Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

The Faculty of landscape Planning, Horticulture and Agriculture Science

Effects of proximity to Poplar trees on the performance of intercropped faba bean and spring wheat

Mohammad Sakil Sarwar

Master´s thesis • 30 ECTH • Advance level
Agroecology Masters Programme
Department of Agrosystem
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Effekter av avstånd till en läplantering av poppel i samodling av åkerböna och vårvete.

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Foreword

I come from Bangladesh which is an Agricultural country in the South Asia. Population of Bangladesh is too large and increasing day by day. Farmers use huge amounts of pesticides and chemical fertilizers to produce more food to meet the growing demands, and they do not know how to produce crops in an ecological way. My studies in the Agro-ecology masters program offer great opportunities to learn the methods and techniques of sustainable crop production without deteriorating our natural resources. During the courses I have visited many organic and conventional farms. I think I have learnt many things from the studies; farm excursion and thesis work about sustainable resource management and land use system which I can apply in the field level when I return to Bangladesh. I believe that all my gained knowledge from field experiment, laboratory work, doing semi structured interview, using different participatory method during farm visit help me in developing my personnel career. I want to apply my research outcomes into the field level of rural community. My ambition is to join as a scientist in agricultural research institute and share my research findings with government extension worker to spread knowledge among farmers and encourage them to grow more trees in their land and maintain farming system in a sustainable way. I believe that the outcomes of my MSc thesis will help encouraging farmers to apply faba bean-wheat intercropping system under agro forestry settings, but arguments need to be complemented by studies on the economic outputs of such systems. Communication and transfer of knowledge between researchers, advisors and farmers also need to be promoted. Different stakeholder of agro forestry network can play an important role to apply my research outcome commercially in the field level. Government should imply sufficient subsidy to grow crops with more trees. Policy maker and environmental group should more concern about climate change in relation to agroforestry settings to conserve the ecology of the ecosystem. There should be a combination of university research center and national agricultural research institution to apply laboratory research outcomes in the farmers field level. Government, private sector, donor groups and agribusiness representative should make proper planning to expand the market for agro forestry so that farmers will be encouraged to grow more trees for utilizing their land sustainably. Agroforestry settings in intercropped field will play a great role in case reduces yield variability in Bangladesh a developing country where environmental pollution is a great threat due to huge amount of chemical substance use.

By coordinating my MSc thesis defense and an agroforestry seminar with invited scientists and stakeholders from the Swedish agroforestry network, I was exposed to new questions which encourage me for further research. I also learnt about practical experiences and gained knowledge from their respective field and became more aware of barriers which they face during applying the methods of growing more trees in the farmer's agricultural field. I think that the most striking issue that was emphasized by the group from the agroforestry network is the economical conditions for the farmer. I am still very much eager to know what kind of difficulties are supposed to be faced by the farmers. In my future activities I want to discuss with small scale farmers, advisors and extension officers about the subsidy and bank loan facility to implement this kind of ecologically sustainable method. In conclusion, attending the Agroecology MSc program and performing my MSc thesis on the topic of combined agroforestry and intercropping have provided me new knowledge and ideas which are very valuable for my engagement in research and extension activities about cropping system diversification.

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Abstract

Faba bean and spring wheat were intercropped and sole cropped in different distance to a row of approximately 20m tall Poplar trees. Measurements of plant height and soil moisture content were taken at approximately 10 m (shade), 17 m (half shade) and 25 m (sun) distance from the poplar trees. Measurements of above and belowground biomass of faba bean and wheat were taken at pod fill of faba bean, in plots located in shade and sun, respectively. Lower amount of soil moisture was measured in shade plots than farther away from the trees, both in July and in August. The growth (height) of faba bean and wheat was higher in half shade plots than in shade plots. There was a significant positive effect of intercropping on the height of wheat. Significantly higher wheat height was measured in shade plot when intercropped with faba bean than wheat as sole crop on 18th of June and 9th of July, 2012. Faba bean plant biomass was higher in shade plots than in sun plots, both in sole cropped faba bean and in intercropping with wheat. Wheat biomass showed an opposite response to proximity to poplar trees: it was lower in shade than in sun both in sole cropped wheat and when intercropped with faba bean. Weed growth was significantly suppressed in faba bean-wheat intercropping both in shade and sun plot. This research work shows the possibilities of the diversification of cropping system. Modern agriculture needs this kind of studies for the conservation of the ecology of the nature in agroecological point of view.

Key words: Agro forestry, Intercropping, Biomass production, Competition, Soil moisture, Light, Nutrient, Sustainability.

Abbreviations:

D M	Dry matter
M	Meter
N-A	Net Assimilation
N	Nitrogen
%Ndfa	Percentage of nitrogen derived from atmosphere
PAR	Photo synthetically Active Radiation
S E	Standard Error

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1.Agroecological perspectives

Food production is mainly depends on fossil fuel, chemical nitrogenous fertilizer, and other chemical substances. Due to climate change, ocean acidification, chemical insecticides pollution, stratospheric ozone depletion cropping system diversification is needed without use of fossil fuel and minimum use of chemical nitrogenous fertilizer.

Farmers often use nitrogenous fertilizer to increase the crop yield production. Excess fertilizer is subject to leaching into different water sources and causing excess algal growth which reduces the water quality and amount of aquatic animal (Gliessmann, 2007). Farmers often use chemical insecticides to control and kill the pest and diseases in their field. Some portion of spray remains on the soil, crop residue, leaves, even in the grain. After raining and irrigation remaining portion of pesticides cause water pollution by surface runoff. Sometimes neighbor field and members of the nearby farm house affected by spraying drift.

Agroforestry systems help to reduce the use of chemical fertilizer, reduce surface run off, nutrient leaching and can maintain the nutrient requirement for the plant by nutrient recycling (Nair, 1993; Auclair, 1999; Gliessmann, 2007).

Agroforestry setting with intercrop promotes to reduce the amount of pest and disease in the field (Thevathasan and Gordon, 2004).

Intercropping legume crop in an agroforestry settings often reduces the application of nitrogenous fertilizer as legume crop fixes atmospheric N in the field (Fujita et al, 1992).

Farmers can get fruit, wood, and varietal kinds of product from trees in an agroforestry system. It is some additional income of the farmers. Agroforestry system helps to reduce the dependency of the society members on oil, fossil fuel as wood biomass can be utilized as bio-energy sources (Christersson, 2010). It increases the employment opportunity for members of the society. People can get environmentally sustainable residual biomass and energy product from the market.

By growing trees in agricultural cropping field farmers can minimize the cost of chemical fertilizer and pesticides uses.

Agroforestry settings with intercropped is such a cropping system to utilize time, space, labor and natural resources efficiently and sustainably (Sommariba et al, 1998; Scholl and Nieuwenhuis, 2004). It is necessary to do natural scientific research in combination with different members of agroforestry network to communicate and motivate farmers for the diversification of this kind of cropping system in the field level. While the knowledge about the low sustainability of modern agriculture is widespread in the society, it seems difficult to transform the knowledge into action plans and obtain the needed changes in cropping system management. The communication of science-based solutions for improved sustainability and the application of this knowledge via extension activities must be even more encouraged and promoted. Agroecological education and research provide tools for meeting these challenges, combining natural scientific, economic and social aspects of sustainability and linking research with communication and action.

2. Introduction

The population of the world increases day by day. Production of food should be maintained in an ecological way without deterioration of natural resources. World agriculture depends on chemical insecticides, chemical fertilizer, hybrid seed and different machinery. Sustainability in agriculture can be achieved by ensuring minimum environmental degradation (Fujita et al, 1992).

Agroforesty is a form of sustainable land use systems, applying methods for the cultivation and management of woody perennials with agricultural crop in the same piece of land (Somarriba et al, 1998).

The main purposes of applying agroforestry are: maximum utilization of time, space and labor, increase crop yield production, getting more woodlots, reduce nutrient loss and production cost of the farmers (Sands, 2005).

In an agroforestry system with poplar and wheat in tropical countries, solar radiation and air temperature was decreased and relative humidity was increased close to the trees. Growth and development of wheat were enhanced by these changes in the microclimate (Fang et al, 2005).

Beneficial interaction between woody plant and non woody crop species are found in several research studies (Currrent et al, 1998; Palaniappan and Sivaraman, 1996; Devendra, 1993). However, tree based intercropping sometimes create negative interaction among crops and tree species (Ong and Rao, 2001; Elevitch and Wilkinson, 2000; Currrent et al, 1998; Litman, n.d.). Shade trees often create competition for below and above ground resources in tree-crops inter-cropping system.

