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Fakulteten för landskapsplanering,
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Mineral nitrogen in spring in two cropping systems with permanent nitrogen supply

Su Liu

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Mineral kväve under våren i två odlingssystem med permanent kvävetillförsel

Su Liu

Supervisor: Senior Lecturer Allan, Andersson, Swedish University of Agricultural Sciences, Department of Agrosystems

Examiner: Prof. Erik Steen, Jensen, Swedish University of Agricultural Sciences, Department of Agrosystems

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Foreword

This thesis is submitted to the Faculty of Landscape Planning, Horticulture and Agricultural Science, which is at Swedish University of Agricultural Sciences, Alnarp for obtaining the MSc degree.

The first course in this programme gave me a strong impression when I visited a sugar beet farm. An advanced farm was totally different as what I thought before. At that time, I was aware of the knowledge which I would learn in this programme was beyond imagination, and subsequent study confirmed my thoughts. PRA tools was a useful method which includes methods of interviews, sampling, group work and visualization. When I did my research, it could help me collect data and information from different aspect. From Prof. Lena Ekelund's course, I understood how important to know the perspectives of farmers and that was an essential way to complete my work in all projects.

I appreciated Dr. Erik Hunter to give me a chance to join the project of "Investigation of Swedish organic milk supply chain". I found my interest in this project, which was *Organic Food Supply Chain*. Unfortunately I could not find a suitable topic for my Master Thesis in this area, but another topic could be a new challenge for me.

With the help of my supervisor Allan Andersson, I learned a lot in process of doing my Master Thesis which was regarding measuring mineral nitrogen content in two cropping systems. I gained plentiful knowledge of nitrogen mineralization, pollution of nitrogen leakage, the effect of different crops in different cropping systems, and influence of permanent nitrogen supply in cropping systems. It was a proper chance for me to practice the methods that I learned before, such as measurement, statistics, data collection, and data analysis. Field trial, literature review and statistic analysis were the most common methods that I used, and all of them provided a lot of help and I hoped they could give me more support in future.

Thinking was the most useful thing that I learned during this two years study. I can always get new ideas or solutions through thinking about a problem from different aspects. On the other hand, when I learn something new, flexible thinking could help me discover something which maybe I was never aware of before.

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I would like to give my supreme thank to my supervisor Allan Anderson for great help and suggestions during the entire period of research. I also thank Department of Agrosystems to provide me a chance to do my Master Thesis and supporting me during the research period. I must thank Jan Eric Englund for guiding me when I did statistic analysis and the help from Maria Ernfors in my field trial. I appreciate to thank my friends and classmates, who are Rafique Ahasan Chawdhery, Nawa Raj Dhamala, Esmaeil Echreshavi, and Dipesh Neupane for giving me help in process of writing and analyzing. I would like to thank course coordinator Christina Kolstrup as well for her support not only in course Master Thesis, but also in many other aspects. Finally, I want to thank my family for their support throughout the two years.

Abstract

The purpose of this study is to find out nitrogen (N) transformation in rotation system from previous crop to succeeding crop in both conventional cropping system and conservation tillage cropping system. The conservation tillage cropping system used some methods like legumes and catch crop with lower inputs of fertilizers and pesticides. Mineral nitrogen (Nmin) was measured under permanent nitrogen supply in both cropping systems in early spring time. Soil samples were collected in March and April in southern Sweden. High content of Nmin was found in field B2 which might be positive for N supply to the crop growing in 2012, but also could be a risk for N leakage if the precipitation is very high. The reasons for this condition might be two due to the previous crop Faba bean in this field. First Faba bean does not recover Nmin from soil, and second Faba bean has residues of plants with high N content. After growing winter wheat, in deep soil layer there was low content of Nmin; and also after growing winter rape seed and spring rape seed, there was low content of Nmin as well. In addition, conservation tillage cropping system had high Nmin. High Nmin in spring has possibility to reduce input of N fertilizers, but massive Nmin in soil may pose a risk for N leakage to contaminate nearby seas and lakes when precipitation is high and crops are growing slowly. This study has practical significance for helping farmers choose correct crops and right management to control Nmin content in different soil layers, for preventing N leakage and keeping balance between cropping systems and environment.

Key words: conservation tillage, soil, crop, farming system, rotation, nitrogen mineralization, nitrogen leakage

Abbreviations

N	Nitrogen
Ni	Nitrogen immobilization
Nmin	Mineral nitrogen
Nm	Nitrogen mineralization
GLM	General linear model
NUE	Nitrogen use efficiency
SOM	Soil organic matter

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1. Introduction

Nitrogen (N) is the most appreciable element for health and quality of plants in cropping systems (Camberato, 2001), and which is supplied in greatest amount; at the same time, nitrogen is most limited (Luce *et al*, 2011). In 1998, the N fertilizer providing is about 90-130 Tg N per year (Galloway, 1998) (Tg=10^{12} g), and it must be higher now because the use of N fertilizer is increased in agricultural systems in recent years, especially in developing countries (Ji, 2001). From interviews with some Chinese farmers, data by using N fertilizer increased 8% annually, and the average amount of nitrogen fertilizer per ha was 375 kg N per year (Zhang, 2010). Large amounts of N fertilizer production cause a serious impact on the ecosystem of the world. Vitousek *et al.* (1997) reported that at the global level, the amount of anthropogenic N fixation now goes beyond all of N fixation from natural sources, and greenhouse gases such as N_2O further affect climate change.

As farmers use N fertilizer, they need to assume a cost of 11 SEK per kg N (Delgado, 2002; Andersson, 2012), and the cost does not include the expense of the application process, overuse of N fertilizer is a burden of farmers in economic level (Table 1), and may also cause the economic losses because of lower yields of farming production (Delgado, 2002). In China, farmers' loss nearly 96.7 billion SEK every year, due to the overuse of N (Zhang, 2010).

