Sveriges lantbruksuniversitet
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Fakulteten för landskapsplanering,
trädgårds– och jordbruksvetenskap

The effects of nitrogen fertilizer rates in a long-term reduced tillage cropping system on dry matter and nitrogen accumulation in an oil radish (*Raphanus sativus L.*) cover crop

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Foreword

I am from an agricultural based country named Bangladesh. I strongly believe that a country like Bangladesh has still the opportunities to do better crop productions by utilizing agricultural recourses in a better way. Agriculture is the backbone of the country and the demand for quality agricultural products are increasing day by day. For better agricultural productions, advanced agricultural knowledge with practical experiences are more essential to find the best ways of farming and to take care of the environment. As a student of agricultural science, I had a dream to find some new ways to develop farmers thinking and their systems of traditional farming toward sustainable crop production throughout the country. To learn more about the modern agricultural advancements, global awareness of environmental issues and the socio-economic interactions of different stockholders within a production system, I applied to the Agroecology master program in Sweden. Past two years of Agroecology studies had a successful training for me to think differently from a farmer's perspective to a researcher's view. The whole program was well designed with focuses on different aspects of production systems, system thinking, ecological friendly approaches, sustainable food systems and practical know how trainings. All these real live experiences were highly necessary for me to understand the whole scenarios behind a successful and sustainable agricultural production system. Project based research training and MSc thesis were the two most important courses to see the closer views of production systems by literature reviews and field works and the ways of expressing my gathered knowledge in a proper scientific way. Finally, the combination of my acquired background knowledge from previous studies and the knowledge from this master program will help me to develop a better eco-friendly thinking perspective for future sustainable agro-systems.

Md. Rafique Ahasan Chawdhery, September 2012

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Abstract

This study was undertaken to evaluate the effects of long-term N fertilizer application rates on dry matter (DM) production and nitrogen (N) accumulation in an oil radish (*Raphanus sativus* L.) cover crop. The N fertilizer application was done to the main crop winter wheat (*Triticum* spp.) before oil radish. The experiment was carried out at the research station (Lönnstorp) at SLU, Alnarp in a long-term experiment with (conventional and reduced tillage systems) different N fertilizer application rates in a crop rotation including cover crops. The autumn cover crop DM production and N accumulation were significantly increased with the increased amount of N fertilizer applications to the main crop. According to the hypothesis, the observations of DM production and N accumulation were expected to be in a linear trend with the N levels but they were highly significant with the N levels without any linear increasing tendency. A socio-economic evaluation of cover crops was estimated by comparing the establishment costs of cover crop and the economic value of N conserved in the cover crop, assuming its value to be similar to the value of synthetic N fertilizer. The results showed that the cost of establishing oil radish as cover crop was not completely compensated by the economic value of N conserved in the system. However, several other beneficial aspects of cover crops are discussed to have positive effects in agrosystems, but their economic valuations are complex. Incorporation of cover crop in cropping system has shown to improve biodiversity, suppress of pests and weeds, reduce soil erosion, improve soil organic matter (SOM) and soil texture and structure. Finally, considering the beneficial environmental aspects of cover crops, introducing more subsidies from national and international levels will increase the interest of farmers to grow more cover crops to improve sustainability of cropping system.

Key words: Dry matter, N accumulation, N fertilizer, cover crop, oil radish, winter wheat, subsidy

Abbreviations

C	Carbon
CEC	Cat ion exchange capacity
DM	Dry matter
EU	European Union
GC	Gas chromatography
GLM	General linear model
Ha	Hectare
IFOAM	International Federation of Organic Agriculture Movement
IRRI	International Rice Research Institute
MIT	Mineralization-immobilization turnover
N	Nitrogen
Nr	Reactive nitrogen
R	Replication
R^2	Coefficient of determination
SE	Standard error
SEK	Swedish krona
SOM	Soil organic matter
USDA	United States Department of Agriculture

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1. Agroecological context

Agriculture was successful in satisfying the growing global demand for food in later half of the 20th century. The yield per unit area of staple food such as wheat and rice is increased in a very impressive way. The increased food production was achieved due to the scientific and technical advances, application of high amounts of inorganic fertilizers, herbicides and pesticides, intensive irrigation systems and developed plant varieties (Gliessman, 2007). This boosting force on food production was partly able to meet requirement of the global food security without considering the long-term consequences and the ecological dynamics of agroecosystems.

To produce more foods, farmers may degrade the natural resources of agriculture- (soil, water and natural genetic diversities) (Gliessman, 2007). At the same time, dependency on nonrenewable fossil fuel and huge doses of synthetic fertilizers created new threats such as climate changes (Gliessman, 2007). Most of the agricultural cropping systems are adapted to satisfy farmers' needs and the flexibilities to consider the objectives of altering new socio-economic considerations (Boiffin, 2001). Advanced agricultural practices are developed to maximize the food and fiber production to meet the demand which increased the dependency of fossil fuel and chemical input in cropping system and at the same time decreased the performance of beneficial interactions (Altieri, 1999). Nitrogen is an essential plant nutrient for plant growth and development (Vitousek and Howarth, 1991). Without considering the losses of N from agricultural lands and their effective way of recycling, it can be a harmful issue to the society and environment (Azam et al., 2002; Reeves et al., 2002).

Food production and fossil fuel combustions are mainly responsible of producing reactive nitrogen (Nr) {nitrogen oxide (NO_x), ammonia (NH_4^+), nitrous oxide (N_2O), nitrate (NO_3^-)}in the atmosphere (Smil, 2001). Increasing food and energy production has influenced the Nr production rate 10 times greater than late 19th century which increased the harmful effect of Nr to the environment (Galloway et al., 2004). Reactive nitrogen affects the biogeochemical processes in the atmosphere and ecosystems. Increased amount of Nr help to increase the crop production through fertilization and the same time, excessive amounts of Nr creates nutrient imbalance and reduce ecosystem biodiversity through acidification and eutrophication (Vitousek et al., 1997; Aber et al., 1998; NRC 2000; Matson et al., 2002; Rabalais, 2002; Tartowski and Howarth, 2000).

Most of the reactive nitrogen produced by human activities comes from chemical fertilizer manufacturing and industrial use (MA, 2005). In 1995, around 100 million ton NH_3 was manufactured for crop production and industrial use (Kramer, 1999). About 86 % of the total NH_3 was used to produce fertilizers and the rest 14 % was spread out in the environment during the production process and other activities such as making of refrigerants, plastic, explosive, rocket fuels etc. (Smil 1999; Febre Domene and Ayres, 2001).

A recent study of global human contribution to the Nr flows showed that it will increase from 165 M ton Nr y^{-1} in 1999 to 270 M ton Nr y^{-1} in 2050 and most of the contribution (about 70 % of N_2O) will come from transition of new agricultural lands and N fertilizer uses (MA, 2005). There are several means of N losses from agricultural lands. N fertilizers used in crop land generally show the low N use efficiency due to losses like denitrification, nitrate leaching losses and ammonia volatilization (Ponnamperuma, 1972; Freney et al., 1990; Singh et al., 1995; Cho, 2003). The main projection of the Millennium Ecosystem Assessment about the future scenarios of N uses is to maintain the boundaries of the N flux in the safe limited sphere by reducing the use of synthetic N fertilizers and by finding alternative biobased N supply resources (MA, 2005).

> *"The most important MA scenario projected that the global flux of nitrogen to the ecosystems will increase by a further 10-20% by 2030 (medium certainty)."* (MA, 2005).

According to Rockström et al., (2009) ecosystems for humanity and bio-physical system of the planet are related with some define processes (climate change, ocean acidification, stratospheric ozone depletion, biochemical flows- nitrogen and phosphorus cycles, global freshwater use, changes in land use, biodiversity loss, atmospheric aerosol loading and chemical pollution). To have a safe planet, all these processes should operate within their safe boundaries. Long-term analysis showed that three (climate change, rate of diversity loss and nitrogen cycle) out of the nine processes has already exceeded their defined boundaries (Rockström et al., 2009).Growing habit of using more agrochemicals and rapid change of land uses in cropping systems can reduce the ecological biodiversity and change the shape of landscapes (Robinson and Sutherland, 2002; Benton et al., 2003; Bianchi et al., 2006; Farwig et al., 2009).

