Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

The Faculty of landscape Planning, Horticulture and Agriculture Science

Effect of Varietal and Species Diversity on Nitrogen Fixation and Nitrogen Cycling in an Organic Faba Bean-Spring Wheat Intercropping System

Nawa Raj Dhamala

Master´s thesis • 30 ECTH • Advance level
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Kvävefixering och kvävecirkulering i sort-och artblandningar av åkerböna och vårvete i ett ekologiskt odlingssystem

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Foreword

I am from an agricultural country: Nepal, where more than 60 % populations are actively involved in agriculture and is the back bone of national GDP. Nepalese agriculture is bestowed with tremendous potential in terms of climatic niches and biodiversity but the paradox is that we have not yet been able to harness the potential and food security always became the challenging issue. Creating sustainable farming system and changing the trend in farming has always been my interest. My admission in Agroecology master program provided me a platform to acquire more knowledge and make contributions to the development of sustainable agro ecosystems.

Two years of study in Agroecology was a very nice training on investigating agriculture from system perspective; an interacting factor of human system, food system and ecological system. Different courses within the program made me trained to formulate and provide suitable approaches to different agricultural production environment including socioeconomic status of the farming communities. Different excursions, farm visits, case studies and report writing were very good learning to work in research and development organizations. The degree has strengthened my vision to reduce environmental impact of modern agriculture production system through increasing the potential of natural system to provide more goods and services. Master thesis and project based research training provided the opportunity to gain more knowledge for developing best crop rotation in organic production system including legumes. The experiences of master thesis exposed myself with advanced tools and develop analytical and research capabilities through field experiment, laboratory works, and field visit in Morocco including interaction with some concerned stakeholders.

Overall, the program strengthened my capacity to deal with sustainability, resource use, land use, multifunctionality and ecosystem services in agricultural production system. I can use the gained knowledge to address both opportunities and barriers in agriculture. In addition, the acquired knowledge will be helpful to provide different management options and alternatives both in mechanized small scale farming making it socially, environmentally and economically viable. I believe that the gained degree has enabled me to develop a scientific career to carry out both education and research, particularly in the fields of ecological agriculture and promoting diversity. To make the program more agricultural oriented and practical, additional courses related to crop production can be added as mandatory or elective.

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I thank Erik Rasmusson for supporting me by providing precipitation data for the particular growing season. I would like to extend my sincere gratitude to Jan- Eric Englund for helping me in data analysis and Ali Hafeez Malik for his support also in data analysis and technical advices as and when needed. My sincere thanks also go to Prof. Cherki Ghoulam and Marney Isaac for their valuable and constructive comments on my study result from field experiment and suggestions to discuss and analyze it. I also wish to thank to all my friends at SLU, Alnarp who cooperated with me and showed their interest to give suggestions, information and possible advice during whole period of experiment and report writing. I am also highly grateful to all the members of department of Agrosystem and SLU administration for their unconditional help and support.

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Abstract

This study was undertaken to evaluate the effect of varietal and species diversity of faba bean and spring wheat on N_2 fixation and N cycling in an organic system. The field experiment was carried out at SLU Alnarp to quantify biological N_2 fixation using ^{15}N natural abundance method. The measurements were taken at two physiological stages of faba bean, at pod filling and at full maturity. In general N_2 fixation, shoot N yield and soil N uptake increased at maturity while the proportion of N derived from fixation, %Ndfa and biomass yield decreased. No significant effect of diversity was found on N_2 fixation but significant effect of diversity on %Ndfa was recorded at full maturity. Significantly positive correlation was found between the amount of N_2 fixed and biomass yield, %Ndfa and N concentration. Soil N uptake positively correlated with shoot N yield but negatively with N_2 fixation. The calculated biomass yield and N_2 fixation per sown faba bean plant showed the increased advantage of varietal mixture and intercropping. The advantages also occurred in residual Nitrogen, Crop Harvest Index, Nitrogen Harvest Index, Nitrogen Balance and Nitrogen Utilization Efficiency. Significantly higher Nitrogen Utilization Efficiency was found in mixture of Alexia, Gloria and Wheat. Highest N balance was found in mixture of Alexia and Gloria. Crop Harvest Index was highest in mixture of faba bean varieties with spring wheat but the growth and development of wheat was highly suppressed in the mixture.

The potential application of the study outcomes in practical farming situations was estimated by a questionnaire study with structural and semi structural questions. The questionnaire was sent to advisors working within the organization "Greppa Näringen" (Focus on Nutrients) program to increase farmers' awareness about agricultures' potential impact on climate change. The interest among responding advisors (13 out of 35 who received the questionnaire) on crop diversification was high. The diversity in cropping system including faba bean was perceived important by a majority of the advisors mainly for developing crop rotation that decrease the need to buy animal feed and industrial N. Marketing, harvesting and susceptibility to drought were the main concerns associated with diversification of faba bean crops. Based on the results from the empirical study and questionnaires I can conclude that diversification of cropping systems is a very important strategy from both environmental and agronomic aspects.

Key Words: Advisors, Cropping system, Diversity, N_2 fixation, N cycling, ^{15}N natural abundance, Questionnaires

Abbreviations

$\delta^{15}N$	Per mill deviation in $^{15}N/^{14}N$ ratio between sample and atmospheric nitrogen
B	$\delta^{15}N$ of faba bean when nitrogen fixation is only the sole source of nitrogen
CHI	Crop harvest index
DM	Dry matter yield
GHG	Green house gas
Ha.	Hectare
LER	Land equivalent ratio
N	Nitrogen
%Ndfa	Percentage of nitrogen derived from atmosphere
NHI	Nitrogen harvest index
NUE	Nitrogen utilization efficiency
SE	Standard error

Abbreviations used for crop varieties

A	Alexia- Faba bean
Dw	Dacke- Spring wheat
G	Gloria- Faba bean
J	Julia- Faba bean

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1. Introduction

1.1 Nitrogen

Nitrogen is one of the most important and key plant nutrients for global food production system (FAO, 2008). Agricultural production and productivity heavily relies on nitrogen (IFA, 2007). Most non legume plants require 20-50 g N to produce one kg of dry matter yield (Robertson and Vitousek, 2009). Present global agricultural production systems annually consume about 150 to 200 million tons of mineral nitrogen (Unkovich et al, 2008) and it is anticipated to increase about three fold during the coming forty years (Good et al, 2004). Worldwide increase in food production to sustain the existing demand has further strengthened the demand of fertilizer and energy use in agriculture production system (FAO, 2008). It is mainly accomplished by increasing N inputs which undoubtedly increase the demand of N fertilizer (IFA, 2007).

Farming systems that promote intensive use of chemical fertilizers, especially nitrogen, only to increase the soil chemical fertility decrease the soil biological fertility and increase the risks for loss of nutrients through erosion, leaching and gaseous emission (Tilman et al, 2002; Kristiansen et al, 2006; IFA, 2007). Nitrogen loss through denitrification releases the green house gas (GHG) nitrous oxide (N_2O). It also affects the stratospheric ozone layer that protects the biosphere from the harmful ultraviolet rays and also regulates the earth temperature. Industrial production, distribution and application of N fertilizer require large amounts of energy. According to UNEP (1998) production of one metric ton of N fertilizer through the Harber-Bosch process consume about 873 $m^3$of natural gas. Similarly in a cropping system where N is applied as fertilizer, it represents about 10-20% of total invested energy (Hauggaard-Nielsen et al, 2009). In cereal it constituted up to 51% of total fossil fuel energy used, in grass-forage it is up to 61% of the total fossil fuel energy used and in pure stand of grass it is up to 80% (Ibid).

Agricultural practices that reduce the biodiversity, by promoting monoculture, simultaneously decrease the ability of natural system to provide goods and services in the ecosystem (Tilman et al, 2002). According to FAO (2010), significant progress towards recovery of soil N via biological processes has been noticed but the progress is slow and not yet meeting the rapidly increasing demand. Therefore, to ensure sustainable farming practices for overall agronomic and environmental benefit, improvement of N use efficiency via enhanced biological N_2 fixation and reduced N losses is crucial (IFA, 2007).

1.2 Nitrogen fixation

Biological N_2 fixation is the process in nature where N_2 gas is reduced to ammonia (NH_3) with the help of the enzyme nitrogenase, adding N to the agricultural system (Wild, 1994; Fageria and Baligar, 2005). The *Rhizobia* species of bacteria living in symbioses with legume plants in their root nodules perform the process using energy from the photosynthesis in the form of ATP (Prasad and Power, 1997). The ammonia formed during the chemical reaction is immediately transformed to ammonium (NH_4^+) in the bacterial cells and becomes directly available to plants. For the natural ecosystem it is the main source of N (Wild, 1997). The N_2 fixation by legumes and its potential transfer to other non legume plants has great importance in nutrient management and sustainable economy of nitrogen (Høgh-Jensen and Schjoerring, 1994). In organic cropping systems, symbiotic N_2 fixation is the key source for the nitrogen supply. However, there is often high variation in N_2 fixation by legumes, caused by environmental variations in plant growth conditions, choice of legume species, geographic location and crop management. Generally, biologically fixed nitrogen by legumes contributes about 30 to 50 gN/m2/year in rotation (Vinther and Jensen, 2000) and legumes can fix 15-25 kg shoot N for every ton of shoot dry matter produced (Unkovich et al, 2008). Because of low losses prior to and during the culture of legume crops, losses of nitrogen are very low when the production system fully depends on biological N_2 fixation (Jensen and Hauggaard-Nielsen, 2003). Low energy use when relying on biological nitrogen fixation by legumes significantly reduces the energy consumption require for nitrogenous fertilizer (Jensen et al, 2011).

1.3 Nitrogen cycling

Agricultural practice directly involve N cycling through N_2 fixation, N uptake from the soil, release of N from plant residues, green manuring, root exudates together with leaching and gaseous losses entering N to atmospheric N cycle. Legumes play a very important role for restoring and maintaining soil organic carbon and residual soil nitrate (Snyder et al, 2009), and the nitrogen balance in the soil plays a key role for soil carbon sequestration (Jensen et al, 2011). Cropping systems containing mixtures of legumes and non legumes with high capacity to take up soil N enhance the efficiency of N_2 fixation by legumes and nitrogen use efficiency of the whole system (Carlsson, 2005). It promotes a tight N cycle with minimum loss and demand of N from external sources. The nitrogen recovery from the soil is higher in legume-non legume mixture than sole cropping (Suleyman, 2003). According to the study by Hauggaard-Nielsen et al. (2009), the efficiency of using nitrogenous resources by legume and non legume when they are grown in different forms of mixture is 30-40% more than sole cropping. Although exports of N in harvested products is the main limitation for N cycling in agricultural production system (IFA, 2007), the N_2 fixed by legumes is not always fully removed with harvested biomass. A portion of the fixed N is also left in residues, root exudates and in soil, providing N pools that can be mineralized and made available to subsequent crop(s) (Yang et al, 2010).

1.4 Crop diversification of legume and cereal

Crop diversification increases the functional traits operating within the system, and interactions of such traits may have positive effects on system productivity and sustainability (Palmborg et al, 2005). Diversified cropping systems based on locally available resources are sustainable from agro ecological and socioeconomic points of view as crop diversification can be adopted differently in different regions considering the agro ecological and socioeconomic situation of farmers (Lin, 2011). Different economic and common practices can be taken into consideration during diversification, for example: crop rotation mixed and inter cropping, adopting different crop varieties. Diversification in terms of new crop varieties can perform better in changing environment condition and such adaptation in agriculture may have positive influence for reducing yield losses and improve the resistance to diseases and pests (McCarl et al, 2001).

Crop diversification with legumes reduces the use of fossil fuel energy and emission of green house gases from mechanized and intensive agricultural production system (mainly carbon dioxide, methane and nitrous oxide) by reducing the use of non-renewable energy sources for production and application of N fertilizers (Nagy, 2001 and Aydinalp, 2008). Applications of low carbon to nitrogen residues with increased diversity in cropping system enhances soil carbon and nitrogen retention and are very important for sustainable food production (Drinkwater, 1998). Cultivation of the crops in mixture, especially legumes and non legumes, not only benefits the supply and use of soil N, but also improves the cropping system productivity by efficient use of a range of resources, including other nutrients other than N, moisture, space and solar energy (Kumar, 2007).

1.5 Varietal mixtures in cropping system

Growing varieties of a same species in mixture is not so common in present agricultural practice, and studies on varietal mixtures of legumes are very rare. Available studies have suggested that increased legume varietal diversity may improve yield stability, resource use efficiency and biodiversity (Helland and Holland, 2001; Vallavieille-Pope, 2004; Biabani, et al, 2008). In addition, varietal mixtures may provide buffering against pests and diseases, and suppressing weeds depending on specific growing conditions (Kaut et al, 2008 and Frankow-Lindberg et al, 2009), intensity of stresses (Cowger and Weisz, 2008) and optimum level of diversity (Helland and Holland, 2001 and Biabani et al, 2008). According to the study result of Biabani et al. (2008) different morphological characteristics and complementarities of varieties improves vegetative growth, seed yield and LER. Similarly growing susceptible and resistance varieties together reduces the incidence of diseases and pests by loss of inoculums, providing physical barriers for the dispersion of spores and enhancing defense mechanism (Vallavieille-Pope, 2004). Such management of disease and pest provides the low input agriculture production, especially by reducing the need of agrochemicals (Vallavieille-Pope, 2004). Recent study outcomes have indicated varietal mixtures as potential alternative against biotic and a biotic stresses in crop production and benefit also can be exploited in forage and pasture production (Frankow-Lindberg et al, 2009). Majority of previous studies have emphasized the need of further investigations and profound knowledge of interaction of varieties and their response to particular agro climatic condition to harness the optimum benefit of mixtures (Kiar et al, 2012). Despite of these facts, studies on role of varietal mixtures on N_2 fixation and N cycling are very limited, and for faba bean there are no published results. Many previous studies on faba bean diversification concentrated on mixtures with cereals, shown to have great potential to enhance N_2 fixation and N cycling, but references on varietal diversity of faba bean itself is very uncommon. I therefore found the investigation of varietal mixtures of faba bean and its effect on nitrogen fixation and N cycling is a new and very interesting topic.

1.6 Faba bean

Faba bean (*Vicia faba* L.) is an important grain legume crop all around the world, having high ability to fix N_2 under broad spectrum of environmental condition and crop rotations together with high N benefit to the subsequent crop (Jensen et al, 2010; Köpke and Nemecek, 2010). It is one of the best break crops in cereal dominated cropping systems and provides high quality protein, feed to pollinators, and a potential alternative to replace soybean meal (Köpke and

Nemecek, 2010). Faba bean is good source of green manure and raw material for bio energy. Even though the total grain production of faba bean has doubled during the last 50 years, and despite its many agronomical, ecological and economic benefits, the areas of faba bean cultivation has declined during the same period (Jensen et al, 2010). Farmers are still hesitating to grow faba bean in commercial scale, mainly due to seasonal and spatial fluctuation in yield and abundance of diseases and pathogens. Therefore the interest to study of faba bean is not confined to N_2 fixation and grain yield, but also for developing sustainable and diversified cropping systems with improved yield stability and reduced dependency on N fertilizers and fossil energy.

2. Aim and hypothesis

The approach of this study is to determine the effect of varietal diversity of Faba bean with and without spring wheat grown as cereal intercrop in organic cropping system on N_2 fixation and N cycling. Stakeholder's perception on crop diversification of legume and inclusion of faba bean in cropping system were studied by a questionnaires with structural and semi structural questions.

2.1 Aim

The main aim of this study was to determine varietal mixtures of Faba bean (*Vicia faba*) grown with and without intercropping with Spring wheat *(Triticum aestivum)* for their possible effect on N_2 fixation and N cycling, including potential implications of the study outcome by understanding the perception of concerned stakeholders.