Nitrogen use efficiency (NUE) is another problem when N overuse occurs. NUE is stated as a way to measure the amount of biomass can be produced per unit of N. It is always used in two systems, which are natural ecosystems (total biomass measured) and agricultural systems (harvested biomass measured) (Dawson *et al*, 2008).Table 1 shows estimated economic losses at 30%, 50% and 70% NUE in different places. It is clear to see that lower NUE leads to higher economic loss, no matter in developing countries or developed countries. As Asia has the biggest farming area (Li *et al*, 2008), therefore it has the highest N supply ($44.9*10^6$ tons) and the most serious economic loss. Reversely, Oceania has the lowest amount of N supply and economic loss. The extent of economic loss in different levels of NUE is nearly same in different regions, almost 46% economic loss produces when NUE is 30%, 34% produces when NUE is 50% and 20% produces when NUE is 70%.

Table1. Nitrogen use (10^6 metric tons) and estimated economic losses in different region at different level of nitrogen use efficiency (*Baligar et al., 2001)*

Region	**N use**	**---Level of Nitrogen Use Efficiency---**		
		30%	50%	70%
	10^6 tons	--------Billions of U.S. dollars-------		
Africa	2.1	1.0	0.7	0.4
North/Central America	12.6	5.8	4.2	2.5
South America	2.4	1.1	0.8	0.5
Asia	44.9	20.7	14.8	8.9
Europe	14.5	6.7	4.8	2.9
Oceania	0.8	0.4	0.3	0.2
World	78.7	36.4	26.0	15.6

1.1. N cycle

Human activities can affect natural N cycle (Figure 1) remarkably by food and energy production. Nowadays, there is more interest than before in the alteration of the N, such as the transformation among different N compounds, moreover the way N is lost to air, water and land which cause environmental and human health problems (Galloway *et al.*, 2008). We have methods and tools to solve pollution in our environment caused by N use, especially for reducing N loss and improving NUE. However, the management which is used for N controlling should be within the context of N cycle, and following the mechanisms of N transition and loss (Delgado,

2002) (Figure 1).

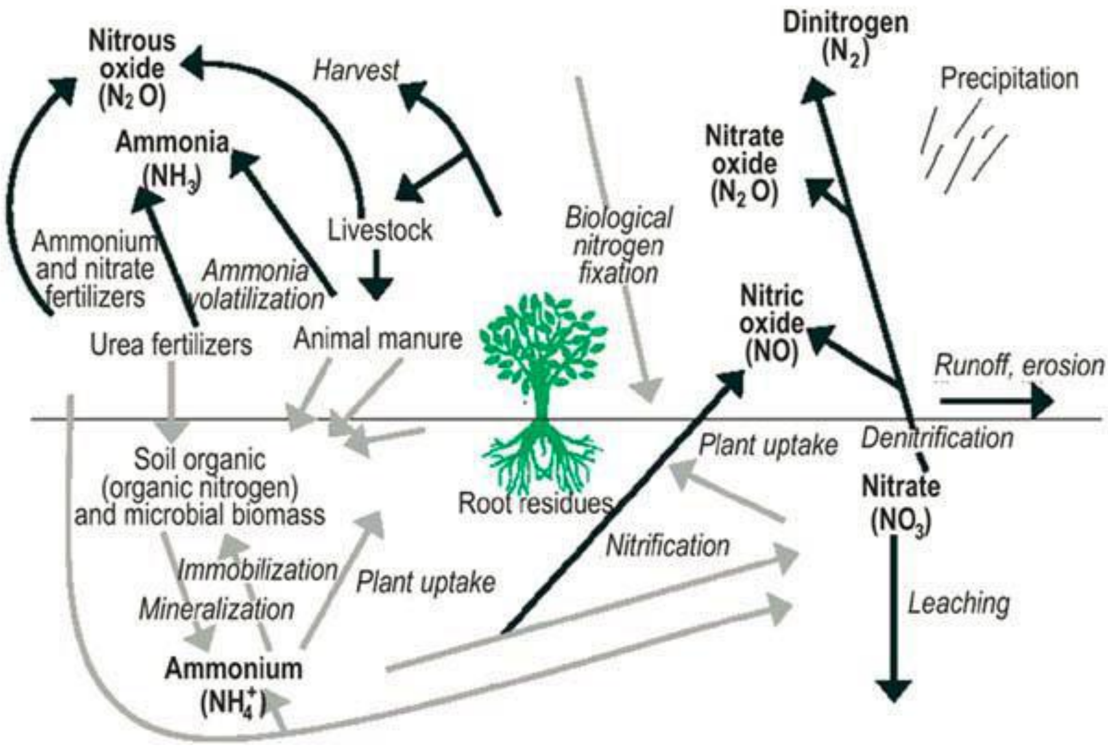

Figure 1. N cycle in terrestrial systems (Resource from lecture by Erik Steen Jensen)

1.2. N loss

Each crop has its own overall demand for N, when the N application rate is higher than the boundary of N uptake, the crops cannot absorb the excess N which is applied continuously (Appel, 1994); and even under the level of the peak of N application, which plants can only accept 50-70% of the supplied N, which is recovered in the aboveground parts (no root system, the N content of root system is generally 10%) (Deenik, 2006 Delgado, 2002).To overuse more N will lead to more serious N loss.

N loss by human activities leads to environmental problems regionally, nationally and globally (Dalgaard *et al.*, 1998). N deposition in terrestrial and aquatic system could cause many sorts of pollutions like acidification, eutrophication, biodiversity transition, and effect on animal systems (Reeves et al. 2002). These sorts of phenomenon are easily found in some countries and the reason to some extent is based on the mistreatment of N application (Swedish Board of Agriculture, 2007).

1.3. N leakage

The condition of N leakage is always happened when soil N cannot be absorbed by crop roots, then the N will be lost with water to deeper soil layer and cause N loss (Wu and Pan, 2008). N leakage is a kind of nutrients leakage. Nutrients leaking from an agricultural system into rivers, lakes and marine areas will cause deteriorating of water quality, eutrophication of underground water and surface water resources (EEA, 2005). N leakage as one channel which is included in nutrient leakage has been focused by many countries (Ulen and Johansson, 2009).