On the other hand, agroecosystems with more diversity can contribute complementary elements (species richness, safe ecosystems, better quality foods) for long-term sustainability (Gurr et al., 2003; Moonen and Bàrberi, 2008). Only few interested farmers are nowadays practicing integrated farming systems (multi-cropping or mixed cropping) to have a larger bio-diversity and less vulnerable production with less chemical input (Warner, 2007). Cover crops have the ability to fix and recycle the N in soil surfaces which can be reached around 200 to 300 kg N ha^{-1} y^{-1} (Vinther and Jensen, 2000). Cover crops can reduce the energy inputs for crop production by decreasing amount of input for manufactured N fertilizers (Jensen et al., 2012). Considering the scenarios of future N fluxes and to reduce the harmful effects, some preliminary steps can be taken in near future:

The net Nitrogen supply in agricultural systems should be decreased and the recycling of N enhanced. In addition N supply by cover cropping and residues incorporations can reduce dependency on chemical N fertilizers requiring large amounts of fossil energy for production. Creating farmer's awareness about cover crops in terms of economical and environmental benefits with more subsides to organic farming section from the government side to change their attitudes toward sustainable crop productions.

2. Introduction

2.1. Background

In a global scale, about 1.5 billion hectares of land is arable and occupied with permanent cropping systems (FAO, 2008). Between 1985 and 2005 the global croplands and pastures expanded by 154 million hectares which increased 47% crop production (FAOSTAT, 2012). Estimates showed that the global population will rise from the current 6.7 billion to 9 billion by 2050 (FAO, 2008). To meet the increasing food demand with limited natural resources, proper nutrient management strategies are the most important factors nowadays. During the last 50 years, N fertilizer contributed to 40 % increase in per capita crop yield (Brown, 1999; Smil, 2002). This ever boosting N application happened without considering any environmental impact (Azam et al., 2002; Reeves et al., 2002). Finding the new ways to reduce the agrochemical dependency to avoid environmental risk is still a greater challenge of sustainable food production system. Use of cover crops can reduce the harmful effects of N losses and recycle the soil N in agroecosystems. Cover crops can supply readily available N to the succeeding crops to cropping systems (Baggs et al., 2000). In addition, synchronizing the cover crops in farming system as mixed cropping or in cropping rotations can reduce N leaching losses by conserving the N in soil surface (McCracken et al., 1994). In a temperate climate region, growing cover crops in off-season can prevent nutrient leaching and at the same a time better recycling of N can be maintained (Thorup-Kristensen et al., 2003).

2.2. Nitrogen in agrosystems

Nitrogen is the most important plant nutrient for agricultural production (FAO, 2008). Various sources of N are synthetic fertilizer, crop residue, green manure, animal manure and soil organic matter (SOM) (Keeney, 1982). According to Christensen (2004), about 1-2 % N is available for the crops among the total N (typically 5-15 t N ha^{-1}) present in the SOM. Nitrogen accumulated by plants can be removed from the cropping system with the harvested crops or lost to the environment as a pollutant (NO_3^-, NO_2^-, NH_4^+, N_2O, NO) if the land is bare fellow. Glendining and Powlson (1991) concluded that long-term effects of using N fertilizers might increase the total amount of soil N content and newly mineralized N, which showed that the old organic N already present in the SOM are not getting into the production system.

Nitrogen mineralization-immobilization turnover (MIT) and the recycling of N depend on different factors and interactions within the soil and the related crops or external input (Christensen, 2004). In agricultural N cycle, synthetic N fertilizers, green manure and biological N-fixation are different additional ways of N input in the soil bodies to enrich the N content. Accumulated residue N are out of the systems with the crop harvest, rest of the N present in soil might be lost by denitrification, N leaching losses, ammonium volatilization, surface runoff, immobilized in the SOM etc. (figure 1) (Christensen, 2004).

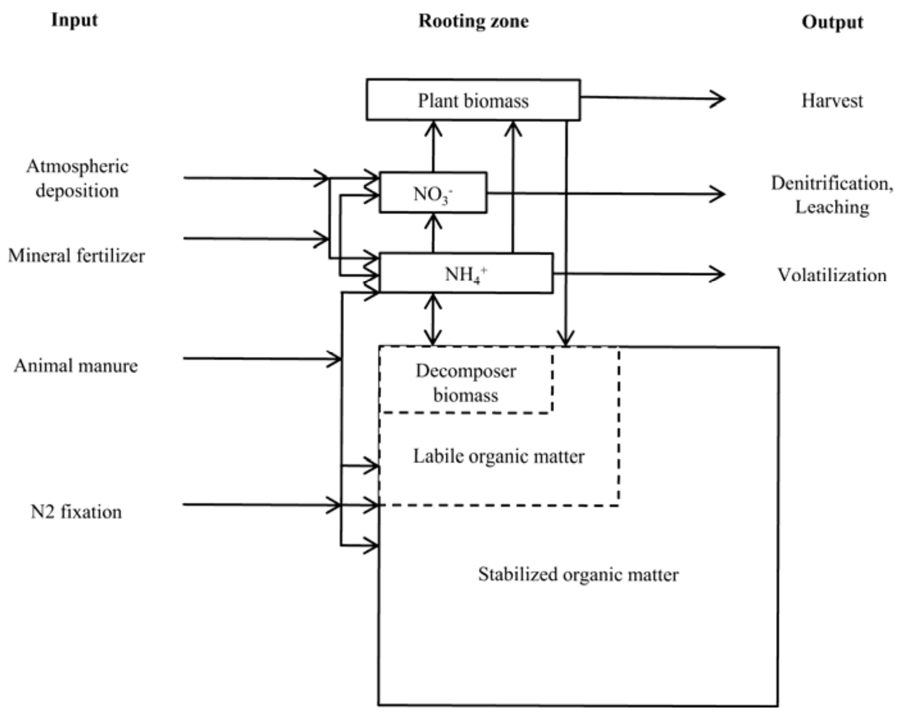


Figure 1: Diagrammatical nitrogen flow in the rooting zone of a general arable soil showing major inputs, outputs and pools of nitrogen. The area of the squares represents the respective amount of nitrogen present in the soil with their forms and importance (modified from Christensen, 2004).

Soil organic matter (SOM) preserves nutrients, but to become available N needs to be mineralized (conversion of soil organic N to its inorganic forms) by soil microbes. Enzymatic processes take places during the organic matter decomposition and release ammonium ($NH4^+$) into the soil solution (Murphy et al., 2003). Mineralization-immobilization turnover (MIT) can be taking place at the same time as microorganisms not only breaks down organic N but also temporarily take up some of the NH_4^+ into their own metabolic processes (Murphy et al., 2003).

2.3. Cover crops function in cropping systems

Incorporation of cover crops in cropping systems in various studies showed their potential abilities to reduce the synthetic N fertilizer input and to build the better soil texture and structure for sustainable agricultural productions (Lu *et al.,* 2000). In humid climate regions, using cover crops can minimize nitrate leaching by taking up the soil inorganic N in plant biomass (Dinnes et al., 2002; Thorup-Kristensen et al., 2003) and at the same time help to decrease N fertilization by supplying N to the succeeding crops during decomposition of incorporated residues (Ebelhar et al., 1984; Wagger, 1989a; Clark et al., 1997).

2.3.1. Benefits of cover crops

Agricultural practices in today's world are not just the concept to produce more foods with more input without paying attention to the health of the environment. Growing public concern about contamination of the environment by agricultural chemicals, reduction of genetic diversity, soil erosion and nutrient losses are promoting the world to find some alternative environmental friendly production systems (Lu *et al.,* 2000). Incorporation of cover crops in cropping systems can reduce the environmental impacts of excess chemical N fertilizer use by reducing its input in agricultural production (Thomsen and Christensen, 1999; Vos and Van der Putten, 2000). The environmental benefits of growing cover crops are as follows:

2.3.1.1. Addition of organic matter for better soil properties

Soil organic matter (SOM) and nutrient accumulation in soil can be enhanced by adding cover crop biomass to agricultural soils. SOM is the reservoir of nutrients and it enhance the building of soil aggregates, which facilitates to stabilize the soil and increasing porosity for root growth, aeration, cation exchange capacity (CEC) and the same time decreases soil erosion and runoff losses (Sainju et al., 1997). Addition of organic matter to agricultural soil can increase the population of soil micro-organisms and recycle nutrients efficiently to improve both the biological and chemical properties of the soil (Goyal et al., 1999). Rahman et al., (2001) showed that 30-40 % more readily available N can be recycled by incorporating the cover crop residues in soil.

