University of
Natural Resources and
Life Sciences, Vienna

Department for
Sustainable Agriculture Systems

Division of Organic Farming

Effects of Pre-crop and Manure Application on Potato Production in a Field Experiment

A Dissertation submitted in the partial fulfillment of the requirement for the Award of Doktor der Bodenkultur (Dr. nat. techn.)

By

TSOLMON NYAMDAVAA

Supervised by:

Ao. Univ. Prof. Dipl. Ing. Dr. Juergen K. Friedel

April 2016

Acknowledgments

I would like to express my gratitude to Ao.Univ.Prof. Dipl.-Ing. Dr. Jürgen Kurt Friedel, my supervisor, for giving me the opportunity to work with him on this project, his support, time and confidence, and for allowing me develop my ideas about soil organic amendments, soil water and nitrogen availability, nitrogen use efficiency on potato by green and farmyard manure applications and biological farming. My appreciation is also extended to Univ. Prof. Dipl.-Ing. Dr.Hans-Peter Kaul and to Univ. Prof. Dipl.-Ing. Dr. Bernard Freyer, my committee members, for their support, useful comments and suggestions. My gratitude goes to Mr. Christoph Gabler, Mrs. Dana Fritzsche former field technicians and Mrs. Sylvia Zeidler laboratory technician of Division of Organic Farming, their excellent assistance helped me get this study successfully done. I thank the staff at the experimental station, of University of Natural Resources and Life Sciences (BOKU), Vienna in Gross-Enzersdorf, lower Austria, especially Dipl.-Ing. Karl Refenner, it would have been too hard to do this work without their opportune aid.

I am so grateful again to Dr. Jürgen K Friedel, for all the time devoted to support me with the statistical analysis of my research data and on my dissertation. His kindness and patience were so valuable to get this study done.

I acknowledge the faculty, students, and staff in the Division of Organic Farming Department for allowing me to be here. For sure these years sharing classrooms, seminars, and informal talks will be significant in my professional life. I would like thank my parents, brothers and sisters for their support from a distance.

With a deep sense of appreciation and gratitude, I thank to Crop science Institute, Agro-biological Department and Foreign Affairs Department of Mongolian State University of Agriculture, for providing me the possibility to pursue doctoral studies at BOKU University, Vienna.

Finally, I want to say many thanks to Jargalsaikhan Dorjsuren my husband and to Delger Jargalsaikhan and Ulzii Jargalsaikhan my children, it would not have been possible for me to complete my studies without their unconditional support and love.

Abstract

The effect of different preceding crops on the agronomic performance of potato was investigated in an organic farming system in eastern Austria. Factorial field trials were carried out on an experimental station of the University of Natural Resources and Life Sciences, Vienna, at Gross-Enzersdorf in three growing years (2009 - 2011) in order to examine the impact of preceding crops, catch crops and manure application on (i) subsequent potato yield and quality, (ii) soil water and inorganic nitrogen availability and (iii) the nitrogen use efficiency under organic management. Treatments included three different preceding crops viz. lucerne, field pea and spring barley, two treatments with / without catch crops as green manure and two treatments with / without farmyard manure application. A factorial experiment was laid out as randomized complete block design in split-split plot arrangement with four replications twice in two consecutive years. Main plots were three different preceding crops for potato, sub plots were with or without catch crop after preceding crop including non-legume oil radish + phacelia for lucerne and field pea and including oil radish + common vetch + field pea for spring barley. The sub-sub plots were without and with farmyard manure at 30 tones ha^{-1}.
The overall tuber yields (fresh, marketable and dry matter) and tuber starch content of main crop potato remained significantly (P < 0.01) less in 2010 than in 2011. The subsequent potato crop response to preceding crop was negligible, there was no indication of a greater tuber yields after legume pre-crops compared to barley. Considering the average values of two years, standard medium (Ø 35 - 65 mm) and large (Ø > 65 mm) sized tubers at harvest were positively affected by catch crops. Catch crops and manure both slightly increased tuber dry matter yield from 4.9 tones ha^{-1} to 5.2 tones ha^{-1} in 2010 only. On the contrary, tuber dry matter yield was not affected by catch crop and manure in 2011. The percentage of small sized tubers (<35 mm in diameter) was measurably increased in 2011 (25.6 %) compared with 2010 (4.7 %). The catch crops as green manures significantly (P < 0.01) increased the percentage of a large sized tuber (> 65 mm in diameter). Tubers contained very few internal defects in both years. Generally, tuber quality was well recorded in 2010 than in 2011, the percentage of tubers with potato virus Y, common scab, malformation, growth cracks and greening was reduced in 2010.