To prevent N leakage happening in farming system more and more serious, many ways are applied to relieve this kind of a bad situation; lower N use is considered as one efficient way of them. Some studies agree that lower N input will reduce the N leakage (e.g. no use of N fertilizer) (Dalgaard *et al.*, 1998). Transition from conventional to organic cropping system has concerned as a feasible way to reduce N-dissipation (Dalgaard *et al.*, 1998). In addition, organic farming system receives more and more attention during recent years and it is used widely in many countries (Aronsson *et al.*, 2007). Nowadays, Some European countries focus on supplying a sufficient amount of N in organic farming system for reducing N leakage (Askegaard *et al.*, 2011). In Sweden and Denmark, N leakage in both organic farming system and conventional farming system has been studied for many years (Dalgaard *et al.*, 1998), and the work is still carrying on.

1.4. N mineralization (Nm) and N immobilization (Ni)

There are many ways to calculate the amount of N leakage in field, and one of them is measuring the difference of mineral N (Nmin), which is regarded Nm in soil during fall, winter and early spring time, because the largest N leakage takes place during this period of time (Askegaard *et al.*, 2011).

Mineralization is a process of conversion of an element from an organic state to an inorganic form by the activities of some microbes (Gilmour, 2011; Agehara and Warncke, 2005). For N, mineralization of organic N is the step to ammonia N: the organic N from soil organic matters (SOM) in soil transfers to ammonium (NH_4^+) (Camberato, 2001). On the other hand, N immobilization (Ni) as a process from ammonium N to organic N (Figure 1) by the activities of microbes in the soil, which is contrary to Nm. Nm and Ni happen in the soil simultaneously; the net Nm is decided by Ni but also relevant with Nm itself. When the net Nm is negative, it means that Ni is stronger than Nm. Mineralization-immobilization turnover (MIT) is a process which has tight relation with the capacity of N supply in the soil to crops and the loss of N to surrounding environment (Lu Cai-Yan and Chen Xin, 2003).

Li *et al* (2008) did a research to understand the recent condition of Nm in conventional farming system in different countries during one year. Due to the data in Table 2, it is easy to find that developed countries have even higher Nm rate than developing countries in conventional farming system. Many factors, especially some parameters in the environmental area, for Nm need to be considered, such as temperature, aeration, SOM, pH, soil moisture, quantity and quality, and the type of soil (Choudhury and Kennedy, 2005; Luce *et al*, 2011; Sierra, 2002; Smith and Sharpley, 1990; Yan *et al*, 2006). From the results which are acquired, Ariharia (2000) reported that the mineralization and N dynamics in cropping system level was important. Ulen and Johansson (2009) even predicted that Nm rates in soils could increase by climate change in future.

Table 2. Comparison among daily and average daily nitrogen mineralization rate per year in conventional farming system in different area (N mg / kg soil and day)

Area	Nitrogen mineralization rate (N mg kg^{-1} d^{-1})	Nitrogen mineralization Average rate (N mg kg^{-1} d^{-1})
Canada		0.75
Denmark	0.30-0.70	0.30
Germany	0.04-0.30	0.17
USA	0.27-0.41	0.34
Greece	0.10-0.65	0.40
China	0.10-1.00	0.21

Resource from Li *et al*, 2008

2. Aim

The aim of this paper is to investigate possibility of effect of the previous crop and N supply on the succeeding crop soil mineral N supply in a conventional cropping system and conservation tillage cropping system, and measure Nmin under permanent differently N supply in the cropping systems in early spring time. Through the result of analysis, the effect of N mineralization by long term permanent N supply, and the relationship between net N mineralization and crop could be evaluated.

2.1. Research questions

1. To investigate the mineral N in two cropping systems which might have an impact on recommended N fertilizing strategy for farmers, and to investigate how long term N supply affect mineral N in soil.

2. Mineral N has also an impact on risk for nitrate leakage from the soil therefore identifies crops and/or cropping system strategies with high risks for leakage.

3. Material and methods

3.1. Cropping system

The investigation was carried out in Scania in southern Sweden (latitude north 55.668, longitude east 13.103) in March and April of 2012 (the shape of the field is shown in Figure 5). It was a long term experiment for conservation tillage with low inputs and maintained high production ability (cropping system B), compared with conventional system (cropping system A) (*Nilsson* and *Christensson*, 2010). The trial started 1993, and in the first twelve years the same rotation model was applied in both cropping systems A and B. The rotation style was winter wheat/triticale (catch crop) – pea/faba bean – winter wheat (catch crop) - sugar beet- spring barley – winter rape seed in six years. The catch crop in cropping system B was rye grass in the first round and oil radish/white mustard in the second round. Cropping system A only had catch crop in the second six years. After the same twice rotation in both cropping systems A and B, the rotation was varied differently respectively (Table 3 shows the rotation styles of cropping system A and B in the last four years).

The two cropping systems were managed with different patterns. Cropping system A was under conventional farming management, with using fertilizers and pesticides, and plowing in autumn by normal tillage. As a comparison with A, B had its own target which was high production without high input. There was no plowing and substituted the smallest level of tillage, and lower inputs of fertilizers and pesticides were utilized as average in cropping system B.

The texture of the soil in both cropping systems is same, which is clay and consist of sand 50%, clay 15 % and organic matter 2-3.5 %.