Crop lands with no left mulches or cover crops in fallow seasons gradually suffer from depletion of SOM pools (Campbell and Zentner, 1993; Aref and Wander, 1998) which affects the environment by increasing N saturation in the soil and N leaching losses (Fenn et al, 1998). According to Roberson et al., (1991), cover cropping enhances the heavy fraction of carbohydrates. These carbohydrates are amended with extracellular polysaccharides (act as a glue to bind the soil particles) produced by soil microbes (Roberson et al., 1995). As an example, vetch (*Vicia* L.) winter cover crops increase the production of extracellular polysaccharide when they are incorporated in cropping system by increasing the plant-microbial interactions (Roberson et al., 1995).

2.3.1.2. Minimizing soil erosion

Soil erosion can reduce the quality of soil and is thus considered as a severe threat to the long- term productivity of agricultural lands (Pimentel et al., 1995). Causes of soil erosion are exposure of soil to rain and strong wind flows in addition with conventional agricultural practices (soil management tools). Type and intensity of tillage operations has direct impact on soil erosion and it decreases retention ability of soil particles (House et al., 1984). Surface residues of cover crops (particularly grass species) can help to reduce soil erosion by facilitating with their well developed root systems (Karlen et al., 1994).

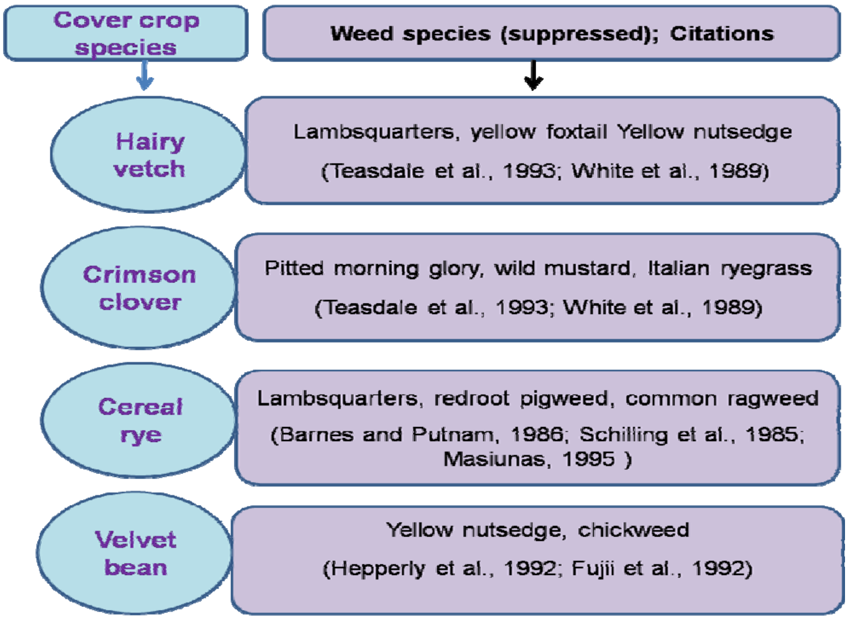
Another experiment in southeastern United States concluded that, residues management with cover crops in agricultural land can reduce soil erosion by 62% compare to no mulches (Langdale et al., 1991). Soil scientists of USDA estimated that, only the United States has lost almost 30 % of the topsoil in last 200 years due to lack of proper soil covers (Tyler et al., 1994). If soil is totally exposed to rain and wind forces the erosion rate is increased in a dramatic way. An experiment showed that as the amount of soil cover decreased from 100% to less than 1%, the erosion rates increased around 200 times (Trimble, 1994).

2.3.1.3. Influences on soil moisture conservation

Soil surface covered with cover crop residues can conserve soil moisture from water infiltration and water holding capacity of the soil (Smith et al., 1987). For example, the production of moisture stress sensitive crops such as corn production can be increased by providing adequate water in the critical development phases. The ability of moisture conservation of cover crops largely depends on sowing time of previous crops and killing (incorporation in soil) times of the cover crops to incorporate their residues with cropping lands. Soils treated with cover crop residues are well structured and easier to operate agricultural operations. Usually incorporation of cover crop residues in soil about 2 weeks before sowing corn (*Zea mays*) has a positive significant effect on yields (Wagger, 1989b).

2.3.1.4. Weed management in crop fields

Cover crops can reduce the weed population for the succeeding main crops in many ways. Firstly, growing cover crops prior to the main crop can occupy the bare land which can inhibit the germination and development of some weed species through the nutrient competition and shading (Teasdale and Daughtry, 1993; Reddy and Koger, 2004). Secondly, incorporation of cover crop residues on soil surface can change the favorable environment for weed seeds germination by altering the availability of light, soil temperature and moisture contents (Creamer et al., 1996). Experiment conducted by Smeda and Weller (1996) found that the residues of cereal rye incorporated with soil surface can inhibit the germination of annual broadleaf and grassy weed species up to 8 weeks after incorporation. At the same time, this suppression mechanism can reduce the use of harmful herbicides and help to save the environment from their toxic effects.



* Hairy vetch (*Vicia villosa),* Crimson clover (*Trifolium incarnatum),* Cereal rye (*Secale cereal),* Velvet bean (*Mucuna pruriens),* Lambsquarters (*Chenopodium album),* Yellow foxtail (*Setaria pumila),* Yellow nutsedge (*Cyperus esculentus),* Pitted morning glory (*Ipomoea lacunose),* Wild mustard (*Sinapis alba),* Italian ryegrass (*Lolium multiflorum*), Redroot pigweed (*Amaranthus retroflexus),* Common ragweed (*Ambrosia artemisiifolia),* Chickweed (*Paronychia P. Mill.*)

Figure 2: Summary of weed suppression by allelopathic effects of different cover crop species (when incorporated) (modified after Baldwin and Creamer, 2005).

Thirdly, cover crops can produce phytotoxic compounds by their allelopathic abilities which can suppress the weed germinations (Putnam, 1988). Selection of the allelopathic cover crop species according to the habitat of the common weeds of a specific area can be a tool to manage the weed problem (Figure 2) (Baldwin and Creamer, 2005).

2.3.1.5. Disease and pest managements

Incorporation of cover crop residues can act as a biological control tool. They can control the soil-borne plant pathogens 1) by increasing the SOM which has direct antagonism effects on the pathogens and 2) by altering the competition for light, energy, water and different nutrients for pest communities. Selection of proper cover crop species can be a difficult task to defeat the pathogen infestations. As an example, cruciferous plants are good enough to inhibit some soil pathogen populations (Lewis and Papavizas, 1971; Subbarao and Hubbard, 1996).

Experiment conducted by Rhoades and Forbes (1986) found that the combination of hairy indigo (*Baptisia arachnifera*) and vetch (*Vicia* L.) cover crops incorporated with a cowpea mulching can cut down the number of root-knot nematodes (*Meloidogyne incognita*). Furthermore, cover crops can protect the main crop from harmful pests by hosting the predator prior to the sowing time (Bugg et al., 1990). Cover crops can destruct the attraction of different pests to the same field for years long (Stark, 1994).