Intercropping can be defined as growing two or more crops simultaneously in the same field for better utilization of light, air, water and nutrients (Scholl and Nieuwenhuis, 2004). Different kinds of intercropping arrangement are used: mixed intercrop, strip intercrops, alley intercrops (Brisson et al, 2008). Intercropping systems are applied to implement sustainable crop production practices to conserve the environment by using natural resources properly

A lot of advantages can be obtained by using intercropping production system, notably by more efficient utilization of light, water and nutrient (Blade et al, 1997). Different root patterns are found in intercrops. Plants can absorb water and nutrient from different layer of the field in intercropping system (Scholl and Nieuwenhuis, 2004). Crop can utilize maximum amount of sunlight in intercropping system. Intercropping system is applied to implement sustainable crop production practices to conserve the ecology of the environment by using natural resources properly (Anders et al, 1994).

Intercropping reduces pest and disease infestation in the field. Farmers can utilize maximum amount of environmental resources, increase soil fertility and reduce the production cost, time and space in intercropping production system (Rao and Kaur, 2007).

Higher plant biomass and seed yield can be obtained in intercropping systems than in sole cropping due to better utilization of light, effective development of root biomass and optimum use of nitrogen when intercrop with N fixing legume crop (Scholl and Nieuwenhuis, 2004). Significantly higher total dry matter production was observed in intercropping system (Wheat-Faba bean) than wheat or faba bean as sole crops and weed control was more effective in case of intercropping system (Eskandari and Ghanbari, 2010). Sometimes intercropping is used to avoid possible yield failure. If yield loss occurs in one crop, then it can be overcome by other crops (Scholl and Nieuwenhuis, 2004).

Water use efficiency is an important factor in intercropping system. Morris and Garrity (1993) reported 18% to 99% higher water use efficiency in intercropping system than in sole cropping.

Intercropping wheat with legume can be practiced to maintain soil fertility and reduce yield loss during adverse climatic situation. Grain yield of wheat was higher when intercropped with N-fixing legume crop species due to increased N availability (Sarandon, 1999).

Significantly higher N accumulation is observed in by wheat,- when intercropped with legume crops than in sole cropping. The yield of wheat was higher in wheat-soya bean intercropping than in sole cropped wheat (Li et al, 2001). Jensen (1986) found a significant influence of intercropping on the N content of wheat grain yield in a three year field study of intercropping faba bean and spring wheat. This kind of cropping system increased the amount of N in wheat grain.

Production of wheat grain and biomass yield is higher in legume-cereal intercropping than sole cropping production system. When the availability of N in soil is poor then legume crops can provide additional N to subsequent crop species via biological nitrogen fixation (BNF) which increases the crop production and N use efficiency (Fujita et al, 1992). BNF depends on various factors: types of cereal species, kinds of legume plants, pattern of root growth, varietal mixture of seeds and some environmental factors like soil fertility, soil pH etc (Fujita and Ofusu-Budu, 1994).

Faba bean (*Vicia faba*) is a grain legume under the family Fabaceae. Faba bean is also known as field bean, broad bean, horse bean and tick bean. Faba bean is usually grown for mature seed production. Some times immature pods are eaten as vegetable (Brink and Belay, 2006).

Faba bean seed is usually used as a source of protein (Brink and Belay, 2006). This crop is also utilized to meet human requirements for calcium, phosphorus, iron, as well as vitamin A and B complex vitamins (Roehl, 1996).

The origin and place for domestication of faba bean is western Asia, from where it was spread to Europe, Africa, central asia. Faba bean was first cultivated between 7000 and 4000 B. C. Faba bean is widely grown in sub tropical regions, higher altitudes of tropical countries, and in temperate regions (Brink and Belay, 2006).

Different kinds of Poplar trees species are planted in the field for different purposes. Poplar species: *Populus nigra, P. euramericana cv rob., P. alba, P. tremula, P. balsamiferas, P. maximowiczii, P. tomentosa and P. euphraetica* are planted in Eastern Europe, Northern and Central Asia for biomass and bio-energy production (Fischer et al, 2005). Hybrid of *Populous trichocarpa* and *Populous deltoids* are used in Washington as bio-energy production trees (Heilman et al, 1993). In Minnesota *Populous deltoids* were planted for biomass and bio-energy production (Isebrands, 2007). In southern and central part part of Sweden hybrid of *Populus maximowiczii* and *Populus deltoides* was used for bio-energy production (Christersson, 2010).

Poplar trees can be planted for biomass and bio-energy production. Closer spacing of polar tree planting was very effective to produce bio energy economically in Minnesota in U.S. Between-tree spacing in the range from 1.2x1.2 m to 1.5x1.5 m can be used to produce 10 to 15 cm diameter tree per acre within 6 to 8 years (Isebrands, 2007). This growth rate may correspond to a production level of 12 – 15 tons of biomass production (bark, plant parts, wood) per hectare and year for bio energy production. According to Isebrands (2007), also the leaves of poplar trees are a potential source for bio-energy, corresponding to around 10% of the total biomass.

Poplar tree and willow woody biomass can be used as sustainable bio-energy sources. Yield production in the northern hemisphere may be in the range 10-15 tones/ha per year (IEA Bioenergy, 2002).

Production of woody biomass can play an economic sustainable role in the society. It can create employment during the process of harvesting, transportation and bio energy production section. In addition new residual waste of biomass and energy product market can build up (IEA Bioenergy, 2002).

A ten year observation of poplar tree growth was observed in the study of Christersson (2010). New poplar clones brought from British Columbia, Canada and planted in south and central Sweden in 1990s. Annual woody biomass was 10-31 m^3 or 3-10 ton DM per hectare and sometimes dry matter production was 45 m^3 or 15 ton DM per hectare with dense planting in southern part of Sweden (Christersson, 2010)

Prices of the oil and fossil fuel increase day by day in Sweden. Farmers can grow fast growing Poplar trees in an intercropping system as a source of energy utilizing as bio fuel, energy and heat which are environmentally sustainable (Christersson, 2010). Combining such sustainable biomass production by planting trees in high within-row density and wide row spacing with agricultural crops produced between the tree rows is thus a highly attractive concept for economically and environmentally sustainable production systems in Swedish agriculture.

To date, most studies of agroforestry cropping systems have focused on sole crops grown together with trees. No previous studies have investigated legume-cereal intercropping systems in association with large trees. This MSc thesis is a pioneering investigation about the affects of poplar trees on faba bean and wheat grown both as sole crops and intercropped in an agroforestry settings.

3. Aims and hypotheses

The overall aim of this study was to investigate how the interactions between intercropped faba bean and spring wheat are influenced by poplar trees in an agro forestry setting. A research experiment was designed to measure the effect of proximity to trees on plant height and above and belowground biomass accumulation of the understory crop. The hypotheses to be tested were: 1) Poplar trees change the competitive interactions between intercropped faba bean and spring wheat; and 2) intercropping faba bean and wheat in an agroforestry system reduces spatial variability in yield and productivity via complementarity in how well the two crops perform under shade and sun conditions, respectively.

4. Materials and methods

4.1. Site description

The experimental site is located in Alnarp, Skåne, Sweden. The field experiment was a part of two years (2011 and 2012) project to investigate yield stability in varietal mixtures of faba bean. The overall project goal is to evaluate potential benefits from growing faba bean in varietal mixtures rather than a single variety to overcome possible yield loss due to unpredictable stress occurrence. The project includes three faba bean varieties at three field sites, grown as sole crops and two or three varietal mixture of faba bean varieties with and without spring wheat (SLU EkoForsk, 2011).

4.2. Experimental design

The entire experiment comprised 15 treatments represented by different species and variety composition (Table 1). The different treatments were sown in field plots measuring 2 x 9m (one plot per treatment), randomly replicated in four blocks. The entire set of 60 plots was again replicated in two sets: one close to a row of poplar trees (shade) planted along the eastern edge of the field (north-south) and the second set far from the trees (sun). The poplar trees had been planted in the experimental area more than twenty years ago in the purpose of providing windbreaks. The exact species of the poplars could not be identified, nor is it known if all trees in the row were of the same species or hybrid, but the size and canopy structure was similar in the entire row. The design comprised three faba bean varieties: Alexia, Julia and Gloria; and one spring wheat variety: Dacke. Seeds of faba bean and wheat were sown on 2nd of May, 2012. All the seeds of faba bean and wheat were produced organically. The varieties of faba bean are available in the Swedish agricultural market and used for commercial production.