2.2 Objectives

- To calculate relative dependency on N_2 fixation and total amounts of nitrogen in different levels of crop and varietal diversity and see its role on N cycling
- To find out opinion of advisors working for sustainable agriculture and sustainable nutrient management in cropping system to know their perception on prospect, potential and constrains of legume based crop diversification including faba bean and cereal in cropping system through questionnaire-based assessments

2.3 Hypothesis

- Increased crop and varietal diversity improves N_2 fixation, and thereby promotes the reliability on legumes for N cycling at the cropping system level.
- Potential benefits of increased varietal and species diversity is well perceived by advisors

3. Materials and methods

Three Faba bean varieties- Alexia, Gloria and Julia were cultivated in field as single varieties and in two- and three-varietal mixtures, with and without spring wheat as cereal intercrop. These three faba bean varieties, as well as the spring wheat variety (Dacke), are current market varieties in Sweden for both organic and conventional producers.

3.1. Site and experimental design

The experiment was carried out at Alnarp, Skåne, Sweden in 2011. The experimental site consisted of a loamy clay soil and was managed according to organic farming practices since 1993. The precipitation during the growing season 2011 was 398 mm. Maximum precipitation occurred in August and minimum in April which was 136 mm and 20 mm respectively. The record of precipitation was taken from Lönnstorp climate station (SLU Alnarp) situated about two kilometers from the experimental site. The field experiment was part of a larger experimental design within a two-year project to evaluate the yield stability in varietal mixtures of *Vicia faba* and spring wheat. The whole project consists of fifteen treatments in four replicate blocks. In my study I have selected nine of these treatments. The allocations of treatments were based on percentage of seed density of each faba bean and spring wheat variety in pure stand and fractions of seed density in mixtures which are shown below in table 1. The size of each experimental unit (plot) was 15m×2m. Sowing was done during the third week of April, 2011.

Table 1: Individual treatments (experimental units) and their crop and species composition with percentage of seed density for each component sown

Treatments	Treatment composition with percentage of each component's seed density when sown in pure stand.	Symbolic representation
A	Alexia (A) 100%	A
B	Gloria (G) 100%	G
C	Julia (J) 100%	J
D	Alexia 70% + Dacke (Dw) 30%	A+Dw
E	Alexia 50% + Gloria 50%	A+G
F	Alexia 35% + Gloria 35% + Dacke 30%	A+G+Dw
G	Alexia 33% + Gloria 33% + Julia 33%	A+G+J
H	Alexia 23% + Gloria 23% + Julia 23% + Dacke 30%	A+G+J+Dw
I	Dacke 100%	Dw

Alexia, Gloria and Julia are three faba bean varieties and Dacke is spring wheat variety

3.2 Observations and data collection

Above ground plant biomass was sampled 1) at pod fill (28-29 July 2011) and 2) at full maturity (6-7 September 2011) stages of faba bean. Root samples of both faba bean and wheat were collected from selected treatments on 12 September, 2011. A 0.25 m^2 area was demarcated in each experimental unit using 0.5m×0.5m metal rectangular frame to fix the sampling area, placed within 4 m from the edge of the experimental plot (total plot length = 15 m).

All plant material inside the metal frame was cut manually above five centimeter from the ground level and separated into faba bean, spring wheat and weed species. Then sampled plants were oven dried at 60ºC for 24 hours (Palmborg et al, 2005; Carlsson et al, 2009). The dried samples were ground in milling machine (Foss Cyclotech 1093).

The ground plant material was further homogenised with metal beads in 2 ml eppendorf tubes, using an eppendorf adaptor and a mixer mill. About 1-5 mg of each plant sample was then placed in tin capsules and sent to the Technical University of Denmark, Risø National Laboratory for Sustainable Energy, Bio systems Division, for isotope ratio mass spectrometer analysis of ^{15}N and N concentration.

3.3 Measurement and Calculation

3.3.1 Biomass production

The total biomass yields were calculated by adding biomass yield of faba bean and weed for sole cropping of faba bean varieties, wheat and weed for sole cropping of wheat and faba bean, wheat and weeds for treatments having mixture of spring wheat and faba bean varieties. The total biomass production expressed in kg per ha was calculated as:

Kilogram per hectare = Measured value in gram per 0.25 m^2 area (x) ×40

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

Since faba bean-spring wheat intercropping had lower seed density per species than pure stands, biomass was also expressed per sown plant by dividing each species' biomass per m^2 with the total number seeds sown per m^2 for each species, respectively. The seed density of faba bean was 80 seeds per m^2 in pure stands and varietal mixtures without spring wheat, and 56 seeds per m^2 when mixed with spring wheat. For spring wheat, the seed density was 600 seeds per m^2 in pure stand and 180 seeds per m^2 when mixed with faba bean.

3.3.2 Nitrogen Fixation

Measurement of N_2 fixation in faba bean was done by using the ^{15}N natural abundance method (Amarger et al, 1979; Cadisch et al, 2000; Carlsson et al, 2009). This method measures the proportion of nitrogen derived from atmosphere (%Ndfa) by legumes comparing deviation from atmospheric ^{15}N abundance ($\delta^{15}N$) values of close non fixing species (Holdensen et al, 2007). It works with the principle that the N_2 fixation process brings change in $\delta^{15}N$ of fixing plant compared to non-fixing neighboring reference plant species (Carlsson and Huss-Danell, 2003). The ^{15}N content of reference plants provides the measure of ^{15}N abundance in soil N available to fixing plant (Hauggaard-Nielsen et al, 2010). The differences in $\delta^{15}N$ between N derived from soil and N derived from atmosphere are reflected by $\delta^{15}N$ of reference plants and B value measured in fixing species.

The percentage of N_2 derived from the atmosphere (%Ndfa) is calculated as:

$$\%Ndfa = \frac{\delta^{15}N \text{ of reference plant- } \delta^{15}N \text{ of fixing plant}}{\delta^{15}N \text{ of reference plant- B value}} \times 100$$

Where, $\delta^{15}N\%$= [15N/14N of sample/15N/14N of standard-1] ×1000 (standard=atmospheric N_2)

The B value is the $\delta^{15}N$ of Faba bean when grown in nitrogen free environment where nitrogen from the fixation is the only N source (Carlsson et al, 2009). Spring wheat grown as cereal intercrop with Faba bean and sampled weed species were used as reference plants. In plots containing spring wheat as cereal intercrop, the mean $\delta^{15}N$ from weed species and wheat were used. It is very important to use correct B values for the accuracy of percentage biological nitrogen fixation by legume (Francisco et al, 2010). A measured B value was available for one of the used faba bean varieties, Gloria, from previous experiments (Carlsson, unpublished data), and this value (-0.36) measured in faba bean whole above ground biomass) was within the range of commonly observed B value for different experiments in different varieties of faba bean (Fan et al, 2006 and Unkovich et al, 2008).

The amount nitrogen fixation per 0.25 m^2 was calculated as:

Nitrogen fixation per 0.25 m^2 per year = Harvested dry matter (g/0.25 m^2/year) ×N concentration (g N/g DM) × PNdfa (Carlsson et al, 2009)

Nitrogen fixation per ha per year= Harvested dry matter (g/0.25 m^2/year) ×N concentration (g N/g DM) × PNdfa×40

3.3.3 Other N pools and crop parameters

Total above ground plant N yield:

The total above ground N was calculated adding N yield from each component species.

  - N in particular species (faba bean/wheat/ weed) =%N/100×biomass yield

- Soil N uptake= Total above ground N yield- amount of N_2 fixed (Hauggaard-Nielsen et al, 2009)
- Residual N left in plant above ground tissue after harvesting of seed= Total shoot N yield- Total seed N yield

The seed N was not measured within this study due to time limitation, but will be included in the overall project. To estimate seed N yields and quantities of residual N, seed N concentrations were approximated based on whole plot seed yield and literature data of protein and N concentrations in faba bean and wheat seeds, respectively (Debaeke et al 1996; Anersson 2005; Alghamdi 2009; Noubissie et al. 2012; Rugheim and Abdelgani, 2012)

Seed N yield of wheat = (2.5/100) ×seed dry matter yield.

Seed N yield of faba bean = (5.25/100) × Seed dry matter yield

Crop Harvest index (CHI) = Grain DM weight/total above ground DM weight (Andersson, 2005)

- Nitrogen Harvest Index (NHI)=Amount of N in grain yield/amount of N in above ground plant part (Andersson, 2005)
- N Balance= Amount of N_2 fixed-Seed N yield (Lo´pez-Bellido et al, 2006)
- Nitrogen Utilization Efficiency (NUE)= Grain dry weight/amount of N in above ground plant part (Dawson et al, 2008)

3.3.4 Land Equivalent Ratio (LER)

LER was calculated to determine the benefit of mixed cropping over sole cropping. A calculation for LER was made for those experimental units which were in the mixture of Faba bean varieties and spring wheat. Individual faba bean varieties could not be distinguished in varietal mixtures, so LER calculations were based on faba bean as one unit irrespective of whether it was composed of one or several varieties. Calculated land equivalent ratio gives the estimate of total land area required under sole cropping to harvest the same yield achieved from mixed cropping (Andersen, 2005) which was calculated adding the partial LER values for individual component crops in mixture applying this formula (Andersen 2005; Bedoussac and Justes, 2011)

$$\mathbf{LER=A_{IC}/A_{SC}+B_{IC}/B_{SC}}$$

Where A and B are component crops grown in mixture

A_{IC}= Crop A in intercropping, B_{IC}= Crop B in intercropping, A_{SC}= Crop A in sole cropping and B_{SC}= Crop B in sole cropping

3.4 Survey of the study outcomes

To estimate the possible implication of the research outcome among farming communities, a questionnaires with structural and semi structural questions was sent to advisors within **Greppa näringen (Focus on nutrients)** working specifically with actions against emissions having potential climate effects. The small survey included advisors working for sustainable agriculture both in organic and conventional farming system with and without livestock. The questionnaire aimed to understand advisors perception on crop diversification, legume cultivation and its possibilities of future development. Focuses were given to prospects, potentials and constraints of crop diversification with legume, faba bean cultivation and their potential role for reducing the environmental impact. The questions are presented in appendix 1.

Further application of the study and areas of potential research on crop diversity of faba bean and wheat or barley was also studied during a visit to university of Cadi Ayyad, Marrakech in Morocco, where I was involved in field visits and laboratory work during February 15, 2012 to February 22, 2012.

3.5 Statistical Analysis

Microsoft office Excel and Microsoft office Word were used to gather, compile, make general calculations and table and graphical presentations of data. Significant differences between the biomass yield, %Ndfa, N concentration, and total nitrogen yield were analyzed with ANOVA and Tukey test using general linear model (GLM) in Minitab 16 and least significant difference test (LSD) in SAS[19]. In cases where the Tukey and LSD tests indicated significant treatment effects despite lack of significance according to ANOVA, the non-parametric two-sample Mann Whitney test was used to verify significant difference between treatments. Pearson correlation analyses were performed using in Minitab. The P-Values calculated in ANOVA and correlation analysis were compared at significance level $P<0.05$. Normality of data was tested in Minitab before analysis and made sure that all the data are normally distributed.

4. Results

The presented results are the treatments (for details about the treatments see table 1) effect on biomass yield, N_2 fixation and parameters associated to N_2 fixation- δ15N, %Ndfa, N concentration and reliability of legume for N cycling. The effects on all the parameters are listed and described as needed for the calculation of N_2 fixation and associated phenomenon. Except for the measurement for root biomass, all the results presented here are based on above ground whole plant parts measured at two different physiological stages of faba bean-one at pod filling stage and another at full maturity of faba been.

4.1 Effect on Biomass Production

4.1.1 Total Biomass Production

The harvested biomass yield ranged between 9 and 10.9 and, 7.3 and 11.9 tons per hectare measured at pod filling and full maturity respectively. Higher biomass was calculated at pod filling stage except from pure stand of Julia (J) and mixture of Alexia and Gloria (A+G). The highest biomass production per hectare was measured in mixture of A+G at both harvesting occasions which was 10.9 tons per hectare at pod filling and 11.9 ton per hectare at full maturity. Lowest biomass was observed in mixture of A, G, J and Dw (A+G+J+Dw) at pod filling stage and in mixture of A and Dw (A+Dw) at maturity (Figure 1).

The variations within treatments (shown by error bar in figure 1) were often higher in mixtures of faba bean and wheat except in mixture of A+G+Dw at pod filling stage. In contrast, at maturity, within treatments variations were higher among sole cropping of Faba bean. Mixture of A+G thus showed increased potential with low variation between blocks when grown in mixture even though it was not significantly different ($P>0.05$) from other treatments.

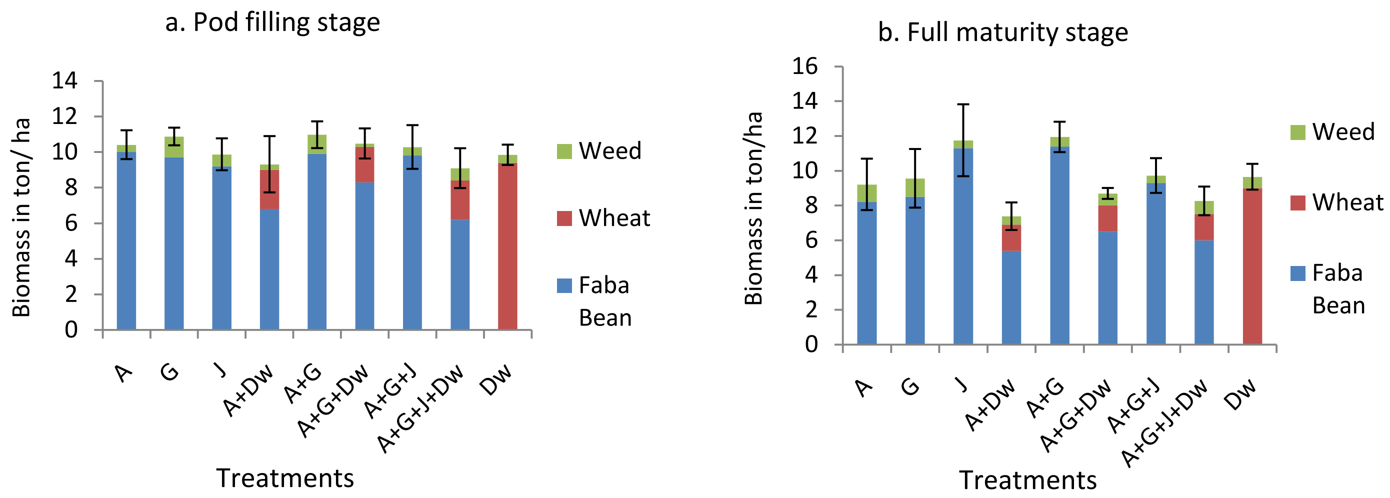

Figure 1: Biomass yield measured in above ground whole plant part at pod filling and full maturity of Faba bean. Each bar is the mean value of four replicates. Error bar represents +/- standard error (SE) calculated from total yield (sum of faba bean+wheat+weeds).

4.1.2 Faba Bean and Wheat Biomass Production

Significantly higher faba bean biomass yields were observed in mixture of A+G and pure stand of J. Both at pod fill and maturity, mixture of A+Dw and mixture of A+G+J+Dw showed lowest faba bean biomass yield.

At pod filling stage, the highest amount of faba bean biomass per plant was recorded in mixture of A, G and Dw (A+G+Dw), while at full maturity, it was highest in mixture of A+G followed by pure stand of J. However, the effect of treatment on faba bean biomass per plant was not statistically significant at neither of the maturity stages. Wheat was highly suppressed when grown in mixture with faba bean, especially at full maturity where amount of biomass per sown wheat plant was significantly ($P<0.05$) higher in pure stand (Table 2).

