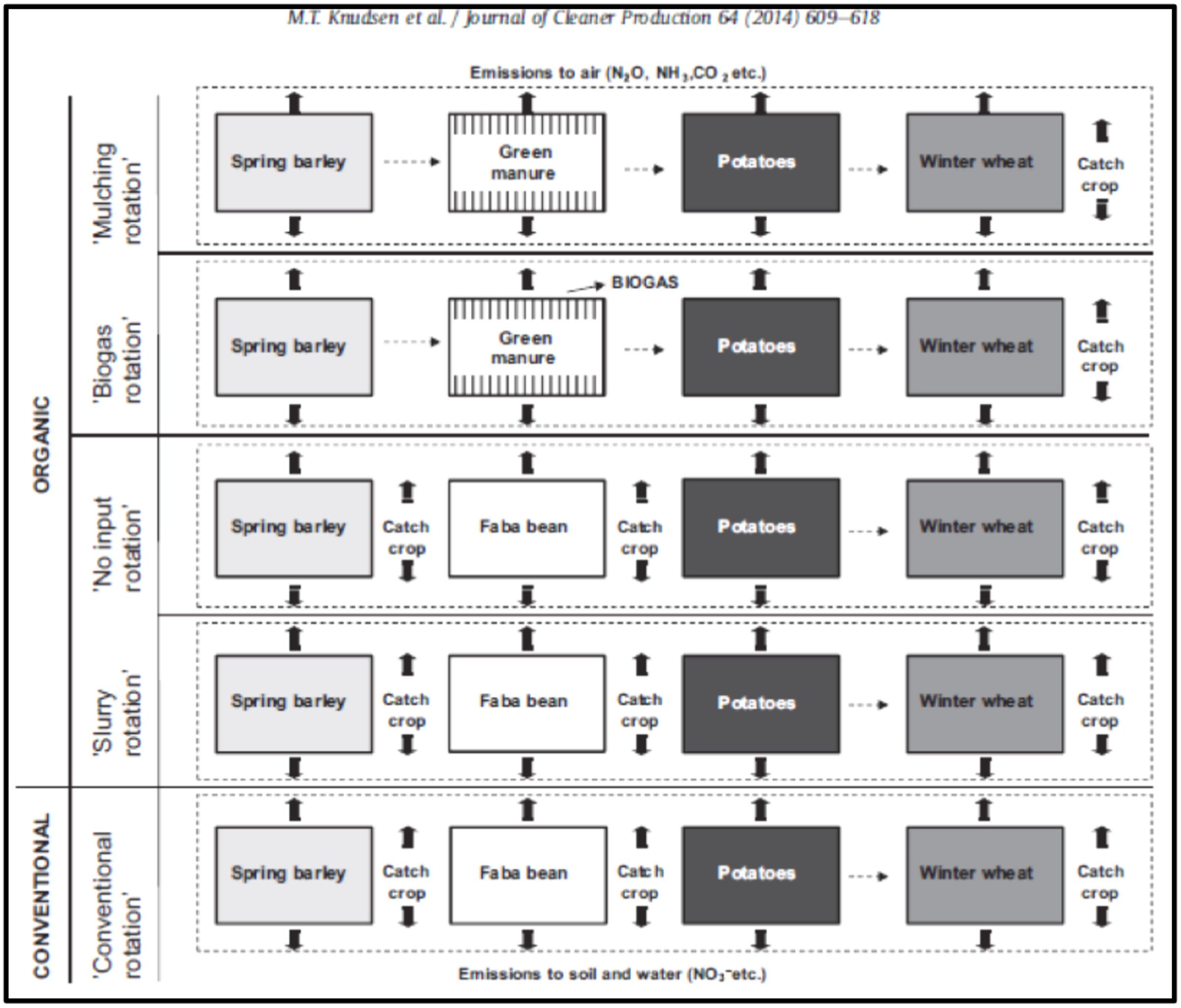

Figure 1: Representation of rotation systems used to conduct comparative analysis, Knudsen, 2014

Table 4 below illustrates the results of the research per rotation scenario in three different areaswith the system boundaries set on farm gate. The statistics related to the kg cash crop of the full crop rotation system highlight the significance of rotation, location and theirinteraction.

The results suggested that the ‘Biogas’ rotation had a significantly lower carbon footprint compared to the rest of the systems. This result is true if we assume that the biogas replaces fossil fuels in the system. The cash crops from the ‘No input’, ‘Slurry’ and ‘conventional’ system have almost the same per kg DM, whereas the ‘Biogas’ had by far the lowest carbon footprint per kg of DM. By selecting legumes in the rotation, fermenting them in the gas station and then returning the residues to the field a farmer can decrease the field’s carbon footprint by a considerable amount. The results were similar to another experiment conducted by (Nemecek, 2011).The range of the carbon footprints values per kg was 302 to 431 g CO2 eq. kg^{-1} DM. Another study conducted by (Michel, 2010)studied rotation systems similar to the ‘Mulching’ and ‘Biogas’, with the only difference being that grass-clover ley was part of the system every six years. The appraoach of this study was slightly different as they only calculated the GHG emission per hectare and not per kg as suggested by (Knudsen, 2014). The GHG emissions calculated by (Michel, 2010)(1034kg CO2 eq.ha) were similar to Kdudsen. The main difference was in the ‘Biogas’ comparable case where the results in kg CO2 eq. ha were higher(448 vs -88CO2 eq.ha). The difference can be interpret by the crop rotation system difference.(Michel, 2010) cultivated grass-clover ley every six years and also utilized only electricity and no heat as (Knudsen, 2014).This explains the lower assumed benefit from the biogas production in the two cases. To sum up, the contributions caused by the green manure were quite considerable. Carbon footprint of organic compared to conventional varied depending on production practice. This indicates a potential for improving the carbon footprint of organic production by using the appropriateproduction management practices.