However, the percentage of growth cracked tubers was significantly (P < 0.01) increased in the plots with manure. A significant interaction (P < 0.01) effect was found between year and catch crop for fresh and dry matter tuber yield and for non-marketable small sized tubers. Tuber yields under organic management were equal whether leguminous or cereal preceding crops were used on this site with a highly fertile chernozem soil. Potato tuber yield showed no significant differences due to either catch crops or manure fertilization, where soil water content and inorganic nitrogen availability in rooting zone were similar in all treatments. Soil inorganic nitrogen (NO_3^--N + NH_4^+-N) contents in 0 – 30 cm soil depth at pre-planting (in March) and during growing period (vegetative growth stage of main crop potato in June) were highly variable among years. Catch crops had a significant effect on soil mineral nitrogen availability for different soil layers (up to 90 cm) at the early growing season (in March) of the following year. Furthermore, there were significant (P < 0.01) differences between the levels of soil inorganic nitrogen contents in treatments with and without catch crop or with and without manure application in 60 – 90 cm soil profile. Nitrate nitrogen content tended to decline with increasing soil depth in the profile for plots with catch crops. The differences among nitrate N contents were dependent on N mineralization from additional organic matter by catch crops in upper soil layer and on nitrate leaching to deeper soil layers. Potato tuber nitrate N accumulation showed no significant differences due to either catch crops or manure fertilization. Apparent N recoveries in this study were 1.6 % and 17.3 % in manure applied and catch crops incorporated plots, respectively. In 2010, nitrogen use efficiency (NUE), as expressed as dry matter yield per kg supplied N by catch crop and manure, was significantly lower than bare fallow or un-manured treatments, respectively following spring barley. In contrast, NUE by manure applied N was significantly higher than un-manured plots following spring barley in 2011. Significant three fold interaction effect (P < 0.01) in nitrogen use efficiency of catch crop was observed between years, preceding crop and manure also the same interaction effect between year, preceding crop and catch crop in manured potato crop. NUE in applied manure plot was very similar for with (1.0 kg DM (kg N)$^{-1}$) and without (1.5 kg DM (kg N)$^{-1}$) catch crop treatments. This work stresses that the use of green and farmyard manures

approved for organic farming must first be carefully considered by potato farmers, with reference to price and their fertilization strategies according to the soil type.

Key words: Preceding crop, catch crop, organic manuring, soil nitrogen availability, potato production, nitrogen use efficiency.

Abstract (in German) / Zusammenfassung

Der Einfluss von unterschiedlichen Behandlungen auf eine Kartoffelkultur wurde auf einem biologisch bewirtschafteten Marktfruchtbetrieb am Versuchsstandort Groß-Enzersdorf in Ostösterreich im Zeitraum von 2009 bis 2011untersucht. Im Rahmen der Studie wurden drei verschiedene Vorfrüchte (Luzerne, Futtererbse, Sommergerste) in Kombination mit zwei Zwischenfruchtvarianten (Schwarzbrache, Gründüngung mit Nicht-Leguminosen oder Gemenge) und Mistausbringung (mit oder ohne), hinsichtlich (i) Bodenwasser- und Mineralstickstoffverfügbarkeit (ii) Kartoffel-Ertrag und Qualität und (iii) Stickstoffnutzungseffizienz untersucht. Das faktorielle Experiment wurde als randomisierter, vollständiger Blockversuch in Split-Split-Plot-Anordnung mit vier Wiederholungen in zwei aufeinander folgenden Jahren (2009, 2010) angelegt. Im jeweils ersten Jahr wurden Luzerne, Futtererbse und Sommergerste angebaut. Nach der Ernte folgte auf einer Hälfte der Parzellen Schwarzbrache, auf der anderen eine Zwischenfruchtmischung ohne Leguminosen bzw. mit Leguminosen nach Sommergerste. Auf Teilparzellen jeder Zwischenfruchtvariante wurden Düngervarianten mit oder ohne Mistdüngung (30 Mg ha^{-1}) angelegt. Im Folgejahr wurden auf allen Parzellen Kartoffeln angebaut.

Der gesamte Kartoffelertrag (Frisch- und Trockmasse, marktfähig) und der Knollenstärkegehalt waren im Jahr 2010 signifikant geringer als in 2011. Es gab keinen größeren Knollenertrag nach Leguminosen als Vorfrüchte im Vergleich zu Gerste. Günstig wirkten sich die Zwischenfrüchte und Mistdüngung auf den Ertrag nur im Jahr 2010 aus, als die Mineralstickstoffverfügbarkeit geringer war. Im Jahr 2011 konnte jedoch kein Einfluss von Vorfrucht und Düngung auf die Kartoffel festgestellt werden. Der Anteil der kleinen Knollen (< 35 mm Durchmesser) war im Jahr 2011 (25,6%) deutlich höher als im Jahr 2010 (4,7%). Die Gründüngung erhöhte signifikant ($P < 0,01$) den Prozentsatz großformatiger Knollen (> 65 mm Durchmesser). Für den Knollenertrag und kleine Knollengrößen wurde eine signifikante ($P < 0,01$) Wechselwirkung zwischen Jahr und Zwischenfrucht festgestellt. Die Knollen zeigten in beiden Jahren nur sehr wenige innere Schäden. Die Knollenqualität war in der Regel höher im Jahr 2010 als im Jahr 2011, da in diesem Jahr der Anteil der Knollen mit Kartoffel-Y-Virus, Schorf, Missbildung,

das Wachstum von Rissen und der Anteil grüner Knollen geringer war. Der Anteil der während dem Wachstum geplatzter Knollen war signifikant (P < 0,01) höher durch Mistdüngung. Eine signifikante Wechselwirkung (P < 0,01) wurde zwischen Jahr und Zwischenfrucht für Frisch- und Trockengewicht der Knollen und für nicht marktfähige, kleiner Knollen gefunden. Es konnte kein Unterschied im Kartoffelertrag durch die verschiedenen Zwischenfrüchte bei organischer Bewirtschaftung auf diesem Standort mit einem fruchtbaren Tschernosem festgestellt werden. Das Kartoffelfrischgewicht zeigte keine signifikante Beeinflussung durch Zwischenfrüchte oder Mistdüngung. Der Bodenwassergehalt und die anorganische Stickstoffverfügbarkeit in der Wurzelzone waren bei allen Behandlungen ähnlich. Der anorganische Stickstoffgehalt (NO_3^--N + NH_4^+-N) in der Bodentiefe von 0 – 30 cm wurde im März vor der Aussaat und während der Wachstumsperiode im Juni gemessen und war zwischen den Jahren sehr variabel. Zwischenfrüchte hatten einen signifikanten Einfluss auf die Bodenmineralstickstoffverfügbarkeit für verschiedene Bodenschichten (bis zu 90 cm) in der frühen Vegetationsperiode (März) des darauffolgenden Jahres. Der Nitratstickstoffgehalt nahm tendenziell mit zunehmender Bodentiefe im Profil für Parzellen mit Zwischenfrüchten ab.