2.3.1.6. Effective tools for N supply and nutrients recycling

Organic N present in the SOM should be transformed to its inorganic forms (NH_4^+ and NO_3^-) by N-mineralization to be utilized by plants (Stevenson and Cole, 1999). After mineralization, plant available N in soil might get lost by leaching or surface runoff which can be decreased by using the cover crops in agricultural system (Rao and Prasad, 1980; Keeney and Sahrawat, 1986). Field experiments conducted at International Rice Research Institute (IRRI) showed that the use of cover crops in cropping systems can effectively reduce the losses of nitrate to aquatic surfaces by taking up the excess N left in the field after the main crops (Shrestha and Ladha, 1998). As an example, rye and crimson cover crops were effective to reduce the N leaching losses in Japan (Komatsuzaki and Gu, 2002). The biomass yield of cover crops and the accumulation rate of N largely depend on the time of establishment, climatic conditions, species and the types of soils (Shennan, 1992). Other factors that affect the N accumulation are soil water content, crop rotation patterns, soil pH, previous N fertilization and tillage operations (Peoples and Craswell, 1992).

Another experiment showed that the fallen leaves of legume cover crops during the development stage contain about 14.2 kg N ha^{-1} per seasons (Bergersen et al., 1989). Incorporation of cover crop residues can increase the nutrient recycling abilities of the soil by altering the biological activities of the soil microbes compared to mono cropping systems (Radke et al., 1988). The N accumulation amount in different cover crops can be verified by the incorporation of previous crop residues management in field conditions (Jensen, 1991a).

Experiment with cover crop N accumulation rates concluded that the accumulated amount of N in legume cover crops were 40 to 70 kg N ha^{-1} and 18 to 32 kg N ha^{-1} after incorporating pea (*Pisum sativum* L.) and barley (*Hordeum vulgare* L.) residues respectively (Jensen, 1991a). The tendency of N losses from soil surfaces are often higher when there is no residue left in the field after crop harvest nor any cover crop to hold the nutrient in the soil (Rahn et al., 2001).

Nyborg et al., (1995) found that the cover crops residue management with reduced tillage cropping system gradually decreases the net N immobilization. Incorporation of cover crops residue can synchronize the soil with available forms of N which can facilitate the uptake by the plants and less N leaching losses (McCracken et al. 1994). Changing the fallow land with cover cropping in off season can increase the SOM pools. Several experiments focused on the crop yield and the N leaching loss measurement effects on the carbon-nitrogen recycling dynamics of soil have shown that the capacity of nutrient retention and the rate of residue decomposition depend on the selection of right cover crop specie (Tisdall and Oades, 1979; Haynes and Beare, 1997).

2.4. Oil radish (*Raphanus sativus* L.) as a cover crop

Oil radish (*Raphanus sativus* L.) is a taproot (an enlarged straight root; root depth varies from 12cm to 0.7 m depending on specie) vegetable crop which belongs to the family *Brassicaceae*. Most commonly grown oil radish varieties are round or long with red or white colors. Oil radish cultivation can be done into two different seasons in a year. First one is summer cultivation with short maturity period (25-30 days) and the other one is autumn cultivation with longer maturity period (40-75 days) (Splittstoesser, 1984). The taproot of oil radish has many lateral roots. This bunchy root system helps loosen and aerate the soil especially in no- tillage cropping system. Deep root system can uptake more N from different soil layers (Swiader et al., 1992). Oil radish as a cover crop has environmental and economical values. It can reduce the N leaching losses by conserving and recycling the N in soil surface, consequently decrease the manufactured N input in crop production which can decrease the total production cost (Wagger et al., 1998a).

Compare to other cover crops, oil radish has moderate DM production and N accumulation (Table 1). Oil radish has short growing period, large N recovery ability and it needs less cultural practices which can attract the attention of farmers to incorporate it in cropping system.

Table 1: Comparison among different cover crops in dry matter and N accumulation. All the values presented in the table represent the average of the minimum and maximum productions.

Cover crops	**Dry matter production ($t\ ha^{-1}$)**	**Nitrogen accumulation ($kg\ ha^{-1}$)**	**References**
Wheat	3.29- 7.67	75- 92	Odhiambo and Bomke, 2001
Oil seed radish	2.52	78.3	Young, 1998
Ryegrass	2.15- 7.94	78- 81	Odhiambo and Bomke, 2001
Italian ryegrass	4.75	85.8	Jensen, 1991a
Perennial ryegrass	3.4	106	Jensen, 1991a
White mustard	0.71	59.6	Jensen, 1991a
Tansy phacelia	0.84	72.2	Jensen, 1991a
Clover	2.8	81	Odhiambo and Bomke, 2001
Hairy vetch	4.4	138	Teasdale et al., 2004
Rye	2.21- 6.29	58- 79	Odhiambo and Bomke, 2001

* Hairy vetch (*Vicia villosa)*, Ryegrass (*Lolium* L.), Italian ryegrass (*Lolium multiflorum*), Perennial ryegrass (*Lolium multiflorum)*, White mustard (*Sinapis alba)*, Tansy phacelia (*Phacelia* spp.), Clover (*Trifolium* L.), Wheat (*Triticum* spp.)

3. Aim, objectives, hypothesis and limitations

3.1. Aim

The main aim of this study was to determine the relationships of N fertilizer rates to the previous main crop on DM production and N accumulation in oil radish (*Raphanus sativus* L.) grown as a cover crop. Moreover, to discuss the possible ways of how cover crops can be environmentally and socio-economically valuable to the farmers. At the same time helps to grow farmers’ awareness about incorporating cover crops in cropping systems.

3.2. Objectives

- To determine the total amount of DM and N accumulation in an oil radish (*Raphanus sativus* L.) cover crop in relation to long-term nitrogen fertilizer application rates.

- To review the relevant literature and summarize the knowledge on the economic cost and benefits for the farmers in relation with growing cover crops.

3.3. Hypothesis

- Dry matter and nitrogen accumulation in an oil radish (*Raphanus sativus* L.) cover crop increase linearly with long- term nitrogen fertilizer application rates to the main crop.

3.4. Limitations of the study

This study only covered the aspects of N fertilizer management with previous crops and their effects on cover crop. As the study was conducted in a specific growing season and at a specific research site (southern Sweden), with specific environmental conditions (temperature, soil types and tillage practices), the results may not be generalized for global aspects. The global perspectives of cover crops in relation to N fertilizer management and socio-economic beneficial contents in cropping systems are discussed on the basis of literature reviews. The original experiment was not designed for a proper statistical comparison which must be considered in the interpretation and conclusion.

4. Materials and methods

4.1. Experimental site

The experiment was carried out at the research station (Lönnstorp) at Alnarp. The experiment has been set up for long-term observation (for 18 years, since 1993 in 12 fields; six in a conventional and six in a reduced tillage system) of the effects of six N fertilizer levels in conventional and reduced tillage systems with a crop rotation (Table 2). The experiment was conducted in one of the field in the reduced tillage system (field number B_5) (Figure 3) where oil radish (*Raphanus sativus* L.) was the standing cover crop. The soil type of the field was Loam soil with 2.5 % SOM and $pH_{(H_2O)}$ 6.5 from 0 to 20 cm. Each field was treated with the same level of N every year (Table 3) and there were seven experimental plots within each block with different replications (five of them were R_1 and R_2 with N levels N_0, N_1, N_2, N_3, N_4 & N_5 and 2 of them were R_3 & R_4 with N_0) (Figure 4). The nitrogen fertilizer (Axan- Yara International) was based on ammonium nitrate, with balanced sulfur content (Total N-27%, nitrate-13.5%, magnesium- 0.4%, sulfur-3.7% and calcium-6%).

Table 2: Crop rotation in the reduced tillage experimental plots (2011)

Ley (Winter rapeseed after harvest)
Faba beans (Winter wheat after harvest)
Winter wheat-2 (**Oil radish** after harvest)
Winter rapeseed (Winter wheat after harvest)
Winter wheat-1 (with undersown Ley)
Sugar beat

Winter wheat (*Triticum* spp.) was the main crop before oil radish. Winter wheat was harvested on 29^{th} of August 2011 and the oil radish was sown on 2^{th} of September 2011. Oil radish was established as a cover crop and there was no actual harvest for oil radish, except in the different N fertilizer application plots.

Table 3: Nitrogen fertilizers supply to the main crop (winter wheat- *Triticum* spp.).