Table 3. Grown crops 2009, 2010 and 2011, and planned crops 2012 in the cropping system experiment, conventional system (cropping system A) and integrated system with low inputs (cropping system B)

Cropping system/field	2009	2010	2011	2012
A1	Oats	Winter wheat	Spring barley	Winter rape seed
A2	Winter wheat	Sugar beet	Spring oats	Winter wheat
A3	Spring barley	Winter rape seed	Winter wheat	Sugar beet
A4	Winter wheat	Spring barley	Winter rape seed	Winter wheat
A5	Sugar beet	Oats	Winter wheat	Spring barley
A6	Winter rape seed	Winter wheat	Sugar beet	Spring oats
B1	Faba bean	Winter wheat (insown)	Ley	Winter rape seed
B2	Winter wheat(and then catch crop oil radish)	Sugar beet	Faba bean	Winter wheat (insown)
B3	Ley	Winter rape seed	Winter wheat (catch crop oil radish)	Sugar beet
B4	Winter wheat (insown)	Ley	Spring rape seed	Winter wheat
B5	Sugar beet (after oil radish)	Faba bean	Winter wheat (insown)	Ley
B6	Winter rape seed	Winter wheat (and then catch crop oil radish)	Sugar beet (after oil radish)	Faba bean

(Oil radish was sown in September 2011 as catch crop in Field B3, but the growth status of oil radish was not good last year, hence there was little influence for growth of sugar beet)

Within each plot, there is a series of inner plots which are permanent places with N supply (Table 4) and have a replicate in each level (Figure 4) except B1 and B2 (there are no N5 replicates in B1 and B2). Each inner plot is 8 m long and 4 m wide.

Table 4. Nitrogen supply to winter wheat in the permanent place for nitrogen experiment in both cropping system A and cropping system B

N level	Total N supply
N0	0
N1	80
N2	120
N3	160
N4	200
N5	300
Field	175

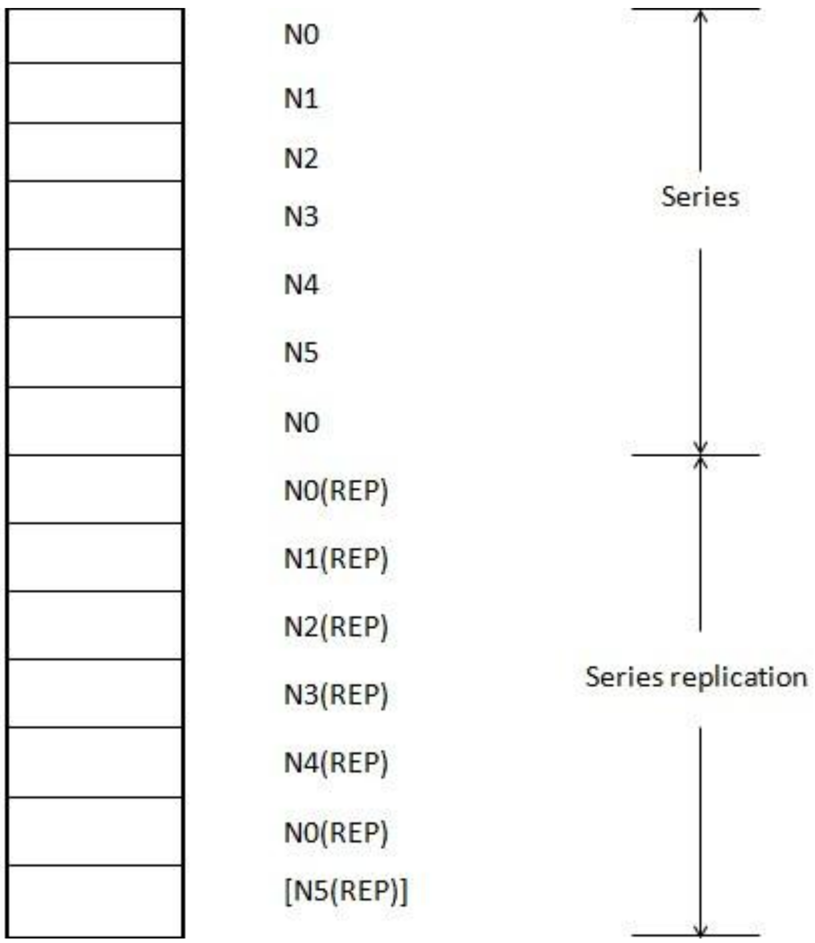

Figure 2. Inner plots with permanent N supply

3.2. Weather data

The weather in winter 2011/2012 was milder than normal winter, but low temperature (below zero) in late January and early February. The soil was not frozen like winter 2010/2011. In December, some places had rain in 80-89mm; the soil was wet at that time. There was not a thick snow cover in south Sweden during January, but only a thin level at the end of the month. There was a temperature reduction in the early February, but mild weather later. The weather was above zero at the end of the month all along (SMHI, 2012). The average temperature was higher than historical record in March 2012. The temperature last ten days in March when soil samples were taking was 10 degree C higher than previous years. And there was not much rain in this month, the soil was not wet. Wind was as normal level, in later March was stronger than early. In general, the weather in March 2012 was milder than the same period in history (AccuWeather, 2012).

3.3. Samples

Soil samples were taken from inner plots of N0, N3, N5, N0 (REP), N3 (REP), N5 (REP), and N field (Figure 4) in plots A2, A3, A4, B2, B3, and B4. The order of taking samples was B4-A4-B3-A3-A2-B2 from 21th of March to 2nd of April in 2012, and the depth of taking samples was divided into three levels: 0-30cm, 30-60cm, 60-90cm. Every sample was taken with six sticks and mixed all soils together in one plastic bag. Twenty-one samples should be taken in each plot [because B2 does not have N5 (REP), hence only eighteen samples were taken from B2]. The samples were kept in a freezer in Alnarp SLU to -18 degree C until delivering to chemical analysis.

All soil samples taken from plots were delivered to EUROFINS accredited laboratory for chemical analysis. The soil samples were extracted by 2M KCl for measuring Nmin. The results were given in mg/100g soil dry matter. With assumption that soil density is the same in all plots the results were converted to kg N ha^{-1} through setting soil volume weight to 1.25kg/dm^3 in layer of 0-0.30m, and to 1.5 kg/dm^3 in 0.30-0.60m and 0.60-0.90m. The converting figures are used by analysis companies when they do analysis from farming fields and experimental trials in Sweden.

Due to all plots were fertilized (except permanent N supply inner plots) before we took samples, so the data of samples from N field were erroneous; therefore, these samples were discarded in statistic analysis.