Die unterschiedlichen N-Gehalte wurden durch die Mineralisierung der Zwischenfrüchte im Oberboden und durch Nitratauswaschung in tieferen Bodenschichten verursacht. Die Zwischenfrüchte und die Stallmistdüngung hatten keinen Einfluss auf den Stickstoffgehalt der Kartoffeln. Die Stickstoffnutzungseffizienz für die Nachfrucht betrug im Durchschnitt der zwei Anbaujahre für 1.6 % für die Mistdüngung und 17.3 % für die Zwischenfrüchte. Die Stickstoffnutzungseffizienz (NUE), ausgedrückt als Trockenmasseertrag pro kg N aus Zwischenfrüchten und Stallmist in der folgende Sommergerste im Jahr 2010 war signifikant niedriger bei Schwarzbrache oder ungedüngten Behandlungen. Im Gegensatz dazu war die NUE von Stallmist signifikant höher als ungedüngten Behandlungen in der folgenden Sommergerste im Jahr 2011. Signifikante dreifache Wechselwirkungen zwischen Jahr, Vorfrucht und Mistdüngung und zwischen Jahr, Vorfrucht und Zwischenfrucht (P < 0,01) in der Stickstoffnutzungseffizienz von Zwischenfrüchten wurden in gedüngten Kartoffelvarianten beobachtet. Die NUE in gedüngten Parzellen war sehr ähnlich mit (1,0 kg DM (kg N)$^{-1}$) und ohne (1,5 kg DM (kg N)$^{-1}$) Zwischenfrüchte. Diese Arbeit unterstreicht, dass die Verwendung von Gründüngung und Mistdüngung im ökologischen Kartoffelanbau von LandwirtInnen sorgfältig abgewogen werden sollte was den Preis und Düngungsstrategien in Abhängigkeit vom Bodentyp angeht.

Schlüsselwörter: Vorfrucht, Zwischenfrucht, organische Düngung, Bodenstickstoffverfügbarkeit, Kartoffelproduktion, Stickstoffnutzungseffizienz.

Table of content

List of tables

List of Figures

Abbreviations

ANOVA	Analysis of variance
BNF	Biological Nitrogen Fixation
C	Carbon
CC	Catch Crop
CS	Common Scab
DAP	Days After Planting
DM	Dry Matter
FM	Fresh Matter
FP	Field pea
FTY	Fresh tuber yield
FW	Fresh weight
L	Lucerne
Leg	Legume
M	Farmyard manure
MTY	Marketable Yield
N	Nitrogen
Nmin	Mineral Nitrogen
NUE	Nitrogen Use Efficiency
OF	Organic Farming
PC	Preceding Crop
PVY	Potato Virus Y
SB	Spring Barley
TTY	Total Tuber Yield
REP	Replication (block)
SDMY	Shoot Dry Matter Yield
WC	Water Content

Chapter 1: Introduction

The potato (*Solanum tuberosum L.*) is one of the staple foods of modern Western Civilization and has a rising role in developing countries. It ranks fourth in the world in term of production with 364.8 million tones annually and is eaten by millions of people in Asia, Africa and the Americas (FAOSTAT, 2014). The world potato sector is undergoing major changes. Until the early 1990s, most potatoes were grown and consumed in Europe, North America and countries of the former Soviet Union. Since then, there has been a dramatic increase in potato production and demand in Asia, Africa and Latin America, where output rose from less than 30 million tons in the early 1960s to more than 368.1 million tons in 2013 (FAOSTAT, 2014), now it's grown in more than 125 countries around the world. Potato can be highly productive, but it has a relatively shallow root system and often requires substantial nutrient input to maintain tuber productivity and quality, Therefore, nutrient management of potato crop is extremely important (Alva et al., 2011). Crop yield, soil nutrient content and agricultural environmental effects are all influenced by fertilizer use (Olesen et al., 2009); soil fertility is especially affected by soil organic matter, which depends on biomass input to compensate mineralization. Nowadays, scientists are faced with many changes in the external environment including the privatization of agricultural research in some countries, increasing globalization, and the rising importance of intellectual property rights, food safety, and environmental quality (Walker et al., 1999). During this time the negative influence of agriculture on the environment was receiving greater attention. Over the last few decades, the world has witnessed a rapid development of the organic agriculture segment (Rodrigues et al., 2006), including many European countries. The role of preceding crop, catch crop and manure can be very important in organic potato farming since synthetic mineral fertilizers are not permitted (Pietsch et al., 2007). Higher biomass return to the soil can increase soil organic carbon and soil total nitrogen (Talgre et al., 2012). Olesen et al. (2009) reported that in organic arable farming, availability of manures is insufficient and this necessitates the use of other sources of nitrogen for full fertilization.

