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Design and Sustainability Assessment of Bioenergy Double Cropping System in Southern Sweden

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Design and Sustainability Assessment of Bioenergy Double Cropping System in Southern Sweden

Design och hållbarhetsbedömning av tvågrödesystem med grödor till både bioenergi och livsmedel i södra Sverige

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Abstract

Due to short growing season harvesting two crops sequentially in one year is not common in Sweden. In this experiment a cropping system was designed where rye was grown as a first crop for production of biomass feedstock for bioenergy. Aim of the study was to design a cropping system that can increase overall crop production and provide food, feed, energy and non-market ecosystem services such as increase annual carbon input and reduce leaching loss of nitrogen in the soil. With these ideas a field experiment was conducted in 2014-15 in Dybäck, southern part of Sweden. Rye was planted as first crop in September 2014 and harvested in green condition for energy production at the end of May, 2015. Blue lupin, soybean, black bean, lentil and buckwheat were selected as second crops and were grown in between June to September, 2015.

It was an interdisciplinary research work. Both quantitative and qualitative methods were used for this study. A literature search was conducted to collect preliminary data to assess sustainability of double cropping system using Sustainability Assessment of Food and Agriculture systems (SAFA) as a concept. Quantitative method was used for determining crop yield and crop residues. Qualitative method was used to investigate possible motives and constraints that might influence farmers' decision to adopt double cropping system through semi-structured interviews.

According to the literatures reviewed, conventional double cropping system requires a high level of water consumption and fertilizer utilization. This system also emits a high quantity of GHG. However, due to high soil coverage the system may enhance soil quality and protects soil from land degradation. Double cropping system also supports a large number of diverse species such as beetles and spiders. Increase yield could result in rise in net income. It should be noted that overall outcome of the double cropping system can greatly vary depending on the country/region, climate, soil, choice of the crops/varieties and, cultivation system (irrigated/non-irrigated, tillage/non- tillage, organic/conventional).

Grain yield of lentil was highest (1.7 t/ha) among all the crops. Grain yield of buckwheat, black bean, soybean and blue lupin were 1.3 t/ha, 0.9 t/ha, 0.6 t/ha and 0.5 t/ha respectively. Production of crop residues was highest in buckwheat (3.2 t/ha). Crop residues production of lentil, black bean, soybean and blue lupin were 2.1 t/ha, 1.1 t/ha, 1.1 t/ha and 0.8 t/ha respectively. Highest annual C input in the soil was determined in buckwheat (304.2 kg/ha). Annual C input in the soil by lentil, blue lupin, black bean and soybean were 214.5 kg/ha, 121.7 kg/ha, 107.7 kg/ha and 101.2 kg/ha respectively. Amount of available N was determined for three crops: buckwheat, lentil and soybean at the depth of 0-60 cm. Total amount of available nitrogen in buckwheat, soybean and lentil were 14.3 kg/ha, 11.3 kg/ha and 9.6 kg/ha respectively. Crops residues are suitable for animal feed and energy production.

Results from five interviews demonstrated that absence of market, lack of suitable machineries to handle second crops and lack of knowledge of double cropping system might be the major barriers of potential adoption of bioenergy double cropping system by the farmers who are growing rye for production of biomass feedstock for bioenergy production.

Key words: bioenergy double cropping system, multifunctional agriculture, ecosystem services, interdisciplinary research, SAFA

Forword

For language barrier, different education system in Sweden than my country and lack of understanding of social science it took me some time to adjust myself in the program and to understand what agroecology means. I have to say I am still learning and trying to understand things. In this program I have learned the most fundamental learning that how complex agriculture system can be. It is important to understand problems from different perspective. In the program I have learned systemic thinking that teach us approaching the food system as a whole and to consider all the relevant components of environment, economy and society. There could be many solutions of the problems in food system. Best solutions are those that can provide environmental, economic and social benefits simultaneously.

In the agroecology program we discuss topics such as ethical issues, animal right, sustainable development and our responsibility as human being. Learning, discussing and reflecting on these issues were not only academic lesson for me but these are the lessons for life.

Studying in agroecology program gave me opportunity to be a part of my class. Fiends from twelve different countries and their thoughtful discussion in the class helped me to understand more the subject matter. Seeing my friends performing better in the class made me more competitive to do well in the program.

Abbreviations

BDC	Bioenergy double cropping system
DC	Double cropping system
EFA	Ecological focus
GHG	Green-house gas
SAFA	Sustainability Assessment of Food and Agriculture systems

Definitions

Bioenergy: Bioenergy is renewable energy which is derived from biomass. Biomass is organic matter derived from plants or animals such as agricultural crops, herbaceous and woody plant materials, human waste and manure (International energy agency, 2015).

Biofuel: Biofuel is a kind of energy derived from biomass (International energy agency, 2015).

Double cropping system: Growing and harvesting two crops one after another in one year in the same field is known as double cropping system. In this system planting of second crop (additional crop) is done after harvesting the first crop (primary crop). It is also known as sequential cropping (Nafziger, 2009).

Bioenergy double cropping system: similar to double cropping system in bioenergy double cropping system two crops are grown one after another and harvested in one year in the same field. However in bioenergy double cropping system purpose of growing one crop or both crops is energy production (Heggenstaller *et al.*, 2008).

Ecosystem services: The UN Millennium Ecosystem Assessment report has described Ecosystem services as the benefits people obtain from ecosystem (Millennium Ecosystem Assessment, 2005). The services can be market or non-market. Market ecosystem services are providing food, feed, and biomass On the other hand non-market ecosystem services are providing regulation, cultural and esthetic and recreational services (Porter, 2009).

Interdisciplinary research: Research that links or integrates theories, concepts, methods, and principles from different disciplines is called interdisciplinary research (Lawrence, 2010).

Multifunctional agriculture: Agriculture that can provide food, feed, energy, ecosystem services for example wildlife management, maintenance of biodiversity, nutrient recycling, carbon sink, improvement of water quality, soil condition and consider role of farming community for strengthen rural unity is called multifunctional agriculture (Van Huylenbroeck *et al.*, 2007).

SAFA (Sustainability Assessment of Food and Agriculture systems): SAFA is an internationally accepted, an extensive multi-criteria assessment tool that assess sustainability taken into consideration all four dimension of sustainability; good-governance, environmental integrity, economic resilience and social well-being (SAFA guideline 2014).

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1. Introduction

1.1. Influence of Demand of Energy and Food on Land

Bioenergy is the largest source of renewable energies which is providing worlds' 10% of energy supply. It has critical role in the energy sector of many developed countries for basic energy, for example cooking and heating space (International energy agency, 2015). Energy crop (i.e. maize, wheat and rye) production for the purpose of biofuel production considerably increased in the last few years (Graß *et al.*, 2013). Two very important reasons to promote biofuel production are, 1) to develop alternative energy source in order to mitigate climate change effects and 2) to reduce dependency on limited amount of fossil fuel (Bacenetti *et al.*, 2014; Erb *et al.*, 2012).

In Europe policies have been promoting for biofuel production through mandatory targets (Stan *et al.*, 2014). EU's Renewable Energy Directives has established policies to promote production of bioenergy from agriculture in Europe. By 2020 EU has targeted to fulfil 20% of total energy supply with renewable energy with individual national targets. By the same year all EU members have to compulsorily share 10% of biofuel in total fuel consumption in transport sector (European Union, 2016).

Swedish Government has set the target to fulfil 50% of its total energy supply with renewable energy by 2020 (Regeringskansliet, 2010). Therefor using crops for biofuel production has been considering very important for investment strategies which inspiring farmers and investors in energy crops (Stan *et al.*, 2014). At present one of major concern of biofuel is its impact on food security by increasing the price of food (Negash & Swinnen, 2013). Higher food price can cause food insecurity mainly to urban poor and the rural landless population (Müller *et al.*, 2007). Increase bioenergy production might also reduce water availability for food production since the available water would be used for biomass for bioenergy (Popp *et al.*, 2014).

Food security has been a big issue for many years. The volume of food consumption is increasing and a pattern of food consumption is changing and will continue to change. The global population is expected to be 9.1 billion by 2050. Most of the population increase will occur in developing countries (FAO, 2009). By 2050 the demand of food would be higher. Nine billion people would want eat like 12 billion people (Braun, 2011). To meet the demand of 12 billion people there would be demand to produce more food. Besides growth in population, changes in the diet and urbanization can affect food security (Popp *et al.*, 2014). People are becoming more urbanized and wealthier. By 2050 70% people will live in urban areas compared to 49% in 2009 (FAO, 2009). The numbers of overweight people in the world were 1.9 billion in 2014 (WHO, 2015). There is increasing demand for food for meeting need for current world population, meeting changes in food habit and improvements in nutrition and quality of food (Harvey and Pilgrim, 2011). Foley *et al.* (2011) estimated by changing diet (using food crops for human consumption instead of using them for animal feed) global food production can be increased by 28% and global supply of food kilocalories can be increased 49%.

Growing and changing demand for food in combination with finding alternate source of energy for transportation and reducing the use of fossil fuel and reducing green-house gas (GHG) emission are the main drivers of increasing competition for land (Harvey & Pilgrim, 2011; Popp *et al.*, 2014; Tilman *et al.*, 2009; Winter & Lobley, 2009). This new competition for land has been termed as "food, energy and environment trilemma" (Tilman *et al.*, 2009).

Besides growth in population, changes in the diet and urbanization, agricultural yield improvement can affect food security (Popp *et al.*, 2014). Despite the fact of improvement in the yield in agriculture at the global level between the years of 1963 and 2005 land under cultivation increased by 30% to produce food (Kastner *et al.*, 2012). At the current rate of changes in agricultural production to increase or to maintain global food security the area under cultivation has to be increased (Ray *et al.*, 2013).

Bioenergy may compete with food sector either directly or indirectly. When food crops are used as feedstock for bioenergy then the competition is termed as direct competition. For example in US 15% of annual global corn production has been used to produce ethanol (Popp *et al.*, 2014). Feedstock for bioenergy production generally takes place in an area that has been used earlier for food or animal feed production. Since the production of food or feed is still necessary therefore no crop growing areas for example grasslands and forests has been "partly" displaced for growing feedstocks. This is an indirect competition. This process of displacing non-crop area is termed as "indirect land use change".

1.2. Influence of Indirect Land Use Change on Environment

Deforestation and forest degradation as a result of indirect land use change can significantly affect loss of biodiversity (Müller *et al.*, 2007) and loss of terrestrial carbon and reduce carbon sequestration (EU, 2016). The GHG saving by increased use of bioenergy is reverting by the risk of GHG emission from indirect land use change because grasslands and forests typically absorb high levels of CO_2. Converting non-crop area into crop growing areas higher the risk of increasing level of CO_2 (EU, 2016). Sometimes clearing native ecosystem of the land is the most money-making way of obtaining land for biofuel (Tilman *et al.*, 2009). Searchinger *et al.*, 2008 have shown that instead of reducing GHG emission from bioenergy, indirect land use change as a result of biofuel production GHG emission would be double. While measuring reduction GHG emission from biofuel studies generally overlook the fact of GHG emission from indirect land use change. Green-house gas emission would be 30% higher if the emission from fuel use, fertilizer production and agriculturally induced land use change would be included. About 6-17% emission comes from land use change (Bellarby *et al.*, 2008 from Garnett 2011). Global GHG emission from land conversion and current agricultural land use are estimated to be more than two and a half times than the total emissions from transport using fossil fuel (Harvey & Pilgrim, 2011).

1.3. Positive Influence of Bioenergy Production

Increased demand of biomass for producing bioenergy not only affecting food security negatively, the affect can be positive also. For example, higher demand for food and biomass for bioenergy production can stimulate the agricultural sector and create new opportunities for rural communities especially in the countries with significant agricultural resources such as countries in Africa (Müller *et al.*, 2007). Similarly, agriculture sector higher demand of biomass can also stimulate forest sector for producing more forest based biomass for energy production (Popp *et al.*, 2014). However stimulating in the forest sectors mainly happening in the countries in Europe and North America whereas in the developing countries deforestation and forest degradation are significantly increasing mainly because of weak governance structure and lack of sustainable management of forest resources (EU, 2010).

There are different views among different stakeholders in agriculture industry, civil society, policy maker and research community about fixing problem agriculture system (Garnett, 2014). For example, according to Popp *et al.* (2014) increasing production from land for food and energy is possible through sustainable intensification without increasing the agricultural land and thus competition for the land would be lower. When "yields are increased without adverse environmental impact and without the cultivation of more land" then the system is called sustainable intensification (The Royal Society, 2009). Sustainable intensification is a recent concern which is not clear enough how might it look like in practice thus it needs to be explored more (Garnett and Godfray, 2012).

1.4. Alternative Crop Production Systems

According to Tubiello (2012) to reduce GHG emission in agriculture sectors different strategies such as improved crop and livestock management and agroforestry practices, enhanced soil carbon sequestration in agricultural soils and improved agricultural operations (i.e. reduced tillage) could be effective. To overcome the problem of food security and environmental problems associated with agriculture production Foley *et al.* (2011) explained the importance of stop expanding agriculture in non-crop areas, closing yield gaps, increase agricultural resource efficiency, and shifting diets and reducing food waste. According to Harvey and Pilgrim (2011) any increased production from land to meet the double demand for food and energy/materials must do without exacerbating anthropogenic climate change. To overcome the trilemma of food, energy and environment Tilman *et al.* (2009) has suggested strategies such as 1) growing biofuel feedstocks from perennial plants grown on abandoned land for agricultural use, 2) using crop resides for as biofuel feedstocks 3) harvesting wood and forest residues sustainably 4) growing double crops or mix cropping system 5) using municipal and industrial waste as feedstock.

The idea of growing double crops is not new. It is more common in the region with longer growing seasons (Gliessman, 1985) for example (mid-) southern United States, western Europe, China, Brazil and Argentina (Groeneveld & Klein, 2014; Fouli *et al.*, 2012). When two crops are consecutively produced and harvested in one year in one land it is called double cropping. In this cropping system planting of second crop is done immediately after harvesting the first crop. Both crops are harvested in same year. It can increase the cropland acreage and have less negative environmental consequences (Nafziger, E., 2009; Borchers, *et al.,* 2014). According to Tilman *et al.* (2009) double crops grown in the summer and harvested for biofuel production before planting main annual crop could be an alternate option of producing biofuel without decreasing food production and without clearing wild lands. In double cropping system possibility of getting higher biomass is more than single cropping system (Heggenstaller *et al.*, 2008, Krueger *et al.*, 2012). Increase biomass production was positively correlated with several ecosystem services for example weed suppression, prevention of nitrate leaching and above ground biomass nitrogen (Finney *et al.,* 2016). However, sustainability of the double cropping system has been increasingly questioned due to the high resource use and negative environmental impact (Zhao *et al.,* 2015) and can affect negatively to the availability of inorganic nitrogen and yield of the next crop (Finney *et al.,* 2016).

1.5. Motivation for This Study

Swedish government and the EU are intended to encourage farmers to increase energy crop production. Depending on economic and political measures, and the Federation of Swedish Farmers (LRF) has committed to increasing energy production to at least 5 terrawatt hours (TWh) energy from agriculture sector (Jonsson *et al.*, 2011). Skåna is committed to produce 3 TWh from agriculture sector by 2020 comparing with 0.3 TWh in 2008 (OECD, 2012). Therefore, there is more demand from the Swedish farmers specially from the farmers in Skåna to grow energy crops which means more competition for land to grow food and fuel. **Therefore a cropping system has been designed that can increase overall production[1], provide food, animal feed, energy and non-market ecosystem services[2]**. Thus, competition for land for food and energy production could be lower also.

Crop growing season in Sweden is quite short. However, in southern Sweden double cropping is used in some extent; i.e. cauliflower (harvest in October) after new potatoes (harvest in June) and 2nd spinach (harvest in mid-September) after 1st spinach (harvest in mid-June) however, the tradition is not very common[3].

Rye is a crop that used for biomass feedstock for bioenergy production. In 2014, 13,397 ha of land were used for rye cultivation (Länsstyrelsen-Skåne, 2015). There is not exact data how much rye is grown for biomass feedstock for biofuel production. To reduce competition for land for food and energy production an experiment had been designed. The experiment is about "bioenergy double cropping system". The basic concept of double cropping (DC) and bioenergy double cropping (BDC) are same, but purposes are different (Heggenstaller *et al.*, 2008). In bioenergy double cropping system one or both crops in DC system are grown for energy production. In our experiment rye was grown as main crop from sept-may for producing biofuel whereas the summer crops/second crops are grown for food production, increase annual carbon (C) input in the soil and reduce leaching loss of mineral nitrogen (N).

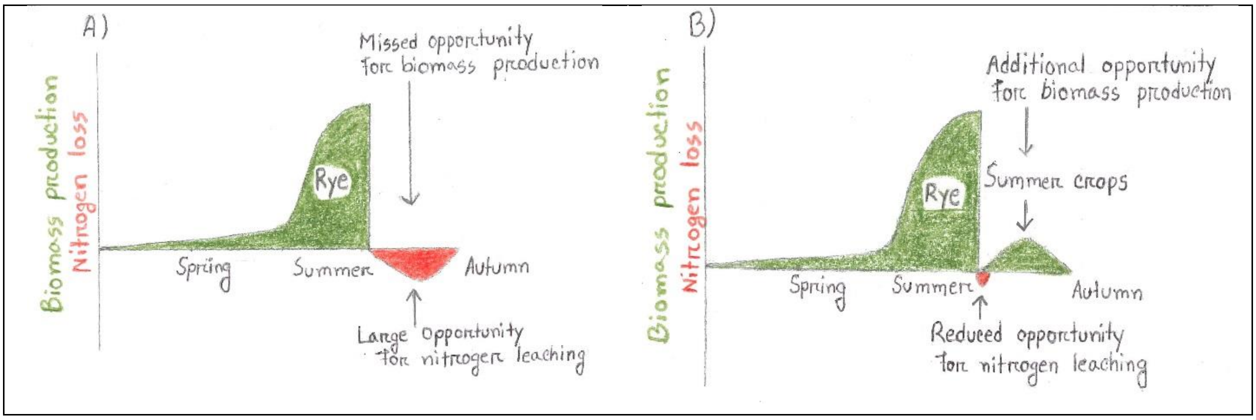

Figure 1. Hypothesized representation of the seasonal dynamics of crop production and N leaching (A) in an annual cropping system (B) in a bioenergy double cropping system (adopted from Heggenstaller *et al.*, 2008).