3.7Literature papers

This subchapter is provided in order to gain a clear overview of the types of reports used in this paper along with the chapters they are used for. Note that the fill list of bibliography is given in the end of this paper.

To gain insight about the effects of crop rotations of organic and conventional farming systems the following articles illustrated in table xxx were used.

Title	Author, Year of publication	Source
Agricultural sustainability and intensive production practices	Tilman et al.,2002	Nature magazine
Diversification practices reduce organic to conventional yield gap	Ponision et al., 2017	Berkeley university
Comparing the yields of organic and conventional agriculture	Seufert et al. 2012	Nature magazine

Table 5: Journal articles used for agricultural systems description

The articles mentioned in table xxx were used to gain insight on how to conduct a comparative analysis. All these studies were published to scientific journals from 2008 and onwards.

Title	Product	Author- Year of publication
Comparative LCA of organic and conventional arable crop rotations on their carbon footprints	Spring barley, fava bean,potatoes, wheat	(Knudsen et al. 2013)
Comparative LCA of organic and integrated farming systems	Potato, winter wheat, beetroot, winter barley and grass clover	(Nemecek et al. 2011)
Comparative LCA of organic and conventional food production systems	Winter wheat, potato, winter barley, spring beans, cabbages, grass clover	(Cooper et al. 2011)
An economic comparison of organic and conventional grain crops in a long-term agro ecological research (LTAR) site in Iowa	Grain crops	(K.Delate et al.,2009)
Comparative LCA on organic and conventional soybean delivered to Denmark from China	Soybean	(Knudsen et al. 2010)
Comparative assessment of fossil energy use in organic and conventional agricultural systems	Grass clover, cereals, row crops and permanent grass	(Dalgaard et al. 2008)

Table 6: Journal articles used to conduct comparative analysis

Title	Author, Year of publication	Source
Crop rotation modelling	N.Detlefsen, 2004	Danish institute of agricultural sciences
Crop rotation modelling—A European model intercomparison	C.Kollas et al., 2015	European Journal of Agronomy
A Literature Review on Frameworks and Methods for Measuring and Monitoring Sustainable Agriculture	FAO, 2017	FAO

From wheat to beet – challenges and potential solutions of modeling crop rotation systems in LCA	Brankatschk et al, 2014	Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector
A systematic representation of crop rotations	Castellazzi et al., 2008	Agricultural Systems 97, 26-33
Measuring Agricultural Sustainability	D.Hayati et al, 2010	Sustainable Agriculture Reviews book series (SARV, volume 5)

Table 7: Journal articles used to conduct comparative analysis

4Results

Overall the nature of the term sustainability is very complex and that makes it difficult to assess. The quantification of the main sustainability indicators is complicated issue, as it is hardly possible to quantify social indicators like the happiness of the farmer or the maintenance of local traditions and environment. Issues arise even when you compare the ecological and environmental factors.

The difference in yield affects the carbon footprint of the rotation systems. The system boundary definition and the unit of measurementis of vital importance as

By breaking down the production process in many different parts we can have a clear idea of what exactly needs to change in a system. The life cycle assessment can be really useful tool to achieve. The research on crop rotation production systems is still limited compared to other monoculture production methods and therefore attention must be turned to that direction.

The crop yield difference of 19.2% worldwide(Ponti,2012) is still too high considering the difference between countries.

The systems yield gap increases in the more agriculturally developed countries and decreases in the developing ones. In many cases, organic rotations are relatively more productive in drought periods (Dobbs et al. 1996, Hanson et al. 1997). This is another fact that highlights the need for proper selection of crop based on the environmental, climatic and economic needs. Cropping systems such as intercropping or cover cropping should be used as a management practice in the organic farming as they create biotic barriers and discontinue the biotic cycle of pests and diseases (Rusch, 2013).

Other promising data concerning organic rotations were related to soil health and energy. Maeder (2002)reported that the energy costs were 53% lower, the use of pesticides and fertilizers decreased by 97% and 34% respectively(Reganold et al, 1987).

In an economic perspective, organic agriculture seems to have a small advantage, mainly because of governmental subsidies, organic premium prices and much lower input costs. Although a risk for a farmer is that he/she faces the risk of losing all the crop due to a pest or a disease, something that makes the choice of choosing an organic production system difficult.

The increasing world population and change in consumption patterns mainly in the developing countries make it clear that we have reached another agriculture related check point. Natural resources such as sources of phosphorous are depleting. Not only do we have to find a way to feed the extra 2 billion people by 2050, but we have to do it in a sustainable way. Organic agriculture must have a place in this effort as it proves to be sustainable in ecological, environmental and social sustainability indicators.

List of abbreviations

CAP	Common Agricultural Policy
C-SB	Corn-Soybean
DM	Dry Matter
EU	European Union
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
IFOAM	International Federation of Organic Agriculture Movements
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
SAFA	Sustainability Assessment of Food and Agriculture systems
LCA	Life-cycle assessment
OECD	Organization for Economic Co-operation and Development
WTO	World Trade Organization

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