Table 1: Individual treatment and their composition according to percentage of seed density in pure stand

Treatment code	Composition (% of seed density in pure stand)
A	Alexia 100%
B	Alexia 70% + wheat 30%
C	Gloria 100%
D	Gloria 70% + wheat 30%
E	Julia 100%
F	Julia 70% + wheat 30%
G	Alexia 50% + Gloria 50%
H	Alexia 35% + Gloria 35% + wheat 30%
I	Alexia 50% + Julia 50%
J	Alexia 35% + Julia 35% + wheat 30%
K	Gloria 50% + Julia 50%
L	Gloria 35% + Julia 35% + wheat 30%
M	Alexia 33% + Gloria 33% + Julia 33%
N	Alexia 23% + Gloria 23% + Julia 23% + wheat 30%
O	wheat 100%

Table 2: Seed density in the treatments used in this thesis

Treatment	Amount of seed per m2	Plant
E	80 seeds	Faba bean (Julia)
F	56 seeds of Julia and 180 seeds of Wheat	Faba bean + Wheat
O	600 seeds of Wheat	Wheat (Dacke)

I worked with one faba bean variety (Julia) and spring wheat (Dacke) in their as sole crop and intercrop plots, thus three plots per block in shade and sun, respectively. I distinguished small (50 x 50 cm) subplots into shade, half shade and sun areas. Shade areas means those plots located closest to the trees (completely shaded until approximately 11 a.m.) and half shade areas means the far end of the shade plot as measured from the poplar trees (Figure 1). Sun areas were not covered by the shade of poplar tree. The shade, half shade and sun area was approximately10 m,17 m and 25m distance from the row of poplar trees (Figure 1).

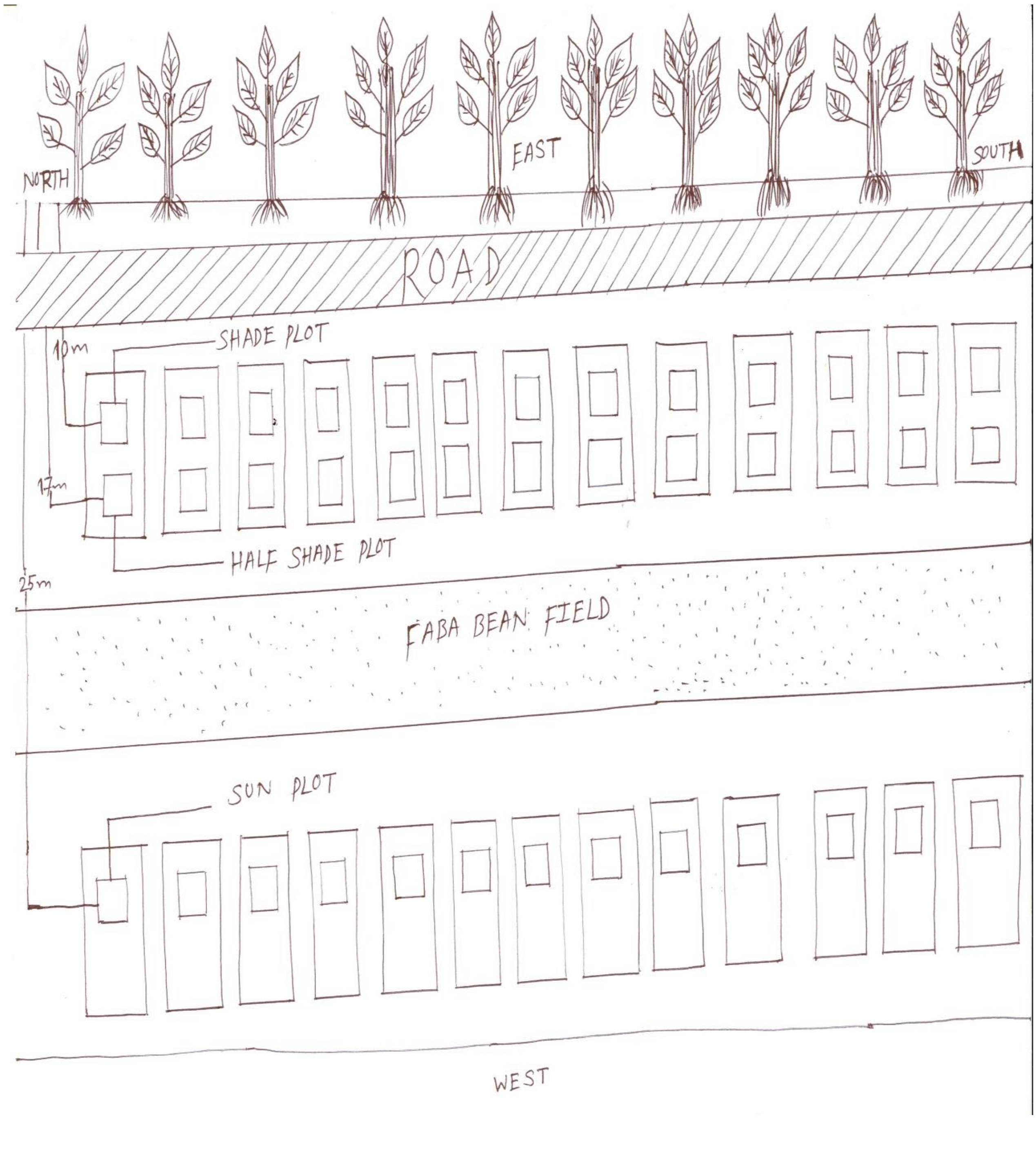


Figure1: Layout of the experimental plots in relation to the tree row.

Figure 2: Shade from the poplar trees covering the eastern set of experimental plots (shade plots). Photo taken from the southern end of the field experiment at approximately 11 a.m. on 9 May. Photo: Georg Carlsson.

Figure 3: Sun plots located outside the range of shade from the poplar trees. Photo taken from the south-west end of the field experiment on 9 May. Photo: Georg Carlsson.

4.3. Data collection

4.3.1. Light measurement

Light measurements were taken by Sunfleck PAR Ceptometer on 26 July, 2012, between 9.30 a.m. and 9.50 a.m on 26 July (Table 3). Each light measurement in one location is consisted of the mean of four measurements. The light intensity in sun increased gradually during the measurement period; see the range and average PAR in table 3.

Table 3: Light measurement (PAR)

Date	Time	Shade	Average PAR	Highest PAR	Lowest PAR
26-07-2012	9.32 a.m. -9.50 a.m.	Shade	129.27	174	93.66
26-07-2012	9.32 a.m. -9.50 a.m.	Half Shade	156.24	218.33	124.33
26-07-2012	9.32 a.m. -9.50 a.m.	Sun	1027.24	1089.33	963.33

4.3.2. Moisture and temperature measurement

Soil samples were taken two times during the growing season: on 3rd July, 2012 and 14th August, 2012. Soil samples were taken by an auger (20 mm diameter) to a depth of 20 cm from the 0.5 m X 0.5 m sub plots in shade, half shade and sun areas. Then the soil samples were oven dried at 105^0 C for 24 hours (Yaski, 2008). Soil temperature was taken by soil thermometer in the same subplots on 26th June, 2012.

4.3.3. Height measurement

Height measurements were taken four times during the growing season: 18 June, 2012; 9 July, 2012; 21 July, 2012; 9 August, 2012. All faba bean and spring wheat individual plants in the 0.5 x 0.5 m subplots in the shade, half shade and sun areas were measured with a measuring stick, and the average plant height per species in the measured area was calculated as:

$$\text{Mean value of the height} = \frac{\text{Total height}}{\text{No.of measured plant height}}$$

4.3.4. Plant biomass

Above ground plant biomass was cut manually at 5 cm above ground on 30 July 2012. The plants were cut from another 0.5 m X 0.5 m adjacent to the subplots used for soil moisture and plant height measurements. Then the plants were sorted into faba bean, wheat and weed and oven dried at 60^0 C for 24 hours (Masoero et al, 2005).

Plant biomass per m^2= Plant biomass per sub plot X 4

4.3.5. Root biomass

Root biomass was taken on 31 July, 2012, from the same subplots as above ground biomass by manually digging up all plants in the 0.5 x 0.5m area to a depth of approximately 15 cm. Roots were washed free from adhering soil before separating into faba bean, wheat and weed roots, and nodules on faba bean roots were counted and separated from the roots before drying each fraction separately at 60^0 C for 24 hours (Masoero et al, 2005).