N fertilizer levels	**N supply for winter wheat (kg ha^{-1})**
N_0	0
N_1	80
N_2	120
N_3	160
N_4	200
N_5	300
Field (rest)	175

They were incorporated in the soil. The harvest of the oil radish was done to measure their desire parameters (DM production, N concentration, N accumulation, C: N ratio). The weather data for the oil radish growth period is given below (Table 4) (as there was no weather station near the experimental sites since end of 2011, the data presented here is from the nearest station Lund-11.2 km west to the experimental site) (SMHI, 2012).

Table 4: Temperature and precipitation data during oil radish growth (adapted from SMHI, 2012).

Months (2011)	Temperature (°C)			Precipitation (mm)
	Maximum	Minimum	Average	
September	25.4	6.5	14.6	57
October	22.4	-0.7	9.4	50
November	13.6	-2.1	6.2	7

4.2. Experimental design

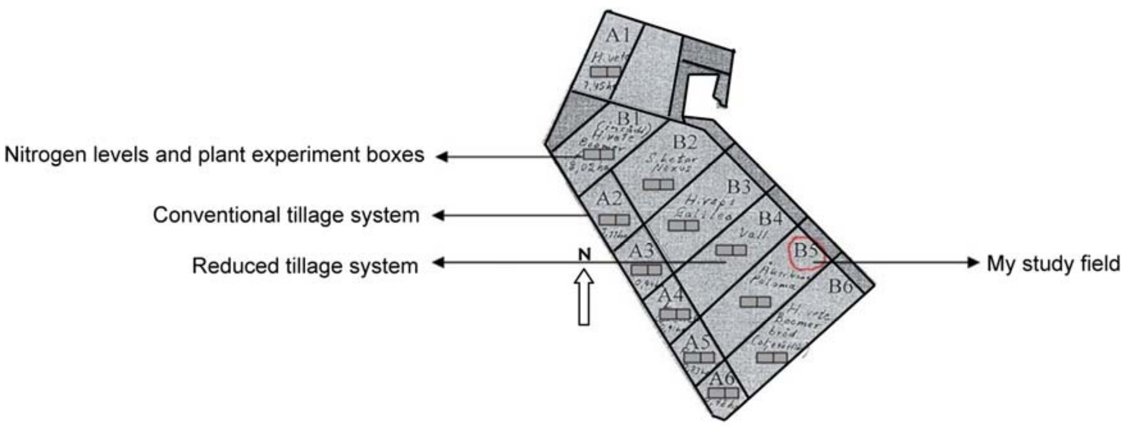


Figure 3: Layout of the experiment

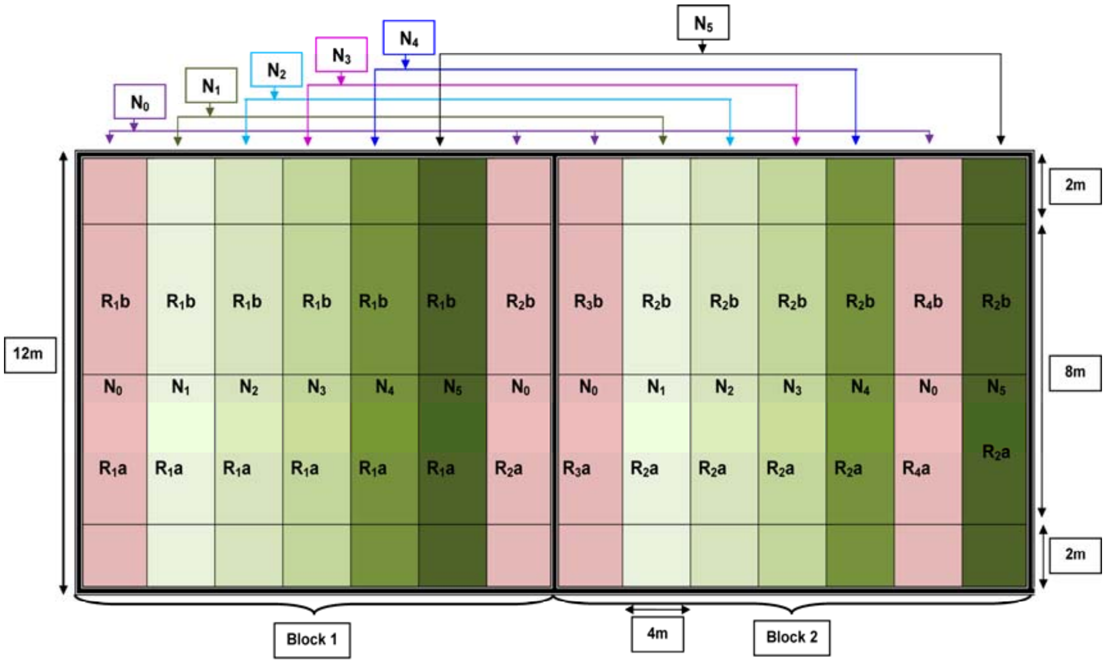


Figure 4: Field layout of the experimental plots.

4.3. Sampling of oil radish cover crop

Harvesting of the oil radish sample was made by hand in 10th of November, 2011. At the time of sampling, the oil radish plant was 69 days old. A (0.5 m^2) iron frame was used to collect the samples (whole plant parts- shoot and root) from each sub- plot with N fertilizer treatments. Collection of the samples was done once in every sub-plot with the iron frame (Figure 5).

Figure 5: Sampling of oil radish (*Raphanus sativus* L.).

The total numbers of experiment plots were 14 and the total sub-replication plots were 28. Each sample was collected in labeled cloth bags and brought to the laboratory.

4.4. Fresh and dry weight determinations

Fresh and dry weights were determined for all the collected samples. At first, all the samples were cleaned with fresh water (room temperature) to remove soil and other particles (stone, seeds etc.). The samples were kept open for 2 hours inside the lab to remove the excess water. For measuring the dry weight, samples were dried in an oven for 72 hours at a temperature level 70° C to remove the moisture.

4.5. Preparation of samples for elemental analysis

4.5.1. Grinding of oil radish samples

Oven dried plant samples were grinded with a 1093 Cyclotec Sample Mill in a fine dust format (particle size about 1mm) to make the tin capsules for elemental analysis. All milled samples were well marked and preserved in air tight containers.

4.5.2. Preparation of tin capsules

Small tin capsules were prepared with the milled plant samples. Acetanilide 10.36% was used as a standard solution for the elemental analysis. A total of 56 (28 samples with 2 replications of each one) samples (average weight 5-6 mg) were weighed out in small tin capsules.

4.6. Nitrogen determination in plant samples by elemental analysis

The samples were analyzed by an elemental analyser according to the Dumas method, Carlo Erba NA1500 (Carlo Erba Strumentazione, Milan, Italy) for N and C analyses (Jensen, 1991b). The analyser can run 30 capsules in a complete rotation and the total 56 samples were analysed by proper rotation sequence. Helium (99.9995%) was used as a carrier gas at a flow rate of 80 mL min^{-1} and Oxygen (99.998%) was used to do the flash combustion. Effective temperature for the sample analysis was 1020°C and the duration of analysis for each sample was 210 seconds. The combustion was taken place in a quartz tube with Cr_2O_3 and silvered Co_3O_4. N_2 and CO_2 were separated in a gas chromatographic column (GC) and the measurements were calculated on an integrator in areas with their respective peaks using EAGER 200 software.

For total N determination, standards (Acetanilide-10.36% N, 1-3 mg) were analysed after every ten samples. The amount of N present in the samples was calculated by using K value method. This K value principle was used to minimize the possible effects of ash accumulations in the combustion tube and combustion efficiency.

4.7. Nitrogen accumulation measurement

Nitrogen accumulation measurement of all the samples was calculated as follows:

$$N_{(accu)} = \% N \times DM/100 \ (g\ N\ m^{-2}) \tag{1}$$

Where,

$N_{(accu)}$ = N accumulation (g N m^{-2})

% N = N concentration (%)

DM = Sample dry matter (g m^{-2})

4.8. C: N ratio measurement

After getting the elemental analysis results of N and C (carbon) amount, the C: N ratios were calculated. The N and C concentrations were measured in whole plant parts (shoot and root).