1.1 Background

More than 16 percent of Austria's farmers are already practicing organic farming and 20 percent of the utilized agricultural areas are managed according to the principles of organic farming. Organic farming is the main driver for agricultural "greening" in Austria. European Union regulations for organic farming limit not only the use of synthetic pesticides but also the application of most chemical fertilizers (European Commission, 1991). Organic farmers do not apply highly soluble artificial fertilizers, but rather use organic fertilizers instead, such as dung, muck, animal slurry, or compost. Arable farms without livestock are particularly dependent on the cultivation of legumes in crop rotation (Tischler and Rech, 2009). Nevertheless, there is an increasing demand for organic products by consumers, who are increasingly concerned about food quality and safety (Lampkin, 1998).

The main nitrogen sources in most organic farming systems are biological N_2 fixation, crop residues and composts, in addition to the soil nitrogen (N) reserve. N availability in organic farming systems integrating forage and amendments becomes very complicated (Liu et al., 2011). The yields in organic farming are restricted by higher proliferation of weeds and diseases, and are dependent on the availability of N mineralized from organic manure and plant debris. The adoption of adequate rotations and management practices, such as weed control, crop residue treatment, use of catch crops, or an appropriate timing and amount of manure application determine the degree to which yields and nutrient losses are affected (Thorup-Kristensen. et al., 2003, Olesen et al., 2009).

1.1.1. Water management and root distribution

Potatoes are a shallow-rooted crop; 90% of the roots grow in the top 30 to 45 centimeters of the soil depth. Potato may be particularly sensitive to weather-related variation in part because it has shallower root system than other crops (Opena and Porter, 1999). Availability of soil water is a major factor that determines yield and quality of the potato crop. Regular or insufficient rainfall can be a serious limitation to potato production, causing low yield. In most cases, a great deal can be done to improve the efficiency of rainwater use. Conservation Agriculture is one way of improving soil moisture management. Cover crops help control erosion, prevent nutrient leaching, fix nitrogen, improve soil conditions, and protect seedling, but also use water, thus affecting soil water relationships for the next crop. Effects are positive when cover crops are managed to improve infiltration and decrease evaporation, or to remove water from a wet soil to allow timely establishment of the next crop. Effects are negative when they limit water to next crop or aggravate a wet soil condition (Paul and Vigil, 1998).

1.1.2. Nitrogen and nutrients

Nitrogen is in most cases the plant nutrient that has the largest influence on crop dry matter production. As a consequence it has been suggested that organically cultivated potato crops may be at risk of nitrogen stress and that this may have detrimental effects on tuber yield formation (Vos, 1995). Again, nitrogen stress and the occurrence of late blight, caused by *Phytophthora* infections, are the two factors generally stated to be most limiting to tuber yield in organic potato cropping (Van Delden, 2001, Finckh et al., 2006);. The use of catch crops in crop production is an attempt to reduce nitrate leaching and to improve the nitrogen nutrition of subsequent crops. Yield response is mainly dependent on the rate at which N is released from preceding crops (Köpke, 1995), but nitrogen mineralization from organic residues may be difficult to synchronize with crop demand (Pang and Letey, 2000). Low N supply will not only result in lower yield but will also reduce tuber size due to reduced leaf area and early defoliation. Tuber yield response is mainly dependent on the rate at which nitrogen is released from organic amendments (Köpke, 1995, Van Delden, 2001) such as animal manures or green manure crops (Neuhoff and Köpke, 2002). On the other hand, excess N leads to dry matter yield in other parts of the plant than the tubers (Goffart et al., 2008). The productivity of arable crops in organic farming is restricted by the supply of nitrogen. Biological N_2 fixation is one of the primary sources of nitrogen in organic farming (Finckh et al., 2006, Vos, 1995). According to van Delden (2001), the mineralization of nutrients from organic fertilizers depends on temperature, moisture and structure of the soil. It is relatively slow in spring and over the growing season it is not sufficient to support crop growth for more than 100 days. Nitrogen nutrition in organic potato cropping can be accomplished either by cultivating potatoes following preceding crops providing relatively high amounts of nitrogen such as legumes (Finckh et al., 2006, Haase et al., 2007b) or by application of organic nitrogen sources (Haase et al., 2007a) as long as they are in accordance with European Union (EU) regulation 2092/91 (European Commission, 1991). Legumes such as lucerne (*Medicago sativa* L.) and pea (*Pisium Sativum L*) have received considerable attention as an important component of organic cropping systems especially in semi-humid and semi-arid conditions because they can supply biologically fixed N to subsequent crops. Total nitrogen contents of legume crops grown in potato rotations can be as high as 240 kg N ha $^{-1}$ (Griffin and Hestermann, 1991), most of which is released during the first year after incorporation. It is important to match nitrogen mineralization patterns with potato nitrogen uptake patterns to optimize the effectiveness of nitrogen released from legume residues. Managing nitrogen inputs to achieve a balance between profitable crop production and environmentally tolerable levels of nitrate nitrogen in water supplies are every grower's goal. The behavior of nitrogen in the soil system is complex, yet an understanding of these basic processes is essential for a more efficient nitrogen management program. A central principle of organic systems is a commitment to regional recycling of nutrients, however, and given the benefits of organic amendments to soil physical, chemical and biological properties, the use of such materials can be considered consistent with the overall objectives of production system ‘redesign’ espoused within certified organic industry standards, as noted elsewhere (Gallandt et al., 1998). The ability of the potato plant to utilize available nutrients and moisture can be hampered by sub-optimal internal plant condition (e.g., presence of disease or insect infestation) leading to reduced photosynthesis, and ultimately reduced yield. Soil nutrients are intensively managed by commercial growers during the entire potato production cycle. The potato plant needs a high level of nitrogen (N) for a fast cycle and high plant growth rate. A higher N availability has a positive effect on stem and leaf growth and intercepted radiation which usually leads to high tuber yield and N accumulation. Giller (2004) noticed that as nitrogen is often the most limiting nutrient for crop yield in many regions of the world, N is decisive for the nutritive value of plant products and plays a key role in the environmental input of agricultural production. Potato cropping regions have been suspected of adding excess nitrate to surface and underground waters in Germany (Honisch et al., 2002) and Canada (Millburn et al., 1990). Organic farming has to be self-sufficient in nitrogen because the use of mineral nitrogen fertilizers is excluded. The main source of nitrogen in organic farming is biological nitrogen fixation, the result of a symbiosis between legumes and nodulating bacteria. lucerne (*Medicago sativa* L.) is the most efficient legume under the semi-humid conditions in Eastern Austria (Freyer et al., 2006). As a result, it is necessary to obtain information from the trial fields in order to estimate soil inorganic N contents under different nitrogen sources such as legume and non-legume preceding and catch crops and farmyard manure application. Therefore, nitrogen management in organic farming systems is very complex. After the harvest of grain legumes, such as field pea (*Pisum sativum* L.), the soil profile may contain more inorganic N, and more organic N may be left in plant residues than after cereals (Lupwayi and Soon, 2009, Hauggaard-Nielsen et al., 2009a, Jensen, 1996). Likewise in conventional potato cultivation, the main factor limiting yield in organic potato cropping is nitrogen (N) ((Vos, 1995, Finckh et al., 2006).