[1] In this study overall production is refers to the total production in one year from different crops in the system.
[2] Services that are not subjected to market trades are non-market services for example nutrient recycling (Filyushkina, 2016)
[3] Oral source, Svensson, S. (2016). Swedish University of Agricultural Sciences, Alnarp

1.6. Aim and Research Questions

Aims are:

1. To design a cropping system that can increase overall crop production and able to provide food, feed, energy and non-market ecosystem services such as increase annual carbon input in the soil and increase accumulation of mineral nitrogen in the system.
2. To assess sustainability of the system through review of literature using SAFA as a concept and,
3. To investigate about possible motives and constrains that might affect farmers to adopt this system

Two main research questions of this study are:

1. What are the advantage and disadvantage in terms of production and sustainable development of cropping system from Bioenergy double cropping system?
2. What are the motives and constrains that might affect farmers to adopt bioenergy double cropping system?

The additional research questions are formulated to provide more detailed answer of the main research questions.

1a) Is it possible to have acceptable yields and biomass from the selected double crops in order to examine the possibility of using crops for human consumption?

Hypothesis: Acceptable yield of double crops could be achieved in Bioenergy double cropping system thus possible to reduce competition between lands for food and energy production.

1b) How does growing double-crops affect the status of available N and total C in the soil?

Hypothesis: Bioenergy double cropping system would ensure ground cover for all the year round that would ensure higher ecosystem services from the cropping system such as less leaching loss of mineral N and more C input in the system.

2) What are the economic, environmental, social and governmental factors that influence farmers' decisions on choosing different cropping system?

Hypothesis: Conservative behavior of farmers in general in Sweden in changing their way of farming might be a hindrance of accepting bioenergy double cropping system.

2. Possible Application of This Study

2.1. Skåne

Skåne is the southernmost part of Sweden well known for its agricultural activities. About 60% of the arable land of Sweden found in southern part of the country. Agriculture in Skåne represents 16% of the total agriculture of Sweden even though the Skåne comprises less than 3% of the total land area of Sweden. In Skåne nearly half the land area was used for production in 2010 (SCB, 2013). It has three types of production sector: animal (28%), crop (39%) and mix animal and crop (33%) (Länsstyrelsen-Skåne, 2015 see Gonzalez, 2015). Skåne has good characteristics in terms of soil and climatic conditions that are favorable to grow variable crops comparing with other parts in Sweden. It is located near markets and export bindings. High labor dynamics are also found here (Gonzalez, 2015).

Crop production in Skåne is mainly dominated by cereal production. Wheat, Barley, Sugar beet, Oil seed rape, Potato, Rye, Corn, Field beans and Peas are the major crop in Skåne. In terms of area Rye is the 5th largest crop. In 2014 the total area under cultivation was 444,413 ha where Rye was cultivated in 13,397 ha of land (Länsstyrelsen-Skåne, 2015).

Conventional farmers in Skåne generally follow four year crop rotation. Sugar beet, barley, oil seed rape or canola and winter wheat are grown sequentially. Winter wheat can be replaced by rye. Rye grown for human consumption is harvested middle of August whereas rye grown for biomass feedstock for bioenergy production harvested in end of June. Organic farmers generally follow 6-8 years crop rotation that might vary a lot. Same crops as conventional farmers also grown by organic farmers additionally they also grow vegetables (carrot, onion, potato), beans and oats depending the type of the soil they have (Gonzalez, 2015; oral source from Svensson, 2016; interview data collected for this study).

Due to the climate change effect the risk of coastal erosion is high in Skåne. It is also one of the most risky areas under the threat of storms and thunder (Swedish Commission on Climate and Vulnerability, 2007). In Sweden wind erosion on arable land in also high in Skåne. When soil is unprotected and is not covered by any vegetation or crop residues the wind erosion is maximum. Thus agricultural activities, climate and crop development determine the rate of wind erosion. In Skåne depending on the type of crop rotation wind erosion is acute in spring when the soil is dry and land is prepared for planting next season’s crop (Bärring *et al.*, 2003). Depending on the outcome of our study there are two possibilities for practical applicability of the proposed cropping system in Skåne:

1. The proposed cropping system could be adopted by the farmers who are already been cultivating rye as bioenergy crop.
2. Farmers who are intending to grow rye as bioenergy crop could integrate rye in their 5th year of crop rotation -

Sugar beet 1st year	Barley 2nd year	Oil seed rape/ Canola 3rd year	Winter wheat 4th year	Rye bioenergy double cropping system 5th year

Figure 2. Integrating rye bioenergy double cropping system in the 5th year of general crop rotation in southern Sweden

2.2. Ecological Focus Area (EFA)

EFA is one of the three greening rules of Common Agriculture Policy (CAP) reform 2014. CAP is agricultural policies of European Union established in 1962 with the aim of improving agricultural productivity. It helps farmers to face challenges in their agriculture production system by providing political framework. It is a very important driving force in agricultural development in Europe. The CAP is funded from the EU (European Commission (EC) budget which accounts around 40% of total EU budgetary expenditure. CAP is based on a two-pillar structure – Pillar 1 and Pillar 2. Pillar 1 consists of direct payments for the farmers and market management measures. Pillar 2 mainly focused on improving the structural and environmental performance of agriculture that includes promoting local/rural development (Cantore *et al.*, 2011). In 1995 Sweden had joined the CAP. The framework has been reformed in 2014. This new reform includes a new element for Pillar 1, the Green Direct Payment. Three compulsory direct green actions under pillar 1 are a) maintenance of permanent grassland, b) the 5% ecological focus areas and c) crop diversification (European Commission, 2013). To claim the direct payment, farmers have more than 15 hectares of arable land must need to have ‘Ecological Focus Areas (EFA)’ on their arable land which might be increase by 7% by 2017. EFA should be in the form of fallow land, filed margins, hedge and trees, buffer strips or by growing cover crop/catch crop or nitrogen fixing crop for example field bean, pea or soybean.

There are many critic of EFA of not being practical enough. In practice framers might use their areas that have been considered unable for single payment therefore no environmental benefit would be achieved. It is possible for the pea farmers to sell their entire area of peas as EFA and make money without achieving any environmental benefits (King, 2014). Furthermore, a very recent paper has concluded that no environmental benefits would be achieved through greening measure and it could exert disrupting impact on nature. The reform will allow a 5% loss in grassland which is Europe's most endangered habitat. The Secretary-General of the EU farm union, Copa-Cogeca, Pekka Pesonen, thinks "it makes no sense to take land out of production when food demand is on the rise, and estimated to increase by 60% by 2050” (Harrabin, 2014).

Depending on the outcome of our study our proposed cropping system could be adopted in the EFA during summer. Thus in addition to the environmental benefits (less leaching loss of N and higher annual input of C) higher crop production could be achieved.

3. Theories and Concepts

3.1. Agroecology

There is more than one definition of agroecology. Altieri and Nicholls (2005) defined agroecology as "application of ecological concepts and principles to the design and management of sustainable agroecosystems". Their idea of agroecology was to develop agroecosystems with the minimum external input (high agrochemical and energy) and take advantage of ecological interactions and synergisms between biological components to support soil fertility, productivity and plant protection. According to Gliessman (2007) agroecology is "the science of applying ecological concepts and principles to the design and management of sustainable food systems". Mendez *et al.* (2012) discussed in the early stage of agroecology it was mainly focusing on applying ecological principles to the design of sustainable agricultural systems. According to Wezel *et al.* (2009) initially agroecology was dealing with mainly with production and protection. Agroecology was mainly used as natural science oriented framework to develop scientific research grounded in the western tradition. However, agriculture is a complex socio-ecological system. For better understanding of complexity of agriculture evolving from different sociocultural situation concept and methods from social science must be integrated more explicitly in the study of agroecology (Mendez *et al.*, 2012). At present there are broader definitions of agroecology. Francis (2003) defined agroecology as "integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions". At present agroecology is dealing with environmental, social, economic, ethical and development issues (Wezel *et al.*, 2009). Dalgaard *et al.* (2003) defined agroecology as "integrative studies within agronomy, ecology, sociology and economics". Ruiz-Rosado (2006) explained "agroecology considers the ecological, social or economic principles making them available to modern agriculture". According to Wezel *et al.* (2009) agroecology is the "study of food production systems, processing and marketing, economic and political decisions, and consumer habits in society". Agroecology has special focus on farmer's perspective, traditional knowledge and smallholder farms. According to Holt-Giménezn and Altieri (2013) traditional knowledge is cultural and ecological basis of agroecology. It is rooted in smallholder system. It is also seen as a barrier of Green Revolution technologies. In 1970s when smallholder farmers had been negatively affected by the practice of green revolution methods many farmers had decided to practice agroecology. To define agroecology Ruiz-Rosado (2006) explained depending on social production relationship farmers' production of food and agricultural products can improve or deteriorate the natural resources. Furthermore, farmer's activities are confined by the market prices and public demands Ruiz-Rosado (2006). Mendez *et al.* (2012) argues agroecologists need to move beyond the farm-scale to consider the bigger force for example market and government institutions—that undermine farmers' cultural practices, economic self-sufficiency, and the ecological resource base.

All the above mentioned definition I have used to develop my understanding of agroecology. For me agroecology is a complete study of social, economic and environmental constraints of food system that try to seek solutions based on ecological principles while giving value farmers' perspective and knowledge. I see agroecology as a vital approach to deal with our food system. **In my study I have used the concept agroecology to get a wider view of cropping system and as an extensive guideline to consider important factors such as market, economy, government institutions and farmers' view point that are related with designing of a cropping system.**

3.2. Multifunctional Agriculture and Ecosystem Services

Modern agriculture has simplified structure of agriculture and ecosystem by replacing nature's diversity with a small number of cultivated plants and domesticated animals (Altieri & Nicholls, 2000). Though the production is high in conventional agriculture system but it has many adverse internal effects for example loss of soil nutrient, loss of biodiversity, and change in land use system etc. External effects for example exporting heavily subsidized food products to less subsidized food producing countries are more acute and negative (Wolfe, 2004). Overemphasis of increasing production through inappropriate physical, chemical and biological manipulation has made the modern agriculture unsustainable (Hill, 1998).

The concept of multifunctional agriculture has been introduction in the1990s. Van Huylenbroeck *et al.* (2007) argued that by using the principle of multifunctionality productive and non-productive functions can be united in agriculture. Along with food production society increasingly expect agriculture to provide environmental and landscape services, water management, social care and integration. Multifunctionality claimed to be the new model to that can unite post-modern agriculture and new societal demands. Van Huylenbroeck *et al.* (2007) conceptualize multifunctional agriculture as performing four functions: (1) green functions consist of environmental and ecosystem services for example wildlife management, maintenance of biodiversity, nutrient recycling, carbon sink; (2) blue functions consists of water management, improvement of water quality, ground water purification, flood control; (3) yellow services includes role of farming for rural cohesion and vitality, exploiting cultural and historical heritages, agro-tourism, and agro-entertainment (4) white functions includes food security and food safety.

There is a link between multifunctional agriculture and the concept of ecosystem services (Porter, 2009). The link is a multifunctional agriculture ensure ecosystem services. The UN Millennium Ecosystem Assessment report has described Ecosystem services as the benefits people obtain from ecosystems. The services are divided into four groups: provisioning, regulating, cultural and supporting. Supporting services is the basis of all the services which is needed for producing and maintaining to maintain all other ecosystem services. Provisioning services include providing food, fiber, biomass; regulation services includes climate, water, disease regulation; cultural service includes providing esthetic and recreation benefits; supporting services includes nutrient cycling, soil formation, primary production (Millennium Ecosystem Assessment, 2005). These ecosystem services can be further divided into market and non-market ecosystem services. Services that are not subjected to market trades are non-market services. The provision ecosystem services come under the category of market ecosystem services whereas non-provision ecosystem services come under the category of non-market ecosystem services (Porter *et al.,* 2009, Filyushkina, 2016). According to Porter *et al.* (2009) value of non-market ecosystem services represent 50-70% of an agroecosystem's total value. European subsidies payment is low to consider it. Therefor subsidy system should consider non-market ecosystem services for its environmental benefits. Furthermore he stated that agroecosystem should be designed keeping non-market ecosystem services in mind. Ecosystem services provide specific guideline how an agroecosystem should be designed and multifunctional agriculture go beyond ecosystem services and consider food security for example making local food available. **In this study the concept multifunctional agriculture used as a guideline to design cropping system that would provide both market and non-market ecosystem services such as grain and crop biomass for food, feed, energy and N regulation and C cycling in the soil.**

3.3. Interdisciplinary Approach

The agricultural system is an open system, interacting with nature and with societies. In the study of agroecology we must look beyond only focusing at energy and material flow of the production system, short term effect of agricultural practice on the environment and on the annual profit of the organization. Environmental consequences of the system on plant and animal, economics of the farm at national and global level and social and health impact of the system on people must be considered (Francis *et al.,* 2003). Agroecology is seen as a discipline that integrates different disciplines where natural science can be used to design the agriculture based on ecological principles whereas social science methods can be used to help us to understand the system by integrating human perspective (Francis *et al.,* 2003, p. 9). According to Ruiz-Rosado (2006) theoretical or methodological components and scientific tools of agroecology have been derived from and complemented by diverse disciplines. Wezel *et al.* (2009) stated study of agroecology requires multi-scale approaches and methods, to include the study of food production systems, processing and marketing, economic and political decisions, and consumer habits in society. According to Buttel (2007) agroecology is an interdiscipline that includes the social and human sciences as well as the ecological and agricultural sciences. Dalgaard *et al.* (2003) mentioned interdisciplinarity is one of the main issues that agroecology has to dealt with. Integrating concepts, methods, and principles from different disciplines is the fundamental characteristic of interdisciplinary research (Lawrence, 2010). Some scientists also describe agroecology as transdisciplinary study (Ruiz-Rosado, 2006; Wezel *et al.,* 2009; Mendes *et al.*, 2012). According to Mendes *et al.* (2012) transdisciplinary approaches value and integrate different types of knowledge systems for example scientific, academic, experiential, local and indigenous. According to Ruiz-Rosado (2006) considering agroecology as a transdiscipline can contribute to the long term sustainability of agroecosystems. Though the concept of interdisciplinarity and transdisciplinary are different however the concepts are complementary rather than mutually exclusive (Lawrence, 2010**). In this study setting of the experiment was more suitable for interdisciplinary approach.** Therefore, in this study interdisciplinary approach had been used by integrating methods and principles from different disciplines.

3.4. Sustainability Assessment of Food and Agriculture systems (SAFA)

In 2009, The FAO and the ISEAL Alliance undertook an initiative to develop common understanding and practical definition of sustainability. There were already been many tools, policies and initiatives assess sustainability but most of them were intended to assess one or few aspect of sustainability rather than address sustainability holistically (Guttenstein *et al.*, 2010). For example LCA (life cycle assessment) sustainability assessment tool qualitatively address many environmental aspects however it ignores the impact of assessed entities on biodiversity and soil and (Schader *et al.*, 2016). Therefore, to provide a common understanding of sustainability 'Conceptual Framework for Sustainability' had been developed (Guttenstein *et al.*, 2010). Later the framework had been developed more over time by FAO and named as SAFA (Sustainability Assessment of Food and Agriculture systems) (SAFA guideline, 2012).

SAFA outlines essential element of sustainability based on international reference documents and conventions (SAFA guideline, 2014, p. v). SAFA is a quite extensive sustainability assessment tools in global supply chain and thus can be adopted in different contexts and scope. SAFA is seen as a holistic framework that assess sustainability taken into consideration all four dimension of sustainability; good-governance, environmental integrity, economic resilience and social well-being (SAFA guideline, 2014, p. 2). There are total 21 themes, 58 sub-themes and 108 indicators in SAFA. The themes had been described briefly in the result part of this study.

SAFA had been constructed targeting mainly to be used by the farmers, companies, NGOs, Government, investors and policy makers to assess supply chains and the evaluation of enterprise(s) in those supply chains (SAFA guideline, 2014, p. 7). Thus, SAFA as a tool is not suitable to assess sustainability of a cropping system. However, it is a complete tool for assessing sustainability. **Therefore, in my study I have used SAFA as a concept to identify important factors for discussing sustainability of a cropping system.**

4. Materials and Methods

In this experiment mixed method had been used. A mixed method is an approach that combines both quantitative and qualitative approach (Creswell, 2009). Quantitative research is a means for testing theories by investigating the relationship among variables (Creswell, 2009, p. 4). Results produced from quantitative methods can be expressed in numbers and can be evaluated and explained by statistics (Taylor, 2005, p. 91). Purpose of qualitative methods is to understand different realities and describe different point of view (Taylor, 2005, p. 107). It is way to explore and understand how an individual person or group of people ascribes a social or human problem (Creswell, 2009, p. 4).

At first a literature search was conducted to collect preliminary data to assess sustainability of double cropping system using SAFA as a concept. Then quantitative methods had been used to determine to yield of grain and crop residues, correlation between grain and crop biomass, correlation between crop biomass and weed, protein content in grain, protein content in straw, C/N ratio in straw, annual C input in the soil and amount of mineral nitrogen in soil.

Qualitative methods had been used to explore and understand what might affect farmers' adoption of bioenergy double cropping system through semi-structured interviews.

4.1. SAFA

In my study SAFA had been used as a concept to assess sustainability of double cropping (DC) system since it is not meant to be used as a tool to assess sustainability of a cropping system. Therefore, in my study it is used as a concept.

Sustainability assessment of DC system has been done through literature review because in my field experiment I did not investigate all the factors that are necessary for assessing sustainability for example biodiversity, soil physical structure etc. To assess the sustainability, I took a simplistic approach by looking upon subthemes of SAFA (indicators if needed). For time limitation review of literature was not contextualized and literature of the experiments conducted all over the world had been used therefore results can greatly vary depending on the country/region, climate, soil, choice of the crops/varieties, cultivation system (conventional/organic, irrigated/non-irrigated, tillage/non- tillage) and so on. Sustainability assessment had done based on one main question: how DC system affects environmental integrity, economic resilience and social well-being compare to single cropping system. Good governance dimension has not been considered since a cropping system itself cannot affect farmers' decision making process. A brief description of dimensions good governance, environmental integrity, economic resilience and social well-being from the SAFA guidebook (FAO, 2014) has been presented below.