4.9. Statistical analysis

Different parameters (DM production, N concentration, N accumulation, C:N ratio) of the collected data were analyzed by using Minitab 16 with ANOVA and Tukey test in general linear model (GLM). P-values of the analyzed data in ANOVA were corresponded at a significance level $p<0.05$. Before analyzing the data with Minitab, the same number of replications among the treatments was maintained.

5. Results

In this section, all the findings from the experiment are presented in text, graphs and table according to their necessity. The presented results are the treatment (long-term N fertilizer rates) effects on the DM production, N concentration, N accumulation and C: N ratios of oil radish cover crop.

5.1. Effects of main crop N fertilizer levels on dry matter production of oil radish cover crop

In the present study, the dry matter production in oil radish cover crop varied from 126 to 220 g m^{-2}. The increasing rates of N fertilizer levels on main crop showed the non-linear significant ($p<0.05$) increasing trend in DM production of oil radish (Figure 6). However, it was only the dry matter production at the highest N fertilizer level which differed significant from the other N levels. The average DM production of oil radish cover crop was 150±21 g m^{-2}.

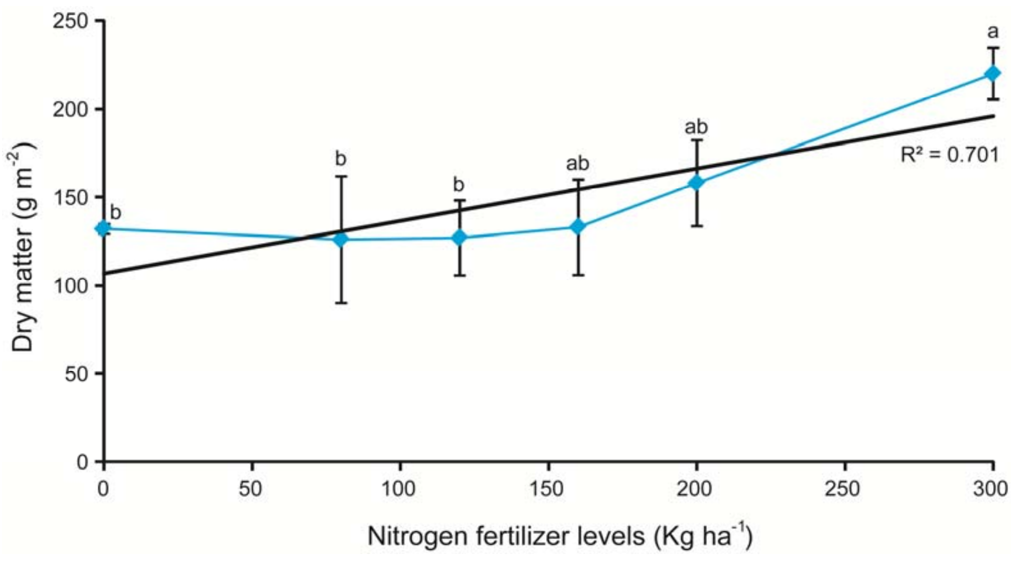


Figure 6: Effects of yearly N fertilizer levels in reduced tillage system on total dry matter production in oil radish cover crop (shoot and root) in field conditions. Here each value represents the mean values of two replications with +/- standard error (SE) and the regression line shows their relative linearity trend.

5.2. Influences of main crop N fertilizer levels on N concentration in oil radish

The nitrogen concentration in oil radish cover crop samples were not significantly ($p > 0.05$) affected with increasing levels of N fertilizer application rates in field condition. The average N concentration in oil radish cover crop was found to be 3.2±0.17 (%) (Figure 7).

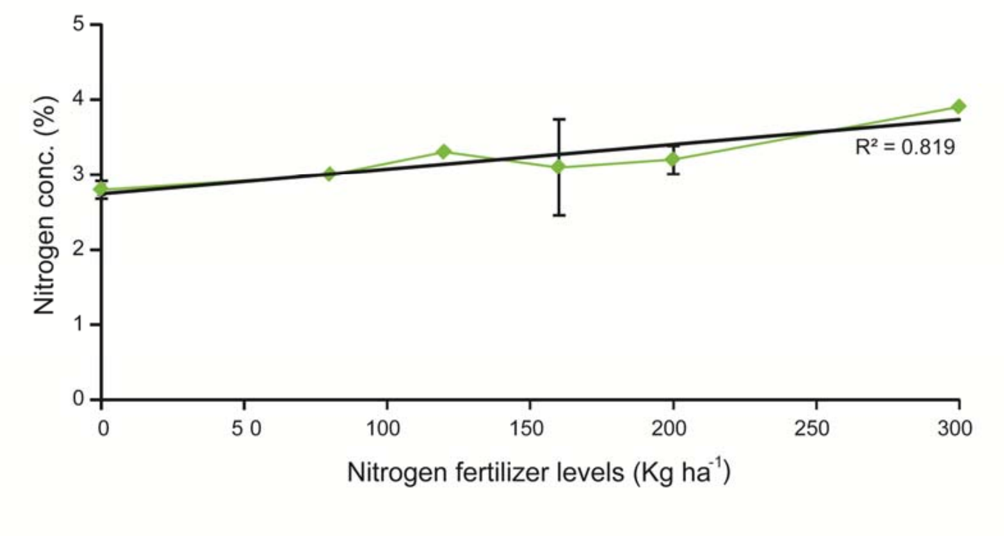


Figure 7: Influences of main crop N fertilizer levels in the plants on N concentration in oil radish cover crop (shoot and root). Here each value represents the mean values of two replications with +/- standard error (SE). The regression line shows their relative linearity trend.

5.3. Nitrogen accumulation in oil radish influences by N fertilizer levels

Nitrogen accumulations were found to increase in relation with N fertilizer applications (Figure 8). Increasing trends in DM production and the N concentrations of the cover crop samples determined the increasing amount of N accumulations. The average N accumulation in oil radish was 4.9±0.50 g N m^{-2}.

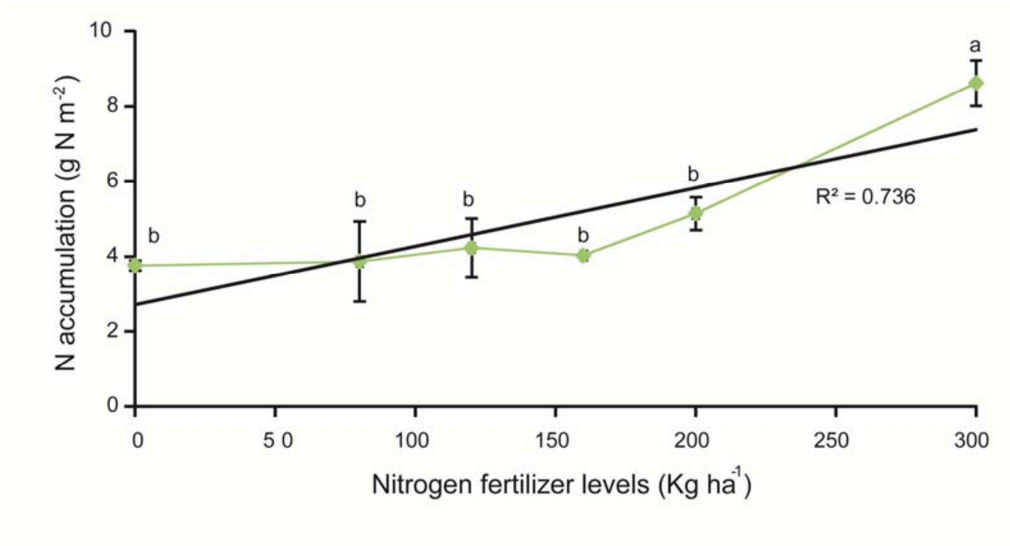


Figure 8: Nitrogen accumulation in oil radish cover crop (shoot and root) influenced by different N fertilizer levels on main crop. Here each value represents the mean values of two replications with +/- standard error (SE). The regression line shows their relative linearity trend.

5.4. C: N ratio of oil radish in different N fertilizer rates

The calculated amount of C: N ratio of oil radish cover crop showed the effects of N fertilizer application rates (Table 5).There was no statistical significant differences among the C: N ratios in term of N fertilizer application rates on main crop.