Table 2: Amount of biomass yield per sown faba bean and wheat plant in gram. Values represent mean value from four blocks for each treatment. Numbers within the same column followed by same letter are not significantly different

Treatments	**Pod filling stage**		**Full maturity stage**	
	Faba Bean	Wheat	Faba Bean	Wheat
A	12.5 a	-	10.3 a	-
G	12.1 a	-	10.6 a	-
J	11.5 a	-	14 a	-
A+Dw	12 a	1.23 a	9.6 a	0.81 b
A+G	12.3 a	-	14.2 a	-
A+G+Dw	14.9 a	1.15 a	11.5 a	0.85 b
A+G+J	12.7 a	-	11.7 a	-
A+G+J+Dw	11 a	1.24 a	10.7 a	0.81 b
Dw	-	1.56 a	-	1.51 a

Highest root biomass (taken after full maturity) was observed in mixture of A, G and J (A+G+J) which was 946 Kg per ha followed by pure stand of A (880 Kg/ha) and J (730 Kg/ha). The variations with in treatments were higher in pure stand of A, mixture of A+ G+J+Dw and mixture of A+G+J (Figure 2). Roots of both faba bean and wheat showed signs of initial decay at the time of root sampling, and the recorded root biomass is most likely underestimated.

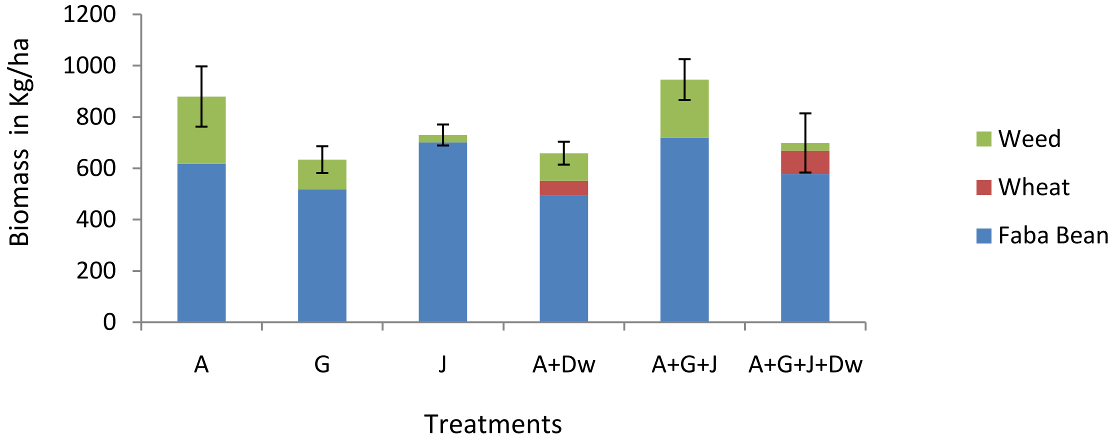

Figure 2: Root biomass yield taken after full maturity of faba bean and wheat taken from six selected treatments. Values represent mean value from four blocks for each treatment. Each bar is the mean value of four replicates +/- standard error (SE).

Correlation analyses between roots and shoot biomass showed a negative relationship at pod fill stage of faba bean and a positive at maturity, but the strength of relationship was very low ($P>0.05$) with correlation coefficient -0.005 and 0.246 at pod filling and full maturity respectively. Total biomass at pod fill was positively correlated with seed yield at maturity, although not statistically significant ($p>0.05$), while total biomass at maturity showed a significant positive relationship with seed yield ($P<0.05$).

4.2 ^{15}N in fixing and reference species (δ^{15} N)

Both Faba bean and reference species (wheat and weeds) showed higher δ^{15} N at full maturity than at pod fill. The δ^{15} N of Faba bean was lower than reference species at both development stages, and wheat always had higher δ^{15} N than weed species (Table 3).

Table 3: $\delta^{15}N$ measured in faba bean, wheat and weed species at pod filling and full maturity of faba beans. Values represent mean value from four blocks for each treatment. The numbers with in the same column followed by the same letter are not significantly different

Treatments	**Pod filling stage**			**Full Maturity stage**		
	Faba Bean	Weed	Wheat	Faba Bean	Weed	Wheat
A	0.92 a	3.72 a	-	2.35 a	4.7 a	-
G	0.52 a	3.8 a	-	1.55 ab	5.05 a	-
J	1 a	4.05 a	-	1.95 ab	3.9 a	-
A+Dw	0.62 a	3.5 a	4.47 bc	1.05 ab	4.22 a	6.4 b
A+G	0.5 a	4.67 a	-	1.45 ab	4.05 a	-
A+G+Dw	0.2 a	4.07 a	5.47 a	0.85 b	4.6 a	6.87 b
A+G+J	1.37 a	3.52 a	-	1.55 ab	4.15 a	-
A+D+J+Dw	1.02 a	4.1 a	5.22 ab	1.05 ab	5.05 a	8.45 a
Dw	-	3.4 a	4.1 c	-	5.17 a	6.06 b

At both pod filling and full maturity, faba bean $\delta^{15}N$ tended to be lower in varietal and species mixtures than in pure stands of single varieties (except for A+G+J and A+G+J+Dw), and at full maturity the faba bean $\delta^{15}N$ was significantly lower ($P<0.05$) in the mixture of A+G+Dw than in pure stand of A. The δ^{15} N for weed species were ranged between 3.4 and 4.67, and 3.9 and 5.17 at pod filling and maturity respectively showing no statistical differences ($P>0.05$) between the treatments. The δ^{15} N of wheat was higher in mixture with faba bean than in wheat pure stands at both measurement occasions, although the effect was not significant for all mixtures (Table 3)

4.3 Nitrogen concentration

The N concentration was lower at pod filling then at maturity faba bean. The N concentration of faba bean at pod filling stage varied between 1.85% and 2.43%. The highest values were measured in mixture of A+Dw and mixture of A+G+J+Dw, and the lowest in pure stand of J and mixture of A+G but were not statistically different (P>0.05). The N content in wheat increased significantly when grown in mixture with faba bean (Table 4).

Table 4 Nitrogen concentrations measured in above ground plant parts of faba bean and spring wheat both at pod filling and full maturity and in root after full maturity. Values represent mean value from four blocks for each treatment. Numbers with in the same column followed by the same letter are not significantly different

Treatments	**Above ground plant part**				**Root**	
	Faba Bean		**Wheat**		**Faba bean**	**Wheat**
	Pod filling	Full Maturity	Pod filling	Full Maturity		
A	2.23 bac	2.82 bc	-	-	0.57 a	-
G	2.38 ba	3.06 bc	-	-	0.6 a	-
J	1.85 c	2.7 dc	-	-	0.72 a	-
A+Dw	2.43 a	2.33 d	1.94 a	1.71 a	0.57 a	1.81 a
A+G	1.9 bc	3.21 ba	-	-	-	-
A+G+Dw	2.16 bac	3.49 a	2.05 a	1.6 a	-	-
A+G+J	2.06 bac	3.1 bac	-	-	0.72 a	-
A+G+J+Dw	2.43 a	3.52 a	2.03 a	1.67 a	0.72 a	1.44 a
Dw	-	-	1.29 b	1.51 a	-	-

N concentration of faba bean at maturity was significantly (P<0.05) affected by the treatments and increased gradually with increase in diversity (with the exception of mixture of A+Dw). The highest (3.52% and 3.49%) were recorded from faba bean-wheat mixture in mixture of A+G+J+Dw and mixture of A+G+Dw respectively. Wheat % N was lower in pure stand than in mixtures with faba bean also at full maturity, although not statistically significant (P>0.05) (Table 4).

As the sample for measuring root N content was taken very late, after drying of all the leaves and decaying of majority of root nodules, the N concentration in faba bean roots was very low compared to aboveground tissues. N concentration in faba been roots ranged between 0.57 and 0.72 and showed a slight but not significant increase with diversity. The N concentration in wheat roots, on the other hand, was similar to in aboveground tissues measured at full maturity.

4.3 Percentage of plant nitrogen derived from atmosphere (%Ndfa)

Figure 3 presents the %Ndfa measured at both physiological stages of faba bean.

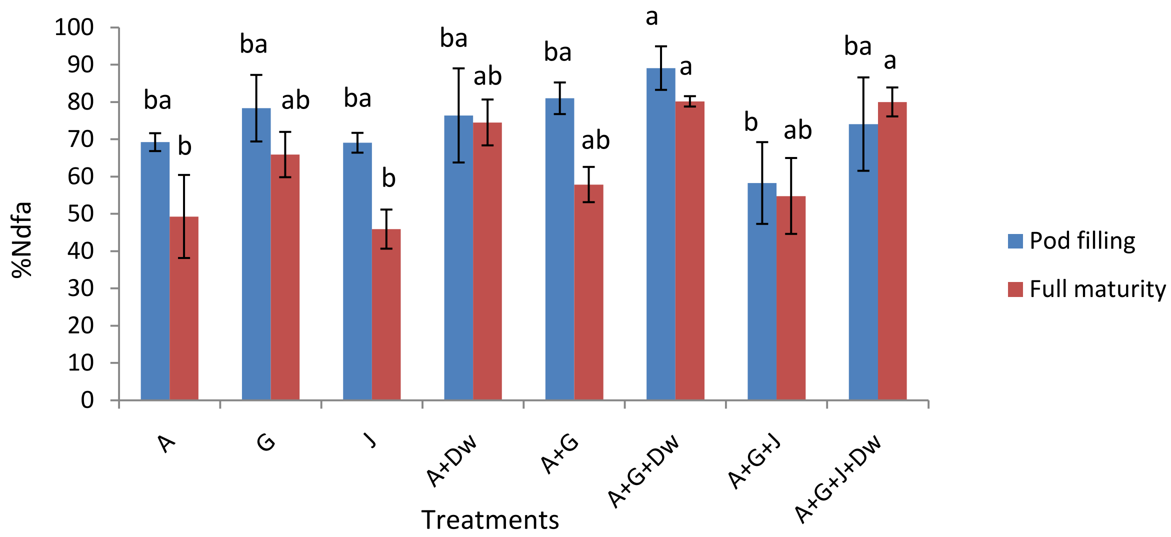

Figure 3: % Ndfa calculated at pod filling and full maturity of Faba bean. Each bar represents the mean value of four replicates +/- standard error (SE)

% Ndfa was higher at pod filling stage except in mixture of A+G+J+Dw. The % Ndfa measured at pod filling stage of faba bean was lowest in the mixture of A+G+J, which was significantly different from the mixture of A+G+Dw. %Ndfa was more strongly affected by the treatments at maturity of Faba bean, where % Ndfa in pure stand of A and J were significantly (P<0.05) different from the mixtures A+G+Dw and A+G+J+Dw (Figure 3).

%Ndfa was positively correlated with faba bean and total biomass yield at pod filling stage, although the correlation was significant ($P<0.05$) only with total biomass yield. On the other hand, at full maturity %Ndfa was negatively but not significantly correlated with faba bean and total biomass yield.

4.5 Quantities of Nitrogen Fixation

Large variations in N_2 fixation per ha were recorded both within and between treatments at both physiological stages of faba bean. At pod filling, variation was higher among mixtures, except pure stand of A, with very high variation in mixture of A+Dw. At maturity, the variations within treatments were higher among pure stands of faba bean varieties. Within treatment variations (variations between blocks) in intercrops and varietal mixtures were generally lower at maturity than at pod fill, except for the mixture A+G. And it was particularly low in mixture of A+ G+ Dw (Figure 4).

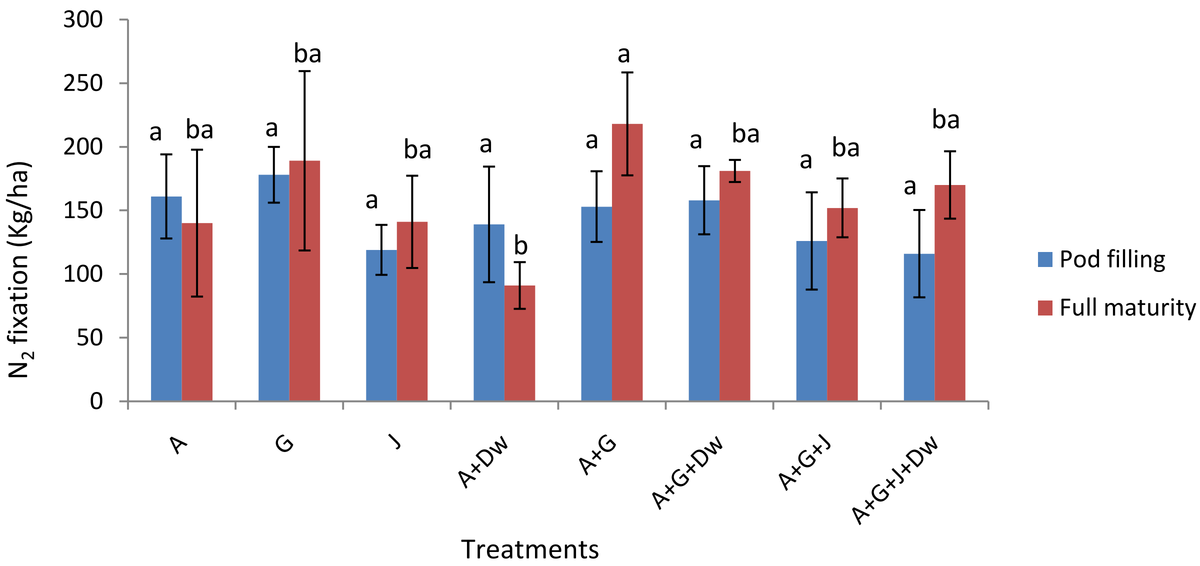

Figure 4: Amount of N_2 fixation calculated at pod filling and full maturity of faba bean in Kg per hectare per year. Values represent mean value from four blocks for each treatment. Each bar is the mean value of four replicates +/- standard error (SE).

The N_2 fixation measured at pod filling stage varied between 116 and 178 kg per hectare per year. The lowest amount was in mixture of A+G+J+Dw followed by pure stand of J and mixture of A+G+J. Pure stand of A and G, mixture of A+G, and the mixture A+G+Dw were among the highest performer (Figure 4).

Except for the pure stand of A and the mixture of A+Dw, the amount of N_2 fixation per hectare and year was higher at full maturity of Faba bean than at pod fill where the N_2 fixation in mixture of A+Dw was significantly lower than N_2 fixation in mixture of A+G. At full maturity, the mixture A+Dw showed low values also in %Ndfa, N concentration and biomass yield.

The calculated amount of N_2 fixation per sown faba bean plant was higher in mixtures of faba bean and wheat at both sampling occasions, except for the mixture A+Dw at maturity. The quantity measured in mixture A+G+Dw at maturity was significantly higher than pure stand of A and J. (Table 5).

Table 5 Quantities of N_2 fixation as gram per sown plant at pod filling and maturity of faba bean. Values represent mean value from four blocks for each treatment. Numbers with in the same column followed by same letters are not significantly different

Treatments	**Pod filling stage**		**Full maturity stage**	
	N_2 fixation	SE	N_2 fixation	SE
A	0.2 a	0.04	0.17 b	0.07
G	0.22 a	0.03	0.23 ba	0.09
J	0.14 a	0.02	0.17 b	0.04
A+Dw	0.24 a	0.08	0.16 b	0.03
A+G	0.19 a	0.03	0.27 ba	0.05
A+G+Dw	0.28 a	0.05	0.32 a	0.01
A+G+J	0.15 a	0.05	0.19 ba	0.03
A+G+J+Dw	0.2 a	0.06	0.3 ba	0.05

There was significantly positive correlation ($P<0.05$) between N_2 fixation and biomass yield calculated at both development stages of faba bean. The relationship was stronger at pod filling stage of faba bean with total biomass and faba bean biomass as shown by regression lines and coefficient in figure 5. This further illustrated the importance of higher productivity to fix more N_2 even though it depends on other parameters like $\delta^{15}N$ of fixing and reference species.