Root biomass per m^2= Root biomass per frame X 4

4.4. Statistical analyses:

Normality test was done before data analysis by Minitab 16. Collected data were analyzed with ANOVA and Tukey test by using GLM (Genaral Linear Model) in Minitab 16 to know the significant ($p<0.05$) differences in case of height, plant biomass, root biomass and moisture content. Tables and graphs were created by Microsoft excel.

4.5. Stakeholder perspective

To evaluate stakeholder perspective on the potential value of agroforestry systems in Swedish agriculture, members from a new Swedish agroforestry network were invited to my MSc thesis defense and a seminar organized on the same day. One of the scientific coordinators of the Swedish agroforestry network, Dr Johanna Björklund from Örebro University, was specially invited to my defense in order to promote the communication of my study outcomes with the community of scientists and stakeholders.

5. Result.

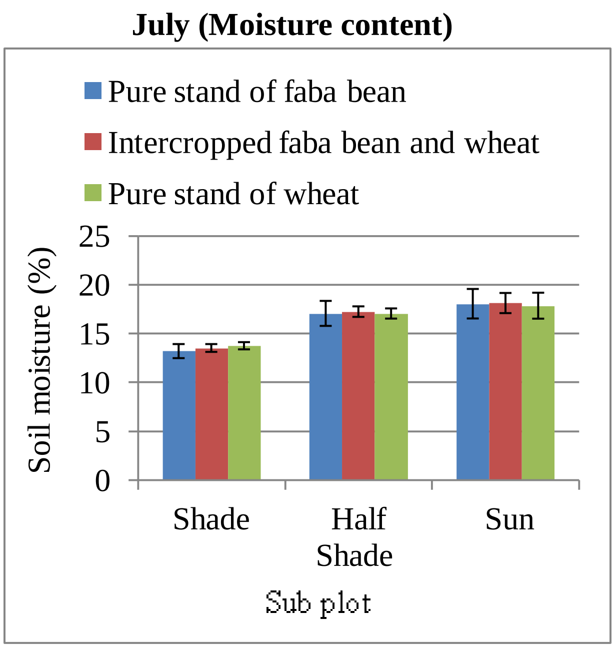
5.1. Effect on moisture

5.1.1. Effect on moisture (july)

The effect of shade and block on soil moisture was statistically ($p < 0.05$) significant, but there was no significant treatment effect (intercropped faba bean and wheat versus each sole crop) in July, 2012 (Figure 4). Soil moisture content was higher in sun plot (far away from the row of trees) than in shade and half shade plots.

5.1.2. Effect on moisture (August)

The effect of shade and block on soil moisture was statistically ($p < 0.05$) significant but there was no significant treatment effect. Soil moisture content (%) was higher in half shade and sun plots than in shade plots (Figure 4).



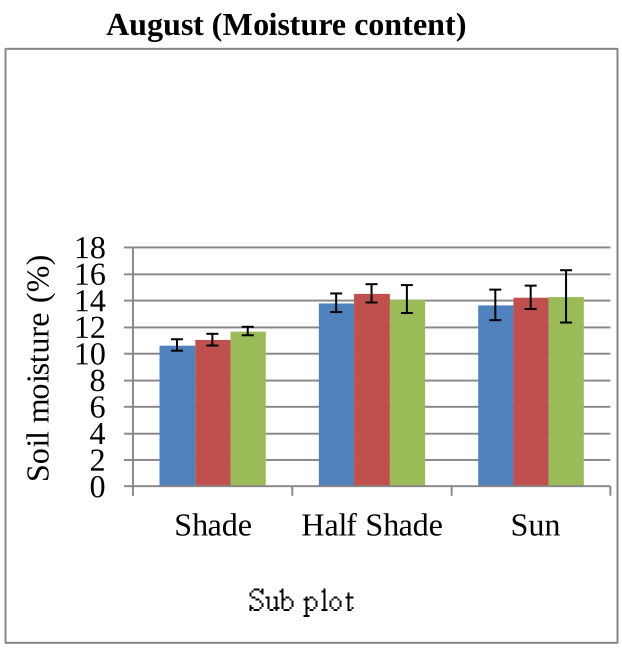


Figure 4: Soil moisture content (%) measured at a depth of 20 cm on 3rd of July, 2012 and 14th of August, 2012. Each bar is the mean value of four replicates +/- standard error (SE).

5.2. Effect on plant height

The heights of both faba bean and wheat plants were generally higher far from the trees (half shade and sun) than close to the trees (shade). Faba bean height was often higher in pure stand, while wheat was often (although not consistently) taller in the intercropping treatment than in the wheat sole crop.

5.2.1. Height of faba bean:

5.2.1.1. Effect on faba bean height (18-06-2012)

The effect of shade on faba bean height was statistically ($p< 0.05$) significant, while the treatment effect was not statistically significant. The height of pure stand of faba bean and faba bean with wheat was higher in half shade plot as compared to shade and sun plots (Figure 5). In sun plots, comparatively higher faba bean height was observed when grown with wheat than in faba bean sole crop, while the inverse effect was found in shade and half shade plots.

5.2.1.2. Effect on faba bean height (09-07-2012)

The effect of shade and block on faba bean height was statistically ($p< 0.05$) significant, while the treatment effect was not statistically significant. The height of pure stand of faba bean and faba bean with wheat was comparatively taller in half shade plot than faba bean as sole crop and intercropped with wheat in shade and sun plot. Lower faba bean height was observed in shade plot as compared to pure stand of faba bean in half shade and sun plot. Comparatively higher faba bean height was observed in intercropping field in sun plot than faba bean with wheat in shade and half shade plot.

5.2.1.3. Effect on faba bean height (21-07-2012)

The effect of shade and block on faba bean height was statistically significant ($p<0.05$), while the treatment effect was not statistically significant. Highest height of pure stand of faba bean and faba bean with wheat was observed in half shade plot as compared to sole crop of faba bean and faba bean intercropped with wheat in shade and sun plot. Comparatively lower height of faba bean and faba bean with wheat was observed in shade plot than sole crop of faba bean and faba bean intercropped with wheat in half shade and sun plot.

5.2.1.4. Effect on faba bean height (09-08-2012)

The effect of shade, block and treatment was statistically ($p<0.05$) significant on height of faba bean. Higher height of pure stand of faba bean was observed both in half shade and sun plot as compared to shade plot of faba bean sole crop. The height of faba bean and faba bean with wheat was lowest in shade plot than pure stand of faba bean and faba bean intercropped with wheat in half shade and sun plot. The height of faba bean was suppressed when grown with wheat in shade, half shade and sun plot than pure stand of faba bean in shade, half shade and sun plot.