Table 5: Effects of different permanent N fertilizer rates on C: N ratios in oil radish cover crop (shoot and root) with their respective +/- standard errors (SE) and significant differences (numbers with the same letters are not significantly different).

N levels (kg ha^{-1})	C:N
0	13.3±0.57 a
80	12.5±0.28 a
120	11.5±0.19 a
160	12.0±2.20 a
200	11.2±0.97 a
300	9.29±0.22 a

6. Discussion

In many ways, cover crops have taken attraction of researchers and the farmers in recent years. In present study, though the result showed that the DM production and N accumulation in oil radish cover crop increased significantly in the higher level of N fertilizer rates only. The increasing rates of N fertilizer were responsible for increasing the DM and N accumulation as residual N fertilizer and presumed higher levels of net N mineralization enhances the production of total DM and the potential amount of crop residues (FAO, 2008). In this study, DM production on the control plot (N_0= 0 kg N ha^{-1}) was more than the minimum N applied plot (N_1=80 kg N ha^{-1}). The controlled plots might have some previous mineralized N from the main crop (winter wheat) which initially influenced the DM production and N accumulation in oil radish plants. At the same time, high input N fertilizer plots supplied more readily available N to the plants which influenced the rapid growth of oil radish and more accumulation of N. The DM production and N accumulation rates in cover crop can be affected by residues management of the previous crops. Other factors that might influence the DM production and N accumulation in oil radish could be the amount of SOM (Nicholson et al., 1996), soil pH (Paul and Clark, 1996), soil types (Ladd et al., 1996) and tillage operations (Russell, 1973).

Nicholson et al., (1996) found that the residues bound N incorporated in the cropping system can produce 30-40% readily available N. These residual N might influenced the preliminary establishment and vegetative growth of cover crop in their early stages. In present study, the DM and N accumulation were 1.3 to 2.2 t ha^{-1} and 38 to 87 kg ha^{-1} at N_0 and N_5 respectively after winter wheat. In another experiment with oil seed radish it was found that the DM and N accumulation were around 2.52 t ha^{-1} and 78.3 kg ha^{-1} respectively (Young, 1998). Jensen (1991a) found that the accumulated N amount in cover crops were 40 to 70 kg N ha^{-1} and 18 to 32 kg N ha^{-1} after pea and barley as main crops respectively.

In the present study, the N concentration in oil radish was more or less similar for all N application rates. It showed that the N concentration in oil radish was not highly affected by the levels of N fertilizers applied. When the sampling was done, the crop was in the vegetative stage. An experiment conducted by Wagger (1989b) found that the variations in N concentration in different cover crops were not significantly varied with N application rates and at the same time few variations were found due to different harvesting times. Odhiambo and Bomke (2001) found that the early sown cover crops had higher N concentrations probably due to higher N uptake in the fall and it exhibited a decline with the late plantation dates.

The result from present experiment showed that the C: N ratios are gradually decreased with the increased amount of N fertilizations. C: N ratios of oil radish in the current study ranges from 9.2 to 13.3. Mineralization-immobilization turnover (MIT) of N in soil can be influenced by the C: N ratios. Generally immobilization occurs in soil when the C:N ratio of the incorporated residue is higher (>25:1) (Powlson et al., 1985). Crop residue with higher C: N ratios (> 90:1) can decreases the mineralization rates and lead to immobilization of N in a long-time incorporation with soil (Torstensson, 1998). Cover crop residues with lower C: N ratios showed the rapid decomposition and quick N mineralization ability of the residues (Barrios and Trejo, 2003).

7. Socio-economic evaluation of cover crops in N conservation

Cover crops have economical benefits in terms of supplying N to the agro-systems, fiber, oil, bio-fuel and protein-rich foods and feeds (Jensen et al., 2012). Considering the present study, the budgetary analysis of the old radish cover crop showed the negative economical balance.

Economical analysis of oil radish in current experiment:

Cost of seeds for oil radish per hectare:

Cost of seeds for oil radish was= 44 SEK kg^{-1}

Total seeds needed = 20 kg ha^{-1}

Total cost of seed= 44×20= 880 SEK ha^{-1}

Tractor operation cost per hectare:

Total tractor hour = 1 hour ha^{-1}

Salary of the operator= 180 SEK ha^{-1}

Cost of diesel= 10.70 SEK lit^{-1}

Total diesel needed= 15 lit ha^{-1}

Total cost of soil preparation= (15×10.70) + 180= 340.5 SEK ha^{-1}

Total cost of oil radish establishment = (880+340.5) SEK ha^{-1} = **1220.5 SEK ha^{-1}**

From current experiment,

It showed that the average accumulation of N by oil radish varied between 40 to 90 kg ha^{-1}
The cost per kilogram of N fertilizer for the previous crop = 11.70 SEK kg^{-1}

The accumulated N value of oil radish cover crop= (40 to 90 ×11.70) SEK ha^{-1} = **468 to 1053 SEK ha^{-1}**

In the present study, the establishment cost of the cover crop was little bit higher than the input cost of commercial synthetic N fertilizer in field condition. Considering only the economical benefits in N recycling, cover crops are still a bit less attractive to the farmers. However, the other beneficial economical evaluations (building soil C content, reduce tillage operation cost, economical benefits by recycling the phosphorus and potassium in cropping systems, reduce herbicides and pesticides input costs, mitigation of climate changes by replacing the fossil fuel use with biobased renewable sources) are also important to observe in terms of monetary system, the cover crops more attractive to the farers.

Various studies have investigated the socio-economic benefits of integrating cover crops into agricultural production. These studies were conducted from short-term to long-term basis on budgetary analysis and social benefits of cover crops. An experiment conducted by Creamer et al., (1996) in Ohio, USA, showed that the main economical benefit of cover crop in tomato production was reduction of input cost by decreasing the use of chemical N fertilizers and pesticides for crop production. Incorporation of cover crops in cropping system can reduce the weed competition and the quality of the yield was better than the conventional farming with chemical treatments. Several experiments with mixture of different cover crops (rye, crimson clover, hairy vetch, big flower vetch) in corn production concluded that corn yields were greater with the combination of cover crops and N fertilizer rather than just N fertilizer applications (Frye et al., 1985; Shurley, 1987; Allison and Ott, 1987).

A study conducted by Giesler et al., (1993) found that hairy vetch cover crop can reduce 67 kg ha^{-1} N fertilizer in cotton production compared to conventional practices. Another aspect of cover crops is to reduce soil erosion which can play a crucial role in terms of economical and environmental benefits. The global costs for soil erosion losses and its direct and indirect impacts on environmental damages are estimated about $400 billion per year (Jones et al., 1997). By incorporating the cover crops in cropping systems this economical damage can be checked effectively. Using cover crops in cropping system can produce more biomass (cover crops biomass from 5 to 8 t ha^{-1}) which contains 150 to 200 kg of N ha^{-1} without any reduction in soil N content (Teasdale and Abdul-Baki, 1998).

Using hairy vetch cover crops in corn with no-tillage systems can reduce the economical risk of the whole production system as they reduce the application of manufactured N, help to maintain the soil tilth and suppress pests and weeds (Hanson et al., 1993). Ott (1987) conducted an experiment with crimson clover cover crop to evaluate the economical returns and energy efficiency in sorghum production. He found that the energy efficiency of variable input in sorghum production was higher with cover crop incorporation in terms of direct energy inputs without cover crops. Another experiment carried by Ess et al., (1994) showed that the economical profitability and energy efficiency of corn production were much higher with cover crops rather than system depending on manufactured N fertilizers.

If the oil radish cover crop will establish in an organic system, there might be a chance to get subsidies (like other organic crops) from the governmental and other organizational levels. European Union (EU) and International Federation of Organic Agriculture Movement (IFOAM) already have their regulations for subsidizing the organic farmers to promote more organic productions. If specifically cover crop growers might get the chance to obtain subsidies from the from national to international regulation authorities, the whole future scenarios of cover crops incorporation in cropping systems might be changed in a positive way.