1.1.3. Crop rotation and catch crops

The crop rotation plays a crucial role in organic crop nutrition. Potato (*Solanum tuberosum* L.) rotations often require organic amendments to maintain or improve soil organic matter levels and soil physical properties (Carter et al., 2004). Organic potato production is typically characterized by extended rotations involving leguminous crop green manures sometimes combined with organic amendments. As for nutrient supply and weed control catch crops in organic farming are very important (Müller and Thorup-Kristensen, 2001). Legumes have received considerable attention as an important component of organic cropping systems because they can supply biologically fixed N_2 to subsequent crops. The potential benefits of growing legumes prior to potatoes include (1) contributions of biologically fixed N_2 to the cropping system, (2) improved yield and quality, (3) improved soil physical properties, (4) suppression of soil-borne potato diseases, and (5) N contributions to subsequent crops (Griffin and Hestermann, 1991). There is little information on the impact of preceding crops on crop development and potato tuber yield in organic farming (OF) systems (Finckh et al., 2006).

The use of catch crops in crop production is an attempt to reduce nitrate leaching and to improve the nitrogen nutrition of subsequent crops. Vos (2009) emphasized that organic manures have regained an important position in crop nutrition. The use of such sources and the environmental issues have triggered many questions on rates of transformation and transport processes involving N in the soil–plant–atmosphere system. The nitrogen released from green manures can be used by succeeding crops (potato in the experiment) throughout their growing period. The ability of catch crops to absorb nitrogen from the soil profile is affected by rate and depth of rooting. With green manure, large amounts of N are applied into soil, but nutrients are released from green manure at a slower rate; also, N from N-fixing bacteria becomes accessible over a long time span. These processes grant steady sources of N for succeeding crops (Freyer, 2003).

Crop management in organic crop rotations must also focus on the prevention of such problems as diseases, pests and weeds. Such problems decrease in the crop rotation enriched with catch crop. There are a lot of soil pathogens that impact potato yield and quality, but the incorporation of green manure cover crops preceding a potato crop can control the pathogens and result in increased tuber yield and quality (Davis et al., 2010). As for nutrient supply and weed control catch crops in organic farming are very important (Müller and Thorup-Kristensen, 2001). Catch crops perform optimal uptake of the nutrients, existing in the soil, solar energy and precipitation, while the incorporated aboveground mass of these plants enrich the soil with organic matter (Bodner et al., 2010). Furthermore, cover crops such as rapeseed and ryegrass are the most efficient weed suppressors and they have the least proportion of weed biomass of the total produced by the cover, they also reduce weed emergence in the following potato crops (Campiglia et al., 2009). Results of such studies demonstrate the importance of green manures and soil ecology to the management of potato.

1.1.4. Manure management

Livestock production is developing dramatically on a global scale, with trends towards increasing concentration on large specialist production units to improve profitability. However, at present, improper management and utilization of manure results in waste of plant nutrients, which are a limited resource, and will therefore threaten the global feed and food supply. Soil application of manure usually results in a positive effect on the growth and yield of wide variety of crops. Manure contains a number of plant macronutrients, primarily N, P, K and varying amounts of S, Ca, Mg, and micronutrients such as B, Cu, Fe, Mn and Zn. The combined effect of bio fertilizers such as animal manure and slurries contribute to the fertility of the soil by adding organic matter (carbon) and plant nutrients to the fields. The total amount of N, phosphorus (P) and potassium (K) in livestock manures produced annually exceeds the industrial production of synthetic N, P and K fertilizers in the world (Jensen, 2013).

1.2. Objectives

The aim of this study was to investigate the growth of three different preceding crops followed by legume and non-legume catch crops and their residual effects on a succeeding potato crop on a silty loam soil. This experiment was designed to evaluate and quantify the effects of preceding crops followed by organic amendments (catch crop-green manure and animal manure) on potato tuber yield and its components as well as to determine the influence of the above-mentioned factors on soil water availability, soil nitrogen availability and nitrogen use efficiency.