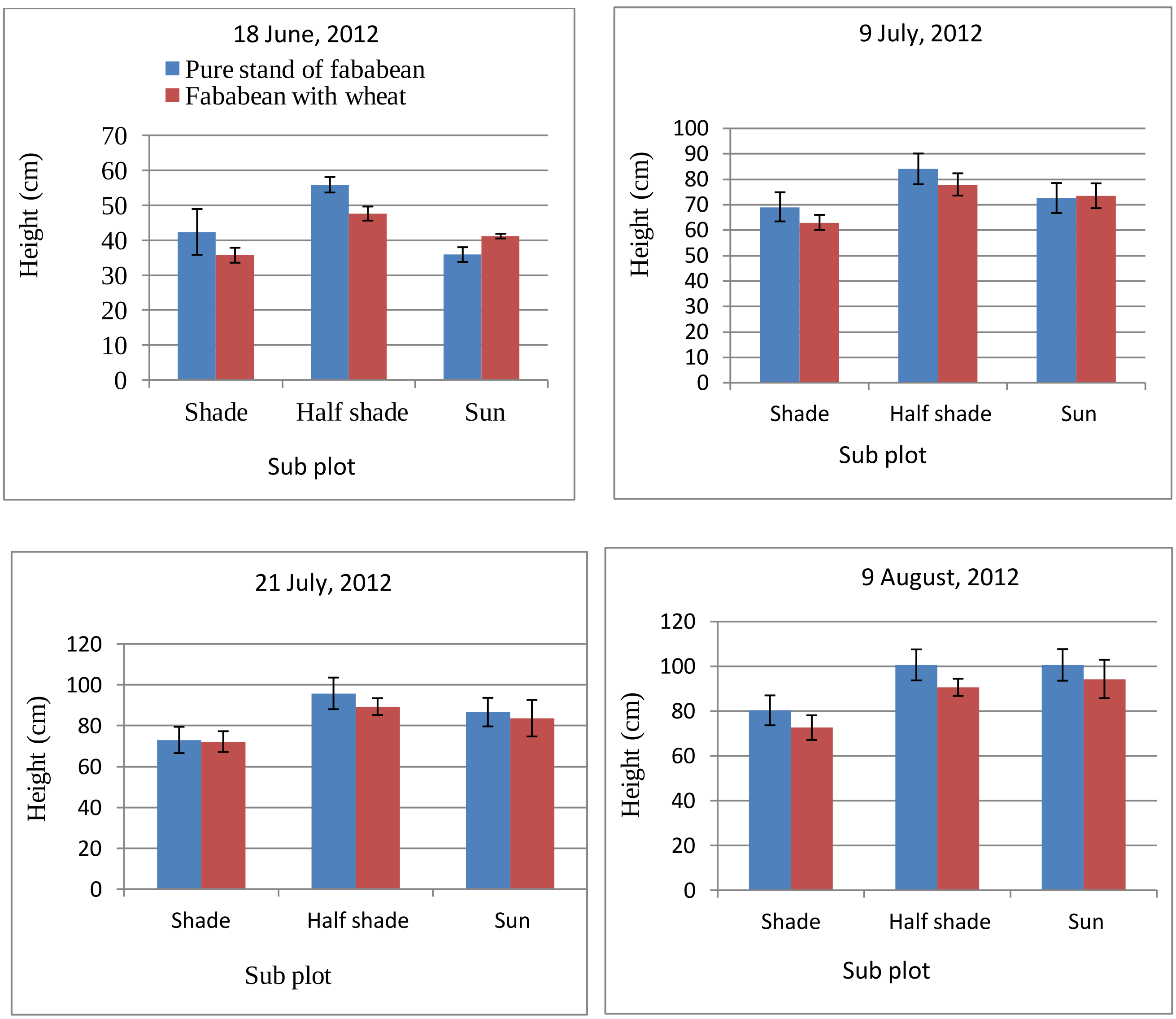


Figure 5: Faba bean plant height measured on 18th of June, 9th of July, 21th of July and 9th of August, 2012. Each bar is the mean value of four replicates +/- standard error (SE).

5.2.2. Height of wheat

5.2.2.1. Effect on wheat height (18-06-2012)

The effect of shade on wheat height was statistically ($p<0.05$) significant. Highest height of wheat both as sole crop and when intercropped with faba bean, was observed in half shade plot as compared to shade and sun plot (Figure 6). In shade and sun plots, comparatively higher height of wheat plants were observed when grown with faba bean than wheat grown as sole crop.

5.2.2.2. Effect on wheat height (09-07-2012)

The effect of shade on wheat height was statistically ($p<0.05$) significant. The height of pure stand of wheat and wheat with faba bean was higher in half shade plots than in shade and sun plots. Higher height of wheat was observed when grown with faba bean in shade, half shade and sun plot than wheat as sole crop in shade, half shade and sun plot.

5.2.2.3. Effect on wheat height (21-07-2012)

There was a significant ($p<0.05$) shade and block effect on height of wheat. The height of pure stand of wheat was higher in half shade plot as compared to the height of wheat as sole crop in shade and sun plot. Slightly higher height of wheat was observed when grown with faba bean in sun plots than in intercropping in shade and half shade. The height of pure stand of wheat and wheat with faba bean was lower in shade plot than wheat sole crop and intercropped with faba bean in half shade and sun plot.

5.2.2.4. Effect on wheat height (09-08-2012)

The effect of shade on wheat height was statistically significant ($p<0.05$). The height of pure stand of wheat was higher in half shade plot as compared to the height of wheat as sole crop in shade and sun plot. Lowest height of pure stand of wheat and wheat with faba bean was measured in shade plot. Comparatively higher height of wheat was observed in sun plot when grown with faba bean than height of wheat intercropped with faba bean in shade and half shade plot.

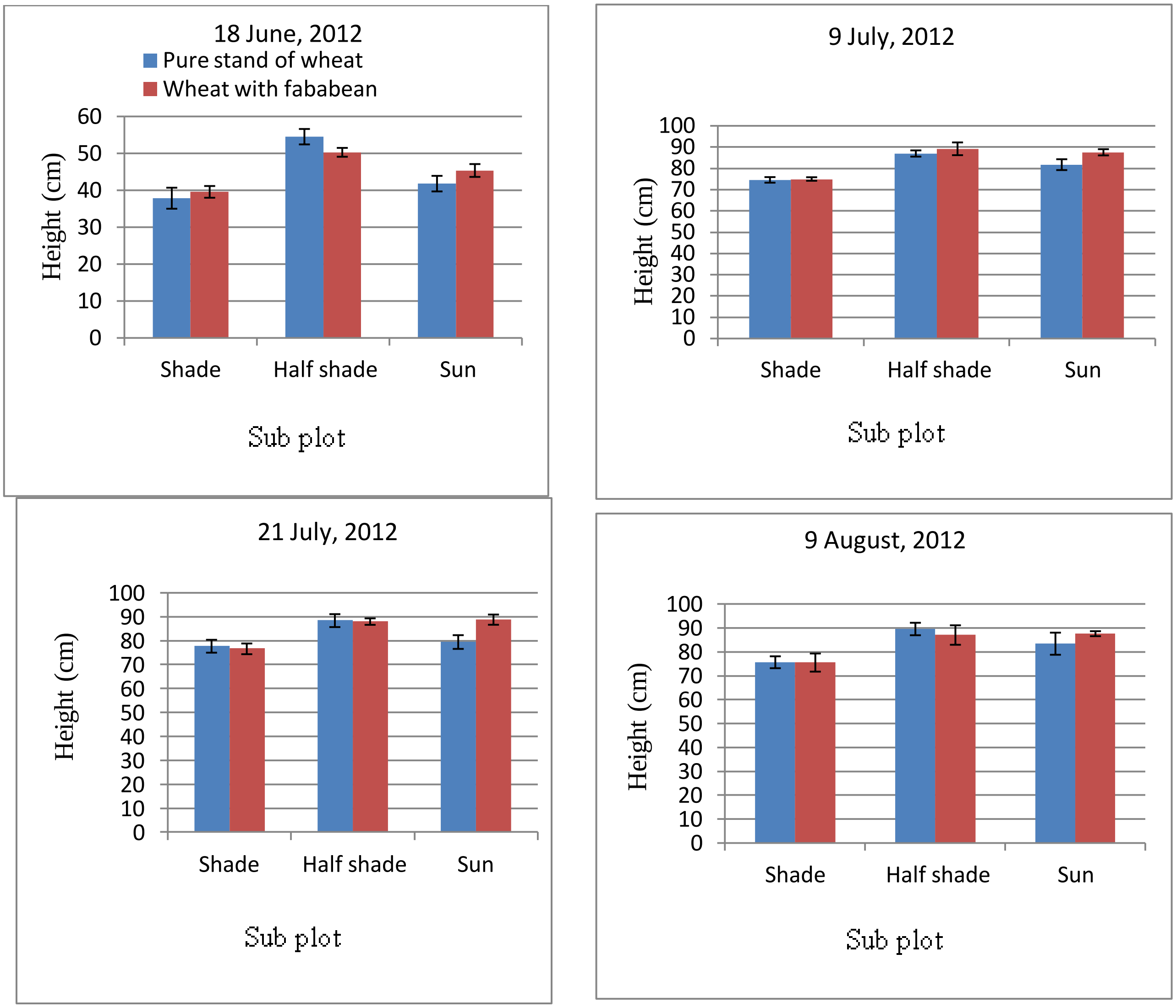


Figure 6: Wheat plant height measured on 18th of June, 9th of July, 21th of July and 9th of August, 2012. Each bar is the mean value of four replicates +/- standard error (SE).

5.3. Effect on biomass production

5.3.1. Effect on faba bean biomass production

Faba bean plant biomass in pure stands was similar between shade and sun plots, while faba bean intercropped with wheat produced more biomass close to poplar trees than under full sun (Figure

7). Suppressed growth of weed was observed in the field of faba bean-wheat intercropping system both in shade and sun plot as compared to faba bean field in both sun and shade plot and wheat as pure stand in shade plot.