8. Conclusion

The management practice of N fertilizer in a long-term cropping system has important role in DM production and N accumulation. Increasing level of N fertilizer has direct effects on DM and N accumulation in the oil radish cover crop in higher N fertilizer levels. The increasing tendencies of DM and N accumulation according to the N fertilizer application rates are not in a linear trend as expected in the hypothesis. Several environmental factors are also responsible for DM production and N accumulation amounts. In this present study, not all the recommended rates of N are equally important for better biomass production and N accumulation. Experimental plots that received N fertilizer from 0 to 120 kg ha^{-1} has the same biomass yield of the cover crop and showed the non-significant effects of DM production in a lower N fertilizer rates. At the same time, when the N application rate is increased (N =300 kg N ha^{-1}) total biomass production is also increased. N accumulation with oil radish cover crop has significant differences only with high N fertilizer rate. From farmer's perspective, the best selection of N fertilizer can be range from (0 to 200 kg N ha^{-1}) as the highest amount of N application has little more biomass and N accumulation but the input cost will be higher with higher chances of environmental contamination. Economic analysis of the cover crop establishment is still more than the cost of synthetic N fertilizers. Several measurements like subsidies, considering environmental safety, nutrient recycling and SOM building capacity are also important to consider. Integrated cropping systems with cover crops are socio-economically beneficial for farmers to maintain sustainable crop production.

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10. Appendix

10.1. Personal reflections on master thesis

The planning of my master's thesis actually started with the Project Based Research Training course. I was looking for some opportunities to work with crop production and nutrient recycling in agrosystems. It was April, 2011 when I talked to my supervisor for the first time about my interest. He is the right person to work with crop production as he is an agronomist and specialist with nutrient management and sustainable food production. We had several meetings to choose the best topic for my thesis. At the same time, I found my co-supervisor who is specialist in nitrogen and carbon management in cropping system. We were talking about different aspects of the thesis work and to share our understanding they provided a very nice office place nearby their corridor. I spent more than one year with both of them and learnt so many new things. I did my Project Based Research Training course with nitrogen mineralization-immobilization turnover and the effects of nitrogen leaching losses to the environment. This course was a milestone for going through my thesis work. I understood the basic mechanisms of nitrogen management under soil and in plants. Then I started my thesis work mainly with nitrogen and cover crops (oil radish). When I started my thesis work it was almost winter and just few days before snowing. We decided to do the field work 2 months prior to the planning. I was collecting my oil radish samples (whole plant-shoot and root) from reduced tillage plots and it was really tough to collect the whole plant with roots without disturbing the soil. I got help from the research station (plots were located in a research station that belongs to SLU) manager to learn the techniques how to do that tough job easier. When I did my field work, I start doing my lab works and ended up with the elemental analysis of the nitrogen in the samples and I was doing different literature studies related with my thesis work. I found some really good result from the experiment and the whole thesis work was a new experience for me. However, the limitations of the thesis were the time duration and the geological location. To understand more functions of cover crops, the time period (only one season) was not enough and the same time for some climatic conditions the result might not be appropriate for all locations.

Different other experiments about oil radish has been conducted for several years and they found some more valuable nutrient such as phosphorus and potassium recycling aspects with oil radish which can be a potential future research investigations. The economical analysis of the crop was done to see the cash value. Beside the economical values, cover crop has a potential contribution to the environment. Cover crop incorporation in sustainable food production will add a new dimension in diversifying the ecosystem and nutrient management strategy. Possible subsidies from appropriate authorities can also help to promote the cover crops more popular to change the farmers' attitude towards these geo-friendly magical crops. Finally, I believe that the current thesis will help to provide information about the sustainable nitrogen management through the cover crops and their beneficial contributions to a future safe planet.

10.2. Farmers' fact sheet

SLU
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Fakulteten för landskapsplanering,
trädgårds– och jordbruksvetenskap

OIL RADISH

IN

NITROGEN MANAGEMENT

FACT SHEET

…Agroecology - Master's Program

Overview

Oil radish (*Raphanus sativus* L.) is a popular vegetable crop that belongs to the family *Brassicaceae*. It has different beneficial aspects of improving soil quality and economical values. The most excitng feature about oil radish as a cover crop is the nutrient recycling ability as it has a well developed root system. It is a fast growing crop and can be planted twice in a year depending on maturity periods (short and long). The short maturity variety needs 25-30 days and the long maturity variety needs 40-70 days in favorable climatic conditions.

Growth potential and Nutrient cycling

Cover crop incorporation in cropping system has economical and environmental benefits. According the current experiment, oil radish has satisfactory biomass production (1.32 to 2.2 ton ha^{-1}) (figure 1).

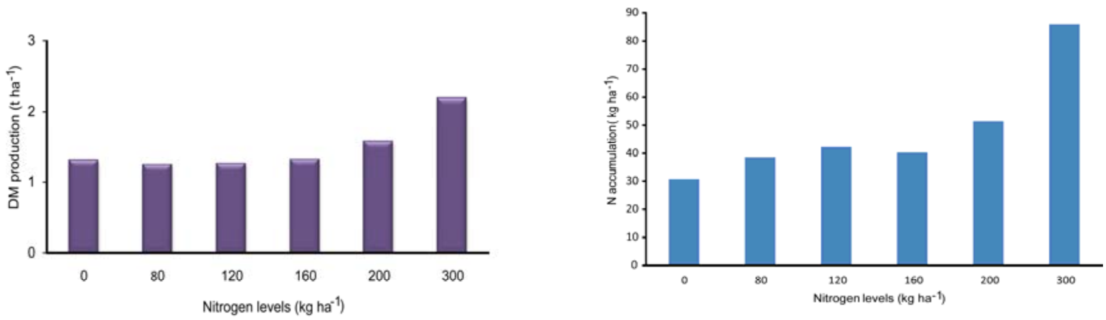

Figure 1: Dry matter production (left) and nitrogen accumulation (right) in oil radish (*Raphanus sativus* L.) cover crop after winter wheat (*Triticum* spp.) in a temperate climatic condition. Nitrogen fertilizer was applied to the main crop.

It has a deeper root system which can utilize more nutrients from different layers of soil. Especially nitrogen uptake and return to the cropping system is one of the best performances done by oil radish as a cover crop.

With the deep root structure, oil radishes can take up nitrogen from deeper soil zones which prevent the nitrogen leaching losses through percolation. Prevention of nitrogen from leaching losses can also be return to the cropping field by incorporating the residues. Average nitrogen accumulation from recent study was 38 to 87 kg N ha^{-1} (Figure 1). Other aspects of oil radish cover crop are the recycling of phosphorus and potassium.

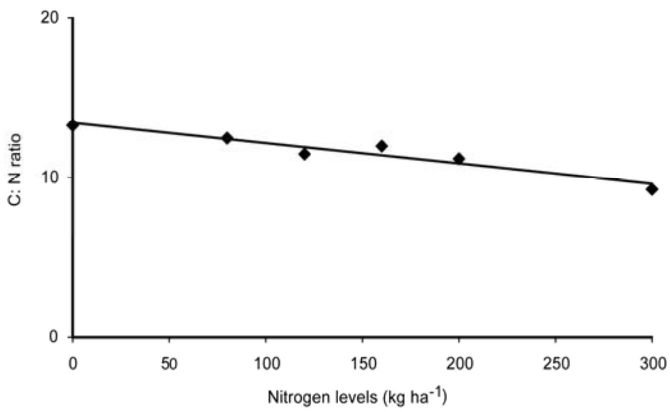

Figure 2: Effects of nitrogen fertilizer rates on C: N ratios of oil radish cover crops.

Residues management

Oil radish residue has low C: N ratios which determine the quality of decomposition and the effects on soil nitrogen mineralization-immobilization turnover (MIT). Net nitrogen mineralization increased by applying more organic residues with lower C: N (<25:1) ratio. In current study the C: N ratio was 11.2 (Figure 2). Incorporating residues in soil help to build the better water holding capacity, suppression of weeds and pests, reduce the pressure on fossil fuel by renewable energy sources.

Recommendation for farmers

- Oil Radish has a potential for N recycling
- It has ability to produce potential amount of biomass
- It is a short duration crop
- Suitable for almost all types of soils

Further reading

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