The main objectives of this study were:

1) To evaluate the complex effect of different pre-crops, catch crops and animal manure on soil water and nitrogen availability;

2) To study the effect of the experimental factors on yield and quality of potato tuber in organic farming;

3) To determine nitrogen use efficiency (NUE) based on catch crop and manure application.

1.3. Organization of the dissertation

This work is organized in five chapters, references and appendix. The first chapter is a general introduction addressing the soil water management and root distribution of potato plant, nutrition problem and some amendments for organic potato fields. The second chapter describes materials and methods of present study.

The third chapter reports the results of a 3-year experiment with three preceding crops, two catch crop treatments including legume crops as green manure, and farmyard manure applied to potato as a succeeding main crop. Therefore, effects of pre-crop, catch crop and farmyard manure on soil water and inorganic nitrogen availability, further on potato yield; N uptake by the crops and nitrogen use efficiency are covered.

The fourth and fifth chapters are addressed to discuss, summarize, and state general conclusions.

Chapter 2: Methodology

The project comprised of two sets of experiments. The first set compares the shoot dry matter yield and their carbon and nitrogen accumulation of three different preceding crops and catch crop treatments, on an organically managed site at Gross-Enzersdorf, east of Vienna, Austria. This set of experiments was carried out in 2009 and 2010.

The second set compares the soil water and inorganic nitrogen availability and succeeding main crop potato's tuber yield and quality after three different pre-crops, two levels of catch crop (with and without) and farmyard manure application (with and without) in organic farming condition. This set of experiments was established twice in 2010 and 2011.

2.1. Site description

The trial is located on the organically managed fields at the research station of the University of Natural Resources and Life Sciences, Vienna (BOKU, Wien) (latitude 48°14′N, longitude 16°35′E, altitude of 153 m above sea level). Soils at the study site are *Calcaric Phaeozem* (FAO, 1998) with a high water holding capacity, a good nutrient availability, a comparably high soil organic matter (2.2 % total organic carbon) and a pH_{CaCl_2} of 7.6 in the Ap horizon (Rinnofner et al., 2008). Soil texture in the experimental site varies from silty loam in the top soil to silty sand in the subsoil (Freyer et al., 2006). The mean annual temperature is 9.6 °C; the average precipitation is 520 mm in experimental area. The experiment was performed under rain-fed condition. Weather conditions of plant vegetative growth period are defined by meteorological station at Schwehat and the data of many years averages are described by central meteorological station Hohe Warte (ZAMG).

2.2. Experimental design and management

The study was established within a backset in three consecutive years 2009-2011. The experiment was laid out as randomized complete block design (RCBD) with a split-split plot arrangement within the four blocks. Six treatments, three different pre-crop (PC) species, followed by either catch crops (CC) or bare fallow were randomly established in four blocks (replicates) in 24 plots in the first year of each experiment. The plot size was 67.2 m^2.

In the second year, twelve treatments comprised a factorial arrangement of three different preceding crops (lucerne, pea or barley), green manure-catch crop management (catch crop or bare fallow control) and farmyard manure (M) application (30 t ha^{-1} or no manure control) using 48 plots 5.6 m × 6 m (plot size was 33.6 m^2) in size. A three-factorial experiment was laid out as a RCBD with four replications (blocks) in a split-split plot arrangement.

Pre-crop: Main plots were three preceding crops for potato: one-year mulched lucerne (*Medicago sativa,* L) variety “Sitel”; field pea (*Pisum sativum,* L) variety “Austrian winter” and spring barley (*Hordeum vulgare,* L) variety “VCU” in both years (2009 and 2010). The preceding crops were sown in the 24 plots on April 14, 2009 and on April 11, 2010. The following seeding rates were used (kg ha^{-1}): field pea (250), spring barley (130) and lucerne (30). Preceding crops’ plant density, based on plant counts (in spring approximately 3 - 4 weeks after seeding) was determined in each plot in 4 places of 0.25 m^{-2}. Weeds were controlled with hand. Pre-crop plots were grown without any amendment in both years. The spring barley was harvested and thrashed for grain at complete ripeness stage (Mid. July) in both years. Other two of pre-crops were incorporated and ploughed at the same time only in 2009, the late vegetating stage in Lucerne and first flat pod stage in field pea. Due to extremely dry start of growing year (in April 2009), the lucerne had not enough biomass to harvest and the field pea could not reach the maturity at harvest. Whereas, lucerne was harvested at flowering stage and field pea and spring barley were harvested and trashed for grain in 2010.

Catch crop: The sub plots were with and without catch crop following the pre-crops. The used catch crops in this study were non-legumes oil radish, phacelia and mixture with grain legume field pea. The catch crops were sown in the 12 plots on 24th August, 2009 and 11th August, 2010. After legume crops (lucerne and field pea), non-legumes (oil radish (*Raphanus sativus* L.) + phacelia (*Phacelia tanacetifolia* L.)) and after spring barley, a mixture (oil radish (*Raphanus sativus* L.) + Phacelia (*Phacelia tanacetifolia* L.) + common vetch (*Vicia sativa* L.) + field pea (*Pisum sativum* L.)) were sown. The following seeding rates were used (kg ha^{-}

[1]): catch crop non legume (oil radish + Phacelia) 18 + 25 kg ha^{-1} and mixture (oil radish + Phacelia + common vetch + field pea) 25 + 25 + 25 + 150 kg ha^{-1} respectively. The catch crop plants were under a mulching regime, the whole plant material remained on the field, corresponding to a green manure system. The catch crops were incorporated and the ploughed down in early November 2009 and 2010 to ca. 18 cm deep in soil.