5.3.2. Effect on wheat biomass production

The effect of treatment on wheat biomass (gm) per m2 was statistically significant (p< 0.05). The biomass yield of wheat in the plot of sun is higher than biomass of pure stand of wheat in shade plot (Figure 7). Highest plant biomass yield were observed in shade pure of wheat and sun pure of wheat as compared to wheat as intercropped with faba bean in shade and sun plot. The biomass of wheat was highly suppressed in shade plot when grown with faba bean while wheat biomass intercropped with faba bean in sun plots was not as strongly suppressed (Figure 6). Highest weed growth was observed in shade plot of pure stand of wheat.

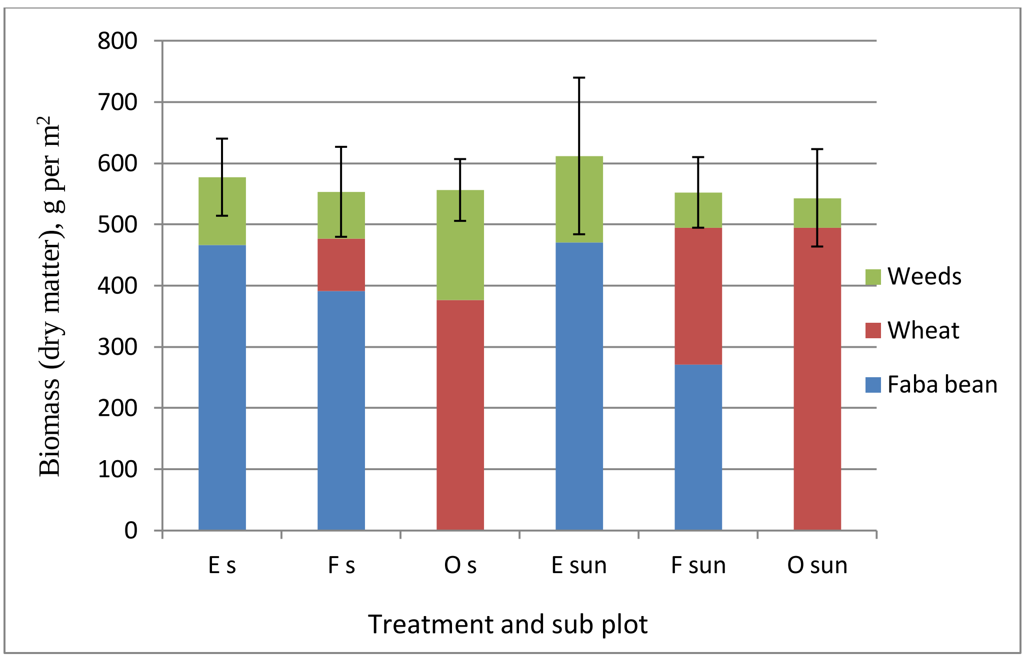


Figure 7: Plant biomass yield measured for above ground whole plant part at pod filling of faba bean. Each bar is the mean value of four replicates +/- standard error (S.E.). E s, sole cropped faba bean in shade plots; F s, intercropped faba bean and wheat in shade plots; O s, sole cropped wheat

in shade plots; E sun, sole cropped faba bean in sun plots; F sun, intercropped faba bean and wheat in sun plots; O sun, sole cropped wheat in sun plots.

5.4. Effect on root biomass

5.4.1. Effect on root biomass of faba bean

In contrast to the above ground biomass, shade had no significant effect on root biomass. The effect of treatment on faba bean root biomass was statistically ($p < 0.05$) significant. The growth of faba bean roots was suppressed when grown with wheat as compared to the root biomass growth of pure stand of faba bean both in shade and sun plot (Figure 8).

5.4.2. Effect on root biomass of wheat

Suppressed growth of root biomass of wheat was observed when grown with faba bean in both shade and sun plot as compared to the root biomass of pure stand of wheat both in shade and sun plot. There was a significant ($p < 0.05$) treatment effect on root biomass of wheat.

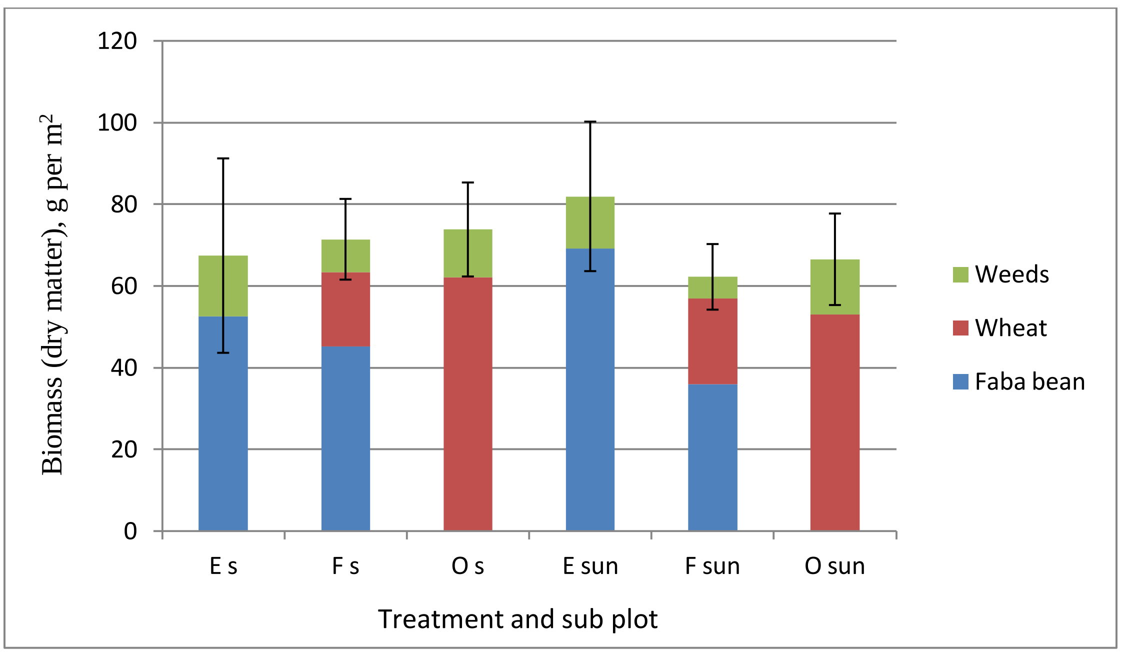


Figure 8: Plant root biomass was measured from below ground plant part at pod filling of faba bean. Each bar is the mean value of four replicates +/- standard error (S.E.). E s, sole cropped faba bean in shade plots; F s, intercropped faba bean and wheat in shade plots; O s, sole cropped wheat

in shade plots; E sun, sole cropped faba bean in sun plots; F sun, intercropped faba bean and wheat in sun plots; O sun, sole cropped wheat in sun plots.

5.5. Effect on root nodule biomass

There is no significant shade, treatment or block effect on root nodule biomass of faba bean. Tendencies were observed for lower root nodule biomass in pure stand of faba bean in shade plots than in sun plot, and lower root nodule biomass in intercropping than in pure stand in sun plots (Figure 9).

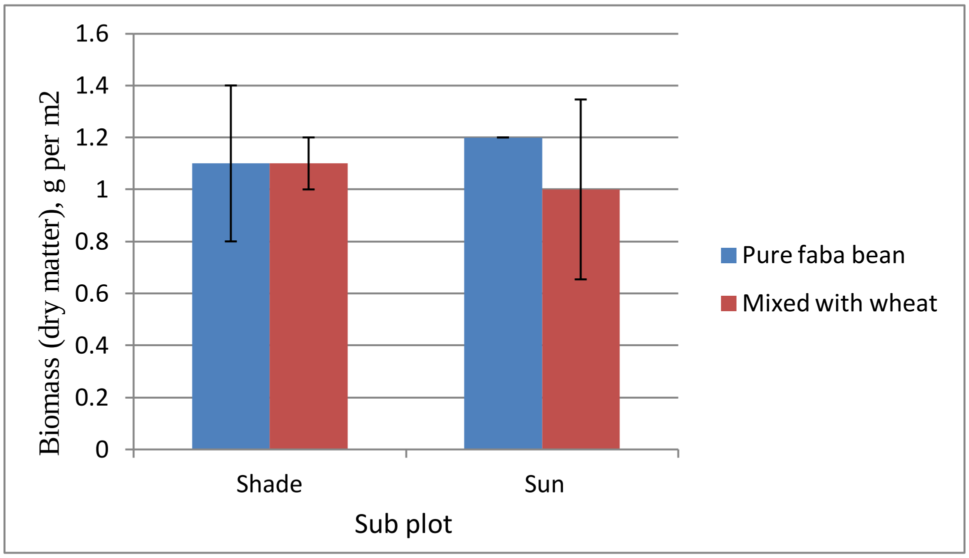


Figure 9: Root nodule biomass (gm) per m^2 was measured from below ground root part at pod filling of faba bean. Each bar is the mean value of four replicates +/- standard error (S.E.)