1. Governance refers to decision making process of the authority and implementing decision by the authority in an organization or in a value chain. Commitments of stakeholders in an organization or in a value chain to attain sustainability are considered in this dimension.
2. Environmental integrity refers to maintaining life support systems that are essential for human survival (i.e. atmosphere, air, water, biodiversity) by reducing negative impact on the environment resulting from human activities. It gives a complete view of environmental sustainability through life cycle approach.
3. In a world of economic instability FAO considered that economic resilience is more important than economic growth. Economic resilience refers to maintaining a positive cash flow, cope with economic changes and shocks in the enterprise.
4. Social sustainability is about satisfying basic human need and peoples' right to satisfy their desire for a better life without compromising the ability of others and future generations to meet their needs.

4.2. Design of The Cropping System

Eleven crops had been selected as second crops[4] for this experiment to investigate their grain yield and production of crop residues[5] after rye[6]. The crops are: fodder pea (*Pisum sativum* L), blue lupin (*Lupinus angustifolius* L), blood clover (*Trifolium pratense* L), red clover (*Trifolium pratense* L), soybean (*Glycine max* [L.] Merr.), black bean (*Phaseolus vulgaris* L), lentil (*Lens culinaris*), green pea (*Pisum sativum* L), buckwheat (*Fagopyrum esculentum* Moench), hemp (*Cannabis sativa*) and sudangrass (*Sorghum sudanense*). However only five crops were able to be harvested successfully. The crops are: blue lupin, soybean, black bean, lentils and buckwheat. Therefore, in this study results of these five crops had been presented and discussed.

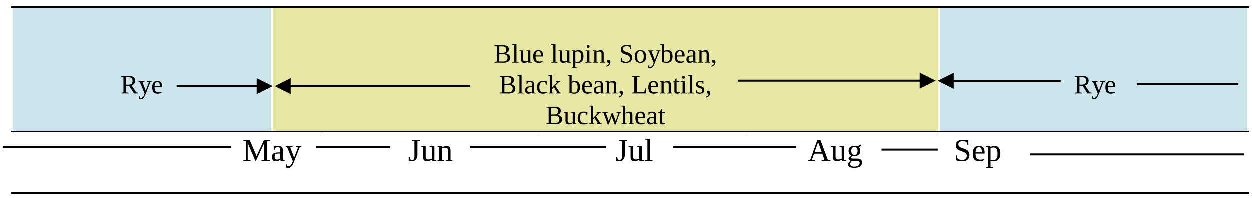

Figure 3. A timeline of bioenergy double cropping system

[4] In this experiment the energy crop (rye) is called as first crop and the addition crops are called as second crop.
[5] In this experiment crop biomass after harvesting the grain is called as crop residues.
[6] Rye was grown for energy production and as first crop. The rye had been harvested earlier than the general harvest time of rye for grain production

4.4. Nature of The Selected Double Crops

According to Jensen *et al.* (2010) development of a successful cropping system depends on the understanding of how new crop responds to biological, chemical, physical, and climatic environment. Therefore, the nature (biological, chemical, physical, and climatic environment) of the Blue lupin, soybean, black bean, lentils, buckwheat mentioned briefly. This information will be used again for discussing the production of these crops.

Blue lupin

Blue lupin (*Lupinus angustifolius* L.) also called narrow-leafed lupin. It belongs to the family leguminoceae. Blue lupin is well adapted in low temperature condition and have high water requirement. Light requirement is also high. Most lupin species can grow in wide range of soil type and fertility condition. They can grow well in sandy soil with good drainage facilities or sandy loam soil with acid to neutral pH (Todorov *et al.*, 1996). Suitable altitude of lupin ranged between 1800 to 2600 masl (meter above sea level) and the total annual rainfall ranges from 1100 to 2300 mm (Yeheyis *et al.*, 2012).

Soybean

Soybean (*Glycine max* [L.] Merr.) belongs to the family leguminosae is one of the most important oil seed crops in the world. Climatic condition in Europe is not very suitable for growing Soybean. In Europe it can be mainly grown in summer. Optimum temperature for growing Soybean is between 25-32°C. It required rainfall of 400-800 mm (Nwokolo, 1996). Though Soybeans can grow in a wide range of soils but moist alluvial soils with a good organic content is favorable for soybean cultivation (Rudelsheim and Smets, 2012). Ukraine, Italy, Romania, Serbia, Croatia and France are soybean producing countries in Europe (Singh, 2010). Soybean is recommended to grow in 3-6 years rotation with maize, winter wheat, spring cereals, sunflower, dry beans, and forage crops. It is recommended not to grow soybean after soybean, sunflower or oilseed rape because common diseases problem (Rudelsheim and Smets, 2012).

Black bean

Black bean also known as black turtle bean which is a variety of common bean (*Phaseolus vulgaris* L). Beans sensitive to cold soils. Soil temperature more than 18ºC is needed for germination. Optimal temperature for plant growth is 20-24ºC (Beebe *et al.*, 2008). Below 20ºC temperature reduced the crop growth. Grain yield increases with increasing plant population. However, after plant density of 139 plants/m^2 no further increase occurred. Ratio of NH_4 and NO_3 is important. Ratio should be equal or amount of NO_3 should be higher than NH_4 (Chandhla, 2005). The recommended crop rotation for bean is 3-5 years preferably with cereals. Potato, corn, winter wheat and cereals are recommended crops for crop rotation with beans (Goodwin, 2003).

Lentil

Lentil (*Lens culinaris*) is the most ancient cultivated crops among the legumes and since then it has made a significant contribution to human diet (Adsule, 1996; Cokkizgin and Shtaya, 2013). Temperature, distribution and quantity of rainfall are the main determinants of lentil production. Lentil is adapted to cool growing conditions. In Europe where winter is too cold lentil is mainly grown in spring and summer (Erskine, 2009). Late sowing will decrease yield and increase protein content (Cokkizgin, 2013). Comparatively lighter soil is important for lentil production than other vegetables (interview data). Rainfall distribution significantly affects performance of lentil (Sharaan *et al.*, 2003).

Buckwheat

Buckwheat (*Fagropyrum esculentum* Moench) is a summer annual crop belongs to the Polygonaceae family. Buckwheat grows best in a cool and moist climate. The ideal growing temperature is about 21°C (Björkman, 2009). Buckwheat is not a frost tolerant plant. It grows best in light to medium textured well-drained sandy loams, loams, and silt loams. It is better adapted to low-fertile soils than most other crops. Northern European climate is very suitable for growing buckwheat. China, Russia and Ukraine are the top producers of buckwheat in the world are (Matz, 1991; Clark, 2007; Popović *et al.*, 2014). Buckwheat is recommended to grow at the same at least 3 years interval to avoid disease problem (Lazanyi & Laszlo, 2009).

4.5. Description of The Site

The experiment was carried out at Dybäck, Skåna Sweden in 2015. Dybäck comes under Skurup municipality. It is situated in the latitude of 55.4406, longitude of 13.4796, 55° 28′ 42″ north and 13° 30′ 7″ east. In Dybäck average temperature and rainfall in June, July, August and September were 13.2ºC, 16.1ºC, 17.8ºC, 13.7ºC and 47.4 mm, 57.4 mm, 43.4 mm, 71.0 mm respectively. Highest rainfall occurred in the month of November (104.9 mm) whereas lowest rainfall occurred in the month of October (27.6 mm). Total annual rainfall was 615 mm (SMHI, 2016). Precipitation and average temperature in summer were measured at Jordberga meteorological station whereas precipitation of October, November and total annual rainfall were collected from SMHI weather website for Skurup municipality.

The soil type at the study site is sandy typical of the region. The experiment was arranged as randomized complete block design with four replications. Each plot was 9 m long and 2 m wide. Rye was harvested at the mid-May. 130 kg/ha was applied for rye cultivation and yield was 13.3 t/ha. Seed densities of the double crops were 190kg/ha for blue lupin, 130kg/ha for soybean, 80kg/ha for black bean, 110kg/ha for lentil and 60 kg/ha for buckwheat. There were no fertilization, irrigation and plant protection for the second crops. Among the legumes, soybean and blue lupin were inoculated for this experiment.

4.7. Observation and Data Collection

4.7.1. Plant sampling

Above ground plant biomass was collected at full maturity stage (9th of October, 2015). Plant samples were collected from each experimental unit by using 0.5m×0.5m metal rectangular frame. All plant material inside the metal frame was cut manually above five centimeters from the ground level. Both crop and weed plants have been collected in big fabric bags. All the bags were clearly labelled with date, year, plot number and treatment number. Plant samples were transported to ovens for drying as soon as possible after collection. Plant materials were dried at 60°C for 48 hours in an air-circulating oven. The dry weights of the samples were recorded to determine total biomass of the plant material. Later weeds were separated from the crop plants and biomass for crop and weed plants were recorded separately for each treatment.

4.7.2. Determination of protein percentage in grain and straw

The dried crop samples were ground in milling machine (Foss Cyclotech 1093). The ground plant material was further homogenized using a mixer mill. About 5 mg of each plant samples and 3 mg of each grain samples were placed in tin capsules for analysis of total nitrogen concentration and C and N ratio. Total nitrogen concentration and C/N ratio were determined by Thermo Scientific FLASH 2000 NC Analyzer. The Thermo Scientific FLASH 2000 is based on the process called Flash Dynamic Combustion. In this method complete combustion of the samples occurred which is followed by accurate determination of the elemental gases produced. Total amount of protein was estimated by multiplying the values of total nitrogen with conversion factor. Conversion factors for blue lupin, soybean, black bean and lentil was 5.4 and for buckwheat was 5.24 (Mariotti *et al.*, 2008).

4.7.3. Determination of biomass

The total biomass yields were calculated by adding oven biomass yield of crop and weed. The total biomass production expressed in kg per ha was calculated as:

Tons per hectare= Measured value in gram per 0.25 m^2 area (x)/25

4.7.5. Determination of mean annual C input in the soil

Below ground plants biomass adds 2.3 higher C in to the stable C pool of soil (Kätterer *et al.*, 2011). Therefore, determination of below ground biomass is very important for determining mean annual C input in the soil every year. In this experiment only above ground biomass was harvested therefore, below ground biomass was estimated by using yield of above ground biomass. Below ground/above ground (B/A) ratios for Blue lupin, Soybean, Black bean, Lentil and Buckwheat used in this estimation were 0.40, 0.19, 0.19, 0.19 and 0.22 respectively (IPCC, 2006).

Below ground biomass yield = B/A ratio x above ground biomass yield

There was no separate B/A ratio for buckwheat therefore B/A ratio of cereals has been used for buckwheat (IPCC, 2006).

Total C input in the soil was calculated by multiplying biomass with humification coefficient (h) and carbon content of biomass. Humification coefficient is the fraction of organic C that converted into stable soil organic matter. For above ground biomass h is 12% and for below ground biomass h is 35% (Kätterer *et al.*, 2011).

C added to stable C pool by above ground biomass = Above ground yield x h x C content in the plant

C added to stable C pool by below ground biomass = Below ground yield x h x C content in the plant

Total C input to stable C pool = C added to stable C pool by above ground biomass + C added to stable C pool by below ground biomass

4.7.6. Soil sampling

Soil sampling had been done early winter (2nd of December, 2015). At that time only the crop residues were present in the field. Soil sampling up to 60 cm is considered important for determination soil mineral nitrogen (Knight, 2006). Therefore, to study the risk of nitrogen leaching soil sampling was carried out from the depth of 0-30 cm and 30-60 cm. The samples were packed in plastic bags and stored at below -18°C.

4.7.7. Determination of NO_3 and NH_4 in soil

There is already a standard procedure for analyzing available soil nitrogen. The procedure consists of extraction with KCl, filtration of the extract, analysis by colorimetry, and conversion of nitrate and ammonium ppm to kg/ha based on bulk density of the soil. The most common extractant for NO_3 and NH_4 is 2.0 M KCI (Knight, 2006).

NO_3 and NH_4 were extracted from 12 samples at a time. Samples were thawed and mixed well by destroying the bigger lumps with a wooden hammer. About 10 g soil samples was extracted with 2M 100 ml KCl in a plastic flask. Second sub samples of 50 g soil weighted in aluminum can and kept in an oven at 105°C temperature for overnight. Plastic flask containing soil and 2M 100 ml KCl were put in a shaker for 45-60 minutes. After 45-60 minutes the tubes were taken out form the shaker and let them stand for 10 minutes for precipitation. About 10 ml supernatant from the plastic tubes were poured carefully in 14 ml PS tubes. The tubes were centrifuged at 4000 rpm for 5 minutes. Clean solvents were poured in a new 14 ml PS flask. The PS flasks were kept in the fridge with a lid on for NO_3 and NH_4 determination in autoanalyzer. Autoanalyzer colorimetrically quantitated NO_3 at 520 nm and NH_4 at 660 nm. The solution was analyzed within 14 days from prepared. Soil N is calculated by using bulk density 1.2 kg per dm^3.

4.8. Semi-structured Interview

Semi-structured interviews were chosen for their flexibility. It is an effective method to get an idea the depth of understanding of interviewee about a particular issue, their attitude towards the issue and how they perceive the social environment (Bryman, 2012). In semi-structure interview interviewers control the interview and decide the type of information would be produced by the interviewee. Both qualitative and quantitative data can be produced depending on the structure of the questions (Bernard, 2011, pp.158, 227).

To estimate the possible implication of the research outcome among farming communities 5 semi-structure interviews had been performed. Depending on the result this designed cropping system could be adopted by the farmers growing rye as energy crop. However, for time limitation farmers growing rye for biomass feedstock for bioenergy production could not be interviewed. Five farmers from southern Sweden had been selected for interviews on the basis of their willingness to contribute their time and share their information and knowledge for this study. The interviews were conducted during the month of March and April, 2016.

The main aim of semi-structure interview was to investigate what are the possible motives and constraints that might affect farmers to adopt double cropping system. Questions were mainly asked to investigate factors[7] for example governmental, environmental, economic and social that are affecting farmers in their selection of current/future crops and cropping system. The questions were mainly open-ended questions are presented in appendix 1. All the interviews were done in English. Each interview lasted around 1 hour. Before the interview all the participants were informed about the objectives of the study.

4.9. Data Analysis

4.9.1. Statistical analysis

Compilation of the data, calculation of mean and standard deviation had been done in Excel. Analysis of variance (ANOVA) was used for the statistical evaluation of differences in mean values between different treatments. This was done in Minitab 16 statistical software, by using the function general linear model. Grouping of information had been done by using Tukey's method and 95.0% confidence for different NO_3, NH_4 and N-min.

4.9.2. Interview data analysis

Data were analyzed using Framework analysis. Interview data were summarized, managed and presented step by step in the stages of familiarization, identifying a thematic framework, indexing, charting, mapping and interpretatio*n*. These stages are considered to be interconnected. To get familiar of the information from interviewees transcriptions were read carefully several times to get a general "*sense*" of information and reflection on its meaning (Creswell, 2009). In the second stage, concept developed from the information need to be categorized. Managing, sorting out of data and comparison within and between the interviews have been done in indexing and charting. To see the relationship and make link between data as a whole have been done in interpretation stage (Rabiee, 2004).

[7] Factors are 4 dimensions of SAFA: governance, environment, economy and society.

5. Results

5.1. Review of Literature Based on SAFA

To analyze sustainability of Bioenergy Double Cropping (BDC) system a summary of scientific literatures mainly on Double Cropping (DC) system has been presented. A review of literature had been collected on DC system instead of BDC since not many studies had been done before on BDC system. All the information about SAFA had been taken from the SAFA Guideline, version 3 (FAO 2013) and SAFA indicators, version 3 (FAO 2013b). Different parameters had been compared in conventional DC system and conventional single cropping (SC) system. Important factors for discussing sustainability of a cropping system selected mainly from the subtheme of SAFA (indicators if needed). The factors are GHG, water withdrawal, water quality, soil quality, species diversity, genetic diversity, use of fertilizer, net income and production (table 1). These factors had been chosen on the basis of availability of literature review. Some other factors that could be relevant for this study for example presence of air pollutant and use of energy however, literature could not been found on these factors. A list of theme and sub-themes of environmental integrity, economic resilience and social well-being dimensions have presented in the appendix.

Table 1. *A summary of using of SAFA as a concept for assembling literatures in the perspective of DC system (here DC means double cropping and SC means single cropping).*

Dimension	**Theme**	**Sub-theme**	**Use of sub-themes in the perspective of DC system**
Good governance			
Environmental integrity	Atmosphere	GHG	Quantity of GHG produced in DC and SC system
	Water	Water withdrawal water quality	Amount of water withdraw and impact on water quality in DC and SC system.
	Land	Soil quality (soil physical structure and soil organic matter-default indicators)	Impact on soil physical structure and organic matter in DC and SC system
	Biodiversity	Species diversity Genetic diversity	Effect of DC and SC system on genetic and species diversity
	Materials and energy use	Material use	Amount of material (i.e. fertilizer) in DC and SC system
Economic resilience	Investment	Profitability (net income -default indicator)	Net income from DC and SC system
	Vulnerability	Stability of production	Crop production in DC and SC system
Social well-being			

5.1.1. Good Governance

Governance is decision making process and implementing decision in an organization or in a value chain. Good governance dimension has not been considered for this review of literature since a cropping system cannot affect farmers' decision making process. However farmers' decision making process or implementing decision can affect sustainability of a cropping system (Craheix *et al.*, 2012). To achieve socially desirable sustainability goals, it is important that the sustainability assessment process would reflect need and value of decision-makers in agriculture from which the action might arise. To achieve this sustainability should be seen as process rather than an endpoint of assessment (Moeller *et al.*, 2013).