Manure: The sub-sub plots were with and without farmyard manure at 30 t ha^{-1} rates and the plot size was 33.6 m^2. Cattle manure was applied to the fields 30 tones ha^{-1} 1 or 2 days before ploughing down to one of the treatments with or without the green manure as a catch crop. A decay or mineralization fraction of manure was used for calculation 23% of the organic N applied in the manure according by Pratt and Castellanos (1981), which was expected to be utilized by the potato crop a year after above mentioned application (Pettygrove et al., 2009).

Main crop: Succeeding main crop potatoes were planted in this field at a seed tuber rate 40,000 ha^{-1} at the end of the first decade of April in 2010 and in 2011. Potato (*Solanum tuberosum L.*) of the Austrian variety “Ditta” was used in the experiment. The factors and the tested factor levels in the field trial are shown in Table 1.

Table 1: Summary of experimental details

Treatment Experiment		1	2	3	4	5	6	7	8	9	10	11	12
2009 & 2010	PC	Lucerne				Field Peas				Spring barley			
	CC	bare fallow		*non - leg.		bare fallow		*non - leg.		bare fallow		**mixture	
	M	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
2010 & 2011	Main crop	Pot	Pot	Pot	Pot	Pot	Pot	Pot	Pot	Pot	Pot	Pot	Pot

*non-leg: oil radish + phacelia; **mixture: oil radish + phacelia + common vetch + field peas; PC: pre-crop; CC: catch crop; M: manure; Pot: Potatoes. Ploughing of all treatments at the same time after harvest of peas and barley that was in Mid. July 2009 and 2010. Catch crops were ploughed down in early November 2009 and 2010 to ca. 18 cm deep. Manure was applied in early November to the fields at 30 tones ha^{-1} farmyard manure.

All preceding crops and catch crops were grown using conventional technology and each plot were 40 rows and row spacing 15 cm. Trails were planted with potato seedling machine. The plots were sprayed with the herbal extract *Bacillus thuringiensis* (Bt) to control Colorado potato beetles when necessary. *Bacillus thuringiensis* (Bt) is a common bacterium-based bio-pesticide as required in 2011 only. Weeds were controlled mechanically by harrowing and hoeing. Potatoes were harvested on 26 August 2010 (142) and 9 September 2011 (150 days after planting) by hand using a crotch.

2.3. Plant sampling and analyses

Total aboveground biomass of the preceding crops were taken in mid. or early July in 2009 (14^{th}) and 2010 (9^{th}), respectively. Due to the very wet weather condition in July 2009, the preceding crop harvest was carried out 5 days later than the second year. The sward of lucerne was cut once at harvest in both years. The catch crop aboveground biomass yield was determined around beginning of November in each year.

Data collection of preceding crop (PC) and catch crop (CC): At harvest, fresh weights of pre-crops and catch crops were determined by hand harvesting from each plot then dried at 60°C to obtain a constant dry weight. Shoot dry matter yield (SDMY) and concentrations of nitrogen (N) and carbon (C) in shoot were determined around mid. July and early November at the time of harvest (date above mentioned) per plot in the preceding crops and catch-crops, respectively. Samples were taken on an area of 1 m^2 by hand clipping at a height of 5 cm above the soil surface. Data from three different preceding crops and two different catch crops were analyzed separately to compare their performance for shoot dry matter yield and their organic compositions (total carbon and total nitrogen). The field pea could not reach maturity at harvest in first experimental year (2009). This can be explained by delayed plant emergency and maturity due to extremely harsh weather conditions during the start of first growing season.

Data collection of main crop potato: The yield parameters such as total and marketable tuber yield non-marketable tuber yield and tuber dry matter yield data is taken per plot at stage of potato maturation. Potato fresh weight yields were measured from 11.2 m^2 (4 m x 4 rows x 0.7 m) taken from the center row in each plot. Tubers were lifted with a crotch on an area and collected by hand; the yield of the entire four rows was weighed in the field.

2.3.1. Determination of dry matter yield

Dry matter yields of preceding crops were measured at harvest (mid. July) for the grain and shoots, which were removed from field in both years. In 2009, the field pea and Lucerne were harvested for fodder and spring barley for grain, whereas DM yields were determined for lucerne shoot and for grain yields both spring barley and field peas, respectively in 2011. In both sampling time, the aboveground plant material collected from 1 m^2 area in each of the plot and subsamples for determination of dry matter concentration were of around 500 g. Shoot dry matter yields of all plant samples were determined after oven-drying. Part of the plant material was dried at 60 °C for 48 h and weighed; the dry matter yield (DMY) was calculated on a dry-weight basis. The all of samples were ground up to a fine powder (≤ 0.5 mm) with a laboratory cutting mill before chemical analyses. Dry matter concentration of mashed potato samples was calculated after measuring the weight loss by heating at 105 ^{0}C in an oven dryer. The dry matter content (%) of the tuber as percentage is calculated with the following formula:

$$Dry\ matter\ content\ (DM),\ \% = \frac{Dry\ weight}{Moist\ weight} * 100$$

The tuber dry matter yield was calculated as fresh tuber yield multiplied by the dry matter content.

2.3.2. Determinations of total carbon and nitrogen concentration

The nitrogen and carbon content of shoots in each pre-crop and catch crop were measured after harvest in July and in November, respectively. Total nitrogen and total carbon of pre-crops (in 2009, grain of barley and biomasses of barley and Lucerne; in 2010, grains of barley and pea, biomass of lucerne) catch-crops were determined on finely milled samples (0.2 g sub-sample) from each plot by dry combustion using an Elemental Analyzer LECO CNS-1000 (LECO Corp.) in the laboratory of the Division of Agronomy of the same University.