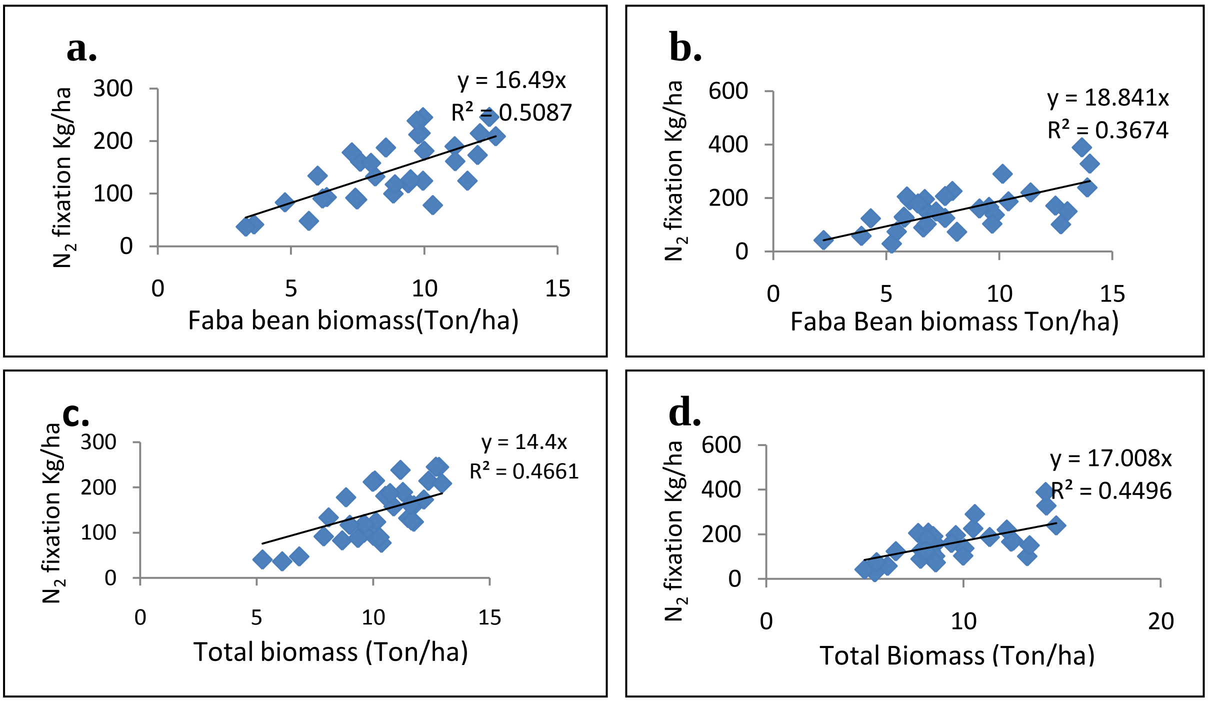

Figure 5: Regression lines and coefficients (R^2) of amount of N_2 fixation for, (a). faba bean biomass at pod filling stage of faba bean, (b). faba bean biomass at full maturity of faba bean, (c). total biomass at pod filling stage of faba bean and (d). total biomass at full maturity of faba bean

The correlation analysis between N_2 fixation and %Ndfa showed large importance of high % Ndfa for high N_2 fixation per hectare per year at both sampling occasions. It was significant ($P<0.05$) at both stages. Although the correlation was stronger with regression coefficient tend to higher at pod filling (Figure 6).

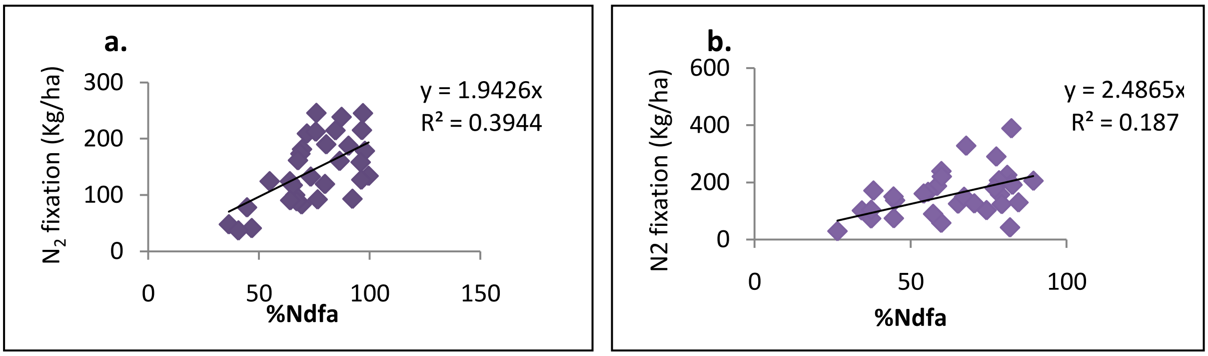

Figure 6: Regression lines and coefficients (R^2) of amount of N_2 fixation for, (a). % Ndfa at pod filling stage of faba bean and (b). % Ndfa at full maturity of faba bean

4.6 Nitrogen Pools and Crop Parameters: (Total shoot N yield, seed N yield, soil N uptake, Residual N, N balance and N harvest index)

Root biomass as proportion of total biomass was very low, ranging from 6 to 10%. So the estimation in this section was made based on above ground plant biomass. The N yield was strongly correlated to N concentration ($P<0.05$) at both physiological stages of faba bean. N yield increased with maturity except in mixture of A+Dw irrespective of low biomass yield. The total shoot N yield calculated at pod filling stage ranged between 134 and 247 kg per ha where no influence of diversity was found. The highest amounts were measured in pure stand of A and J followed by mixture of A+G+Dw and the lowest measured in pure stand of Dw but were not statistically different ($P>0.05$) (Table 6).

Table 6: Above ground plant N yield, seed N yield, soil N uptake, residual N and N balance in Kg per hectare and NHI in percentage. Values represent mean value from four blocks for each treatment. Numbers within the same column followed by the same letter are not significantly different.

Treatments	**Pod filling stage**		**Full maturity stage**					
	Total shoot N yield	Soil N uptake	Total shoot N yield	Seed N yield	Residual N	Soil N uptake	%NHI	N Balance
A	238 a	77 a	269 ab	107 b	163 ba	129 bac	47.8 ba	33.2 a
G	247 a	69 a	295 ab	132 ba	164 ba	106 bac	51.9 a	57.2 a
J	190 a	71 a	312 ab	139 a	173 ba	171 a	47.7 ba	2.2 a
A+Dw	215 a	76 a	162 b	*65.5*	*97*	71 c	*39.8*	*25.3*
A+G	215 a	62 a	384 a	123 ba	262 a	166 a	32.6 ba	95.6 a
A+G+Dw	229 a	71 a	269 ab	*76.9*	*192*	88 bc	*28.9*	*104*
A+G+J	212 a	86 a	305 ab	145 a	160.3 ba	153 ba	51.62 a	6.53 a
A+G+J+Dw	206 a	90 a	254 ab	*85.9*	*169*	84 c	*34.9*	*84.3*
Dw	134 a	134 a	156 b	45.5 c	110.2 b	156 a	29.2 b	-

The quantities represented by Italic letters include the estimated values for the treatments where seeds of faba bean and wheat were not distinguished. Calculation was made based on seed N yield and proportion of biomass yield of faba bean and wheat in particular treatment using harvest index from pure stand and two or three variety mixtures of faba bean and pure stand of wheat.

N yield at full maturity ranged between 156 Kg and 384 kg per hectare per year. The variation in N yield was higher at maturity of faba bean where N yield in mixture of A and G was significantly ($P<0.05$) higher than pure stand of Dw and mixture of A+Dw. For both harvesting occasions the lowest performer was the sole cropping of spring wheat which was mainly due to low N concentration compared to faba bean (N concentrations are presented in Table 5)

There was no effect of treatment on soil N uptake by faba bean and wheat at pod filling stage of faba bean where the uptake ranged between 62 and 134 Kg per hectare per year. The highest uptake was in pure stand of Dw. The soil N uptake also increased across the maturity of crops except in mixture of A+Dw and mixture of A+G+J+Dw. At full maturity soil N uptake varied between 71 and 171 Kg per hectare per year and was significantly lower in treatments having mixture of faba bean and wheat (Table6).

The harvesting of faba bean and wheat seed were done together and the proportion of harvested seeds were not distinguished from the mixture. Therefore seed N and attributes in faba bean/wheat intercrops were estimated assuming that the species proportion in the seed N yield would be the same as the species proportions in total biomass. Due to uncertainties in the assumptions used for calculating seed N attributes in faba bean/ wheat mixtures, these treatments were not included in the statistical analysis for seed N yield, residual N, NHI and N balance (values in italic in table 6 excluded from statistical tests).

The harvested seed N yield varied between 45.5 and 145 kg per ha per year, with the highest value in the mixture of A+G+J. The seed N yield in pure stand of wheat (Dw) was significantly lower ($P<0.05$) than in the faba bean treatments, due to low N concentration in wheat seeds compared to faba bean seeds. The proportion of seed N to total shoot N yields (NHI) ranged between 29% and 52%. No significant effect of treatment was found ($P>0.05$) but significant block effect occurred. The highest NHI was measured from pure stand of G and mixture of A+G+J and the lowest measured from pure stand of Dw. The performances of pure stands of faba bean were nearly equal. The rough estimation (shown in Italic letters) based on NHI and proportion of biomass harvested did not show any effect of diversity. The values estimated were within the calculated ranged but close to lower range (Table 6).

Residual N is an important benefit from N_2 fixing species, adding N to the cropping system. The mixture of A+G showed highest potential to provide N to subsequent crops, and the lowest residual N was measured from the pure stand of Dw. The rough estimated value also showed increase effect of mixture in A+G+Dw (Table 6).

The N balance calculated as the difference between total N_2 fixation and seed N yield showed high benefit, *i.e.* surplus of fixed N, from mixture of A+G. Lowest N balance was found in pure stand of J and the three-varietal mixture of faba bean. The variation occurring between two-varietal and three-varietal mixture of faba bean was mainly due to high variations between individual varieties. Except mixture of A+Dw, the estimated N balance based on NHI and proportion of biomass yield also showed the increased potential of mixture of faba bean and wheat (Table 6)

4.7 Efficiency of Resource use- (Intercropping performance, NUE and crop harvest Index)

LER was calculated to evaluate the intercropping performance over sole cropping. No significant (P>0.05) treatment effect was found at none of the measurement occasions. The higher LER at pod filling stage indicated higher benefit from intercropping for vegetative growth. LER above unity was found only for the mixture of A+G+Dw at pod filling stage (Table 7).

The crop harvest index (CHI: grain harvest per total aboveground biomass) at the full maturity varied between 18 and 32% and was positively correlated with %NHI. Except in mixture of A+G, the % CHI was higher in mixtures. The %CHI increased in mixture of A+Dw, mixture of A+G+J and mixture of A+G+Dw compared to pure stand of faba bean and wheat. Significantly lowest %CHI (measured from non-parametric two-sample Mann Whitney test) was measured in pure stand of Dw and mixture of A+G (Table 7)

The NUE (seed yield divided by aboveground N yield) was highest in mixture of A+Dw and lowest in mixture of A+G. NUE remained similar in all other treatments but it was comparatively higher in pure stand of Dw (Table 7).

Table 7: CHI and NUE calculated in all treatments and LER calculated only in treatments having mixture of faba bean and spring wheat. Values represent mean value from four blocks for each treatment. Numbers within the same column followed by the same letter are not significantly different.

Treatments	**Pod filling**	**Full Maturity**		
	LER	CHI	LER	NUE
A	-	23 bac	-	9.11ab
G	-	28 ba	-	9.89 ab
J	-	25 bac	-	9.08 ab
A+Dw	0.93 a	32 a	0.86 a	14.6 a
A+G	-	20 bc	-	6.21 b
A+G+Dw	1.07 a	28 ba	0.75 a	9.06 ab
A+G+J	-	29 a	-	9.83 ab
A+G+J+Dw	0.9 a	24 bac	0.83 a	8.08 ab
Dw	-	18 c	-	11.7 ab

5. Survey of application of study outcome

The study involved a questionnaire sent to a small group (35 persons) of advisors within Greppa Näringen (Focus on nutrients), working in direct contact with farmers in questions related to climate change. The response rate was 37% (13 persons). Among the responding advisors, 46% provided advisory services in conventional farms with animals and 23 % in conventional farms without animals. Fifteen percent of respondents worked with advice for organic farmers with animal production and the remaining 15% with mixed farming (conventional and organic). About 15% of total respondents also provided advisory services for the farmers who solely raise livestock, with no on-farm crop production.

5.1 Perception on Crop diversification

A majority of the responding advisors (77%) showed positive interest in growing diversified crops (Figure 7), and 80% answered yes to the question “Do you suggest growing crop mixtures to farmers (varietal or species mixtures)?” (Question No. 7 in Annex 1). The reasons for suggesting crop mixtures were mainly for soil nutrient management, reducing the use of chemical fertilizer (60% of advisors) and stable and greater yield (40 and 30% advisors).

About 20% of the advisors suggest mixed crops as a means to enhance diversity. According to some advisors diversity also has potential for preventing crops from diseases and pests (Question No. 7 in Annex 1). The majority of respondents expressed positive interest on diversified cropping system from the perspective of resource management, higher and stable yield and cropping system sustainability, while some skepticism was expressed against the suggested benefits of diversified crops to prevent outbreaks of disease and pest (Figure 7).

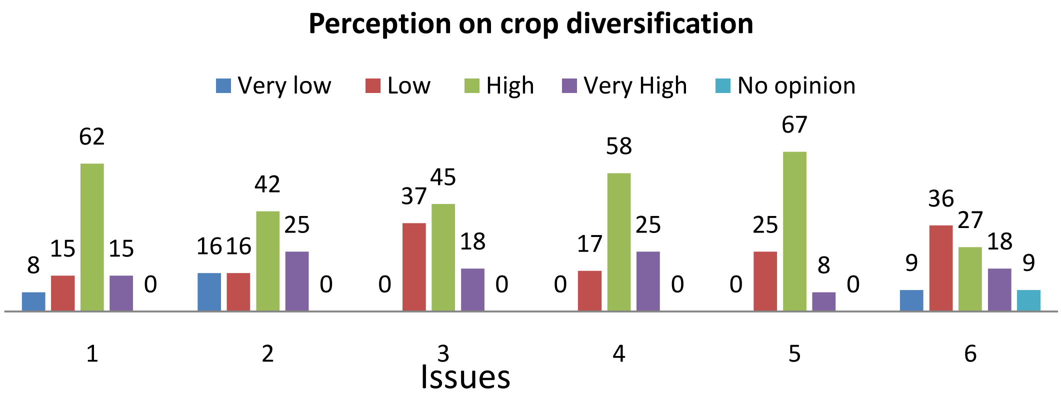

Figure 7: Perception of advisors on prospects and potentials of crop diversification based on their interest and opinion. The values represent the percentage of responding advisors.