5.1.2. Environmental Integrity

Environmental integrity refers to maintaining life support system of essential for human survival (i.e. atmosphere, air, water, biodiversity) by reducing negative impact on the environment. Apparently wheat-corn or wheat-maize is the most studied double cropping system (and most available literature on internet) for measuring different environmental factors. Therefore, most of the information presented here is based on corn-wheat double cropping system. Results might greatly vary depending on the choice of the crops. Themes are presented below:

<u>Atmosphere</u>

Atmosphere in SAFA discuss about maintenance of clear air. Two sub-themes are 1) GHG, and 2) air quality. Mostly studies have been done on the GHG emission from DC system whereas literatures on the presence of air pollutant (i.e. pollen, bacteria, fungi, SO_2, NO_X, volatile organic compound) surrounding the cropping system could not been found.

Nitrous oxide (N_2O) is a major GHG and the most powerful ozone-depleting compound. N_2O depends on several factors for example season, rainfall, type of the soil, type of the crop, use of fertilizer and tillage (Senbayram *et al.*, 2014). Anthropogenic source of N_2O emission for example type and amount of fertilizer use is could be higher in conventional DC system comparing with conventional SC system. For example, Qin *et al.* (2012) measured yield scale N_2O emission in winter wheat-summer corn DC system. The result indicated that annual N_2O emissions increased with the increase of rate of fertilizer. N_2O emission was 8.0 g N_2O/kg of N when N application rate was 136 kg N/ha/yr. Therefore, in conventional system depending on the use of fertilizer in DC system the rate of N_2O emission could be higher.

<u>Water</u>

Maintaining the cycle of natural water and preserving water resources are main purposed of theme Water. Two sub-themes are withdrawal of water and water quality.

Water requirement is higher in double cropping system. In wheat-maize DC system for wheat, water demand ranges from 358 to 550 mm/year. For maize, it ranges from 440 to 585 mm/year. For the two crops, the total water demand is in the range of 800–1100 mm/year (Wang *et al.*, 2008).

Reduction in water quality mainly due to the leaching loss of N is higher in absence of crops and high soil temperature and moisture content that elicits mineralization of N. N leaching is supposed to be lower in organic crop production system than conventional system. However the argument is not true all the time. Inorganic N is often released from organic sources during periods when there is no crop uptake of N that makes organic N is more vulnerable to leaching than inorganic fertilizer (Kirchmann *et al.*, 2016). Depending on the nutrient use efficiency of the crops more ground cover could be beneficial to reduce leaching loss of N.

Land

Maintaining and preserving soil resources are main purposes of theme Land. Two sub-themes are soil quality and land degradation. To assess sustainability of DC system effect of DC system on soil quality (i.e. soil organic matter and physical structure).

DC can reduce soil exposure between two harvest season thus it can help to protect the soil from wind and water (Borchers *et al.*, 2014). Concentration of soil organic carbon in the 0-5 cm layer increased by 18% with single crop corn and 26% with double crop rye-corn in a 3 years experiment. At 0-5 cm depth average soil organic matter for corn was 23.83 g/kg and for corn-rye was 24.3 g/kg (Krueger *et al.*, 2012). Comparing with single crop system double-cropping system exhibited superior soil structure with up to 57% better visual soil structure scores (Liesch *et al.*, 2011). In single crop system lands are kept bare therefore it stores more water in soil profile and thus increase drainage losses of water (Fouli *et al.*, 2012).

Biodiversity

Biodiversity theme refers to protecting all forms of biodiversity in the area under cultivation and to utilize ecosystem services generate by the greater number and species diversity plants animals and microorganism. There are 3 sub-themes: ecosystem diversity, species diversity and genetic diversity. How DC system affects species diversity and genetic diversity in comparison to SC system had been studies here.

In pennycress-corn double cropping system number and species of spider was higher comparing with the commonly used cultivation system in Germany: mustard-corn, green fallow-corn, and bare fallow-corn. Total number and species of spider in pennycress-corn double cropping system was 4442 and 45, respectively. In bare fallow-corn cropping system total number and species of spider was 2060 and 39, respectively (Groeneveld *et al.*, 2015). In pennycress-corn system total number of ground beetle was higher than total number of ground beetle in single crop corn system (Groeneveld & Klein, 2015).

Materials and energy

In theme materials and energy sustainability assessment have been done based on energy efficiency and recycling. Sub-theme included are: material use, energy use and waste reduction and disposal. Intensity of fertilizer use[8] in conventional DC system in comparison to SC system has considered for review of literature.

Fertilizer requirement in DC system is could be higher or lower than SC system depending on the choice of the crops. For example, in a two-year experiment sole-crop corn was fertilized with total 112 kg/ha nitrogen fertilizer and triticale-corn and triticale-sorghum DC system required total 157 kg/ha nitrogen fertilizer whereas triticale-sunn hemp DC system required only 34 kg/ha nitrogen fertilizer. Triticale-corn and triticale-sorghum systems removed 83% more N comparing with single crop corn system. Though the use of phosphate (P) and potassium (K) fertilizers were same in both DC and SC system however it was found in the experiment that triticale-corn and triticale-sorghum DC systems removed 41, and 177% more P and K, respectively comparing with the single crop corn system (Heggenstaller *et al.*, 2008).

Economic resilience

In a world of economic instability FAO considered that economic resilience is more important than economic growth. Maintaining a positive cash flow, cope with economic changes and shocks are important for achieving economic resilience. Sustainability assessment of economic resilience is based on 4 themes, i.e. investment, vulnerability, product quality and information, and local economy.

Investment

In an organization sustainability is assessed on the basis of investment of the organization to sustainable development of the community and to improve overall performance of the organization. Sub-themes are internal investment, community investment, long-ranging investment and profitability. In the context of DC system net income[9] and production[10] in DC system in comparison to SC system had been considered in this study (table 1). Investment and effect of DC on farm income and profitability of farm could be relevant for assessing sustainability of DC system however, no literature have not been found.

Net income

Net income found to be higher in DC system. Study done in 1996 Southeastern Kansas showed net revenue from crop rotation with double crop ranges between $120-185/acre, whereas net income from crop rotation with single crop was between $100-120/acre (Burton *et al.*, 1996).

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[8] Intensity of material use is a performance based indicator. Fertilizer as a material thus comes under sub-theme material use.
[9] Net income is default indicator of profitability.
[10] Stability of production is subtheme of vulnerability. Here production in DC system has been studied.

In rye+hairy vetch-pumkin cropping system $ 2610 /ha can be earned from bioenergy feed stock and value of pumpkin can be ranged $1400 to 1800/ha. Total farmgate value, of bioenergy feed stock and pumpkin could exceed farmgate value of the conventional pumpkin system (Williams, 2014).

Production

Production is higher in DC system than the production of single crop. Total dry matter production in corn-rye and corn-barley double cropping system were about 22.8 t/ha and 19.7 respectively whereas dry matter production of sole crop corn and rye were were 17.1 t/ha and 16.9 t/ha (Fouli *et al.*, 2012). Yield of sole crop maize 17.7 t/ha whereas yield of maize after wheat 14.6 t/ha and yield of wheat was 13.15 t/ha respectively (Senbayram *et al.*, 2014). Total dry matter production by triticale-corn and triticale-sorghum/sudangrass were 22.7 t/ha and 23.0 t/ha whereas total dry matter production for the sole crop corn was 18.2 t/ha (Heggenstaller *et al.*, 2008).

However, there are also experiments that have shown lower yield in double cropping system. Depending on the choice of the crop in DC system total dry matter production can be lower than sole crop. Heggenstaller *et al.* (2008) showed total dry matter production of triticale-sunn hemp was 15.1 t/ha whereas dry matter production for the sole crop corn was 18.2 t/ha. The dry matter yield of Corn was found to be reduced by 15-25% in rye-corn double cropping system comparing with single cropping system of corn. Average dry matter yield of corn in single crop system was 18.3 t/ha. Total dry matter yield in corn-rye double cropping system was 16.7 ton/ha (Krueger *et al.*, 2012).

In organic system the yield is lower comparing with the conventional system. However, organic farming is regarded as environmental friendly and provide more ecosystem services comparing with conventional system (Reganold & Wachter, 2016).

Social well-being

Social sustainability is about satisfying basic human need and peoples' right to satisfy aspiration for a better life without compromising the ability of others and future generation (SAFA Guideline, 2014). There are 6 themes in social well-being dimension, i.e. decent livelihood, fair trading practicing, labor rights, equity, human safety and health, and cultural diversity. Study the effect of double cropping system on social well-being is important especially 1st and 6th theme, i.e. decent livelihood and cultural diversity. Double cropping system could be used to provide a culturally appropriate and nutritionally adequate diet[11]. However, farmers should also have access to the equipment, capital and knowledge of growing double crops (see the objective of sub-theme fair access to means of production).

Right use of double cropping system could also be used to achieve food sovereignty (sub-theme of cultural diversity). It could be possible for the farmers to grow their food suitable in the local climatic condition (see the objective of food sovereignty in SAFA). However, for time limitation and lack of literatures detailed study of these subthemes could not be done in this experiment.

[11] Providing culturally appropriate and nutritionally adequate diet is objective of sub-theme *quality of life.*

5.2. Field Experiment

The main aim of the study was to design a cropping system that can increase overall crop production and able to provide food, feed, energy and non-market ecosystem services (i.e. increase carbon input in the soil and reduce nitrogen leaching). At first grain yield was determined. Main use of the grains is human consumption. Crop residues could be used for animal feed, energy production or for C input in the soil. Protein content in crop residues was determined to investigate use of straw for animal feed, C/N ratio in straw was determined to investigate use of straw for energy production. Annual C input in the soil by the crop residues was determined and at last amount of available Nitrogen in the soil

5.2.1. Grain yield

The highest grain yield per hectare was measured in lentil 1.7 t/ha whereas lowest grain yield was observed in blue lupin (0.5 t/ha). Grain yield in lentil was significantly different (P<0.05) then the grain yield in blue lupin, soybean (0.6 t/ha) and black bean (0.9 t/ha). Grain yield of lentil was significantly similar with the grain yield of buckwheat (1.3 t/ha). Standard deviation (SD) was highest in soybean means yield variations were different in different plots. Lowest SD was observed in buckwheat.

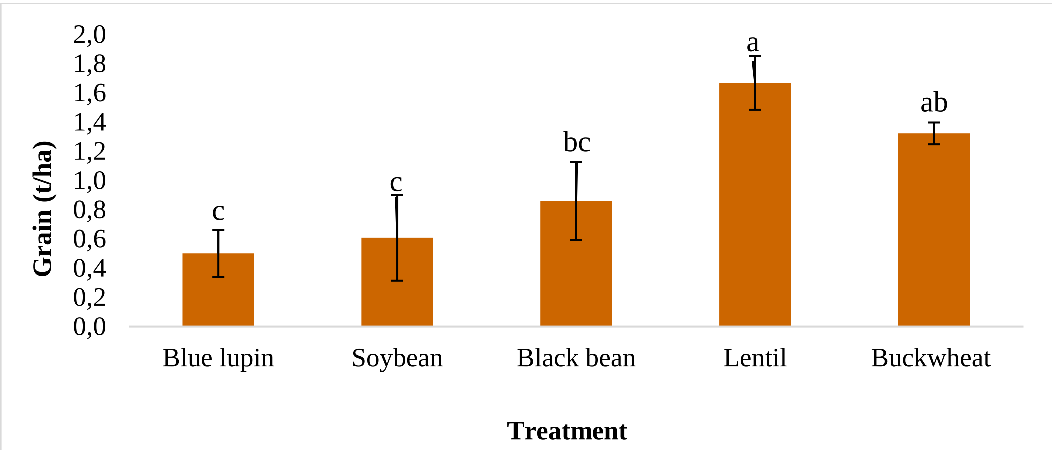

Figure 4. Grain yield measured in above ground whole plant part harvested at full maturity of the crops. Each bar is the mean value of four replicates. Error bar represents standard deviation (SD) calculated from biomass. Letters on the top of the error bar indicates significant different among the mean value of the treatmnets (tukey's, p<0.05, n=4).

5.2.2. Crop residues

The highest crop residues (plant biomass without grain) production was measured in buckwheat (3.2 t/ha) and lowest crop residues production was observed in blue lupin (0.8 t/ha). Crop residues production of buckwheat (3.2 t/ha) was significantly different ($P<0.05$) than the blue lupin (0.8 t/ha), soybean (1.1 t/ha) and black bean (1.1 t/ha). No significant difference ($P>0.05$) was found between lentil (2.1 t/ha) and buckwheat (3.2 t/ha) which is same as grain yield. Highest SD was observed in buckwheat and lowest SD was observed in blue lupin and black bean.

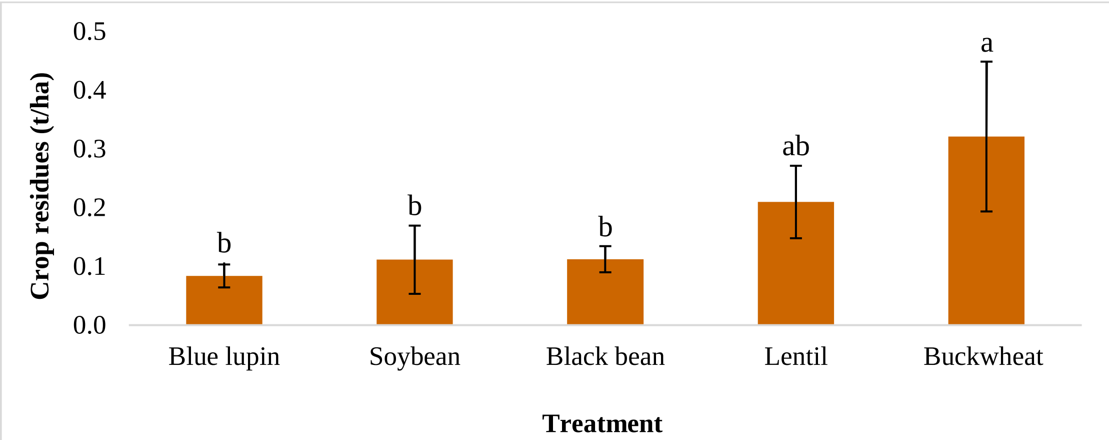

Figure 5. Biomass yield measured in above ground whole plant part harvested at full maturity of the crops. Each bar is the mean value of four replicates. Error bar represents standard deviation (SD) calculated from crop yield. Letters on the top of the error bar indicates significant different among the mean value of the treatmnets (tukey's, $p<0.05$, $n=4$).

5.2.3. Total biomass

Though crop biomass yields of blue lupin, soybean, black bean, lentil and buckwheat were statistically different but no significant difference had been found among the treatments in total biomass (crop + weed). Weed density in blue lupin (2.2 t/ha) was significantly higher ($P<0.05$) than the rest of the treatments. Lowest weed density was found in buckwheat, 0.3 t/ha. Weed densities in soybean, black bean and lentil are around 1.0 t/ha.

Table 2. *Total biomass yield (crop + weed) measured in above ground whole plant part harvested at full maturity of the crops. Mean values were determined from four replicates. Letters in rows indicate significant different among the mean value of the treatmnets (tukey's, $p<0.05$, $n=4$)*

Treatment	Mean value of total biomass (crop + weed) in t/ha	Mean value of weed biomass in t/ha
Blue lupin	3.5 a	2.2 a
Soybean	2.8 a	1.1 b
Black bean	2.9 a	1.0 b
Lentil	4.5 a	0.8 b
Buckwheat	4.8 a	0.3 b

5.2.4. Relation between grain and crop biomass

The relationship of crop biomass (grain + crop residues) and grain yield was determined. The result showed that crop biomass of all the treatments had linear relationship with the shoot biomass. However in buckwheat the regression line is almost vertical, means crop biomass varied in different plots whereas the grain yield almost same.

Regression linear lines were different for each crop. Regression linear line of black bean, blue lupin, buckwheat, lentil and soybean was based on the equation is based on the equation y=-0.57+1.64x with r.sq=0.91, y=-0.34+1.99x with r.sq=0.84, y= -14.78+14.60x with r.sq=0.67, y= -1.02+2.87x with r.sq=0.51, y=0.19+2.51x with r.sq=0.91 respectively.

Here "x" is grain yield (t/ha) and "y" is crop biomass (t/ha).

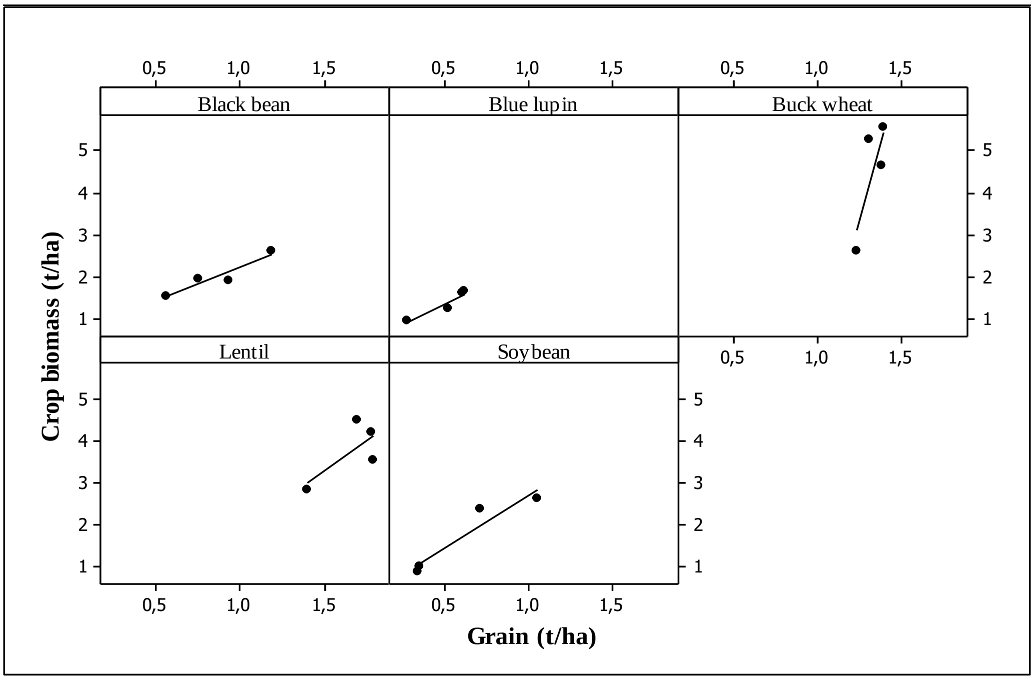

Figure 6. Correlation between crop biomass (t/ha) and grain yield (t/ha).