3.4. Statistic analysis

ANOVA general linear model (GLM) and regression analysis were used in process of statistic analysis by software of Minitab release 16 package. ANOVA GLM was based on Nmin value, ammonium-N (NH_4^+-N) value and nitrate-N (NO_3^-N) value in permanent N supply trials in spring 2012 in three different soil layers of 0-0.30m, 0.30-0.60m, 0.60-0.90m, respectively. There were three N levels involved in both ANOVA GLM and regression analysis, which were N0=0 kg N ha^{-1}, N3=160 kg N ha^{-1}, N5=300 kg N ha^{-1}. The regression analysis was about the content of N min, NH_4^+-N, and NO_3^-N in different soil layers with permanent N fertilizer supply in two cropping systems (A/B). The regression was used to answer what the permanent N supply meant for the found Nmin. Tukey Simultaneous Tests were applied in both methods for pair-wise comparisons of means. Level of significance was $P<0.05$, it would be stated unless it was modified.

4. Results

4.1. Mineral nitrogen in soil in spring influences from crops and cropping systems

Field B2 (Faba bean 2011 before undersown winter wheat 2012) had high Nmin in the 0-0.90m soil layer, on average 73.5 kg N ha^{-1} for all N treatment. Moreover, this field had high NH_4^+-N and NO_3^--N except the 0.30-0.60m layer of NH_4^+-N; especially NO_3^-N in 0.30-0.60m and 0.60-0.90m layers, 16.6 kg N ha^{-1} and 16.8 kg N ha^{-1} were nearly twice than other fields (Table 5). Field B3 (winter wheat 2011 and catch crop before sugar beet 2012) had high NH_4^+-N in both 0-0.30m and 0.30-0.60m soil layers, and this field also had high NO_3^-N in 0-0.30m layer. Field B4 (spring rape seed 2011 before winter wheat 2012) had the lowest NH_4^+-N in 0.30-0.60m layer, which was 2.2 kg ha^{-1}.

Table 5: Content (kg N ha^{-1}) of mineral nitrogen (Nmin), ammonia-nitrogen (NH_4^+) and nitrate-nitrogen (NO_3^-) measured in March 2012 in different soil layers. (N0=0, N3=160, N5=300 kg N ha^{-1})

	Nmin	**NH_4^+**			**NO_3^-**		
	0-0.90m	0-0.30m	0.30-0.60m	0.60-0.90m	0-0.30m	0.30-0.60m	0.60-0.90m
Cropping system/field							
A2	35.8b	3.4b	2.2c	1.7b	12.3bc	8.2b	8.0b
A3	35.1b	4.0b	2.5bc	1.9ab	13.0bc	7.4b	6.4b
A4	31.7b	3.9b	2.5bc	2.0ab	12.1c	6.1b	5.0b
B2	73.5a	8.1a	3.1ab	2.6a	26.4a	16.6a	16.8a
B3	49.5b	6.7a	3.6a	2.4ab	18.9b	10.5ab	7.3b
B4	42.4b	4.7b	2.2c	1.7b	15.7bc	9.7b	8.4b
Nitrogen Supply							
N0	36.4a	4.9a	2.8a	2.0a	13.3a	7.5b	5.9b
N3	44.8a	5.2a	2.5a	2.0a	17.8a	9.3ab	8.0ab

N5	50.9a	5.0a	2.7a	2.1a	17.3a	12.2a	11.5a

In each section, mean values within columns followed by different letters are significantly different (Turkey P<0.05)

Field A2 (spring oats 2011 before winter wheat 2012) had the same lowest NH_4^+-N in 0.30-0.60m soil layer as B4. Field A4 (winter rape seed 2011 before winter wheat 2012) had low N min in 0-0.90m layer and NO_3^-N in 0-0.30m and 0.60-0.90m layers.

4.2. Mineral nitrogen in spring influences from permanent nitrogen supply.

From Table 5, it can be found that there were no significant differences in Nmin and NH_4^+-N in all levels of soil layers due to permanent nitrogen supply. The average Nmin of N0 was 36.4 kg N ha^{-1}, N3 was 44.8 kg N ha^{-1}, and meanwhile N5 was 50.9 kg N ha^{-1}. The average NH_4^+-N was nearly same in three different soil layers. In 0.30-0.60m and 0.60-0.90m soil layers, N0 had low NO_3^-N, and N5 had high NO_3^-N

Table 6 and Table 7 were used to answer what the permanent N supply meant for the found Nmin, NH_4^+-N and NO_3^-N. In cropping system A, Nmin had increased to an extent by supplying higher N in the permanent N trials. For field A4 the regression line for Nmin was 17.1+0.0948N. It means that estimate of Nmin for field A4 if no N permanently was supplied was 17.1 kg N ha^{-1}, and it will rise with 0.0948 kg N ha^{-1} per kg permanent N supply ha^{-1} so if e.g. 100 kg N ha^{-1} is permanently supplied the estimated Nmin will be 26.58 kg N ha^{-1}. In field B2, without N fertilizer supply year 2011, Nmin was estimated to 69.9 kg N ha^{-1} with no N permanent supply and it will increase by 0.0297 kg N ha^{-1} per kg N permanent supply.

In cropping system B, Nmin had same extent situation with system A. In field B2, NH_4^+-N decreased by 0.0041 kg N ha^{-1} with per kg of N permanent supply in 0.30-0.60m soil layer, NO_3^-N increased in 0-0.30m layer but decreased in other two soil layers (0.30-0.60m and 0.60-0.90m) with low R^2 values. In field B4, NH_4^+-N decreased in all three different soil layers with higher N supply annually, but the extent were not very large. In field B4, all three soil layers had NH_4^+-N decrease with per kg of N permanent supply, and R^2 values in layers 0-0.30m and 0.60-0.90m were high.