Issues: *(1) Interest about growing of diversified crops, (2) Potentials and possibilities of crop diversification for efficient resource management, (3) Potentials and possibilities of crop diversification for higher and stable yield, (4) Potentials and possibilities of crop diversification for Cropping system sustainability (economically sustainable with minimized negative environmental impact), (5) Potentials and possibilities of crop diversification for Adaptation to reduce the effect of climate change in crop production (variation in e.g. temperature and rainfall within and between growing seasons), (6) Potentials and possibilities of crop diversification for Prevent outbreaks of diseases and pests*

5.2 Perception on legume based crop diversification

About half the number of responding advisors (46%) thought that legume based crop diversification is important for soil N management and reducing agriculture contribution to GHG emission via decreased N fertilizer application. A similar proportion expressed the importance of perennial forage legumes for reducing agricultures contribution to GHG emissions via reduced need for tillage and weeding. Of the responding advisors, 50% agreed that legume based crop diversification is very important to reduce the amount of imported feed like soybean. Less than 10% were negative thinking that legume based crop is not an important approach to enhance ecosystem services and economic benefit. (Figure 8)

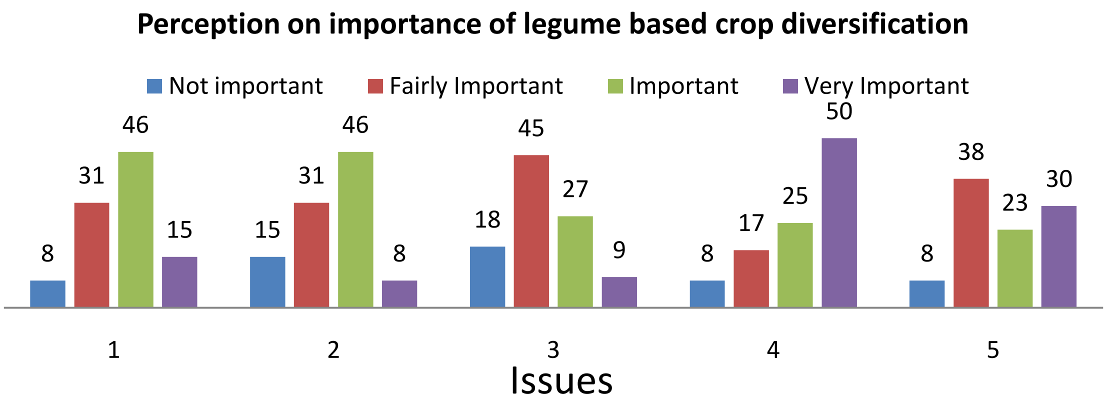

Figure 8: Perception of advisors on importance of legume based crop diversification. The value represents the percentage of responding advisors

Issues: *Importance of legume based crop diversification, (1) For soil N management (2) For reducing agricultural contribution to green house gas emission decreasing the frequency of nitrogenous fertilizer application, (3) For reducing agricultural contribution to green house gas emission reducing the need for tillage and weeding specially considering perennial legume in the crop sequence (4) For reducing agricultural contribution to green house gas emission reducing the amounts of imported feed (e.g. soybean), (5) From economic production point of view*

5.3 Problems associated with diversified cropping system

Most of the advisors (64% and 27%) indicated harvesting and marketing as the main problems associated with diversified cropping systems. About 10% indicated plant protection as a main problem. A lower proportion considered land preparation, sowing and intercultural operations as main problems. The responding advisors further indicated overall crop management and state of knowledge of farmers as additional possible limitations of diversified cropping system (Question no. 8 in Annex 1). Main difficulties in harvesting are expected to be due to difference in maturity time between associated species/varieties and rain during harvesting time.

5.4 Inclusion of Faba bean in cropping system

About 85% of responding advisors suggested including faba bean in cropping system. They suggested growing faba bean mainly for animal feed production, reducing the need to import protein feed and providing possibilities to sell harvested grain. Some advisors also suggested growing faba bean to enhance biological N_2 fixation, green manuring and soil fertility maintenance, but these aspects were promoted in less extent.

Some answers and comments indicated that the considered inclusion of faba bean in cropping system depends on context and situation of farming, or expressed that faba bean cultivation is important to control the weed (especially black grass in clay soil), for selling the product to animal feed production and adapting varied crop rotations (Question no. 9 in Annex 1). Reasons for not suggesting faba bean were low economic returns, difficulties in establishment, problems with diseases and pests, low familiarity with the crop, drought, late maturity, difficulties to harvest the crop, and limited offset of the harvested products Eighty five percent of responding advisors recommended reducing the chemical fertilizer to faba bean by 100% of what would be applied to a non-legume crop, and almost 70% suggested that also the amount of N fertilizer can be reduced in succeeding crop. Fifty percent suggested reducing the fertilizer application to the following crop by 20 Kg/ha, and few (12.5%) recommended reducing by 30 to 40 kg/ha or more (Question no. 10 in Annex 1).

5.5 Inclusion of legumes and Faba bean in cropping system

Regarding the importance of faba bean and cereal combination in cropping system, about half of the respondent advisors considered this combination as an interesting alternative for resource use and yield stability. One third of them considered it to be fairly interesting alternative and about 22% gave their negative response considered that it is not an interesting option from the perspective of resource use and yield stability (Question no. 12 in Annex 1). Concerning inclusion of faba bean in cropping system 37.5% of the respondent advisors suggested growing faba bean in pure stand. A similar proportion of advisors suggested growing intercropping with wheat. Less proportion of advisors (12%) suggested growing mainly in pure stand and a minor proportion intercropping with some other crops (Question no 11 in Annex 1)

From the perspective of management of N, crop sequence and soil borne pathogens, a large proportion of advisors (46%) thought it is optimal to grow legume in every five to seven years or in every three to five years (23%). Few (less than 20%) advisors considered it optimal to grow legumes more often than one year or less frequent than every seven years. (Question no. 4 in Annex 1).

Regarding inclusion of faba bean in cropping system taking aspects of nitrogen management, crop sequence, and soil borne pathogen pressure into account, large proportion of advisors recommended to include it once every five to six years if the faba bean is only the legume in rotation. On the other hand, the majority of responding advisors recommended less frequent inclusion of faba bean if crop sequence also includes pea and grass-clover leys. No one of the responding advisors thought it is optimal to include faba bean more frequent than every three years (Figure 9)

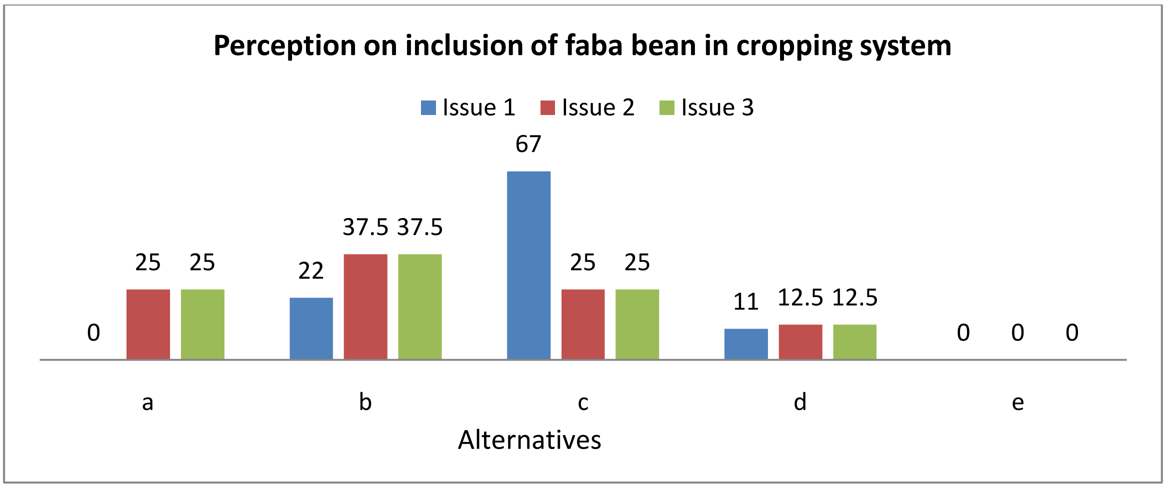

Figure 9: Perception of advisors on optimal frequency of inclusion of faba bean in crop sequence under different cropping management systems. The value represents the percentage of responding advisors

Alternatives: *(a)Less frequent than every eight years, (b) once every seven or eight years, (c) once every five or six years, (d) once every three or four years, (e) more frequent than every three years.* **Issues:** *Optimum frequency of inclusion of faba bean on the same field in cropping system taking aspects of nitrogen management, crop sequence, and soil borne pathogen pressure into account, (1). If faba bean is only legume in crop rotation, (2) If crop sequence in field includes both Faba bean and pea, (3). If crop sequence includes Faba bean, pea and grass-clover leys.*

Most responding advisors agreed on the importance of faba bean in developing varied crop rotations, potential source of protein feed to animals, good pre crop to wheat and efficient N management reducing the application of N fertilizer.

5.6 Perception on importance of interaction between advisors and farmers

The experience among responding advisors was that farmers were very interested in having more knowledge about crop production in relation to climate, and that the farmers were satisfied with the advice about nitrogen loss and climate-friendly production . Forty two percent of responding advisors mentioned that meeting about the relationship between farm management and climate impact was clear and useful tool to reduce the farm climate impact. More than 50% advisor's thought it was useful to widen the farmer's knowledge and was an eye opener but not enough to provide any tools directly to reduce the climate impact. According to some other advisor's experience it was too complex to apply at farm and farmers level. The discussion with the farmers in the meeting about cultivation of legumes was also related to reduce the climate impact reducing GHG. According to more than 50% advisors, growing more legumes were also associated with reduction in long distance import of protein feed and cultivation of protein crop. About one third of advisors realized that the farmers became more inspired from the meeting about to increase the volume of cultivation. On the other hand, some still realized doubts among the farmers caused by risks for N loss and environmental impact of legume cultivation. According to them it needs further discussion if the legume can be a better option in any rotation to grow.

5.7 General comments from the advisors based in questionnaires

According to advisors the aspects of diversity and faba bean production also depends on particular farming situation availability of local protein feed, problem of weed and weed management. The responding advisors further pointed out that there is wide variation in yield of legumes, such as faba bean from 800 to 4500 kg/ha. They also highlighted the importance of ecological farming staring from farmer's level together with the suggestion that farmers must be better paid of reducing CO_2 and adapting such a cropping system. Famers must be compensated for growing protein crops encouraging reduced tillage to increase the NUE. One advisor also mentioned that "GHG in agricultural production is emotional issue for both advisors and farmers. It is natural and cannot be omitted"

Advisors further suggested that the importance of diversified cropping system with legume not only confined for animal consumption but also for agro ethanol, biomass and biogas. But it still needs a lot of field trials to make the system more fit in particular farming situation. The low volume of cultivation of faba bean as grain legume was suggested to be due to the high popularity of pea and less practice on faba bean.

6. Discussion

6.1 Field experiment

The measurements showed substantial differences in N_2 fixation, N parameters and resources use efficiency between the two physiological developments stages of faba bean. The diversity positively influenced the %Ndfa and N content, with significant effects at maturity, but the amount of N_2 fixation did not follow the same trend.

Although the measured results depend on many controlled and uncontrolled factors, biomass yield, % N and %Ndfa were the principle parameters directly affecting the amount of N_2 fixation per ha per year. The % Ndfa is directly regulated by $\delta^{15}N$ of reference and fixing plant and the B value used (Cadisch et al, 2000). The higher $\delta^{15}N$ observed at full maturity was the reason for low %Ndfa (Cadisch et al, 2000). According to Tunner et al (1987), the $\delta^{15}N$ also depends on numbers of factors like: crop management, cropping system, growth stage of plant, soil N availability and biotic and a biotic stresses. The result might also be influenced by the choice of B value, which was set to -0.36 for all three faba bean varieties used in the study. Although measured B values were similar between different faba bean varieties in another study (Francisco et al, 2010), it cannot be excluded that our three varieties do differ in ^{15}N discrimination, and consequently their B value. In order to correctly take possible varietal differences in B into account, specific experiments must be performed with the chosen faba bean varieties grown under N-free conditions under conditions as similar as possible to those in the field experiment. The wheat and weed plants grew together with faba bean in the same soil during the same time, which are key prerequisites for good choice of reference plant which should share the root and aerial environment with the N_2-fixing plant (Killan et al, 2001)

The calculation of amount of N_2 fixation depends on biomass yield of faba bean. To account for the 30% seed density occupied by wheat in intercropping treatments, N_2 fixation per sown faba been plant was also calculated and compared. The mixture of faba bean and spring wheat showed higher N_2 fixation per sown faba bean plant at both measurement occasions. This effect can be explained by the mineral N acquisition by wheat making faba bean more dependent on fixed N (Huaggaard-Nielsen et al, 2009). The low value for mixture of A+Dw at maturity, despite this treatment having highest %Ndfa, might seem unexpected but is due to very low biomass yield measured at maturity.

The significant positive relationship of biomass yield and N_2 fixation confirmed the importance of plant productivity for N_2 fixation (Carlsson and Huss-Danell, 2003). The three faba bean varieties varied widely in parameters of N_2 fixations and N pools, suggesting genetic variability in the evaluated traits (Amerger et al, 1979; Brunner and Zapata, 1984) There was big variations in %Ndfa among treatments, and the majority of observations were below 80%, lower than other studies where %Ndfa in faba bean was higher than 90% under optimum climatic condition (Lo´pez-Bellido et al, 2006). The occurrence of low %Ndfa values in the present study may be a result of sub-optimal conditions for N_2 fixation and/or high soil N availability allowing the faba bean crop to use soil nitrogen and reduce its dependence on N_2 fixation. The latter explanation is more likely, since high biomass was produced also in pure stand of unfertilized wheat, indicating good growth conditions and high soil fertility. The field has been managing organically and cropped repeatedly with legumes in rotation.

The variation in results observed at the two physiological stages of faba bean highlight the importance of harvest management on productivity and soil N dynamics in cropping system (Amarger et al, 1979). Early harvesting at active vegetative growth stage can leave more N to the system if the biomass is left as green manure avoiding the removal of N in harvested seeds but it limits the time for N_2 fixation during later season. Harvesting at maturity gave substantially higher N yield and N_2 fixation. Even though the biomass increased only for pure stand of J and mixture of A+Dw at maturity, the residual N was almost near to total N yield at pod filling stage in majority of treatments except pure stand of A and G and mixture of A+Dw. The faba bean variety A suffered highly from late harvesting showing decreased biomass yield and N_2 fixation because it suffered most from lodging and loss of leaves across the maturity. Furthermore, significant ($P<0.05$) effect of block on several measured parameters (faba bean biomass at pod filling; N concentration, LER and NHI at maturity) indicated that other factors than treatment influence crop yield, competitive ability, N_2 fixation and N parameters (Hauggaard-Nielsen et al, 2009). These other factors might include *e.g.* other nutrients than N, variations in growing environmental and plant and soil conditions (Brunner and Zapata, 1984 and Kumar, 2007).

The variations in faba bean soil N uptake between the two maturity stages indicate that the crop was highly dependent on N_2 fixation at earlier stage and soil N at later stage. Increase in $\delta^{15}N$, soil N uptake, N yield and N content at maturity has also been observed in other studies, showing increased reliance on soil available N after active vegetative growth and decreased fixation (Hauggaard-Nielsen et al, 2010). The high %Ndfa, N yield and LER of mixture of A, G and Dw at pod filling stage indicated greater degree of N recovery and complementarity between faba bean and wheat (Hauggard-Nielsen et al, 2009) and reduction in LER at maturity could be due to reduction in biomass yield of wheat. The highest N balance (95 kg/ha) and residual N (262 kg/ha) by mixture of A+G showed its highest potential to provide soil N to the subsequent crops, which are important traits for NUE and crop yield avoiding depletion of soil fertility (Fageria and Baligar, 2005). The measured N balance and residual N parameters in this study are underestimated because they do not include root biomass and N, and are expected to increase by about 10% if including roots (López-Bellido et al, 2006). Furthermore, the fact that seed N was not measured but calculated from literature data on faba bean and wheat seed N concentrations impose important uncertainties in the estimations of seed N, residual N, NHI and N balance. Optimally, harvested seeds should have been separated into faba bean and wheat fractions and analyzed for N concentrations, but there was no possibility to manage those tasks within the timeframe of this MSc thesis work. Nevertheless, the estimates obtained so far show very interesting effects of crop diversity on potentially beneficial N balances. These findings are very useful for the scope of the larger project, in which the data will be complemented with seed N analyses together with results from more treatments, sites and an additional growing season.