5.2.5. Relation between weed density and crop biomass

In general the relation between crop biomass (grain + crop residues) and weed density is negative. Higher weed density reduces crop yield. Yield loss varies depending on crop species, environment and associated weed species (Gallandt and Weiner, 2015). Black bean and lentil biomass had negative relation with weed density according to the theory mentioned before. In buckwheat the relationship was slightly negative. Weed densities remained almost similar regardless the yield of crop biomass. In blue lupin and soybean the relationship was positive means yield of crop biomass were not affected by weed densities.

Regression line linear of black bean, blue lupin, buckwheat, lentil and soybean was based on the equation y=2.030-0.5437x with r.sq=0.36, y=-0.7023+2.137x with r.sq=0.89, y=0.5302-0.05961x with r.sq=0.38, y2.431-0.4460x with r.sq=0.89, y=0.3251+0.4505x with r.sq= 0.54 respectively.

Here "y" is weed density (t/ha) and "x" is crop biomass (t/ha).

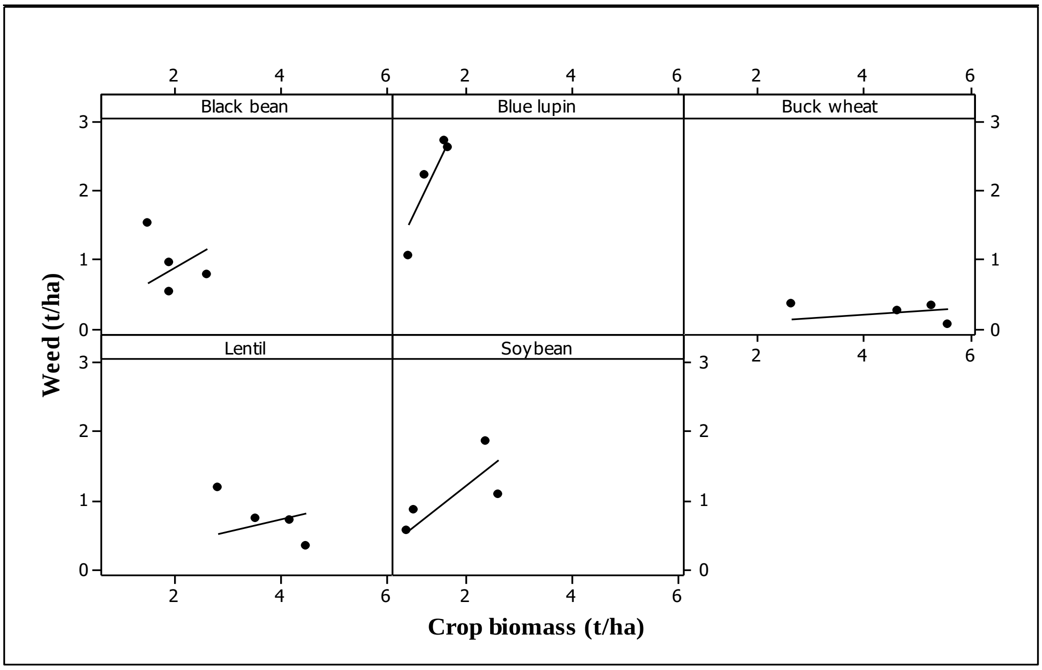

Figure 7. Correlation between weed density (t/ha) and crop biomass (t/ha).

5.2.6. Protein content in grain

Protein concentration in the grains ranges between 9.9-35.5%. Buckwheat has the lowest protein concentration whereas blue lupin has highest protein concentration. Significant difference (P<0.05) had been found among the treatments. No significant difference (P>0.05) had been found between blue lupin and soybean, and black bean and lentil. Highest and lowest SD were observed in lentil and soybean, respectively.

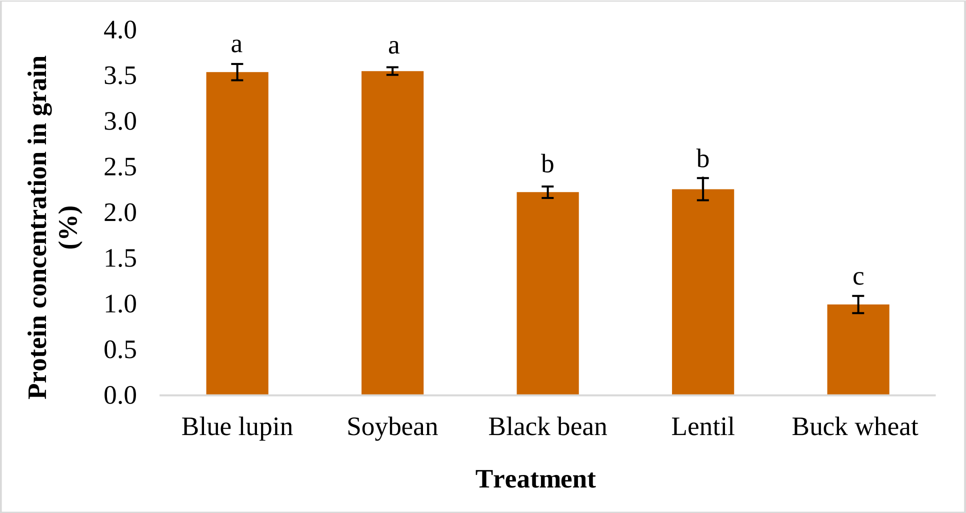

Figure 8. Protein concentration in the grain harvested at full maturity of the crops. Each bar is the mean value of four replicates. Error bar represents standard deviation (SD) calculated from crop yield. Letters on the top of the error bar indicates significant different among the mean value of the treatments (tukey's, p<0.05, n=4).

5.2.7. Protein concentration in straw

Highest and lowest protein content were found in soybean (10.9%) and buckwheat (4.8%). Protein content in both grain and straw were lowest in buckwheat. Though grain protein concentration was highest in blue lupin however straw protein concentration (8.1%) was lower than the soybean (10.9%), black bean (10.7%) and lentil (9.7%). Significant different (P<0.05) had been found among the treatments however no significant difference (P>0.05) had been found among soybean, black bean and lentil. SD was lowest in buckwheat and highest in soybean.

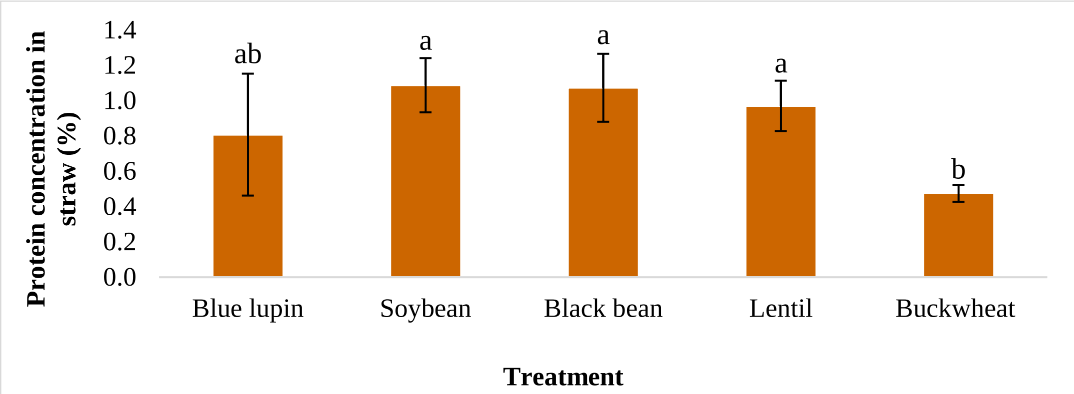

Figure 9. Protein concentration in above ground whole plant part harvested at full maturity of the crops. Each bar is the mean value of four replicates. Error bar represents standard deviation (SD) calculated from crop yield. Letters on the top of the error bar indicates significant different among the mean value of the treatmnets (tukey's, p<0.05, n=4).

5.2.8. Carbon and nitrogen (C/N) ratio in straw

C/N ratio ranged from 20.9 to 45.9. C/N ratio is highest in buckwheat (45.9) which was significantly different than the C/N of soybean (20.9), black bean (21.0) and lentil (24.2). Blue lupin had second highest C/N ratio (32.2) and highest SD in among the treatment.

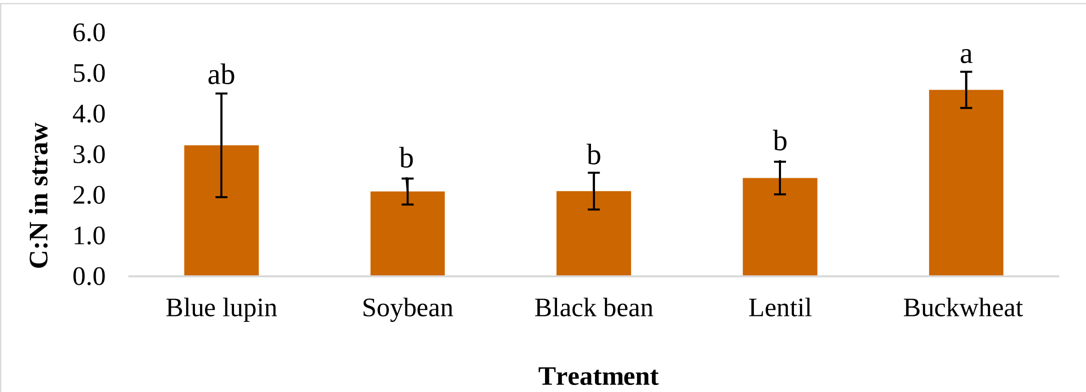

Figure 10. C/N ratio measured in above ground whole plant part harvested at full maturity of the crops. Each bar is the mean value of four replicates. Error bar represents standard deviation (SD) calculated from crop yield. Letters on the top of the error bar indicates significant different among the mean value of the treatmnets (tukey's, p<0.05, n=4).

5.2.9. Annual C input in the soil

Carbon inputs by above ground crop residues and below ground crop residues varied significantly among the treatments ($P<0.05$). Annual C input by above ground residues and below ground residues were significantly higher ($P<0.05$) in buckwheat which were around 160 kg/ha and 145 kg/ha respectively. Annual C input by above ground residues and below ground residues in lentil were similar, around 108 kg/ha for both above ground and below ground residues. Annual C input by both above ground crop residues and below ground crop residues were almost similar for black bean and soybean (around 100 kg/ha). Total annual in blue lupin is around 122 kg/ha. Annual C input mainly depends on the production of crop residues. Higher the production higher the annual C input.

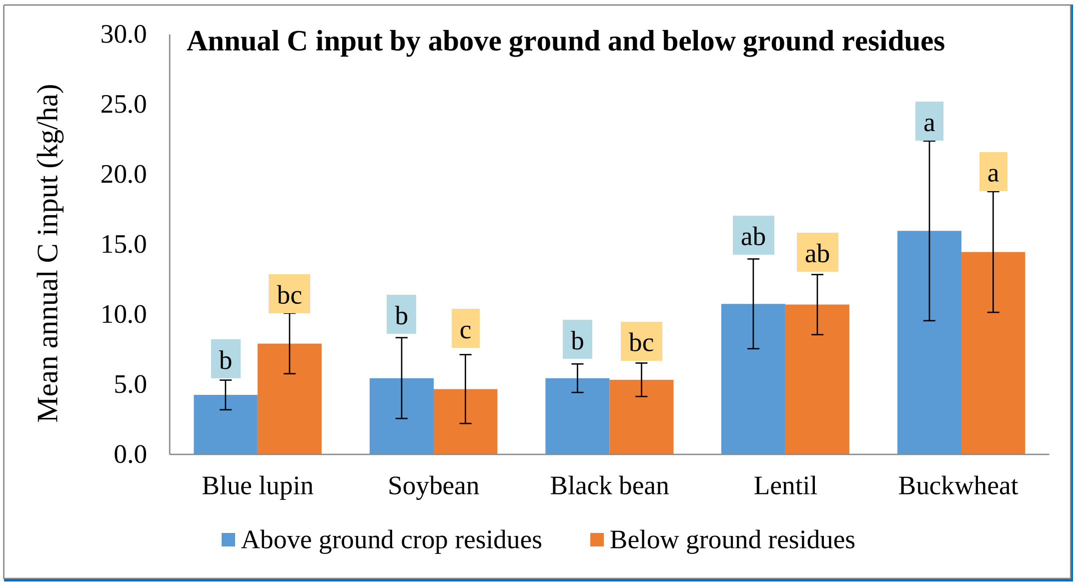

Figure 11. Mean annual C input by the above ground crop residues and below ground residues. Each bar is the mean value of four replicates. Error bar represents standard deviation (SD) calculated mean of C input by above ground crop residues and below ground residues. Letters on the top of the error bar indicates significant different among the mean value of the treatmnets (tukey's, $p<0.05$, $n=4$). Similar color letters represents significant difference among each other

5.2.10. Mineral Nitrogen in the soil

Mineral nitrogen was tested to determine the amount of available nitrogen in the system. No significant difference (P>0.05) had been found among the treatments for NH_4 and NO_3 at any depth (0-30 and 30-60 cm) of soil. Total min-N is higher in buckwheat however SDs were very high as well. For NH_4 at 0-30 cm depth highest value was 3.2 kg/ha in buckwheat. At 0.30 cm depth amount of NO_3 is higher than amount of NH_4 for all the treatments. Highest amount of NO_3 at 0-30 cm depth was in lentil (4.0 kg/ha). Amount of NH_4 is lowest at the depth of 30-60 cm for all the treatments. Amount of NO_3 at 30-60 cm depth was highest in buckwheat (5.8 kg/ha).

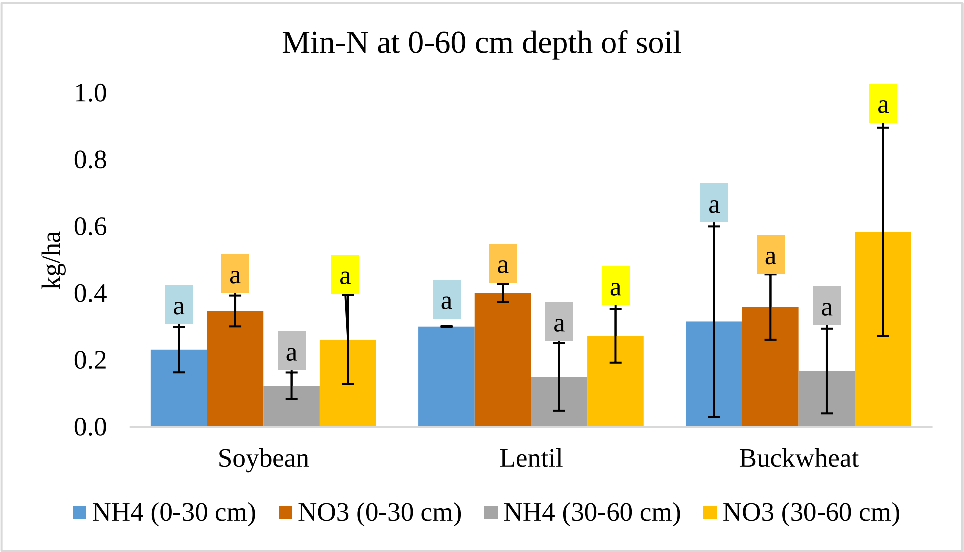

Figure 12. MinN at 0-60 cm depth of the soil. Each value represents mean of three replicates. Error bar represents standard deviation (SD) calculated from mean value of NH_4 and NO_3 at 0-30 and 30-60 cm depths of soil. Letters on the top of the error bar indicates significant different among the mean value of NH_4 and NO_3 at 0-30 and 30-60 cm depths of soil (tukey's, $p<0.05$, n=3).

5.3. Interview data

Data of semi-structured interview have been presented in text and are divided into five parts: 1) Information about the farmers and current cropping system in Southern Sweden 2) Economic, Environmental, Social and Governmental factors that influence farmers' decisions of choosing current crops and cropping system 3) Impact of current cropping system on the economy, environment and social well-being, and 4) Economic, Environmental, Social and Governmental factors that influence farmers' decisions on choosing different crops and cropping system. Quotes have been presented in order to illustrate the views of the respondents. Most of the quotations are direct citation and some quotations have been rephrased.

1. Information about the farmers and current cropping system

Five farmers had been selected to interview. All the farmers were male and aged between 40-63 years. The respondent's farms ranged from 72 to 1300 ha. Four of the farmers had conventional farm and one farmer had organic farm. All farmers had background of family farming. Additionally they have education in Agriculture particularly Master in Agriculture, Master in Agronomy, Law and Economics. Three farmers were from the Trelleborg municipality and two other farmers were from Kristianstad and Höganäs municipality, hereafter farmers were referred as Trelleborg 1, Trelleborg 2, Trelleborg 3, Kristianstad and Höganäs.

In southern Sweden crop rotation mainly varies from 4-7 years. For conventional farms most common crop rotation is for 4 years with Sugar beets, wheat, barley and rape seed oil, sequentially. Some other crops in the rotation are Maize, Rye, Fava bean, Red clover, Pea and grass for seed production. Depending on the type of soil the organic farm followed two types of crop rotation. Crop rotation in clay soil includes similar crops as conventional farms and sandy soil has been used for growing vegetable for example carrot, potato and beans. Crops are mainly sold to the companies for biogas, alcohol, sugar, bread, vegetable oil production and used as feed for the animals.

2. Economic, Environmental, Social and Governmental factors[12] that influence farmers' decisions of choosing current crops and cropping system

From the farmers' interviews more information were gathered on governmental factors affecting famers' decision comparing with economic, environmental and social factors affecting farmers' decision of crops and cropping system. Therefore, data have presented separately for governmental factors, and economic, environmental and social factors.