Table 6: Regression equations between content (kg N ha^{-1}) of mineral nitrogen (N min) and ammonia-nitrogen (NH_4^+) measured in March 2012 in different soil layers and nitrogen supply in the permanent nitrogen trials (N) in the cropping system (A/B) fields (2-4). (N0=0, N3=160, N5=300 kg N ha^{-1})

	Nmin		NH_4^+					
	0-0.90m		0-0.30m		0.30-0.60m		0.60-0.90m	
	Equation	R^2	Equation	R^2	Equation	R^2	Equation	R^2
A2	23.5+0.0806N	0.658	3.67-0.0016N	0.086	2.10+0.0003N	0.026	1.51+0.0015N	0.629
A3	28.7+0.0364N	0.528	3.54+0.0028N	0.262	2.34+0.0008N	0.197	1.83+0.0005N	0.051
A4	17.1+0.0948N	0.890	3.62+0.0018N	0.265	2.08+0.0030N	0.700	1.70+0.0016N	0.249
B2	69.9+0.0297N	0.119	7.09+0.0078N	0.593	3.59-0.0041N	0.591	2.46+0.0014N	0.139
B3	39.8+0.0633N	0.838	5.81+0.0061N	0.439	3.55+0.0005N	0.091	2.12+0.0020N	0.183
B4	37.7+0.0306N	0.469	5.91-0.0079N	0.563	2.47-0.0018N	0.200	2.31-0.0037N	0.701

Table 7: Regression equations between content (kg N ha^{-1}) of nitrate-nitrogen (NO_3^-) measured in March 2012 in different soil layers and nitrogen supply in the permanent nitrogen trials (N) in the cropping system (A/B) fields (2-4). (N0=0, N3=160, N5=300 kg N ha^{-1})

	NO_3^-					
	0-0.30m		0.30-0.60m		0.60-0.90m	
	Equation	R^2	Equation	R^2	Equation	R^2
A2	11.6+0.0046N	0.031	3.88+0.0281N	0.698	0.70+0.0477N	0.827
A3	11.9+0.0061N	0.206	5.89+0.0099N	0.335	3.76+0.0171N	0.950
A4	7.28+0.0315N	0.735	1.48+0.0304N	0.873	0.97+0.0265N	0.798
B2	22.0+0.0355N	0.544	16.7-0.0005N	0.000	18.1-0.0105N	0.122
B3	15.8+0.0203N	0.798	8.16+0.0155N	0.601	4.35+0.0189N	0.811
B4	14.1+0.0102N	0.574	7.18+0.0165N	0.735	5.70+0.0174N	0.513

Overall, cropping system A had lower value of Nmin but quicker increase by permanent N supply than cropping system B. According to Table 6, fields A2, A4 and B3 were influenced by permanent N supply obviously, and R^2 values were high. The influences of these three fields all evidently happened in their parts of NO_3^-N especially in the deep soil layer (Table 7), and R^2 values were all almost high. Some fields had negative increase by permanent N supply, such as NH_4^+-N of A2 (0-0.30m), B2 (0.30-0.60m) and B4 (all three soil layers), and NO_3^-N of B2 (0.30-0.60m and 0.60-0.90m).

5. Discussion

5.1. Comparison

5.1.1. A2 and B2

In field B2, the Nmin had high value (Table 5), which was same as Thorup-Kristensen (1994) argued that the Nmin in soil is higher below legume than other crops. An explanation to that might be legumes can fix N from air by themselves based on the function of nodule bacteria inside (Peoples *et al*, 2004), Nmin could increase by N fixation, and after these bacteria died, the N would release to the soil. In this trial, there was no N fertilizer supply when legumes were planted; it was possible that some parts of N in soil in field B2 was fixed by N fixation with the help of Faba bean. However, Nmin in soil could not only come from N fixation, Jensen *et al* (2010) mentioned that Faba beans' subsequent contribution to the N remainder of cropping system come from other three ways: (1) unused soil Nmin and rhizodeposits N after crop growth, (2) organic residues and nodulated roots after harvesting, (3) animal manures and urine if Faba bean was used as animal feed or its residues were grazed. In this trial, first two ways could have contribution to content of N in B2, so the whole content of N could be made of N fixation and the way (1) and (2). According to the result of high N content soil, the succeeding crop should be high N demanding crops and have long growth period to use N more efficiently.

Some special things happened in layer 0.30-0.60m and 0.60-0.90m in Field B2. Based on the results from Table 6 and Table 7, the average value of NH_4^+-N decreased in layer 0.30-0.60m with higher N supply, which meant weaker Nm or stronger Ni happened in this layer when higher N applied. On the other hand, NO_3^-N had same extent with NH_4^+-N but in both 0.30-0.60m and 0.60-0.90m, but the values were not significant.

Comparing with B2, A2 N content was less than half of B2. The crop in 2011 in field A2 was spring oat and winter wheat in this year. The data showed that A2 NH_4^+-N in all three soil layers was low. In Table 6, a particular regression equation appeared in 0-0.30m soil layer, which showed that lower NH_4^+-N value with higher N supply. This equation meant that the value of NO_3^-N in the same layer ought to be lower as well, and naturally Nm would be weaker. In all three soil layers of Field A2, NO_3^-N was relatively high, which meant Nm was active when spring oat was planted. With increasing depth of soil found NO_3^-N increased more with high permanently N supply. In addition, the intensity of Nm became stronger. Nevertheless, due to low total Nmin, the effect of spring oat was good.

5.1.2. A3 and B3

A3 had medium value of Nmin in cropping system A (Table 5). The extent of decreasing of N content was significantly quick in deeper soil layer. The crop in A3 was winter wheat in 2011, which had long root system. Winter wheat has ability of Nmin uptake down to a depth of 1.5m (Moller and Reents, 2009). Deeper root system helps winter wheat absorb N from deeper soil and decreasing N content in arable land, especially for nitrate leaching (Thorup-Kristensen *et al*, 2009). Hence, the NO_3^-N content in 0.60-0.90m was low, according to this tread it could be predicted the decline of NO_3^-N would keep this falling extent in deeper layer.

B3 had same condition in system B as A3 in system A. It had middle value of Nmin, but compared with A3 the value of NH_4^+-N were high in 0-0.30m and 0.30-0.60m. The same situation happened in A3 as well, but the differences with other fields in system A were not significant. The value of NO_3^-N in 0.60-0.90m soil layer had a similar result as A3 due to growing winter wheat. The crop in 2012 is sugar beet which can absorb N down to 3 m according to Stevanato et al (2010), the phenomenon of NO_3^-N decline in deeper soil layer could be more obvious in autumn 2012 than 2011.