The LER lower than unity and very low biomass yield per sown wheat plant in mixtures compared to wheat pure stands indicated low complementarities and poor competitive ability of wheat. The present study thus show some disagreement with previous findings that legumes are weak competitors in cereal legume intercropping due to the small and shallow root system and low competitive ability for soil N in legumes as compared to cereals (Fan et al. 2006). The weed biomass was found to be increased at maturity in most of the treatments including treatments having mixture of faba bean and wheat and pure stand of Alexia (Figure 1). The reasons behind such results could be early lying down of some varieties of faba bean after flowering promoting the weeds, limiting light and vegetative growth of wheat. Another reason could be that the experimental conditions and setup actually favored faba bean growth more than wheat. Faba bean grew very tall and reduced the ability of wheat to utilize sunlight (Figure shown in Annex 2). On the other hand, despite the weak competitive ability of wheat, intercropping significantly increased %Ndfa in faba bean as compared to treatments without wheat. Thus, even a low proportion of a cereal that is under shade of a dominating legume crop seems to be sufficiently competitive for soil N and stimulates the legume to increase it s dependence on N_2 fixation. But the potential advantage of intercropping utilizing resources optimally was not realized in the experiment as indicated by the value for NUE which were low in the mixtures except in mixture of A+Dw.

Both the CHI and NHI observed were considerably lower than generally observed range in faba bean (Andersson, 2005 and Lo´pez-Bellido et al, 2006). The low range of CHI and NHI could on one hand make significant contribution to soil N because high CHI is associated with net reduction in soil N due to higher harvested N, although, on the other hand, these are important traits for yield improvement, protein supply and economic benefit (Carranca et al, 1999). The calculated NHI indicated highest efficiency in allocating N to grain production by pure stand of J and mixture of A+G+J, which is important for reducing the N losses since available N was maximally utilized for grain production in these treatments (Fageria and Baligar, 2005). The positive correlations between NHI and CHI further indicated that optimum use of N improve the overall seed productivity (Andersson, 2005). The mixture of A+ G+J therefore would be recommended for both CHI and NHI and mixture of A+Dw for the CHI. On the other hand, if the goal is to maximize the N balance, the mixture of A+G should be recommended for its high input of fixed N remaining after the crop.

The grain yield is the ultimate product and it is strongly associated with the vegetative growth of the plant as indicated by significantly positive correlation between total biomass yield and seed yield. The reason behind higher biomass yield in treatment pure stand of J and mixture of A+G at maturity was the high seed yield.

Thus the study outcome of the experimental part showed different application in farming situation based on the purpose of growing a faba bean crop. The shoot N yield was higher among the pure stand of A and G and mixture of A+G+Dw when harvested at pod filling. When harvested at full maturity it was higher in mixture of A+G and mixture of A+G+J. The residual N was highest again in mixture of A+G, suggesting high ability to supply N to the following crop. Together with high %Ndfa and low soil N uptake in mixture of A+Dw, mixture of A+G and mixture of A+G+Dw at pod filling and mixture of A+Dw, mixture of A+G+Dw and mixture of A+G+J+Dw at full maturity showed a high dependency on fixed N_2 in those mixtures.

The result for residual N and N balance suggested that more N will be put into the system from mixture of A+G. The result showed that even after the harvesting of seed up to 262 Kg

N/ha can be retained in the soil for next crop. In addition, some proportion of N is also added to soil through degradation of root and aerial plant parts during crop growth, thus not accounted for in these measurements (Carlsson, 2005). All these phenomena of N_2 fixation and N yield add N to the system and make the system less reliant on industrial N, but care must also be taken so that large amounts of residual N do not increase the environmentally disturbing losses of N.

The studied treatments were part of a larger project, and I believe that there will be considerable knowledge gain when my results are put into the context of the whole project. Furthermore, the analysis of root biomass and N concentration was an additional aspect brought into the project by my own interest. The differences in N concentration between the two growth stages of faba bean, and consequent effects on total N pools and N_2 fixation, are of high interest for N management. However, important N balance parameters could not be fully quantified at both stages since root biomass was measured only once after full maturity. The observed poor relationship between root and shoot biomass further increase the curiosity to evaluate their relation at different growth stages. Future research should therefore be compare residual N pool at both physiological stages including root samples. Thus, an important outcome of my work with this MSc thesis is that a more complete study of the influence of underground productivity on N pools and plant parameters, evaluating above ground and below ground biomass yield and N cycling parameters can be integrated in the ongoing overall project.

6.2 Application of study outcomes

The survey comprised only a very limited number of advisors, which limits the possibility to make conclusions and interpretations in a wider context. Nevertheless, the received responses and comments were interesting and useful for the study. It was evident from the advisors' perception that diversity in cropping system is important for developing best crop rotation and overall cropping system sustainability. The responses supported the vision that there is high possibility and potential of crop diversification and inclusion of faba bean in Swedish farming system. Advisors positive response on different aspects of crop diversifications indicated that diversity including legume is very important for soil N management, animal feed production, resource management and high and stable yield. It is equally important for soil N fertilizer management reducing the use of industrial N. This indicated that diversified cropping system including legumes can play very important role to reduce the emissions of GHG through reduced production, distribution and use of N fertilizer, reducing energy inputs in cropping systems, as also has been suggested in other studies (Nagy, 2001, Carlsson and Huss-Danell, 2003; Carlsson, 2005; Zentner et al, 2011).

The low interest of some advisors on aspects of diversification indicated that such strategies may not be beneficial in all farming and socioeconomic conditions (Wivstad et al, 1987; Sullivan, 2003). The negative response also could be due to knowledge gap or less understanding and awareness, indicating scope for more investigation, learning and understanding from interactions with farmers (Driver and Kravatzky, 2000). The information gap also can be explained by the role of faba bean mainly for protein feed as perceived by some advisors.

The response of advisors suggested that including faba bean when establishing diversified crops is not the main problem, but that farmers are more concerned with harvesting and marketing management of the product. This showed the great demand of investigations and studies to synchronize the harvesting time and develop more drought and water resistant crops and crop management practices. Advisors agreed with numerous services from including faba bean in cropping systems: N_2 fixation, soil fertility, green manuring, protein feedr reduced climate effects, promotion of diversity and beneficial crop rotations. However, most advisors were reluctant to recommend growing very frequent in rotation, they mainly recommended growing faba bean for animal feed production and soil N management once in five to seven years. This indicated that they were aware of risks that too frequent cropping with faba bean may promote the occurrence of pathogens and pests. There also could be other reason which is unidentified which provides more scope for future investigation. The complex interactions between positive effects of faba bean on crop production and N management and potential negative effects via increased risks for pathogens and pests show the need for holistic and systematic knowledge, including aspects of economy, agronomy and plant protection (Allahyari, 2009). This also highlights the need of more information and knowledge about faba bean and associated services up to the farmer level, in line with findings by Haily and Rick (2002). They have emphasized that knowledge is the primary requirement to think anything from the wider perspective.

85% advisors recommended that upon including faba bean in the cropping system the application of chemical fertilizer can be strongly reduced. This highlights the beneficial role of faba bean in cropping system to supplement the N fertilizer saving energy use during its production and distribution. The advisors experience after meeting with farmers suggested that farmers were interested to have more knowledge about crop production and climate chance. The suggestion of advisors to pay farmers for ecological farming including legumes indicated the need of sustainable development and encouragement to farmers. Promotion of farmers in their own farming condition, making use of resources that are present and familiar, is a beneficial way to facilitate the production based on well-known ecological and social systems that are best suited in that particular area (Eksvärd, 2009; Sette and Watts, 2010). Furthermore, the advisors suggested requirement of further research on different aspects of crop diversification, indicating a large interest but also experience that the research conducted so far is still insufficient in order to reach farmer's level and application. Interaction with advisors and farmers is likely very helpful for developing scientific investigations that can provide new knowledge for promoting crop diversification and solving potential problems associated with diversified crops. It is because new knowledge and investigation provides the way to handle and manage the things and finding the way out for the solutions of any problems ((Larsson et al, 2009)

Personal gain of experience and knowledge about crop diversification in Morocco

The field visit and laboratory work at university of Cadi Ayyad, Marrakech in Morocco during one week in February 2012 was very interesting. It was helpful to strengthen my knowledge about growing faba bean in different condition of soil and climate. The farming situation in Morocco is different from Swedish Agricultural system, but the same crop combinations were under investigation with the main purpose to develop novel crop combinations which perform well under shade and in dry soil. Marrakech is arid region having alkaline soil. So the research was investigating whether faba bean-cereal intercropping systems might be of high potential when analyzed across contrasting environmental conditions

I visited different trials of faba bean with wheat and barley. The trials were established to investigate the different benefit from the diversity and possible factors affecting the intercropping and legume performances like: effect of previous crop, performance of faba bean when grown sole or with other legumes or barley or wheat. Other trials included evaluation of performance of faba bean under full sunlight and shade. This reflected that there are a lot of potential areas for investigation to exploit diversity in cropping system. The visit was useful to understand the potential research areas and application of crop diversification of faba bean and wheat or barley. I also learnt some more aspects and areas of studies which have high importance in agriculture, including soil and biochemical properties of the rhizosphere, nodulation, relationship between nodule biomass and plant productivity, and soil nitrogen and phosphorous availability.

Field and laboratory works were important to learn more about plant sampling from the field, biomass calculation, preparation of samples for mineral and biochemical analysis. The laboratory works were further helpful to gain more skill on manual separation of root nodules from faba bean, and rhizosperic soil from faba bean and barley. I also studied the general methodology of sample preparation for phosphorous analysis from rhizospheric soil.

7. Conclusions

Crops and varietal mixtures of faba bean and spring wheat are important to increase the proportion of legumes' nitrogen derived from N_2 fixation, %Ndfa. Mixtures also increases N_2 fixation and plant productivity as demonstrated by biomass production and N_2 fixation calculated per sown faba bean plant but it is not always true for N_2 fixation per hectare per year. N_2 fixation per hectare per year highly depends on interaction of biomass yield, N concentration of plant tissue and %Ndfa. Not all forms of mixture are equally important for N_2 fixation and legume role for close N cycle but different extent of varietal mixture of faba bean highly benefit to enhance N pools and crop parameters. Where mixtures of the faba bean varieties Alexia and Gloria were found to supply more N to the following crop through increased N balance and residual N. Mixtures of Alexia and Gloria; Alexia, Gloria and Julia; and Alexia, Gloria and the spring wheat variety Dacke may be considered to promote high shoot N. Mixtures of faba bean varieties and spring wheat are valuable for enhancing N_2 fixation as they highly depend on fixed N shown by very low soil N uptake. Harvesting management is another parameter that highly influences N_2 fixation and N cycling. The cereal in intercropping with legume not always benefited from cereal perspective, but it improves legume reliance on N_2 fixation which is important for N cycling at the cropping system level.

Even though the survey included very few numbers of advisors, the general view of advisors regarding the diversity of crops and species was very useful for the study. Crop diversification including legume can be well developed among farming communities and will have much environmental, social, economic and agronomic benefit. Farmers in Sweden mainly grow faba bean and its mixture for animal feed production. There are comprehensive possibilities for developing novel cropping systems including faba bean mainly to supply protein feed, increase diversity, and soil fertility. Swedish farmers are aware of role of legumes in cropping system and reducing climate effect of N fertilizer through N_2 fixation by legumes, but the understanding and state of knowledge can still be improved. The solutions of the potential problems associated with this crop like: harvest management, marketing of the product and plant protection should be prioritized for future investigation and study. The potential of mixture of faba bean and wheat or barley should also be investigated with the aim to develop cropping systems which can perform well under different biotic and a biotic stresses like shade, drought, salty soil and infestation by diseases and pests.

References

Alghamdi, S. S. (2009). Chemical composition of Faba bean (Vicia faba L.) Genotypes under Various Water Regimes. *Pakistan Journal of Nutrition, 8 (4): 477-482*

Allahyari, M. S. (2009). Agricultural sustainability: Implications for extension systems. *African Journal of Agricultural Research, 4 (9):781 -786*

Amarger, N., Mariotti, A., Mariotti, F., Durr, J.C., Bourguignon, C. and Lagacherie, B. (1979). Estimate of symbiotically fixed nitrogen in field grown soybeans using variations in 15N natural abundance. *Plant Soil, 52:269–280*

Andersen, M. K. (2005). Competition and complementarity in annual intercrops- The role of plant available nutrients. Ph. D Thesis, The Royal Veterinary and Agricultural University, Copenhagen, Denmark

Andersson, A. (2005). Nitrogen Redistribution in Spring Wheat, Root Contribution, Sprike Translocations and Protein Quality. Doctoral Thesis, Swedish University of Agricultural Sciences, Faculty of Landscape Planning, Horticulture and Agricultural Sciences

Aydinalp, C., and Cresser, M. S. (2008). The Effect of Global Climate Change. *American-Eurasian J. Agric. & Environ. Sci., 3 (5): 672-676, ISSN 1818-676*

Bedoussac, L. and Justes, E. (2011) A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to Durum wheat-wither pea intercrops. *Field Crop Research, 124: 25-36*

Biabani, A., Hashemi, M. and Herbert, S. J. (2008). Agronomic performance of two intercropped soybean cultivars. International Journal of Plant Production, 2 (3): 1-7

Brunner, H. and Zapata, F. (1984). Quantitative assessment of Symbiotic nitrogen fixation in diverse mutant line of field bean (Vicia faba minor). *Plant and Soil, 82: 407-413*

Cadisch, G., Hairiah, K. and Giller, K. E. (2000). Applicability of the natural ^{15}N abundance technique to measure N_2 fixation in *Arachis hypogaea* grown on an Ultisol. *Netherlands Journal of Agricultural Science 48: 31-45*

Carlsson, G. and Huss-Danell, K. (2003). Nitrogen fixation in perennial forage legumes in the field. *Plant and Soil, 253: 353–372*

Carlsson, G. (2005) Input of Nitrogen from N_2 Fixation to Northern Grasslands. Doctoral thesis, Swedish University of Agricultural Sciences

Carlsson, G., Palmborg C., Jumpponen, A., Scherer-Lorenzen, M., Ho¨gberg, P. and Huss-Danell, K. (2009). N_2 fixation in three perennial Trifolium species in experimental grasslands of varied plant species richness and composition. *Plant Ecology, 205: 87-104*

Carranca, C. A., Varennes, A. D. And Rolston, D. (1999). Biological nitrogen fixation by fababean, pea and chickpea, underfield conditions, estimated by the 15N isotope dilution technique. *European Journal of Agronomy , 10 : 49–56*

Cowger, C. and Weisz, R. (2008). Winter Wheat Blends (Mixtures) Produce a Yield Advantage in North Carolina. *Agronomy Journal, 100 (1): 169-177*

Dawson, J. C., Huggins, D. R. and Jones, S. S. (2008). Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. *Field Crops Research 107: 89–101*

Debaeke, Ph., Aussenac, Th., Fabre, J. L., Hilaire, A., Pujol, B. and Thuries, L. (1996). Grain nitrogen content of winter bread wheat *(Triticum aestivum* L.) as related to crop management and to the previous crop. *European Journal of Agronomy 5: 273-286*

Drinkwater, L. E., Wagoner, P. and Sarrantonio, M. (1998). Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature, 396: 262-265*

Driver, T. and Kravatzky, A. (2000) Participatory learning and action or Participatory acting? *PLA Notes* 38.