2. 1. Economic, Environmental and Social

Most of the farmers have been growing same crops for many years with some minor changes thus they have following similar cropping system and crop rotation. Participant mentioned market price of the crops, demand of the industries and yield are the reasons of choosing particular crops. Some traditional crops give higher yield, well paid and give stable amount of income for example sugar beet. Sugar beet is known as contract crop. Farmers have contract with companies to a fix amount of sugar beet every year. Generally yield is high and stable in sugar beet thus farmers get a steady income every year. For some crops farmers gets higher amount money from the biofuel industry for example growing pea for biogas plant gives good income. Furthermore, farmers mentioned traditional crops have stable market. Farmers are well informed of the market.

"I have been growing more or less same crops over the years. It is a stable system. I know what could be the problem with this system. I am not fond of experimenting" (Trelleborg 2)

Environment and soil which are very favorable for growing commonly grown crops in this region. Farmers are also well aware of the advantages of having more crops in their system. One of the farmers mentioned whenever he had done some changes in their cropping system the reason was biological, to avoid problems with diseases and to improve soil condition.

"*The changes in crop rotation is mainly biological, to have the soil in good condition in long term. You can have rotation of Sugar beet and Malting barley. But after some time it will certainly give some problems. You get diseases and soil will be tired. The more crops you can put the better condition and long term capacity of the soil*" (Trelleborg 3)

Same as conventional farm market demand and prices of the crops are important deciding factors choice of crops for organic farm. Additionally they need to consider weed and nutrients. Supposed

"*It is organic. You have to think about weed and nutrients. You have to mix clover and nitrogen fixing crops and which crops are possible to sell, the best paid crops, which price you got last year. You have to contact companies for vegetables."* (Kristianstad)

"*I don't think it will be lentil this year. It must be light soil and we don't want to have lentils where we will have carrot and onion, then it will be lots of weeds there. Lentils compete very badly with weeds*." (Kristianstad)

[12] These factors are also dimension of SAFA: Economy, Environment, Social and Governance

2. 2. Governance[13]

Participant mentioned that government policies doesn't have much influence on the crops they are growing but policies mainly influence the way they are growing crops. For example, EU policies about utilizing area for crop production (i.e. EFA), reducing nitrogen leaching (i.e. limiting the time for fertilizer application), selection of pesticide and fertilizer etc have to be followed by the farmers.

"*Government policies have impact on how I am growing. I have been growing same crops all the time. They have big impact on how I am growing.*" (Trelleborg 2)

There were both positive and negative reactions about CAP. Some farmers think it is a very good system for environment. Some other farmers think CAP is not practical enough. For example one of the options of EFA is farmers can keep 1-20m of ploughed area on the edge of the field. The soil remains black and leaching is substantial from this part of crop land which make the option unpractical. All the countries in Europe agreed on same rules made the system difficult and rigid. Farmers think good things can be done in many different ways. Instead of paying money on the activities of the farmers money should be provided on the outcome of the environment. Farmers also showed their dissatisfaction about short-sighted CAP. They think instead of taking holistic approach to solve the problems one problem has been taken into account at a time and thus policies have been changed more often. Farmers have to deal with new rules every couple of years.

"*CAP is considering about environment. I think it is good. EFA is good. Good for small animals. They will have little more place. It is good for the environment………………….. We must try to do something else better for the environment. We can't do things we are doing for many years. We must learn to do something else. I think it's a good way to learn. We must force to try*" (Höganäs)

"*That's something good about subsidies that you take care about the landscape and get some money in return. Because every people from the cities they like to see beautiful landscape and we are working for that.*" (Trelleborg 1).

"*I think CAP is a good thing from the beginning. But when all the countries agreed on the same rule it became so rigid. Good things can be done in many differ ways. One common rule does not fit to everyone*." (Kristianstad)

"*Subsidy system in Sweden it is very much action oriented it is not result oriented. You are paid for the actions but you are not paid for the environmental result*" (Trelleborg 3).

[13] Here government means decision making process of the government institution for example national or EU government.

By action farmer meant that subsidies are given to the famers depending on their activities. For example planting on a special day, using buffer strip etc to achieve environmental benefits. But these benefits cannot be seen. Our farmers think if the system is changed and farmers are given money based on the environmental result for example money for saving certain amount of nitrogen or phosphorus then the payment system could be more efficient.

"*Everybody thinks how to grow their food. I think it is ok but it is a complex system. If one politician or group think this is necessary and the idea goes to all the way to some laws then they crash with other laws. You don't take the whole problem. You take a problem one by one. All the laws are very short sight. You think just for one or two years. Then you have whole different rules to work with. We are not working with 3 months; we are working with 4-5 years result.*" (Trelleborg 2)

All the farmers said that they are satisfied with the amount of money they are getting for following CAP. But they think instead of paying money for the land money should be paid on the crops. However, some farmers are strongly against subsidies and think EU government should stop this system.

"*I am satisfied with subsidies but I do not see a very bright future of it. I rather prefer a free market without any subsidies. It will be difficult in the begging but it will pay later with the crop instead*" (Trelleborg 1)

"*There should be more money for the product, not for the land." (Höganäs)*

"*I think a subsidy is a stupid system. You should have money when you sell the crops not with subsides*." (Kristianstad)

It is difficult to follow the CAP for the farmers. It is complex and difficult to understand. Additionally in Sweden government rules are stricter than EU rules. Farmers have to do lot of paper works which takes time and farmers get no money for that time. In spite positive and negative ideas about subsidies framers are quite dependent on it.

"*We try to be little dependent on subsidies. The subsidies pay 10% of the turnover of the farm. Of course that could be in a bad year that means we have a loss. But in a good year it doesn't matter. So you can see it as an insurance.*" (Trelleborg 3)

"*The economics of the year is in the level of subsidies. If you do not have any subsidies you don't have any result. That is how you are dependent on the subsidies in Sweden in Average.*" (Trelleborg 2)

3. Impact of current cropping system on the economy, environment and social well-being

3. 1. Economic

Maintenance of the machineries, chemicals (fertilizer, pesticides), labor, transport and interest of the land were mentioned as major expenses of the farms by the participants. All the farmers are satisfied with their yield but at the same time they think the yield can be higher. Organic production is not as high as conventional production but the price for organic crops are higher. All the farmers mentioned that their farm incomes are quite stable. However, price of the crops fluctuate a lot on different years on different crops. Participant mentioned salary for worker, expense for seed, fertilizer and pesticides, and maintenance of machineries are higher in Sweden thus overall production cost is much higher in Sweden than rest of the world.

"*The farm income is quite stable. I can't do much about it. It is European market and problems around that. We need disaster some part of the world to get the price up*." (Trelleborg 1)

"*We totally dependent on world market*" (Trelleborg 2)

"*Crop price fluctuate very much depending on how good harvest is this year in Denmark, Germany, Holland. Price in different European countries affect crop price in Sweden*" (Kristianstad)

"In Sweden it is expensive to take out but it is difficult to meet world's price. We must do for the products. We should have money for the processing food in the farm."(Höganäs)

"*My challenge is what you could say is profitability. The price of the product has gone down substantially*." (Trelleborg 3)

Participant from Kristianstad mentioned that because of the reason that he has many crops the income is quite stable. Participant with several products from the farm for example crop + chicken, crop + milking cow mentioned that it is helpful keep the farm economy stable. Some farmers are positive about having more income in next 5 years. However, some farmers think that average income of next five years will decrease. Money from the CAP has been decreasing and will be deceased more in coming years.

3. 2. Environmental

Farmers from Trelleborg region mentioned weed as their one of the main problems. Farmers with lot of experience are manages to handle weed problem efficiently. It is also difficult to choose chemicals in conventional system. Farmers must have permission from the government to use specific kind of chemicals and there are not so many options available. They have mentioned weed problem as a main barrier to convert the farm into organic.

"*One problem I face, I most worried about is this grass weed I talked earlier about. It is called Ren-kavle in Swedish. It does not die of pesticide anymore. In the area we have quite a lot of it*" (Trelleborg 2)

"*Organic is good. But I think I do not have time and it also have a lot of grass problem. We do not have anything to keep it down in ecologisk*" (Trelleborg 1)

Farmers from Trelleborg also mentioned nitrogen leaching is the main problem of the system. A farmer from Trelleborg mentioned ploughing down the green leaves of sugar beet into the soil causes a lot of leaching for the farmers. However producing biogas from the green leaves of sugar beet could be a way of get rid which would reduce the leaching loss (information from the farmer coded as Trelleborg 1). Another farmer from Trelleborg said:

"*If you strictly see my 72 ha land nitrogen leaching is not a problem for me. But you have to take responsibilities*" (Trelleborg 2)

Three other farmers think their soils are quite stable however they also have considered leaching as a problem. One farmer has mentioned that leaching is not a problem in his soil.

"*Every 10 years we do nutrient test, Nitrogen and phosphorus. We have idea how much nutrients the soil needs. ……………………………......No problem with nitrogen leaching. We use fertilizer from the cow and buy from the market. We always put in every year so soil quality is not a problem."* (Höganäs)

One farmer mentioned double cropping system could be good way of reducing leaching. This could also help to have less black soil. Farmers normally have black soil during the winter. Heavy rain can cause more problems during the winter with no soil cover. It can cause more nutrient leaching. Farmers have mentioned to have green grass for soil covering.

"*I have a big focus on the time when the fields are empty to do something decent……… In winter; around august we have black time all the way to spring time. So we need something around that time to make good of it.*" (Trelleborg 1)

"When it is a lot of rain it takes a little more time for water to go down. For that it is important to have green grass for the soil. Roots of the grass go down in the soil and it's good for the soil microflora" (Höganäs).

Participant with cows mentioned rotate cows with the crops is very healthy for plant nutrition. Some grasses for example alfalfa grown for the cows can go deep down into the soil, uptake nutrient and make them available for the following crops in that land.

Organic farms have some problem with diseases of vegetables for example root knot nematode in Carrot and late blight in Potatoes and Onions.

"*Late blight comes from the wind; it can be from rotation but mainly from the wind*" (Kristianstand)

3. 3. Social

Most of farmers do not have any personal advisor for the farm. Some gets help from the companies where they sell their products. Taking decision by reading newsletter are newspaper articles were very common among the participants. They have mentioned that they informally discuss with their neighboring farmers, collogue and friends about crops.

"*I don't have a personal advisor. I know quite a lot of people. I get letters from different advisor. With my education I don't have to have a personal advisor. I have neighbors, my fellows in the board, newsletter, meeting on the parties you talk about Sugar beet growing…………………….. I talk with quite a lot of people and make my own decision.*" (Trelleborg 2).

"*Every year we go out around the fields different farmers, look at the problems that farmers having in his fields. We have some advisor from companies. We discuss what to do and bring that learning to my farm. In combination of letters and spraying advisors we go further.*" (Trelleborg 1).

Number of worker in the conventional farms ranged between 0-5. Worker requirement in organic farm is higher than conventional farms. Number of worker in organic farm ranged 1-15 depending on the season. Most of the farm has family members working in the farm. When they have to take big decision they discuss with the family members and full time workers and farm managers. Salaries for the workers decide by the communal.

"*We have one girl in the cow. She has lot of ideas. She has a good education in animal. We listen to her a lot*" (Höganäs)

Both maintenance for machineries and labor is expensive in Sweden. Most of our farmers prefer to use machineries than labor. Farmers had reduced the number of their labor in last several years. However some farmers mentioned about their effort to do good for their workers.

"*We have heavily invested in new machineries. Before, 2 years ago we are almost 10 people working in the farm. We reduced the number of people and invested much more in the machineries*." (Trelleborg 3)

"*For the cow milking robot is very expensive but you do not need so many people*" (Höganäs)

"*You can reduce the cost of the labor substantially when you buy bigger machines.*" (Trelleborg 3)

"*I have one employee. I used to have three but I still have this man. The reason I have him is he has small handicap. By helping him I give something good back to helping people. He drive tractor and I have also someone to work with and the days become more funny."* (Trelleborg 1)

"*We have communal and they recommend the payment for the workers. 22,000 Crown in one month. We try to go after that to help them*" (Höganäs)

4. Economic, Environmental, Social and Governmental factors that influence farmers' decisions on choosing different crops and cropping system

4. 1. Economic

Farmers' choice of cropping system depends on the choice of the crops. Most of the farmers think growing a non-traditional crop is not a problem at all. The difficult part is to find suitable buyers for the crop.

"*For a new crop it is hard to get a market. You can grow any crop at all. But you have to have buyers who will give economic results you are satisfied with*" (Trelleborg 2)

"*For all the crops it is very easy to be a producer but it is very difficult to be a seller*" (Trelleborg 3)

"*If you want to grow something new you must know how to sell it or can I have money for it. If there is market for the crops or if it is profitable or not*" (Höganäs)

"*At the end money says everything. If you don't make success you don't get any money. If you don't get any money the bank says: hello we need money for you*" (Trelleborg 1)

Market price is an important factor for introducing different crops such as legume in the system. If legumes are grown in the system the yield would be acceptable but they might not give the same income comparing with the common crops for example Sugar beet, Barley, Oil seed rape and Wheat.

"*Peas have not had the best income. You cannot have the income from peas match with the income I have from my crops*" (Trelleborg 2)

However, participant from Kristianstad (organic farm) thinks different than other farmers both about finding a market for a new crop and growing legume in the cropping system.

"*It is not very difficult to introduce a new crop. All the crops I am growing there are market for those crops*" (Kristianstad)

There is a very big market for organic beans. Not much money compare to the Carrot and Onion. But it is better than growing Wheat or Barley" (Kristianstad)

Participant from Kristianstad explains how including beans in double cropping system might reduce the yield of the first crop. Beans are susceptible to frost therefore, they cannot be planted before May. First crop should be harvested in before May. Thus if the first crop is Lay only one harvest is possible instead of three or four harvest. However yield of bean would not be affected by double cropping system.

Not having suitable machineries for harvesting new type of crop can be a problem both for the farmers with small and big lands to integrate a new crop in the system. It is not profitable for the farmers with small land to invest money for new machines. Whereas farmers with big lands who already have machines are confined to choose crops that suits their existing machineries.

"*Machine is the reason we can't choose different crop.*" (Trelleborg 2)

Transport is also a problem. Since production in agriculture is bulk therefore, it is expensive to transport the product too far from the production site.

4. 2. Environment

Couple of farmers mentioned they have been trying to grow different crops in their system. Participant from Höganäs said that he had tried to grow Buckwheat. But it seems like bees does not like Buckwheat and there was a reduction in honey production.

Soil type is an important factors for selecting new crops for the system. Generally clay soils are not good for growing beans and vegetables. Farmers with clay soil cannot select any crops in spite of their interest of growing new crops.

"*The new crop has to fit in the cropping system, machineries. It has to be with the soil. For example, we cannot grow potato because the soil is too sticky. You lose lot of soil because lot of soil attach with the potato. It has to be other crop……………………………………………. We have quite heavy soil, quite high content of clay. The vegetables much better in sandy and lighter soil*" (Trelleborg 3)

Farmers mentioned availability of water in their region can be good for growing grasses (e.g. clover) that are water dependent. Later the grasses can be used for biogas industry.

"*One thing is also interesting that we have quite a lot of water. You can actually grow wheat or some kind of grass that are water dependent. Then you can take up and use it for biogas factory*." (Trelleborg 3)

4. 3. Social

Social system can play a very strong role to diversify the cropping system. There is always a forerunner who tries the system first. Seeing someone growing successfully different crops and trying different system encourage farmers to adopt the system.

"*If you are going to start with a new crop you have to see someone growing it. So you can see, yes, it is working*" (Kristianstad)

"*There are always forerunners who test the system then it spread mouth to mouth*" (Trelleborg 3)

4. 4. Governance

Farmers think national and EU government are the main groups who can help farmers in diversifying the system. Government should understand how the system works in the field before implementing a new law, in other words laws should be more action oriented. Farmers also wants government disseminate knowledge of farmers who has been testing and trying new system and crops to other farmers.

"*Government and EU are the main. When you have to develop something they have to understand that they have to higher up the system. They must understand how it will work on the field.*" (Trelleborg 1)

Knowledge of about the new crops for example, when to sow the new crop, how much is the machine maintenance, how to control weed and pests are very important that farmers would need have to diversify their cropping system. Farmers think advisor can help them by proving

"*I think it is advisor who very much helps to find out the right system. Farmers would like to have knowledge*." (Trelleborg 3)

6. Discussion

6.1. Sustainability Assessment

Assess sustainability of DC system based on review of literature was complicated since outcome from a cropping system can greatly vary depending on the geography, choice of crops and management of the system (tillage/non-tillage, organic/inorganic, source of organic materials).

GHG emission depends on the amount of fertilizer use. More N_2O emission occurred when the amount of fertilizer use is higher (Qin *et al.*, 2012). In general rate of use of fertilizer in DC system is higher than SC system however use of fertilizer greatly varies choice of crops. For example, single crop corn requires higher fertilizer than double crop corn-sunn hemp system (Heggenstaller *et al.*, 2008). In our experiment fertilizer had been applied for the first crop (rye) and no fertilizer was used for the second crops. Therefore, one advantage of the system is in terms of N_2O emission from fertilizer use growing double crops in the system would not cause additional N_2O emission than the N_2O emission from single crop rye production.

Though lower GHG emission occurred with lower use of fertilizer however in DC system requirement of fertilizer is higher and lower use of fertilizer reduces yield significantly (Qin *et al.*, 2012). In DC system the demand of water is also high. Less use of water reduce crop production (Wang *et al.*, 2008). In designed cropping system no additional water and nutrient had been used for second crops which could be other advantages of this cropping system.

Reduction in water quality by the leaching loss of N could be reduced when there is more soil cover (Romic *et al.*, 2003). In our experiment that soil is designed to be covered all the year round and no fertilizer was used in the second crops. Thus based on these two facts of high soil cover and less use fertilizer we expect leaching loss of N could be lower in our system. However, production of double crop might negatively affect the availability of inorganic nitrogen and yield of the next crop (Finney *et al.*, 2016).

Total production of biomass is higher in DC system (Rainbault *et al.*, 1990; Heggenstaller *et al.*, 2008; Fouli *et al.*, 2012; Senbayram *et al.*, 2014). However dry matter production varies depending on the choice of crops (Heggenstaller *et al.*, 2008).