5.1.3. A4 and B4

There was no difference between A4 and B4 in Nmin. It was found in Table 5 that no matter NH_4^+-N or NO_3^-N had low value in all three soil layer. It seemed that spring rape seed and winter rape seed both had positive effect of controlling N content in soil. Comparing with winter rape seed, spring rape seed was better according to the results which were shown in Table 5. The NH_4^+-N in field B4 was lower than A4, which would lead to weaker Nm. The same result could be found in Table 6, the average value of NH_4^+-N had decline extent with higher N supply in all three layers (the result in 0.30-0.60m was not significant).

5.2. Influence of crops

The crops planted in A3 and B3 (winter wheat in 2011 and sugar beet in 2012) were the same; however, they were different in A2 (spring oat in 2011 and winter wheat in 2012), B2 (Faba bean in 2011 and winter wheat in 2012) and A4 (winter rape seed in 2011 and winter wheat in 2012), B4 (spring rape seed in 2011 and winter wheat in 2012) (Table 3).

According to the results which were analyzed by statistic method, the Nmin content in soil in field B2 was high. Before year 2012, the previous crop in B2 was Faba bean. Inversely, A4 had low Nmin content among all fields, and the foregoing crop in that field was winter rape seed (Table 5). The result was as same as the one in 2011 fall, the highest Nmin was measured after Faba bean in system B (45.7 kg N ha^{-1}) and the minimum one after winter rape seed in system A (13.8 kg N ha^{-1}) (Andersson, 2012).

Overall, Faba bean can influence N content of soil in different ways and the effect was apparent (Crews and Peoples, 2005). This was the main reason why field B2 had highest Nmin value. Sugar beet and winter wheat have deep root system to absorb N from deeper soil layer, which can help to solve the problem of nitrite leaching. Spring rape seed and winter rape seed are both good at controlling N content, and spring rape seed is better.

5.3. Influence of cropping systems

The higher Nmin in cropping system B than cropping system A was easily observed from analysis result. This is an advantage when reducing input of nitrogen fertilizer, but system B faces to stronger N leakage risk and Nm, and has to be controlled more carefully (Askegaard *et al*, 2011). The reason to high N content in cropping system B was some management practices like, legumes and catch crops were used. Because the samples were taken from plots under permanent N supply trial, the higher N content in cropping system B soil proved that less N should be fertilized cropping system B, or the N content could be excessive. Pimentel et al (2005) reported that organic farming system could reduce agrochemical input to improve environment and farm economics. Although the cropping system B in experiment was not totally organic (lower chemical input than cropping system A), it still showed similar results to support Pimentel's perspective.

5.4. Influence of permanent N supply level

Previous studies had elucidated more N addition would lead to more Nm (Ma *et al*, 2011; Logah *et al*, 2011), and the same results could be seen in this experiment, the Nmin increased by higher N supply, but the differences were not significant. The NH_4^+-N in three N supply levels was same, but higher N supply led to higher NO_3^-N, which was particularly significant in deeper soil layer. An explain for the result was due to diverse kinds of crop utilization. N application of different crops should be combined with crop demand, soil condition and weather change, more or less N supply would lead to serious N leaching or malnutrition of crops (Appel, 1994).

5.5. The meaning of this trial to farmers

According to the results, it is discovered that the effect of previous crops to succeeding crops is important. When farmers do rotation or grow catch crops, they need to understand the influences of different crops. Some farmers in developing countries have question of how to choose crops in organic cropping system to reduce N supply. For instance in China, farmers are always restricted by some existed models of rotation in crop production (e.g. wheat-maize), but no idea to create new styles (Peng *et al*, 2005). Application of crops and cropping systems should be appropriate. In this long term experiment, there are many different crops that are used in cropping systems, and those had shown some different effects of controlling N. Legumes' effect in this experiment is perceptible. After using legumes, some high N-demanding crops are suitable for next year in the same field. On the other hand, the root system is also important for N leakage occurrence. Different length of roots can absorb N in different soil layer, and if farmers want to control the N leakage in deeper soil layer, they should grow some crops or catch crops which have deeper root systems like winter wheat; however, the root depth is also decided by crop duration, soil type and other conditions (Kirkegaard and Lilley, 2007).

How to manage cropping system is a barrier for some farmers. According the interviews with some Chinese farmers, over 60% of them have no idea of choosing different management model but an immovable model (Ji, 2001). In addition to correct crops and cropping systems, proper management is a key factor in controlling Nmin. The example in this trial was after growing Faba bean in Field B2, the N content in soil was quite high, so that after Faba bean there should be kind of careful management for preventing N leaching, and tried to grow high N-demanding crop in next round of rotation, or using catch crop to reduce N content in soil.

When Nmin is high in soil, it is no doubt NH_4^+-N and NO_3^-N are high in the same level and then there is a risk to N leakage. This experiment showed the N dynamic in different soil layer under permanent N supply in two cropping systems, and revealed the extent of Nm with different crops rotation styles. The result of the experiment has practical significance for helping farmers find out a proper solution if their field has the same condition as this experiment, and then control the N content to improve NUE and reduce N leakage to keep balance between their field and environment nearby.

5.6. Mineral N causes N leakage

Controlling Nmin is important in cropping systems. When there is no need for N, less Nmin means less N leakage happens in cropping system. Trying to find efficient ways of N use to control Nmin and N leakage is a global challenge (Cassman *et al*, 2002), and it is a target of this experiment and some other previous studies as well.

5.7. Socio-economic issue

The trial can help farmers increase knowledge and awareness in order to change their traditional behavior of cropping system management. In Sweden, there is a programme for reducing N leakage to the environment which is called Greppa Näringen, and in this programme farmers have averagely decreased N use by 800 tonnes per year after improving their management such as using catch crops (Greppa Näringen, 2012). Due to the lost of N fertilizer is almost 11 SEK per kg N for Swedish farmers (Von Blottnitz *et al.*, 2006); they can save 8800000 SEK per year. The programme of Greppa Näringen is also made for animal farms. Yearly, dairy farm can reduce 9.4 kg N ha^{-1}, and pig farm can reduce 13.8 kg N ha^{-1} (Greppa Näringen, 2012), which can save 103.4 SEK and 151.8 SEK per ha respectively.