6. Discussion

6.1. Agronomical consequences of intercropping and agroforestry

In diversified cropping systems such as intercropping and agroforestry systems, competition for above and below ground resources increases, leading to a more efficient capturing of resources. In this thesis I have studied two levels of diversification: 1) intercropping of two annual crops; and 2) annual crops combined with trees in an agroforestry system. Combining these two levels of diversification lead to new discoveries about competitive interactions in intercropping systems: wheat seemed more affected by the competition from trees than faba bean. According to my findings, growing intercrops of two or more annual crops in an agroforestry system can have positive effects on reduction of spatial yield variability of the annual crop, via complementary effects between the two crops. Faba bean performed slightly better close to trees and wheat performed better far from trees, higher height of wheat was observed when intercropped with faba bean, the intercrop was stronger in competing against weeds than the two sole crops irrespective of proximity to trees.

Increasing the level of diversification gradually decrease soil moisture: soil moisture was lower close to tress and. Millan and Pallardy (2001) reported that soil moisture content was reduced in the maize field close to the row of silver maple without trenching the roots of trees.

The amount of soil moisture was lower in shade plot in the month of July and August. There may be some competition for soil moisture between trees, faba bean and wheat as sole crop and intercrop because the roots of Poplar tree may spread up to several meters in to the field. On the otherhand, there was a road in between the poplar rows and edge of the field. It can restrict the spread of roots into the field of faba bean and wheat. There was some open space between the road and the edge of the field where most often tractor move to change the driving direction. Soil compaction occured due to heavy weight of the tractor and compact soil has weak water holding capacity (Vinar, 1980). In a glasshouse experiment investigating the effect of less soil moisture content on nodule development in faba bean, the amount of nitrogen derived from the atmosphere (Ndfa) was reduced by 37% due to lack of water (Abelhamid 2011). Fewer numbers of nodule and biomass was recognized in that study, which is similar to the tendency (although not significant) for lower nodule biomass in faba bean grown as a sole crop in shade plots as compared to sun plots in my study (Figure 9).

Higher plant height of both faba bean and wheat was observed in half shade plot on 18th of June, 9th of July, 21th of July and 9th of August, 2012. Soil moisture was higher in half shade plots than in shade plots in July and August. Wheat was more susceptible to proximity to trees than faba bean and this was most likely caused by soil moisture competition affecting wheat stronger than faba bean. The orientation of the tree row in a north-south direction and the placement of the experimental plots east-ward from the tree row means that the half shade plots were shaded until approximately 10.30 a.m., and the shade plots were shaded until approximately 11.30 a.m. Even though there were only very small differences in PAR between shade and half shade plots during the measurements between 9.30 and 9.50, half shade plots received full sun light earlier in the day than shade plots. Thus, also competition for light is likely to have influenced the differences in faba bean and wheat performance close to trees and far from trees. From other studies it is also known that shade tree reduces the soil temperature so that biological activity of soil also decreased (Heuveldop and Lagemann, 1981). Trees compete with plant for water during dry season. Peng et al (2009) has found a negative effect of tree competition on the growth and yield of sole crop soya bean and maize in their study. PAR (Photosynthetically Active Radiation), biomass production of soya bean and maize and seed production of soya bean and maize was significantly decreased by the effect of shade tree.

The height of wheat was higher in shade plot close to the row of trees in intercropping with faba bean than wheat as pure stand on the date of 18th June and 09th July, 2012. Trees can play an important role to increase plant height by maintaining the nutrient balance in the crop field. Rooting pattern is very important for efficient nutrient acquisition and recycling. Shade trees can also reduce soil erosion and wind speed, and increase infiltration and develop soil fertility (Heuveldop and Agemann, 1981). Trees such as *Gliricidia sepium* may help to reduce the leaching of nutrient under surface run off irrigation. It decreases nutrient leaching in intercropping system than sorghum as sole cropping (Auclair, 1999). Beer et al (1998) measured the annual litter fall of shade trees to be 14 tons ha^{-1}yr^{-1}, with strong positive influence on soil fertility (Beer et al, 1998). Maghembe et al (1999) found that biomass production increased from 4.5 tons ha^{-1}in sole crop maize to 9.2 tons ha^{-1} and 11.7 tons ha^{-1} when grown with *Gliricidia* trees in organic and conventional farming system. *Gliricidia* is a genus in the legume family, capable of symbiotic nitrogen fixation, and *Gliricidia* trees provide nitrogen inputs to the benefit for intercropped annual crops.

When faba bean was intercropped with wheat, higher biomass of faba bean was observed in shade plots which are close to the row of Poplar trees than in sun plot in my masters thesis experiment. Soil moisture and PAR (Photosynthetically Active Radiation) was lower in shade plot. Faba bean was apparently more tolerant to such abiotic limitations than wheat when the two crops were grown together.

The growth of weeds was strongly suppressed in faba bean-wheat intercropping field both in shade and full sun plot. The growth of weeds was lower in faba bean-wheat intercropping system than wheat sole cropping because fewer amount of natural resources (light, water, nutrient) was available for weed growth (Hamdollah, 2011). Weed growth was higher in the shade plot of pure stand of wheat and full sun plot of pure stand of faba bean in the experimental field. Higher growth of weed was observed in Faba bean, lupin and barley (unfertilized) sole cropped area in Hauggaard-Nielsen et al (2008) study of dual grain legume (pea, faba bean and lupin)-barley intercropping.

A positive effect of intercropping was found in cowpea-maize intercropping system in the southeast of Iran under research center, University of Zabol about the effect of cowpea on microclimate in cowpea-maize intercropping and sole cropping system. PAR (Photo synthetically Active Radiation) was highest at cowpea and maize intercropping field. The amount of soil temperature was higher at maize mono crop and lowest temperature was found in the field where cowpea grows as mono crop. Highest and lowest soil moisture was measured at cowpea and maize as sole crop respectively (Ahmad et al, 2010). Reynolds et al (2007) stated that net assimilation (NA), photo synthetically active radiation, plant biomass growth and seed yield was decreased when soya bean or crop grown with shade tree on mono cropping. There is a significant co relation between growth and net assimilation (NA).

The amounts of root and root nodule biomasses in pure stand of faba bean were slightly lower in shade plot than sun plot in the experimental field. A research carried out at Xichang, China in 1986-90 to observe the effect of shading on faba bean cultivar ‘Xichang Debai’ in 50% and 20% shading found lower belowground plant biomass under shade. Insufficient photosynthates substance was measured under shade, so that the number and biomass of nodules was less and it hampered N and C metabolism. Total N deposition was limited and early nodule senescence was recognized in that study (Xia, 1995).

Shade duration and light intensity depends on the length and form of the canopy structure, distance between crop field rows of trees, pattern and direction of tree rows arrangement and length of the shade during day period (Jackson, 1989).

Some measures can therefore be taken to reduce the competition of light between trees and crop:

1) Wide spacing can be maintained between trees with crops.
2) Trees that have low canopy width and containing high porosity can be planted.
3) Regular pruning and thinning can be done to make a proper shape of canopy to penetrate light in to the under story crop (Reverst et al, 2010)

6.2. Agroecological benefits and ecosystem services in agroforestry systems

Agro forestry is more sustainable than traditional forestry in social, economical and ecological point of view. Depending on the climate and socio-economical conditions, a wide range of tree species can be utilized in agroforestry systems, *e.g.* trees providing wood for construction and fuel, or medicinal value, which increase farmers’ income. The farm family gets different kinds of product which are utilized for the household economy. Trees in agroforestry systems can also maintain the environment in an ecological way by nutrient and water recycling and act as buffers in bad climatic conditions (Peng et al, 2009).

Agroforestry helps to reduce soil erosion, reduces surface runoff and increases the diversity of the farming system (Blanco and Lal, 2008, Nair, 1993). Fallen leaves of trees, dead plant parts and crop residues promote recycling of nutrients and act as a cover of the soil, reducing the negative impacts of heavy rainfall (Nair, 1993).