In DC system planting of the second crop might be delayed by the first crop which ultimately can reduce the production of second crop (Krueger *et al.*, 2012). Late planting of the second crop reduce the crop and grain yield (Egli & Bruening, 2000). Depletion of soil water and NO_3 by the first crop can also reduce the yield of the second crop (Krueger *et al.*, 2012). In our experiment rye does not hamper the planting date of the second crops since rye harvested in green condition for energy. However, rye might deplete water and nutrient that might hampered production of the second crops.

Literatures have shown double cropping system extent the time of vegetation cover that harbor high number of insects (i.e. web building spider and beetle) (Groeneveld and Klein, 2015; Groeneveld *et al.,* 2015). Though increase proportion of non-cropping cover is seen as an efficient measure of increase biodiversity however number and species of ground beetle was lower in non-cropping sites than DC wheat-maize system (Liu *et al.*, 2010). In organic system biodiversity is 10.5% higher than conventional system (Schneider *et al.*, 2014). In our system year round vegetation cover and use of no fertilizer on the second crops might have positive result on biodiversity.

Income is higher in DC system since it gives more than one source of income (Burton *et al.,* 1996; Williams, 2014). However, net income from double cropping system largely depends on the yield. Again, yield depends on season length and climatic and weather factors for example soil moisture, limited time for harvesting and planting. Depending on these factors yield from single crop and double cropping system might be the same thus net income could be the same also (Burton *et al.*, 1996).

Summary

According to the literatures reviewed, conventional double cropping system requires a high level of water consumption and fertilizer utilization. This system also emits a high quantity of GHG. However, due to high soil coverage the system is good for improving soil quality and protects soil from land degradation. Double cropping system also supports a large number of diverse species such as beetles and spiders. Increase yield could result in rise in net income. It should be noted that overall outcome of the double cropping system can greatly vary depending on the country/region, climate, soil, choice of the crops/varieties and, cultivation system (irrigated/non-irrigated, tillage/non- tillage, organic/conventional).

In our experiment there was no irrigation and fertilization for the double crops. Thus growing double crops in our system does not make the whole system more water and nutrient demanding comparing with single crop rye system. Furthermore, no additional use of fertilizer on double crops cause no additional emission of GHG from this system.

Studies on DC system have been mainly done to investigate economic and environmental factors. For assessing overall sustainability of DC system measurement of social sustainability is also important.

6.2. Multifunctional Cropping System

6.2.1. Crop production

6.2.1.1. Blue lupin

Among all the lupin species blue lupin has the lowest level of productivity (Todorov *et al.*, 1996). Yield of blue lupin generally vary between 1.5 t/ha - 2.3 t/ha in Kraljevo, Serbia (Mihailovic *et al.*). In other studies, grain yield of blue lupin were found 2.0 t/ha at Mecklenburg-Western Pomerania, Germany and 2.9 t/ha at Aberystwyth, UK (Heidel, 2005; Fraser *et al.*, 2005). Grain production in our experiment is much lower than the average yield

Todorov *et al.* (1996) mentioned dry matter yield of blue lupin can be 4.7 t/ha. Depending on the varieties dry matter yield varies between 6.6 – 8.4 t/ha. However, seedbeds were treated with fertilizer (P_2O_5 and K_2O), pre-emergence herbicides and insecticides (Fraser *et al.*, 2005). Yeheyis *et al.* (2012) claimed for forage dry matter yield was 0.7 – 1.6 t/ha when the samples were taken during the time of 50% flowering. Crop residues in our experiment are lower comparing with the findings with other experiments and furthermore our crop was harvested at full maturity.

In our experiment a positive correlation between total crop biomass and weed densities has been observed in Blue lupin (figure B). Furthermore, weed density was significantly higher ($P<0.05$) than all other treatments (table 1). That means blue lupin competed badly with weed. Ultimately weed took over the plots and some blue lupin plants manage to grow and give yield. Weeding done at seedling and just before the flowering stage gives high dry matter yield (Fraser *et al.*, 2005). If weeding would be done in our experiment the yield might be higher.

Protein content in blue lupin grain ranges between 30.0-35.8% (Fraser *et al.*, 2005). Depending on the maturity of harvest Lupin silage contains 13-18% protein (Lardy and Anderson, 2009). Although straw protein content in our experiment is lower (8.1%) but the grain protein % (35.4%) comparable with the literature. Since the protein content in straw in low the instead of feeding crop residues to animals it can be used for bedding materials or can be incorporated into the soil or can be used for biogas production which has been discussed later.

6.2.1.2. Soybean

US, Argentina and Brazil are three top soybean producing country in the world where average yield of is (2.8 t/ha) comparatively higher than the yield rest of the world (1.5 t/ha). In India the average yield is around 1 t/ha (Singh, 2010). In Sweden yield of soybean can be ranged from 1-2 t/ha (Modig 2015). Genetic improvement of soybean cultivars and improvement in cultural practice are two main reasons of higher yield in US (Board and Kahlon, 2011). Grain yield of soybean in our experiment (0.6 t/ha) is very low comparing with other results. Temperature during the cultivation period in the experimental area (15.2°C) was much lesser than the average temperature (25-32°C) for soybean cultivation (Nwokolo, 1996) which could be a reason of low yield. Tacarindua *et al.* (2013) argued temperature higher than 25°C significantly reduces seed and dry matter yield.

Although Soybean has moderate moisture requirement of 400-800 mm rainfall (Nwokolo, 1996) but it is sensitive to water stress and irrigation is recommended especially in light soil (Rudelsheim and Smets, 2012). In our experiment soybean received rainfall of 219.2 mm during the cultivation period (June-Sept) which could be another reason of low yield of soybean in our experiment. Irrigation could have been done to improve the yield. Soybean received 65‑85% of its needs through the symbiotic nitrogen fixation process. Therefore, no nitrogen fertilizer or a very little dose of fertilizer is recommended. However, potassium and calcium are important for the growth of plant and grain yield and Sulphur is needed for formation of protein (Singh, 2010). Lack of nutrient management in our experiment might be responsible for low yield.

Above ground biomass (not dry) of soybean ranged between 5.13 - 8.21 t/ha at Lexington, Kentucky, US (Egli & Bruening, 2000). Crop residue in our experiment is much low 1.1 t/ha. Above mentioned factors that affected the grain yield might have affected also the vegetative growth of soybean. Grain yield and crop residues yield are almost similar in soybean and blue lupin (figure 4 and 5). Moreover, correlation between total crop biomass and weed density is positive in soybean which is similar to blue lupin (figure B). Although weed densities is significantly lower in soybean than blue lupin (table 1). Seed density was much higher in blue lupin (190 kg/ha) than in soybean (130 kg/ha).

The protein content in soybean is approximately 40% (Singh, 2010). Protein content in Hay is 16.6% (Lardy and Anderson, 2009). In our experiment protein content in grain and straw were 35.5% and 10.9% respectively. Unfavorable environmental conditions and delayed planting date decrease the growth, development, yield, oil and protein content of Soybean (Hu & Wiatrak, 2012). Similar as blue lupin crop residues can be used for bedding materials or can be incorporated into the soil or can be used for biogas production.

6.2.1.3. <u>Black bean</u>

Our experimental yield is comparable with the experiment done by Blackshaw *et al.* (2000) Taber, Town in southern Alberta, Canada. The lowest and highest yields were 0.4 t/ha and 3.2 t/ha respectively. However, weedicides and hand weeding were done in their experiment. An experiment was done in Bohuslän, western Sweden in 2016 found that yield of black bean is around 0.5 t/ha. (Andersson 2016). However yield of black bean in Sweden can be as high as 1.5 t/ha to 2.0 t/ha (Modig 2015). In Canada average yield of colored bean is 1.7 t/ha (Goodwin, 2003). In Brazil new cultivars from different Brazilian breeding can give a yield of 1.7 t/ha to 4.9 t/ha (Barili *et al.*, 2015). Lack of water during vegetative and/or reproductive growth stages is one of the most limiting factors for bean growth. Water stress at the time of growth stage significantly reduced grain yield (Boutraa & Sanders, 2001). Beebe *et al.* (2008) reported 3.3 t/ha yields at 896 mm annual rainfall and 24.3°C in an experiment done in four different sites (Palmira, Popayán, Quilichao and Darién) in Colombia. In our experiment the total annual rainfall and average temperature during the growth period were lower, 702 mm and 15.2°C respectively. Below 20ºC temperature reduced the crop growth (Chandhla, 2005). Yield reduction in our experiment is probably mainly because of low temperature.

In our experiment grain yield and crop residues yield of black bean are significantly similar to soybean (figure 1 and 2). However, seed density was much lesser in Back bean (80 kg/ha) than in soybean (130 kg/ha).

There is negative correlation between total crop biomass and weed density in black bean which is different than other two bean treatments (blue lupin and soybean) in our experiment (figure 7). Blackshaw *et al.* (2000) mentioned that adequate weed control is one of the major problems of bean production. A two-year experiment in Michigan, US had shown the highest grain yield (4.5 t/ha) has been observed when weeds were controlled using chemicals (Holmes and Sprague, 2013). However, Blackshaw *et al.* (2000) observed hand-weed control generally gives better yield than herbicide treatments. Adequate weed control is recommended to increase the production of Black bean.

The protein content of Black bean in our experiment (22.2%) is comparable with the protein content mentioned by Nwokolo, 1996 (23%). Straw protein content in Black bean is similar to Blue lupin and Soybean (figure 9) however grain protein content is much lower (figure 8).

6.2.1.4. Lentil

Generally grain yield of lentil vary from 1.1-2.9 t/ha (Cokkizgin and Shtaya, 2013; Sharaan *et al.* 2003; Bicer & Sakar, 2010). In Canada yield varies 1.3 to 2.1 t/ha (Agriculture and Agri-Food Canada, 2016). Lentil production in our experiment (1.7 t/ha) is similar with these ranges. In Sweden grain yield of lentil can be ranged between 1-2 t/ha (Modig 1015). Usually no nitrogen fertilizer for lentil production is needed since it has ability to fix atmospheric nitrogen (Cokkizgin, 2013). High rainfall allows longer vegetative and reproductive growth that increases grain yield. The mean rainfall during vegetative and reproduction stage was 76 mm and obtained yield was 2.3 t/ha in Diyarbakir, Turkey (Bicer & Sakar, 2010). In our study mean average rainfall was 54.8 mm (June-Sept). Irrigation during growth stages would be helpful to get higher yield.

Lentil competes very poorly with weed. Crop yield losses mainly because of crop - weed competition for nutrition, moisture and space (Yenish *et al.,* 2009). However in our experiment weed density in lentil (0.8 t/ha) comparatively lower than the weed densities in blue lupin, soybean and black bean (table 2). The correlation between total crop biomass and weed densities is negative in lentil. Weed densities before and during crop emergence is critical for production and have higher effect on crop yield (Yenish *et al.*, 2009). Weed control during the critical period is recommended to improve the yield of Lentil.

In our experiment grain protein content was slightly lower (22.6%) than the usual protein percentage found in literatures, 28.6% (Adsule, 1996) and 27.7% (Lardy and Anderson, 2009). However, straw content is 9.7% which is higher than the recommended protein content (6.9%) by Lardy and Anderson, 2009.

6.2.1.5. Buckwheat

Buckwheat grows very well in organic cropping system. AN experiment done in Zlatar, Serbia. Oljača *et al.* (2012) presented highest yield of 1.4 t/ha in organic cropping system which is similar with the yield in our experiment (1.3 t/ha). Average yield of buckwheat in Europe is 0.9 t/ha which is similar as average yield in the world. However in some European countries Buckwheat yields is comparatively higher than the average European yield. For example in France and Poland the average yields are 3.2 t/ha and 1.1 t/ha respectively (Popovic *et al.*, 2014).

Appropriate sowing date, rate of fertilizer application and crop management practice can significantly influence buckwheat yield. With the optimal planting date, N rate (100kg N/ha) and planting pattern yield can be 2.5 t/ha in Arak, Iran (Sobhani *et al.*, 2014). At Nagykálló, Eastern part of Hungary when the planting was done in Sandy soil in early June same as our experiment the obtained yield was 0.4 t/ha (1.8 t/ha) higher than our experiment (Lazanyi & Laszlo, 2009).

Yield depends on the type of cultivar. Novosadska variety at Bački Petrovacin in Serbia can produce significantly higher yield (2.6 t/ha) than Godijevo, Bamby and Češka (Popovic *et al.*, 2014). Evaluating the yield of 5 cultivars in the region of Molise and Basilicata, Italy, the highest and lowest yields computed as 1.53 ton/ha was attributed to cultivar La Harpe and 0.76 ton/ha to cultivar Bamby, respectively (Brunori *et al.*, 2005). Average grain yield in our experiment (1.3 t/ha) might be the highest yield that can be achieved for this particular type of buckwheat variety. Figure A, treatment buckwheat showing there was not much difference in grain yield however the amount of total biomass was different in different plots. Choosing different cultivar might give different results.

Buckwheat competes very well with weed (Clark, 2007). Weed density in Buckwheat (0.3 t/ha) was significantly lower ($P<0.05$) among all the treatments. At figure B, buckwheat treatment showing though the total biomass is different in different plots but weed densities were almost unchanged.

Appropriate sowing date, rate of fertilizer application and crop management practice also influence significantly on protein content of buckwheat. With the optimal planting date and N rate (100kg N/ha) protein content was observed 15.24% (Sobhani *et al.*, 2014). In our experiment protein content was 9.9% which was lower than the content mentioned by Sobhani *et al.* (2014). This might be because of lack of proper nutrient management. Buckwheat is a heavy feeder of phosphate (Lazanyi & Laszlo, 2009). Lack of phosphate in the system might reduce the protein percentage in grain. However, straw protein percentage (4.8%) matches with the protein percentage found in the literature, 4.9% (Lardy and Anderson, 2009).

6.2.2. Other factors that might affected crop production

Several other factors for example weather summer in 2015 might affected the yield of double crops in this experiment. According to Andersson, 2016 summer 2015 was not very suitable for growing bean. The beginning of the summer was wet and cold which continued to be similar whole summer which might affect the bean production. Summer with good weather would increase the production of the crops.

Growing rye as first crop might affect the yield of double crops. Rye is well known for its allelopathy effect on the subsequent crops. Allelopathy effect of the rye might reduce the yield of the second crop (Raimbault *et al.*, 1990). This allelopathic effect in rye is due to the presence of phytotoxic benzoxazinones compounds. Exposure to benzoxazinones compounds might inhibit germination and growth, and can induce death of sensitive species (Schulz *et al.*, 2013). Extended period of growing rye in spring might also affect the yield of double crops by using too much water and NO_3. Available soil NO_3 can be decreased up to 59% compared with system without rye (Krueger *et al.*, 2012).

6.2.3. C/N ratio

Lower C/N ratio in crop residues is desirable for faster decomposition after incorporating them into the soil. Lower the C/N ratio higher the proportion of nitrogen and faster the crop residues decomposition (Fageria *et al.*, 2005). For biogas production, C/N ratio of plant biomass within the range of 20–30:1 is especially suitable. The C/N ratio depends on number of factors for example plant species, soil, climate, fertilizer management, time of harvest and way of preservation (Herout *et al.*, 2011). In our experiment C/N ratio of soybean, black bean and lentil comes under this range. Whereas the C/N ratio in blue lupin and buckwheat is slightly higher, 32.3 and 45.9, respectively (figure 10). Thus Soybean, Black bean and Lentils crop residues are more suitable for biogas production than Blue lupin and Buckwheat.

When C/N ratio is more than 30 lower level of nitrogen hamper microbial growth thus lower the efficiency of biogas process (Risberg *et al.*, 2013). However, it is still suitable to produce biogas from plant materials with high C/N ratio. In that case straws are treated with steam and co-digest with cattle manure. An experiment done by Risberg *et al.* (2013) wheat straw with C/N ratio 98 co-digested with cattle manure can produce stable amount of CH_4 gas however the amount of gas is low (0.13-0.21 N L CH_4/kg VS).

Residues from biogas plant can be used use as fertilizer however it is considered less valuable since it contains low amount of nitrogen. However, it contains high amount of carbon which can be very important for low carbon containing soil (i.e. sandy soil). High carbon content and fibrous materials of residues can improve structure and water holding capacity of soil (Risberg *et al.*, 2013).

6.2.4. Annual C input in the soil

Total C inputs to the soil from whole crop residues (above+below ground) vary significantly with rotation and cropping frequency (Shrestha *et al.*, 2013). Carbon accumulation is generally much higher with higher production (Campbell *et al.*, 2007). Soil organic C can be increased about 0.33 t/ha of annual C input above 2.4 t/ha whereas it decrease about 0.33 t/ha of C input below 2.4 t/ha (Shrestha *et al.*, 2013). In our experiment annual C input by double crops is lower than 2.4 t/ha since the biomass is not very high comparing with the main crops growing for longer time. But annual C input from double crops could be an additional source of C in the soil which would otherwise remained fallow. Rate of C gain in the soil also depends on management practice. However, changes in the rate of C due to changes in management practice also varies depending on the type of soil. Degraded soils sequester more C than non-degraded soil and gain in soil organic C is high in clay soil (Campbell *et al.*, 2007). It takes many years to see changes in soil organic C however if best management practice could adopt significant increase in soil organic C had seen in a short period of 6 years in land that had previously been degraded (Campbell *et al.*, 2000).

6.2.5. Nitrogen status in the soil

North European agricultural condition characterized by sandy soil and surplus of rain water increase the risk of nitrogen leaching loss specially during the autumn and winter (Manevski *et al.*, 2015). However, in any season soil without any ground cover can be subjected to leaching loss of nitrogen. Highest nitrogen leaching normally occurs on uncovered soil (Romic *et al.*, 2003). Two of our participants mentioned black soil and leaching as their main problems in their farming system. Ground covers during the summer can uptake soil N and reduce the potential for leaching losses. Additionally, the cover crop utilizes excess water in the soil which also helps limit leaching losses (Creamer and Bladwin 1999).

In our experiment there is no significant difference was found at the amount of total min-N between legume and non-legume treatments. However, generally legume represents on average 25-35 kg/ha more min-N than cereals (Peoples *et al.*, 2015). In our experiment total amount of mineral nitrogen in the soil differ considerably comparing with the literatures. Average Min-N in Lentil 87 kg/ha (Peoples *et al.*, 2015). Amount of min-N can greatly vary between the years (Ikerra *et al.*, 1999).