Eksvär, K. (2009) Exploring New Ways Systemic Research Transitions for Agricultural Sustainability. Doctoral Thesis Swedish University of Agricultural Sciences Uppsala. Acta Universitatis agriculturae Sueciae. 2009:44

Fageria, N. K. and Baligar, V. C. (2005). Enhancing Nitrogen Use Efficiency in Crop Plants. *Advances in Agronomy, 88: 97-185*

Fan, F., Zhang, F., Song, Y., Sun, J., Bao, X., Guo, T. and Li, L. (2006). Nitrogen fixation of faba bean (Vicia faba L.) interacting with a non-legume in two contrasting intercropping systems. *Plant and Soil, 283:275–286*

FAO, 2008. Current world fertilizer trends and outlook to 2011/12.Food and Agriculture organization of the United Nations, Rome

FAO, 2010. Current world fertilizer trends and outlook to 2014. Food and Agriculture Organization of the United Nations, Rome

Frankow- Lindberg, B. E., Brophy, C., Collins, R. P. and Connolly, J. (2009). Biodiversity effect on yield and unsown species invasion in a temperate forage ecosystem. Annals of Botany, 103: 913-921

Good, A. G., Shrawat A. K., Muench D. G. (2004). Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? *Trends Plant Science, 9: 597-605.*

Hailey, J. and Rick, J. (2002). Learning Leaders: The Key to Learning Organisations Development in Practice 12 (3 and 4): 398–408

Hauggaard-Nielsen, H., Gooding, M., Ambus, P., Corre-Hellou, G., Crozat, Y., Dahlmann, C., Dibet, A., Fragstein, P. V., Pristeri, A., Monti, M. and Jensen, E. S. (2009) Pea-barley intercropping for efficient symbiotic nitrogen fixation, soil N acquisition and use of other nutrients in European organic cropping systems. *Field Crop Research, 113: 64-71*

Hauggaard-Nielsen, H., Holdensen, L., Wulfsohn, D. and Jensen, E. S. (2010). Spatial variation of N_2-fixation in field pea *(Pisum Sativum L.)* at the field scale determined by the ^{15}N natural abundance method. *Plant Soil, 327:167-184*

Helland, S. J. and Holland, J. B. (2001). Blend Response and Stability and Cultivar Blending Ability in Oat. Crop Science, 41: 1690-1696

Høgh-Jensen, H. and Schjoerring, J. K. (1994). Measurement of biological dinitrogen in grassland: Comparision of the enriched ^{15}N dilution and the natural abundance methods at different nitrogen application rate and defoliation frequencies. *Plant and Soil, 166: 153-163*

Holdensen, L., Hauggaard-Nielsen, H. and Jensen, E.S. (2007). Short range spatial variability of soil $\delta^{15}N$ natural abundance effects on symbiotic N_2-fixation estimates in pea. *Plant Soil 298:265–272*

IFA, 2007. Sustainable Management of Nitrogen Cycle in Agriculture and Mitigation of Reactive Nitrogen Side Effects. International Fertilizer Industry Association. Paris, France

Jensen, E. S. and Hauggaard-Nielsen, H. (2003). How can increased use of biological N_2 fixation in agriculture benefit the environment? *Plant and Soil Science, 252: 177-186*

Jensen, E. S., Peoples, M. B. and Hauggaard-Nielsen, H. (2010). Faba bean in cropping system. *Field crop research, 115: 203-216*

Jensen , E. S., Peoples, M. B., Boddey R. M., Gresshoff, P. M., Hauggaard-Nielsen, H., Alves, B. J. R and Morrison, M. J. (2011). Legumes for mitigation of climate change and the provision of feedstock for bio fuels and bio refineries A review. *Agronomy for Sustainable Development, DOI 10.1007/s13593-011-0056-7*

Kaut, A. H. E. E., Mason, H. E., Navabi, A., O'donovan, J. T. and Spaner, D. (2008). Organic and conventional management of mixtures of wheat and spring cereals. *Agronomy Sustainable Development, 28: 363- 371*

Kiar, L. P., Skovgaard, I. M. and Ostergard, H. (2012). Effect of inter-varietal diversity, biotic stresses and environmental productivity on grain yield of spring barley variety mixtures. *Euphytica, 185 (1): 123- 138*

Kilian, S., Berswordt-Wallrabe, P. V., Steele, H. and Werner, D. (2001). Cultivar-specific dinitrogen fixation in Vicia faba studied with the nitrogen-15 natural abundance method. *Biol Fertil Soils, 33:358–364*

Kristiansen, P., Taji, A. and Reganold, J. (2006). *Organic Agriculture.* A Global Perspective. CSIRO Publishing. Pp 25-33

Kumar, A. (2007). Effects of legumes on growth, yield and quality of pop sorghum in inter and mixed cropping system. Department of Agronnomy, College of Agriculture, Dharwad University of Agricultural Sciences, Dharwad.

Köpke, U. and Nemecek, T. (2010). Ecological services of faba bean. *Field crop research, 115: 217-233*

Larsson, J., Ekelund, L., Carlsson, M. (2009) *Trends in the Development of Collaboration between Horticultural Research, Education and Industry*. Department of Work Science, Business Economics and Environmental Psychology SLU (Swedish University of Agricultural Sciences) Box 88, SE-230 53 Alnarp Sweden. 55-64

Lin, B.B. (2011). Resilience in Agriculture through Crop Diversification Adoptive Management for Environmental Change. *Bio Science, 61 No. 3:183-193*

López-Bellido, L., López-Bellido, R. J., Redondo, R. and Benitez, J. (2006). Faba bean nitrogen fixation in a wheat-based rotation under rainfed Mediterranean conditions: Effect of tillage system. *Field Crop Research, 98: 253-260*

López-Bellido, F. J., López-Bellido, R. J., Redondo, R. and López-Bellido, L. (2010). B value and isotopic fractionation in N2 fixation by chickpea (Cicer arietinum L.) and faba bean (Vicia faba L.). *Plant Soil, 337:425–434*

McCarl, B. A., Adams R. M. and Hurd, B. H. (2001). *Global Climate Change and Its Impact in Agriculture. (Website:* http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/879.pdf)

Nagy, C. N. (2001). Agriculture Energy Use of Adaptation Options to Climate Change. *Prairie Adaptation Research Collaborative (PARC): 1-8*

Noubissie, J. B. T., Bell, J. M. and Yadji, H. T. (2012). Studies on Variability and Gene Effects of Seed Protein Contents in Cameroonian Bean (Pheseolus vulgaris) Cultivars. *Journal of Agriculture and Social Sciences. 8:17-23*

Palmborg, *C.,* Scherer-Lorenzen, M., Jumpponen, A., Carlsson, G., Huss-Danell, K. and Högberg, P. (2005). Inorganic soil nitrogen under grassland plant communities of different species composition and diversity. *OIKOS, 110: 271-282*

Prasad, R. and Power, J. F. (1997). Soil Fertility Management for Sustainable Agriculture. Lewis Publishers, Boca Raton, New York. Pp 131

Robertson, G. P. and Vitousek, P. M. (2009). Nitrogen in Agriculture: Balancing the cost of an essential resource. *Annu. Rev. Environ. Resour, 34: 97-125*

Rugheim, A. M. E and Abdelgani, M. E. (2012). Effects of microbial and chemical fertilization on yield and seed quality of faba bean (Vicia faba). *International Food Research Journal, 19 (2): 417-422*

Sette, C. and Watts, J. (2010). Group Facilitation Skills for Participatory Decision Making: Report of a Follow-up Outcome Evaluation. ILAC Working Paper 11. Institutional Learning and Change (ILAC) Initiative - c/o Bioversity International Via dei Tre Denari 472°, 00057 Maccarese (Fiumicino), Rome, Italy

Snyder, C. S., Bruulsema, T. W., Jensen, T. L. and Fixen, P. E. (2009). Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture Ecosystems and Environment, 133(3-4) Special Issue: Sp. Iss. SI: 247-266*

Sullivan, P. (2003) Overview of cover crops and green manures. Foundation of Sustainable Agriculture, Appropriate Technology Transfer for Rural Areas (ATTRA) *(www.attra.ncat.org)*

Suleyman, S. (2003) Performance of some forage grasses or legumes and their mixtures under dry land conditions. *European Journal of Agronomy, 19: 401-409*

Sutton, M. A., Erisman, W., Leip, A., Van, G. H. and Winiwater, W. (2011). Too much of good things. *Nature, 472: 159-161*

Tilman, D,, Cassman, K. G., Matson, P. A., Naylor, R. and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418: 671-677.*

Turner, G. L., Gault, R. R., Morthorpe, L., Chase, D. L. and Bergersen, F. J. (1987). Differences in the natural abundance of 15N in the extractable mineral nitrogen of cropped and fallowed surface soils. *Australian Journal of Agricultural Research, 38: 15-25*

UNEP, 1998. Mineral Fertilizer Production and the Environment Part 1: The fertilizer industries manufacturing process and environmental issues. Tech. Rep. 26-Part 1. United Nation Environment Program, Paris

Unkovich, M., Herridge, D., Peoples, M., Cadisch, G., Boddey, B., Giller, K., Alves, B. and Chalk, P. (2008). Measuring plant-associated nitrogen fixation in agricultural systems. Australian Center for International Agricultural Research (ACIAR)

Vallavieille-Pope, C. D. (2004). Management of disease resistance diversity of cultivars of a species in single fields: controlling epidemics. *Plant biology and pathology, 327: 611-620*

Vinther, F. P. and Jensern, E. S. (2000). Estimating legume nitrogen fixation in grass clover mixtures of grazed organic cropping system using two 15_N Methods. *Agriculture, Ecosystem and Environment, 78: 139-147*

Wild, A. (1994). SOILS AND THE ENVIRONMENT: AN INTRODUCTION. Cambridge University Press. P. 81

Wivstad, M., Mårtensson, A. M. and Liunggren, H. D. (1987) Field measurement of symbiotic nitrogen fixation in an established lusern ley using ^{15}N and an acetylene reduction method. *Plant and Soil, 97: 93-104*

Xu, G., Fan, X. and Miller, A. J. (2012). Plant Nitrogen Assimilation and Use Efficiency. *Annual Review of Plant Biology, 63:5.1-5.3*

Yang, J. Y., Drury, C. F., Yang, X. M., Jong, R. D., Huffman, E. C., Campbell, C. A., Kirkwood, V. (2010). Estimating biological N_2 fixation in Canadian agricultural land using legume yields. *Agriculture, Ecosystems and Environment 137: 192–201*

Zentner, R. P., Basnyat, P., Brandt, S. A., Thomas, A. G.,Ulrich, D., Campbell, C. A., Nagy, C. N., Frick, B., Lemke, R., Malhi, S.S. and Fernandez, M. R. (2011). Effects of input management and crop diversity on non renewable energy use efficiency of cropping system in the Canadian prairie. *European Journal of Agronomy, 34:113-123*

Annexes

Annex 1: Questionnaires sent to the advisors

The response rate has been calculated based on numbers of responding advisors out of thirteen. The percentages respondent for the particular answer option comprises proportion of advisors responded particularity for that question for provided options.

Basic information about the informant:

Name:

Address:

In which system of farming are you providing the majority of your advisory service?

Response options	No. of respondent	Percentage
a. Organic with animal	2	15%
b. Organic without animal	-	-
c. Conventional with animal	6	46%
d. Conventional without animal	3	23%
e. Mixed (both organic and inorganic)	2	15%
f. Other: Livestock Production, organic farming	2	15%

General questions about legumes

1. Is legume based diversification of cropping systems (= inclusion of more legumes in the cropping system) important for soil nitrogen management?

Respondent	No of advisors		
100%	13		
Response options		No. of respondent	Percentage
a. Not important		1	8%
b. Fairly Important		4	31%
c. Important		6	46%
d. Very important		2	15%

Further Comments: "Legume is very good pre crop for winter wheat".

2. Is legume based diversification of cropping systems (= inclusion of more legumes in the cropping system) important for reducing agricultures contribution to greenhouse gas emissions

1 advisor=8% "No, it is only important as a good pre crop"

A. Via decreasing the frequency of nitrogenous fertilizer application?

Respondent	No.of advisors		
100%	13		
Response options		No. of respondent	Percentage
a. Not important		2	15%
b. Fairly Important		4	31%
c. Important		6	46%
d. Very important		1	8%

More comment: "Depends on price of fertilizer and harvesting"

B. Via reducing the need for tillage and weeding specially considering perennial legume in the crop sequence?

Respondent	Non Respondent		
85% (11 advisors)	15% (2 adviors)		
Response options		No. of respondent	Percentage
a. Not important		2	18%
b. Fairly Important		5	45%
c. Important		3	27%
d. Very important		1	9%

C. Via reducing the amounts of imported feed (*e.g.* soybean)

Respondent	Non Respondent		
92% (12 advisors)	8% (1 advisor)		
Response options		No. of respondent	Percentage
a. Not important		1	8%
b. Fairly Important		2	17%
c. Important		3	25%
d. Very important		6	50%

3. Do you consider legumes are important to include in cropping system from economic production point of view?

Respondent	Non Respondent		
100% (13 advisors)			
Response options		No. of respondent	Percentage
a. Not important		1	8%
b. Fairly Important		5	38%
c. Important		3	23%
d. Very important		4	30%

4. How often do you consider it optimal to include legumes on the same field, taking aspects of nitrogen management, crop sequence, as well as soil borne pathogen pressure into account?

Respondent	Non Respondent		
100% (13 advisors)			
Response options		No. of respondent	Percentage
a. More often than every year		1	8%
b. Every three to five years		3	23%
c. Every five to seven years		6	46%
d. Less frequent then every seven years		1	8%
e. In every 3-5 years for hay and silage in row with peas and beans		1	8%
f. Once in every four years		1	8%

Questions about crop diversification:

5. How high is your interest or how strongly you recommend in growing diversified crops, for example mixtures of different varieties of the same crop or combinations of different crop species (one example could be cereal and legume)?

Respondent	Non Respondent	
100% (13 advisors)		
Response options	No. of respondent	Percentage
a. Very low	1	8%
b. Low	2	15%
c. High	8	62%
d. Very high	2	15%

6. What is your opinion about the potential and possibilities of growing crops in combinations for example mixtures of different varieties of the same crop or combinations of different crop species (Cereal and legume mixture again could be one example) for:

   A. Resource management (efficient use of *e.g.* land, water and nutrients)

Respondent	Non Respondent	
92% (12 advisors)	8%(1 advisor)	
Response options	No. of respondent	Percentage
a. Very low	2	16%
b. Low	2	16%
c. High	5	42%
d. Very high	3	25%

B. Higher yield and yield stability

Respondent	Non Respondent	
84% (11 advisors)	16% (2 advisors)	
Response options	No. of respondent	Percentage
a. Very low	0	0%
b. Low	4	37%
c. High	5	45%
d. Very high	2	18%

C. Cropping system sustainability (economically sustainable with minimized negative environmental impact)

Respondent	Non Respondent	
92% (12 advisors)	8% (1 advisor)	
Response options	No. of respondent	Percentage
a. Very low	0	0%
b. Low	2	17%
c. High	7	58%
d. Very high	3	25%

D. Adaptation to reduce the effect of climate change in crop production (variation in *e.g.* temperature and rainfall within and between growing seasons)

Respondent	Non Respondent	
92% (12 advisors)	8% (1 advisor)	
Response options	No. of respondent	Percentage
a. Very low	0	0%
b. Low	3	25%
c. High	8	67%
d. Very high	1	8%

E. Prevent outbreaks of diseases and pests

Respondent	Non Respondent	
84% (10 advisors)	16% (3 advisors)	
Response options	No. of respondent	Percentage
a. Very low	1	9%
b. Low	4	36%
c. High	3	27%
d. Very high	1	18%
e. No opinion	1	9%

7. Do you suggest growing crop mixtures to farmers (varietal or species mixtures)?

a. Yes, b. No,

Respondent No.	Respondent %	Non Respondent No.	Non Respondent %
10	77%	3	23%

Yes		No	
No. of Advisors	Percentage	No. of Advisors	Percentage
8	80%	2	20%

A. If *Yes*, Why? *(Here you can chose several options)*

Options with reasons	No. of respondent	Percentage
a. For greater yield	3	30%
b. For stable yield	4	40%
c. To prevent from occurrence of different diseases and pests	1	10%
d. Soil nutrient management reducing use of chemical fertilizer	6	60%
e. For diversity	2	2%
f. Any other	1	10%

General comments from some advisors: "It depends on local protein feed situation, system of farming, availability of land type, economy of the farmers and supply of protein feed available."