Agroforestry promotes carbon sequestration, there by helping to decrease the green house production in the environment and building up soil fertility (Blanco and Lal, 2008).

Tree based intercropping systems reduce nutrient leaching and increase soil fertility by nutrient cycling (Auclair, 1999). Agroforestry setting helps to reduce use of chemical nitrogenous fertilizers in the field to meet up plants nitrogen demand. Reducing the nitrogen applications is very important for the environmental sustainability of cropping systems, since excessive applications of chemical fertilizers lead to nitrogenous losses to nearby water sources and cause eutrophication which badly affects the aquatic environment and human health (Gliessmann, 2007).

Tree based intercropping systems can also help to reduce pest population in the field because higher amount of natural enemies was observed in this kind of cropping system (Thevathasan and Gordon, 2004). The amount of Lady-bird beetles was abundant in the agroforestry experimental plots as the field was affected by aphids.

Agroforestry helps to reduce the use of pesticides in adjacent fields. Pest populations as well as non target pest species (predator and parasitoid) can reduce quickly after applications of chemical insecticides. But sometimes the number of pest increases more than before as the population of the beneficial insect decreases (Gliessmann, 2007). Ground and surface water contamination occur by the application of pesticides through surface run off in to the entire food chain and hamper our natural ecosystem (Gliessmann, 2007). Sometimes huge amount of same type of pesticides use build up pesticide resistance.

Agroforestry systems are more sustainable than traditional farming system in Himalaya region. Yield production was low in that region due to inferior soil fertility and soil erosion by surface run off. Plant diversity and production in the Himalaya region increased after applying agroforestry via decreased nutrient leaching and soil erosions and increased soil fertility (Wellstead, n.d.).

Tree-based intercropping system increases soil production capability by increasing the number of microbe and fauna in the tropics. Soil nutrient condition increases through nutrient recycling process. In Indonesia agroforesty systems are utilized as economically, ecologically and bio-physically sustainable land use system to ensure food security, increase farmers average income and conserve the ecosystem and increase biodiversity (Kang and Akinnifesi, 2000)

In the USA agroforesty system applied as a means of improving crop production, utilization of natural resources, diversification of land use system and rural economy and build up a combination of farmers, productivity and rural society (USDA, 2011)

Production of maize in most of the areas of Malawi was very low without using chemical fertilizer. Majority of the farmers are small scale farmers. After applying agroforesty system by the World Agroforesty Centre and its partner in the countries of eastern and southern Africa in the beginning of 1990s, maize production increases dramatically. Farmers intercropped legume tress (*Gliricidia sepium*, *Calliandra calothyrsus* and *Leucaena* species) which provide nitrogen inputs via symbiotic nitrogen fixation of benefit for intercropped maize plantation (World Agroforesty Center, n.d).

All these examples show that agroforestry has a high potential to increase the environmental, and economical sustainability of cropping systems. My finding that intercropping of two annual crops in an agroforestry system can reduce spatial yield variability and competition against weeds is an important milestone in the further development of sustainable agriculture. Plantations of poplar trees could therefore be combined with legume-cereal intercrops for efficient use of land and nutrients in the production of food and bio-energy.

7. Conclusion

The amount of faba bean biomass in pure stand was nearly similar in shade and sun plots. In case of faba bean-wheat intercropping, higher amount of faba bean biomass was observed in shade plots than in sun plots. Highest wheat height was often measured when intercropped with faba bean as compared to wheat as pure stand. Lower weed growth was observed in faba bean-wheat intercropping field both in shade and sun plot. From the above discussion I conclude that light level was sufficient for faba bean plant growth and wheat plant height. Interspecific competition between faba bean and wheat for soil moisture and light would not limit faba bean plant biomass growth and sufficient wheat height. There is a significant positive effect of faba bean-wheat intercropping close to the trees in case of faba bean plant growth and control of weed growth. Soil moisture was comparatively lower in shade plot than half shade and sun plot. Plant biomass reduction of wheat may therefore be due to competition of soil water. This MSc thesis has provided new findings about possibilities to combine agroforestry and intercropping of annual crops for cropping system diversification and sustainability. In particular, promising results with respect to reduction of spatial yield variability and weed competition were found in intercropped faba bean and wheat both under shade from Poplar trees and under sun conditions.

Farmers can use the outcomes of the experiment as an indication that increased cropping system diversity will improve the environmental and economic sustainability of their production. By combining trees for wood or fruit production with intercropped legume and cereal crops, farmers will be able to reduce the cost of applying nitrogenous fertilizer to the field as legumes fix atmospheric nitrogen from the atmosphere. Intercropping of agricultural crops in agroforestry systems is also promising for weed suppression, which influence farmers to reduce the application of huge amount of herbicide in the field. However, in order to obtain strong arguments and be able to convince farmers to apply this strategy for cropping system diversification, my thesis needs to be complemented with studies of the economic yield for the farmer. Notably, the value of the wood or fruit production from trees needs be evaluated and compared with possible economic gains or losses in the annual crops resulting from the introduction of trees. In the next step, the environmental and economic value from integrating trees that sequester C with agricultural production should be estimated and presented to the farmers.

8. Stake holder seminar

My thesis presentation was announced to the Swedish Agroforestry network, and one of the scientists involved in this network, Dr Johanna Björklund at Örebro University, gave a seminar that was coordinated with my presentation. In addition, two representatives who are active both in the agroforestry network and in food production from a forest garden also attended my presentation and Johanna Björklunds seminar. The many questions from the three network representatives highlight that my thesis work is of large interest for stakeholders engaged in promoting agroforestry systems in Sweden. All three had a strong interest about my studies and suggested me to extend my research on this field in future to promote the diversification the cropping system. In this section I summarize the questions and outcomes from the discussions that took place after my presentation and Johanna Björklunds seminar.

One of the representatives of the Swedish agroforestry network focused on the advantages of pruning of the branches of trees in agroforestry field. According to him pruned branches and leaves act as an organic matter and increases the soil fertility of the subsequent crop field.

One representative asked me about the pest and disease infestation of the field. Experimental field was highly infested with aphid, so that abundant amount of predators (lady bird beetle) was found in the field. Agroforestry setting has a great influence to increase the availability of the natural enemies. Johanna Björklund asked me if I graded the amount of aphid in the shade and sun areas. Then she suggested me to compare the amount of aphid in different shade condition in the future studies.

Jan Erik Mattsson, department of Agrosystems, told about the availability of Vole in the agroforestry cropping system in Sweden. There may be some possibilities of yield loss due to dig the hole by Vole in the field and suggested us to aware of this kind of unwanted animal.

Johanna Björklund emphasized more in the discussion part of my presentation and in her seminar on the role of agricultural crop with more trees in carbon sequestration in the field. Alley cropping can play an important role in C sequestration, increase diversity and farmers income (Udawatta and Jose, 2012).

According to Johanna Björklund, comparison of economic grain yield in different plots in the field would be better to convince the farmers to adopt this kind of new invention because farmers always pay importance on commercial grain production as a parameter to transfer from one cropping system to another.

There was some discussion about the role of extension and advisory service to motivate farmers from traditional farming system to this kind of new cropping system. Extension or advisory service can play a great role to promote this kind of new invention in the farm level. They should communicate directly with farmers to know about the problem to imply this kind of new cropping system and send the problems to research institute and take immediate action to solve the problem. There should be good communication of farmers, extension service or advisory service and researcher to get the desire out comes.

One message from Johanna Björklunds seminar was that farmers possibility to obtain subsidies for pasture is restricted to a maximum tree density of 60 trees per ha, which is very low density for an agroforestry ir silvopastoral system. Governments should imply more subsidy and bank loan facility to encourage farmer to grow more trees in their agricultural land.

In the developing counties big company pay farmers to grow more trees as it sequester C. If this kind of financial support will be given to the farmers, then diversification of cropping system can be promoted to optimize C Sequestration.

The concept of Agroforestry system Sweden as well as in many other countries in temperate regions is new. EURAF (European Agroforestry Federation) was established in Paris in 2011 to promote agroforestry system in the farmers' field level. 1st conference was held in October, 2012.

The seminar and discussions show the increasing engagement of researchers and stakeholders in different networks and activities that promote agroforestry and cropping system diversification. This trend is very promising for the development of agricultural production systems towards increased sustainability. Obtaining insights about interactions between researchers and stakeholders in the Swedish agroforestry network was very interesting for my own learning and has given me stronger possibilities to promote agroforestry and intercropping in my future career.

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