Availability of nitrogen in the soil can vary depending on rainfall distribution and intensity, plant growth, uptake of nitrogen during growing period and production of total biomass (Romic *et al.*, 2003). There is usually a rapid increase of soil min-N after rain. The accumulation of min-N is higher if the rain follows by a dry period. Dry period results less leaching loss of nitrogen. Min-N rapidly reduced again shortly after increase (Ikerra *et al.*, 1999). In our experiment soil sample has been collected on the 2nd of December, 2015. November was the rainiest month of the year with the total rainfall 104 mm. On the other hand October was the driest moth of the year with the total rainfall 22.5 mm. That means in October due to less rainfall there was high accumulation of nitrogen in the soil which became available during November due to high rainfall. Moreover, just 10 days before soil sampling (21 and 22 of November, 2015) total rainfall in two days was 30.7 mm which was the highest rainfall in the whole month.

Low amount of min-N in this study probably was due to the downward movement of nitrogen, denitrification, volatilization and, N uptake by plants. However, uptake by the plant was less important in this case since the crops over matured during the time of soil sample collection (Ikerra *et al.*, 1999).

There was no control treatment in this experiment. Therefore measuring the effect of double crop on N condition in soil comparing with no double crop could not been done.

6.2.6. Overall discussion

Main aim of this study was to design a cropping system that can increase production and provide ecosystem services. Growing double crops instead of keeping land fallow during the summer would increase the overall[14] production of the system. We found that yield of the double crops were optimistic for further research specially the yield of buckwheat, lentil and black bean. Additional yields from the double crops would higher the overall production which is one advantages of this system. Other advantages are besides providing food, crop residues could be used for animal feed, energy production or for annual C input in the soil (non-market ecosystem service) and uptake soil N and reduce the potential for leaching losses. However, decision of using crop residues for market or non-market ecosystem services largely depends on the decision of the farmers. Non-market ecosystem services can also increase total value of the agriculture system if they are considered more in European subsidy payment system (Porter, 2003). Growing food and energy from same land would be helpful to reduce competition for land for food and energy production. Higher crop production from the available land might impede indirect land use change for crop production for food or energy purpose. Food security could also be improved by making local food available to local people. However to make local food available for the people further study of market structure, economy of the crops and consumer demand are necessary. Besides increasing crop production and reducing agriculture's environmental impact to solve the problem in agriculture it is also important to change our dietary intake. More food and food calories can be available for human by increasing allocation crops for human food instead of animal feed (Foley *et al.*, 2011).

The crops we tested as additional crop does not necessarily have to be grown after rye. They can be also grown as single crop during the summer. Nitrogen fixing crops: blue lupin, soybean, black bean and lentil can be grown during the summer in Ecological focus area (EFA) by the farmers in southern Sweden.

To develop successful cropping systems it is important to determine how cultivation of second crops affect the productivity of subsequent crops (Jensen *et al.*, 2010). Water and nutrient uptake by the double crops could make less water available in the system thus it might affect the production of the subsequent crops which could be disadvantages of the cropping system.

[14] In this study overall production is refers to the total production in one year from different crops in the system

6.3. Farmers’ Perspective

6.3.1. Current cropping system in southern Sweden

We have identified a number of factors influencing farmers’ decision of choosing common crops and existing cropping system in southern Sweden. The factors are government regulation, market structure, climate, biophysical condition (i.e. soil) and tradition. Vuillot *et al.* (2016) reported farmers with intensive specialized farms perceive economic constraints (market prices) as a major factor influence their practice on the other hand farmers with integrated and mixed crop-livestock farms perceive emphasize regulatory constraints (EU’s CAP) as main major factor influence their practice. In this experiment though we have not categorized our farms as intensive specialized farms and mixed crop-livestock farms however all the farmers pointed out that market price of the crops and government regulation influence their practices greatly.

At present farmers has to make decisions under high external pressures from world’s volatile market, national laws, environmental regulations and subsidy programs. Kohler *et al.* (2014) mentioned that farmers are subject to face mainly two kind of pressure: 1) political pressure from institutions and public regarding the way they practice their farming system and their behavior towards the environment, and 2) pressure in terms of land use linked to local and regional development processes for example residential settlements, industrial or commercial areas, transportation and infrastructure. These pressure along with economic condition for example market, European subsidies and climatic condition control farmers’ behavior. As a result of these pressure farmers often found themselves as a sufferer of “economic harassment” (Kohler *et al.*, 2014). There are more and more demands on the farmers as well as law and regulations have been charging more often. These uncertainties affecting farmers to plan ahead and the way they manage their farm (Darnhofer *et al.*, 2010). In our findings farmers also mentioned about their dissatisfaction of more often changing laws of CAP and difficulties to cope the cropping system with them.

Though CAP has started with an idea of improving a fair standard of living among farmers through increasing productivity and support internal prices to consumers, however it has created environmental and socio-economic problem among farming communities. Agricultural policies through subsidiaries, price regulations, legislation, and extension had enforced a structural change towards industrialized agriculture. These changes leaded to increased field size, specialization and intensive production (Bjorklund *et al.*, 1999). Agricultural intensification and specialization have negative effect on biodiversity and cause other environmental problems in agro-ecosystem (Ahnström *et al.*, 2008). Zhu and Lansink (2010) reported subsidy dependency also has negative impacts on farm efficiency. Due to the well payment from the government farmers become less motivated to do well in growing crops and become more dependent on subsidies.

All our interviewed farmers had reduced the number of worker in their farm in last several years and became more mechanized. The trend of reducing number of agriculture worker has been seen all over the Sweden. The number of labor work in agriculture has dropped by 10%

between 2000 and 2010 (Agricultural Census in Sweden, Eurostat 2012). CAP reforms by decoupled agricultural payment could be a reason of reducing number of farm labors. Moreover, cost of land, cost of labor and increase the size of rented land affects negatively the number of farm labors. Hiring labor to work at rented land decrease profit significantly. However, hired labor and family labor are substitute to each other that means reducing the number of hired labor means increasing the number of family labor (Kaditi, 2013).

The latest CAP reform was in 2014 was started reduce the negative impact of agriculture on the environment and enhance the efforts of farmers to follow better agricultural practices. However, our participants have pointed out that greening measures are not practical enough. The crop diversification measures (three crop rule) can be criticized particularly. It might cause negative effect on small farms and for those who used contractors. Adding more crops in the system would increase management cost of the farmers for the new crops and reduce efficiency. Moreover, possibilities of achieving environmental benefits are not so evident and the measure will have less environmental benefits than crop rotation (DEFRA, 2012). In Sweden production cost will become higher comparing with the neighboring countries for example Denmark, Germany and Netherland (Andersson, 2015). Our participants also mentioned about rigidity of CAP. To follow one common rule in all countries in Europe is difficult for farmers since the farmers in different countries have very little things in common (Zahrnt, 2009). Local circumstances must be taken into account specific policy areas for example environment and rural development (DEFRA, 2012).

The economic pressures on the farm works is in the favor of choosing existing cropping system. The markets for commonly grown crops are well established and farmers are well informed of the market structure and the buyers. Farmers perceive that in the existing economic and price support structure it is easier to earn money by producing couple of well-adapted crops than broader mix of crop species (Ahnström *et al.*, 2008) which is relevant with the result of our experiment.

Weed, leaching loss of nutrient and black soil problems were pointed out by our participants in their cropping system. These are common problems with modern agriculture (Altieri & Nicholls, 2000). Other problems that we have identified but were not mentioned as problems by our participants are using high level of fertilizer and pesticides. However, our participants agreed that chemical is big part of farm expenses. There are also indirect costs of using chemical on environment and public health for example contamination of water bodies and diseases (ibid). However it is difficult for the farmers to make management decision when society demands cheaper food and environmentally friendly production practices at the same time (Ahnström *et al.*, 2008). Therefore, these environmental problems related with agriculture are only subjected to solve by changing in techniques but social, cultural and economic issues that are the reason for these crisis should be taken into consideration (Altieri & Nicholls, 2000).

6.3.2. Farmers’ perspective about changing their cropping system

A farmer’s decision about adopting a cropping system based on several external factors such as climate change, markets, regulations and the availability of new technologies. Farmer’s own goals about production requirements, economics, and knowledge of environment and attitude to take risk are the personal factors that influence farmer’s decision of adopting cropping system (Tanaka *et al.*, 2002).

Our conventional farmers see the replacement of common crops grown in the region as a distant action. One of the major problems is associated with the lack of a stable market for these uncommon crops. Though farmers see environmental benefits of uncommon crops however farmer’s practical decision mainly guided by profit. Our finding is in accordance with the finding of a study done in UK by Carr and Tait (1991). According to their study agricultural productivity, efficiency and economic motives were stronger than environmental motives even though farmers are aware of environmental problems.

Not having suitable machineries for other crops mentioned by the farmers as limiting factor of diversifying their cropping system. The problem is similar with the soil also. Farmers have heavy soil are not suitable to grow vegetables. To solve these problems requirement of understanding of complex faming system is essential (Gonzalez, 2015). Adding more crops in the system would also increase the work load. One solution of this problem can be employing refuges as farmhands. A three-year pilot project has been taken in Switzerland in 2014 to allow refugees to work on the farms. It has been expected that through the successful implementation of the project both farm owners and refugees would be benefited by employing refuges in the farms. Farm owner would be benefitted by being able to access workers locally instead of employing seasonal workers outside of the country outside of the country. Refugees would be encouraged to be a part of the society in a better by learning national language and achieving financial independence (Chandrashekhar, 2015)

Couple of our participants has experimented with some uncommon crops for their region for example corn and buckwheat. Participants think that advisors can help farmers to choose the right system and right technique. Diffusion of farmer’s success stories was also identified by the participants as an important factor to motivate other farmers to try with different crops and cropping system. Improve communication and dissemination of concept of agroecology, intensification of sustainable production system and climate smart agriculture is important for successful implementation of concepts in practice (Gonzalez, 2015). Social institutions for example government, agricultural associations and local networks can play an important role in the dynamic process of diversification by promoting and sharing the knowledge of farming systems and motivating the farmers to adopt the new system (Bacon *et al.*, 2012).

Our participants agreed that organic crops have good market price and demand however lack of knowledge of controlling weed as a main problem to convert from conventional to organic. Effective weed control was seen as most important factor affecting success of conversion form conventional to organic by other research. It has been suggested that using bioactive natural products as an alternative of synthetic chemical herbicide can be an alternate option of controlling weed in organic system (O’Sullivan *et al.*, 2015). Acs *et al.* (2009) reported that policy incentives, such as taxes on using chemicals and subsidies would facilitate the conversion from conventional to organic.

6.3.3. Summary

Market price of the crops and government regulation influence farmers' practices greatly. Farmers find it difficult to cope their cropping system with the more often changing laws of CAP. An established market and good income from the second crops could be motivate farmers to adopt the system. From interview result it was interpreted that that absence of market, lack of suitable machineries to handle second crops and lack of knowledge of double cropping system might be the main barriers of potential adoption of bioenergy double cropping system by the farmers who are growing rye for biomass feedstock for bioenergy production.

7. Conclusion

Main aim of the study was to design a cropping system that can increase production, provide food, animal feed, biomass for energy and non-market ecosystem services. We found that yield of the double crops were optimistic for further study. Non-market ecosystem services can also be achieved by adopting this cropping system. Providing both food and biomass for energy might be helpful to reduce competition for land for food and energy production and indirect land use change. Furthermore, the cropping system might also be helpful to increase the local source of food.

Second aim of the study was to assess sustainability of the system literature review using SAFA as a concept. Our review of literature suggested that depending on the management practice the bioenergy double cropping system could be environmentally sustainable system and could increase income. Not many studies have done on effect of DC system on social factors. Therefore, to assess overall sustainability of DC system studies of social factors are also important.

Our third aim was to investigate motives and constrains that might affect farmers in their adoption of bioenergy double cropping system. Our interview results showed that farmers possibly adopt a new cropping system but their decisions are mainly guided by economic motives. An established market and good income from the second crop could be motivate farmers to adopt the system. On the other hand, absence of market, lack of suitable machineries to grow second crops and lack of knowledge of double cropping system might be the main barriers of potential adoption of bioenergy double cropping system by the farmers who are growing rye for biomass feedstock for bioenergy production.

8. Recommendation

This study identified that yield of second crops in bioenergy double cropping system were optimistic for further research specially the yield of buckwheat, lentil and black bean in southern Sweden. Further study could be done to investigate grain quality. It is very important to investigate effect of double cropping on water and nutrient availability on subsequent crops. Therefore, further study could be done to investigate effect of growing crops in double cropping system on the water and nutrient availability of the subsequent crops. Furthermore, performance of the second crops in different management practices for example in different water and nutrient management system could be done in order to find out best management practice for growing double crop.

In this experiment none of the participated farmers were growing rye for energy production. Further study could be done by interviewing farmers who are growing rye for biomass feedstock for bioenergy and studying their cropping system (i.e. crop rotation) in order to gain a better understanding of farmers' perspective of adopting bioenergy double cropping system.

Farmers growing winter wheat for energy production possibly grow double crops in their system since winter wheat and rye for biomass feedstock for bioenergy production have similar production period. Therefore, another areas of research interest could be investigating production of double crops after winter wheat and how to set best bioenergy double cropping system in farmers' crop rotation system.

9. Personal Reflection

It is possible to reduce competition between food and energy for lands by designing a multifunctional cropping system that would provide food, energy, non-market ecosystem services. However, reducing competition for land between food and energy and providing ecosystem services greatly depends farmers' land use decision. For example, if the second crops in this study that had been produced were to use for animal feed or for energy production instead of human consumption the objective of reducing competition for land would be undermined. Similarly, if crop residues was to be used for animal feed or for energy production the idea of providing ecosystem services by adding C in the soil from crop residues would be undermined too. In this scenario the role of researchers is to provide with possible alternatives even though research communities are not in the position to decide the purpose of growing crops. Nevertheless, this could assist the farmers to make the right choice suitable for their own requirements.

The study was challenging. The research worked needed careful planning. Literature search, field work, interview, data analysis and writing up were required to be completed within the given period of time. It was also important to focus in order to achieve the overall aim of the study. The research was interesting. The experience of setting up aims and objectives planning, designing and executing a project was a steep learning curve. It was a good opportunity to gain understanding of such a complex topic and learn how to manage a project.

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12. Appendix

Appendix 1. A list of theme and sub-theme of SAFA

Dimension	Theme	Sub-theme
Good governance		
Environmental integrity	Atmosphere	GHG
		Air quality
	Water	Water withdrawal
		water quality
	Land	Soil quality
		Land degradation
	Biodiversity	Ecosystem diversity
		Species diversity
		Genetic diversity
	Material and energy use	Material use
		Energy use
		Waste water reduction and disposal
	Animal welfare	Animal health
		Freedom from stress
Economic resilience	Investment	Internal investment
		Community investment
		Long-ranging investment
		Profitability
	Vulnerability	Stability of production
		Stability of supply
		Stability of market
		Liquidity
		Risk management
	Product quality and information	Food safety
		Food quality
		Product information
		Value creation
	Local economy	Local procurement
Social well-being	Decent livelihood	Quality of life
		Capacity development
		Fair access to means of
	Fair trading access	production
		Responsible buyers
	Labor right	Rights of suppliers
		Employment relation
		Forced labor
		Child labor
		Freedom of association and right
	Equity	to bargaining
		Non discrimination
		Gender equality
	Human safety and health	Support to vulnerable people

	Cultural diversity	Workplace safety and health provision Public health Indigenous knowledge Food sovereignty

Appendix 2. Questionnaire for the farmers

I. Background

1. Can you describe about yourself? What is your age, profession, education and family?
2. what kind of farm do you have? organic or conventional?
2. How long have you been farming?
3. How big is your farm? How many employees do you have?
5. What are the challenges you face as a farmer in the Skåne region?

II. Cropping system

1. Crop

- Which crop do you grow, how many ha for the crops, how many products do you get, from which product you get maximum money, where do you sell them
- How do you select your crop?
- Are you happy with yield?
- Would you like to have some other crop as your main crop?
- Do you think if you grow legume in your field the yields would be acceptable?
- There is market of new crop?
- Income from the bioenergy crop or hay

2. Crop rotation

- Can you describe your crop rotation system? Including cover crops, catch crops, fallow periods and tillage.
- Have you made any changes in your crop rotation ever since you have started farming? If yes then how many times, why and what are the changes?

3. What is the major expense of your cropping system?

4. From where or whom you can get advice when needed?

III. Environmental aspects

1. What are the main problems of your crop and cropping system? Insect, nitrogen leaching, biodiversity-

IV. Economy aspects

1. Do you have another source of income?

2. Do you have stable income from your farm?

3. Are you satisfied with your farm income?

4. Has your income increased over the last five years? How and what are the reasons?

5. Subsidies:

- Do you receive any kind of subsidies?
- What is your opinion about subsidies? Are you satisfied with them?
- How much you are dependent on subsidies

6. Do you have any crop insurance? What kind of crop insurance? For which crop?

V. Social aspects

1. How do buyers/consumers impact the way you produce and the selection of crops in your farming system?

2. Government policy

- How does government policy impact the way you product and select crop for your farming system
- Do you follow CAP?
- How do you want to utilize your EFA?
- Do you think you have to face economic loss because of EFA?

3. Do you receive technical assistance from government agencies or private consultations? Has the advice been useful?

4. Are you involved in any group of farmers?

5. Do you share information with other farmers in the region about the management of your farming system?

6. Have you participated in making decisions concerning agricultural policies? If so ... how?

7. Worker:

- How many workers are assisting you on the farm?
- Do they have good level of wage?
- Do they have any opinion on decisions on crop production?

VII. Diversification cropping systems

1. How feasible might it be to introduce new crops in your cropping system? What crops do you think what could be introduced? e.g. Introduction of legumes, catch crops, cover crops.

2. What are the greatest obstacles to strengthen the diversification of your cropping systems?

3. What kind of support do you think is necessary for the farmers when they decide to diversify their cropping systems? By the government, the EU, the advisory companies?