Catch crops can make it possible to reduce input of N fertilizers to succeeding crop. For instance, in legume-barley system, the absorption of barley can vary from 13 to 66 kg N ha^{-1}; of course the effect of absorption is also decided by factors of soil condition and weather (Thorup-Kristensen, 1994). If this figure was available for China and if this legume-barley system was used in China, farmers could save 53 kg N ha^{-1} and 583 SEK per ha with this system. The cultivation of catch crop after crop harvesting in autumn can reduce N leakage in winter time and early spring, the amount of N leakage could be up to 200 kg per ha (Landman, 1990). It depends on how much N left in the soil, but the effect could be good for when regional NUE is low. In that case, farmers can save 2200 SEK per ha per year by using catch crop. The cost for establish catch crop has to be taken in a consideration.

The crop which was planted in this trial also has economic benefit for farmers, like legumes. Tauer (1989) showed that legume could have economic benefit of 17017 million SEK by decreasing 1.547 million tons N fertilizer around world，which included expense in process of N application. There was not a relevant calculation in developing countries, but it should have comparable benefit in most developing countries (Hardarson, 1993). The Faba bean which was used in the experiment is a main food in some African countries like Egypt and Sudan (Saxena and Stewart, 1983). If the cropping system could be used in those countries, farmers would get economic benefit from not only reduction of investment in farming but also food supply.

Based on the discoveries that were found in this experiment, fertilizer saving was a main way to create economical benefits of farmers. No matter farmers use program Greppa Näringen, Catch crop, or legumes, they all can save the input of N so that reduce the investment of fertilizers. The effect would be more conspicuous in developing countries and the countries which have large area of organic arable lands.

6. Conclusion

Legumes (Faba bean) can increase N content in soil available for the subsequent crop; thus it should be coordinated with high N-demanding crops in rotation cropping systems. In addition, conservation tillage cropping system had high Nmin under permanent N supply. It means that the need of N is not strong, excessive Nmin has to managed very carefully to avert N leakage taking place. The whole experiment has been carried on for 19 years, and will continue in future. This study only includes data and information in spring for one year. More researches are needed to get more reliable results and more analysis. Moreover, different farmers should use suitable crops and cropping systems follow their special geographical and weather condition.

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8. Appendix

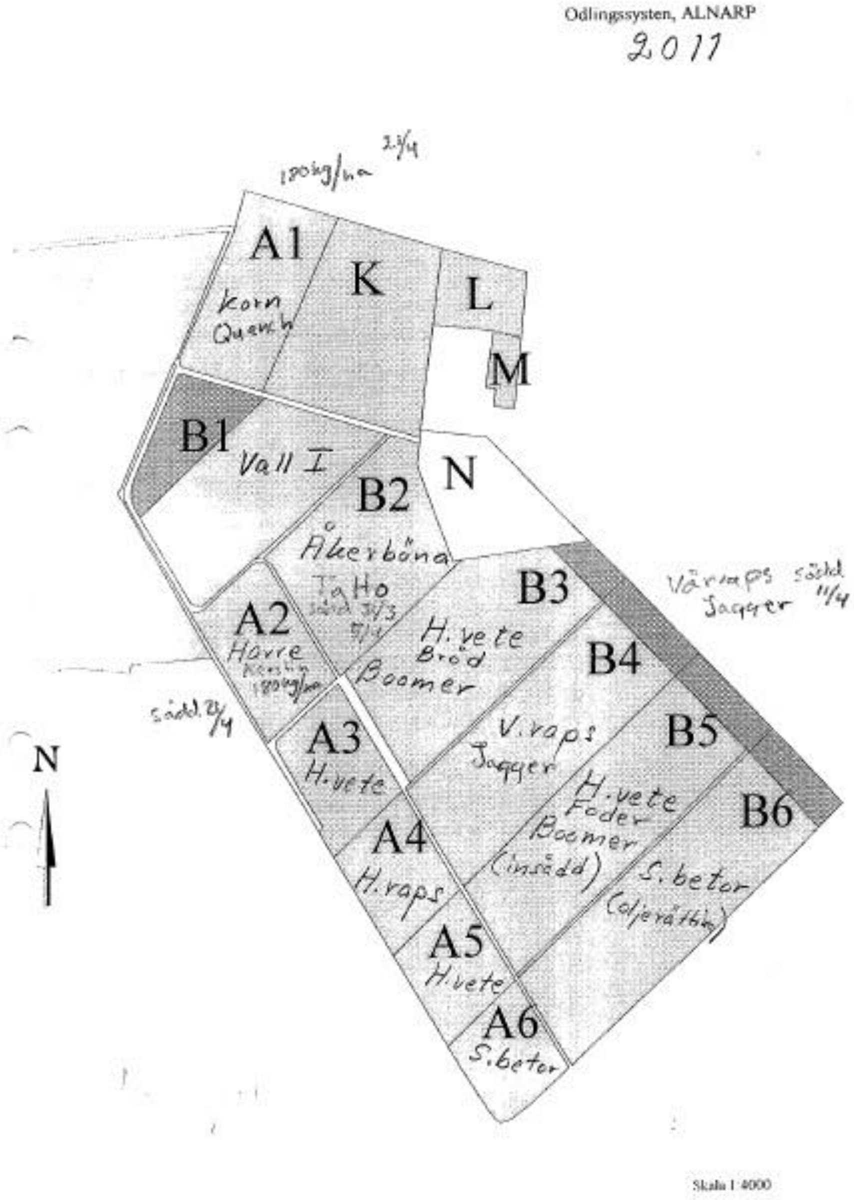

Figure 3. Plots of experimental field (the same field was used this year) (the varieties of crops in each field refer to Table 3)

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