B. If *No*, please state your main reason in few words

"Most of farmers grow peas or beans for seed production or to feed the pig and this system is not very popular among all the farmers."

8. What do you think (based on your knowledge and experience of work) is about the main problem associated with growing diversified crops (varietal or species mixtures)?
   You can choose multiple options indicating the order of difficulties with numbers 1, 2, 3 … (1 being the most important problem)
   a. Land preparation
   b. Sowing
   c. Intercultural operation
   d. Plant protection
   e. Harvesting
   f. Marketing
   g. Any other: overall processing and management of the crop, storage technique and methods of feeding, the state of knowledge of the farmers, farmers are almost not used to for this crop. (Summarized from the advisors comments)

   Responses:

Respondent	Non Respondent
84.6% (11 advisors)	15.4% (2 advisors)

Problems	a.Land preparation		b.Seed sowing		c.Intercultural operation		d.Plant Protection			e. Harvesting		f. Marketing		
Order of importance	2	5	2	6	2	4	1	2	4	1	2	1	2	3
No. of advisors	1	1	1	1	1	1	1	2	1	7	4	3	1	2
Percentage	9	9	9	9	9	9	9	18	9	67	36	27	9	18

Specific questions about Faba bean

9. Do you suggest growing Faba bean (*Vicia faba*) in farmer's fields?

Responding advisors	100%
a. Yes	b. No
No. advisors=11=85%	No. advisors = 2=15%

If *Yes*,

What can be the main purpose of including Faba bean in their cropping system?

[*You can choose multiple options indicating the order of importance with numbers 1, 2, 3 … (1 being the most important purpose)*]

a. Animal feed production
b. Reducing the need for imported protein feed
c. Nitrogen fixation
d. Soil fertility
e. Green manure
f. For selling the harvested grains
g. Any other

(Percentage calculated among the advisor who recommended growing)

Problems	a.Animal feed production		b.Supplementing protein feed			c.Nitrogen fixation			d. Soil fertility				e.Green manure			f.Selling for grain		
Order of importance	1	2	1	2	3	2	3	4	1	2	3	4	3	4	5	1	3	6
No. of advisors	8	2	4	2	2	1	3	2	2	2	1	1	1	1	2	3	1	1
Percentage	9	73	36	18	18	9	27	18	18	18	9	9	9	9	18	27	9	9

Comments from advisors: Also can be used to control weeds, other befit depends on situation of farm, crop rotation and animal feed production (Summarized).

If *No*, Why not? (Why you don't recommend Faba bean?)

[*You can choose multiple options indicating the order of difficulties with numbers 1, 2, 3 … (1 being the most important problem)*]

(Percentage calculated among the advisor who recommended not growing)

Reason options	Order of difficulties	No. of advisors	Percentage
a. It is not economically interesting	1	2	100
b. This crop is difficult to established	3		50
c. There are no animals on the farm / no recipient of the crop	2	1	50
d. Problem with diseases and pests are extensive	3	1	50
e. Unfamiliar with advantage of growing this crop	3	1	50

Other comments: "Too low price compared to Malt barley, Bread Wheat, Sugar beat and it is difficult to harvest"

10. To what extent do you recommend reducing N fertilization when you suggest growing Faba bean in crop sequence as compared to a non-legume crop (= "normal" application)?

Respondent		Non Respondent	
8 Advisors	62%	5 Advisors	38%

A. In the Faba bean crop itself

Reason options	No. of advisors	Percentage
a. Reduction by one fourth of normal application	-	-
b. Reduction by one third of normal application	-	-
c. Reduction by one half of normal application	1	12.5
d. Reduction by two third of normal application	-	-
e. No N fertilizer application at all	7	87.5

B. How much would you reduce the nitrogen rate on a succeeding cereal crop (the year after the Faba bean crop)?

Amounts recommended (kg/ha)	No. of advisors	Percentage
0	1	12.5
20	4	50
30	1	12.5
40	1	12.5
100	1	12.5

11. Do you suggest growing Faba bean mainly in pure stand or in mixture with cereal crops, for example spring wheat or oat?

Respondent	Non Respondent
61.5% (8 advisors)	38.5% (5 advisors)

Options	No. of advisors	Percentage
a. Only in pure stand	3	37.5
b. Mainly in pure stand, a minor proportion intercropping	1	12.5
c. Mainly in intercropping with (Wheat-37.5 and hay or silage crop-12.5%)	(3+1)	50
d. Only in intercropping with………………..	-	-

12. Do you consider Faba bean in combination with cereal mixtures an interesting alternative for resource use and yield stability?

Respondent	Non Respondent
69% (9 advisors)	31%(4 advisors)

Alternatives	No. of advisors	Percentage
a. No	2	22
b. Fairly interesting	3	33
c. Interesting	4	45
d. Very interesting	-	-

(The following three questions, 13-15, aim at understanding if and how the frequency at which you recommend growing faba bean on the same field depends on whether the farm includes other legumes, which may potentially influence the abundance of pathogens with a wide host range)

13. If faba bean would be the only legume in your crop rotation, how often do you consider it optimal to grow Faba bean on the same field, taking aspects of nitrogen management, crop sequence, and soil borne pathogen pressure into account?

Respondent	Non Respondent
69% (9 advisors)	31%(4 advisors)

Options	No. of advisors	Percentage
a. Less frequent than every eight years	-	-
b. Once every seven or eight years,	2	22
c. Once every five or six years	6	67
d. Once every three or four years	1	11
e. More frequent than every three years	-	-

14. If crop sequence in field includes both Faba bean and pea, how often do you consider it optimal to grow Faba bean on the same field, taking aspects of nitrogen management, crop sequence, and soil borne pathogen pressure into account?

Respondent	Non Respondent
61.5% (8 advisors)	38.5% (4 advisors)

Options	No. of advisors	Percentage
a. Less frequent than every eight years	2	25
b. Once every seven or eight years,	3	37.5
c. Once every five or six years	2	25
d. Once every three or four years	1	12.5
e. More frequent than every three years	-	-

15. If crop sequence includes Faba bean, pea and grass-clover leys, how often do you consider it optimal to grow Faba bean on the same field, taking aspects of nitrogen management, crop sequence, and soil borne pathogen pressure into account?

Respondent	Non Respondent
61.5% (8 advisors)	38.5% (4 advisors)

Options	No. of advisors	Percentage
a. Less frequent than every eight years	2	25
b. Once every seven or eight years,	3	37.5
c. Once every five or six years	2	25
d. Once every three or four years	1	12.5
e. More frequent than every three years	-	-

16. In your opinion and understanding what are the main advantages and disadvantages of including Faba beans in the cropping system?

Advantage- Good price of yield, helpful to for diversified crop rotation, good source of protein to animals, good pre crop to wheat and less nitrogen require for next crop

Disadvantages: difficulties in harvesting and susceptible to drought, low economic return, market and harvest problem and Late maturity (Summarized from the advisors comments and suggestions about advantages and disadvantages)

Questions on the experience of advisory meetings with farmers about strategies to reduce agricultural impact on climate change

You have most likely performed climate advisory meetings with several farmers. Please try to provide answers that represent your overall impression based on all climate advisory meetings that you have performed. You can of course mark several options, preferably by adding remarks about which alternative is most representative, as for example:

21. Did you get the impression that the meeting about the relationships between farm management and climate impact was useful for the farmer?
    - a. Yes, it resulted in clear and useful "tools" to reduce the farms' climate impact
    - b. Yes, it was useful to increase the farmer's knowledge but was not enough to provide any tools to directly reduce climate impact *- most frequent impression*
    - c. It was an "eye-opener" *- second most frequent impression*
    - d. Strategies to reduce climate impact were perceived as important but too complex to apply at the farm level
    - e. No, unfortunately, the farmer mainly experienced complexity and confusion related to these issues *- one out of ten cases*
    - f. Any other……………………………………………………………

[Also you can choose multiple options indicating the order of importance with numbers 1, 2, 3 … (1 being the most important)]

17. Did you get the impression that the meeting about the relationships between farm management and climate impact was useful for the farmer?

Respondent	Non Respondent
92% (12 advisors)	8% (1 advisor)

a. Yes, it resulted in clear and useful "tools" to reduce the farms' climate impact

Order of importance	No. of advisors	Percentage
2	3	25
1	2	17

b. Yes, it was useful to increase farmer's knowledge but was not enough to provide any tools to directly reduce climate impact

Order of importance	No. of advisors	Percentage
5	1	8
2	1	8
1	6	50

c. It was an "eye-opener"

Order of importance	No. of advisors	Percentage
2	3	25
1	4	33

d. Strategies to reduce climate impact were perceived as important but too complex to apply at farm level,

Order of importance	No. of advisors	Percentage
4	1	8
3	1	8

e. No, unfortunately, the farmer mainly experienced complexity and confusion related to these issues,

Order of importance	No. of advisors	Percentage
3	1	8

f. Any other……………………………………………………………

18. Was any relationship between increasing the cultivation of legumes and reduced climate impact mentioned during the advisor meeting? (please remember that multiple choices are possible)

Respondent	Non Respondent
92% (12 advisors)	8% (1 advisor)

a. Yes, in the sense that growing more legumes reduces greenhouse gas emissions related to the use of mineral N fertilizers

Order of importance	No. of advisors	Percentage
2	3	25
1	5	42

b. Yes, in the sense that growing more legumes reduces long-distance import of protein feed and the climate impact related to cultivation of protein crops in other parts of the world1

Order of importance	No. of advisors	Percentage
2	1	8
1	7	58

c. Yes, and the farmer became interested in increasing the proportion of legume crops on their fields as a direct result of the meeting

Order of importance	No. of advisors	Percentage
3	1	8
2	1	8
1	2	17

d. Yes, but also risks of nitrogen losses in intensive legume cultures were discussed, and it was unclear whether growing more legumes has exclusively positive environmental impact

Order of importance	No. of advisors	Percentage
1	1	8
3	1	8

e. No, there was very little discussion on such relationship
f. Any other…"There is still a big discussion if the legume can be a better option in any rotation"……………………………………….

19. Please give a small comment if you want to say and share anything additional regarding crop diversification, legume cultivation, fertilizer use and available resource management for sustainability in agriculture production system.

- Farmers are interested to gain knowledge about the climate. They are happy with advice about nitrogen loss and production as best for climate.
- Farmers must be better paid of reducing CO_2 and for the adaptation of such a cropping system.
- There is high variation in yield from 800 to 4500 kg/ha.
- Climatic variation may be other difficulties to grow crop in mixture, i. e. too much rain and difficulties in harvesting due to different maturity time.
- Diversified cropping system is also important for agro ethanol production
- Still needs a lot of field trials about diversification because the system did not work in us and Canada especially in sorghum and cotton.
- Pea is comparatively easy to grow but if the farmers have the problem of pathogen and soil borne disease
- Reduced tillage and plough the field after legume will good for good farming
- Farmers should also be compensated for growing protein crops. (Points were summarized from advisors comments and suggestions)

General impression of one informant, Maria Berglund, on agriculture and green house gas

-‟ GHG and agricultures role in climate change is an emotional issue for many farmers, and some advisors. They may question that agricultures should mitigate GHG emissions (I've heard argument such as: Much of the agricultural GHG emissions are, more or less, 'natural' and can't be omitted, e.g. enteric fermentation is essential for ruminants. In addition, farmers produce products that consumers ask for, hence, the consumers ought to be 'blamed' for these emissions) and they may claim that everything that has to do with agricultural GHG emissions is so uncertain that there is no point to do anything".

‟I think that deforestation and land use change (e.g. savannahs that are transformed to pastures or arable land) are severe issues. Hence, we need to decrease the import of products that drive deforestation and unsustainable land use change. We do not fully understand the magnitude of the negative environmental impacts of such land use change, and these effects are for sure underestimated in the farm-level CF calculation tool provided by Focus on

Nutrients. Hence, the advantages of cultivating legumes as means to decrease the import of soy and palm oil by-products are not fully accounted for and are hard to see for the advisor”

Annex 2: Photos from field experiment

Photo 1: Faba bean and spring wheat in mixture at early stages of their growth (Photo by Georg Carlsson)

Photo 2: Faba bean and wheat plants at active vegetative growth stage (Photo by Nawa Raj Dhamala)

Photo 3: Fully matured faba bean plant before harvesting of grain (Photo by Georg Carlsson)

Photo 4: Faba bean plant at full maturity heavily lodged (Photo by Gerog Carlsson)

Annex 3: Personal reflection on master thesis

I still remember when I and my supervisor were discussing possible topics for my master thesis within area of my interest. I could not restrict my enthusiasm and was fully devoted to bring the best in the thesis. Spending almost one year with my supervisor being involved in Project Based Research Training and Master Thesis was very nice time with full of new experiences and learning. It was a very nice learning and understanding about most valuable practices and innovations like: N_2 fixation, N cycling, biomass production and optimizing diversity of species and varieties in organic system. I feel very lucky for getting this opportunity to study about varietal mixtures of faba bean as very limited studies have been done in this field.

Sometime I used to think that I was not specific on particular issue. Now I realized that the whole work was very nice insight to some nitrogen and crop parameters studied within very short period of time. I am quite convinced that the experiment and analysis made for N_2 fixation and parameters associated with N_2 fixation was quite sufficient considering the time span and volume of work. Still, the estimations made based on literature references and some crop parameters are not exact and might be pointed out as possible limitation of study. But those calculations were also the areas of my research interest and have strengthened my knowledge. Of course, to investigate more about these crop and N parameters including reasons for the results I found in the empirical study through experiment become the potential study area for the future. The results which were contradictory to the previous findings might also be of potential research areas for future investigations.

The survey on implication of study outcome was another valuable experience from master thesis. Even though the target group of advisors was quite low, the comments and information they provided were great learning for me. I came to realize that interaction with concerned stakeholders can provide many new areas of investigation and precepts of study including hidden realities being very close to real farming situation. As advisors mentioned that harvesting and marketing management are the main problems associated with growing crop in mixtures, it was opposite with my initial thought. The advisors concerns and understandings regarding climate change and sustainable agriculture were very surprising to me. I found them very aware on role of legume in cropping system and problem associated. Their understandings regarding faba bean and its inclusion in cropping system were also unbelievable.

I believe that this thesis will be useful to provide information about importance of sustainable management of N input in organic system enhancing diversity. The perception of advisors has highlighted the importance of interaction with concerned stakeholders for optimum use and transfer of technology to enhance sustainable development in agriculture.