2.4. Soil sampling and Analysis

In each year, soil water and inorganic nitrogen content in the soil profile was determined in the all 12 treatments on four occasions and three different depths; 0-30, 30-60 and 60-90 cm. In 2010, soil was sampled from 0–30 cm depth twice: on March 15th prior to seeding and on June 23rd during vegetation period, and from 30–60 and 60–90 depths once on March 15th by a Core Soil respectively. In 2011, soil was sampled from all three different depths twice for inorganic N analysis in March 29th, and in June 13th; respectively. The soil was sampled for analysis of extractable nitrate and ammonium by taking three cores per plot from 0-30 cm, 30-60 cm and 60-90 cm depths using an auger (22 mm in diameter). Soil cores were placed in a clean container and mixed well obtained approximately 500 g of soil that was placed in a plastic bag (one sample per plot). The samples were stored in a cooling bag and in a freezer until processing the laboratory analyses.

2.4.1. Determination of water content in soil

The gravimetric water content was measured in each soil layer (0-30; 30-60 and 60-90 cm). Soil samples were dried for approximately 24 hours at 105^{0}C in the drying chamber until it reaches constant weight. Then the soil dry weight was determined.

The gravimetric water content of the soil as percentage was calculated with the following formula:

$$Water\ content\ (WC),\ \% = \frac{(Soil\ moist\ weight - Soil\ dry\ weight)}{Dry\ weight} * 100$$

2.4.2. Determination of soil inorganic nitrogen

Soil inorganic N content (nitrate nitrogen (NO_3^--N) + ammonium nitrogen (NH_4^+ -N)) in soil samples were determined using N-min analyze method ÖNORM L 1091 (Osterreichisches Normungsintitut, 1999) in the laboratory of Division of Organic Farming. Inorganic nitrogen extracted in calcium chloride ($CaCl_2.2H_20$) solution (0.0125mol L^{-1}). The samples were mixed by hand and approximately 50 g of each soil sample was placed into a plastic bottle together with 200 ml of extraction solution ($CaCl_2.2H_20$). Soil samples for determination inorganic nitrogen were a 1:4 soil and extracting ratio and a shaking duration of 0.5 h in a circular shaker.

Each bottle was tightly sealed and shaken on a shaker. The extracted solution was filtered through a Whatman No. 40 filter paper. The filtrate was then stored in a fridge at -20 °C until analysis. The NO_3^- and NH_4^+ concentrations of the filtered extracts were analyzed by absorption photometry.

Determination of nitrate N content in soil: The soil NO_3^--N was determined by micro titer plates of the filtered extract with mixed reagent (NEDD Reagent: *Sulfanilic acid* by equal volume parts). The micro titer plate completely filled with set of samples was incubated at 37^0C for 30 min in the micro-titer plate reader and micro-titer plate was measured at 540 nm immediately (Laboratory of Division of Organic Farming (IfÖL labor), University of Natural Resource and Life Science, Vienna).

Determination of ammonium N content: The soil ammonium NH_4^+ - N was determined by micro titer plates of the filtered extract with mixed reagent (Deionized water: 0.3M NaOH: Sodium *nitroprussid salicylat* solution, 1:1:1) and *Dichloroicyanuric* acid. The micro titer plate completely filled with set of samples was shaken in the micro titer plate reader and incubated at 25^0C for 30 min and micro-titer plate was measured at 660 nm immediately in laboratory, Division of Organic farming (IFÖL). The concentrations of NO_3^--N and NH_4^+-N were converted to quantities per hectare (kg ha^{-1}) using bulk densities of 1.62, 1.58 and 1.57 g cm^3) for the 0–30, 30–60 and 60–90 cm horizons respectively (Raza, 2010).

2.5. Assessment of tuber yield and quality parameters

At harvest, analyses were focused on the determination of the tuber total and marketable yield, graded tubers, tuber specific gravity of the each treatment and to test external and internal quality of tubers. A 25 kg sample of tubers from each plot was retained and stored at 9^0C until graded for tuber yield and quality analyses. Marketable yield was defined as tubers with diameters greater than 3.5 cm and without visible blemishes (rotten, green, misshaped, or growth cracked tubers). Total culls (green, growth cracked, misshaped, and rotten tubers) of tuber yield were removed and weighed at the grading line.

An around 12 kg potato sub samples were collected from each plot and the tubers were sorted into three size- classes: small < 35 mm, medium = 35 - 65 mm and large > 65 mm tuber diameter and weighed each of them. External and internal qualities of tubers were reported as a percentage of total yields. Determinations of tuber dry matter concentration and tuber nitrate nitrogen concentration are performed in the laboratory of IFÖL, at BOKU, Vienna. Tuber dry matter yield was calculated as fresh tuber yield multiplied by the DM content.

2.5.1. Tuber Specific Gravity and Starch content

At harvest (140-150 days after planting), potatoes from the field trials were graded and specific gravity of tubers was determined. Specific gravity was calculated from a sub-sample of marketable tubers (graded > 35 mm) from each plot within each block and treatments using weight in air/ weight in water method (UWW-Under Water Weight, official method of the European Community) (Haase, 2003) based upon 5000 g potatoes. Sub-samples of 5000 g were washed with tap-water and weight of wet potato tubers in water was measured with a KUV 2000 balance. Specific gravity was calculated with the following formula:

$$Specific\ gravity\ (SG) = \frac{Weight\ in\ air}{(Weight\ in\ air - Weight\ in\ water)}$$

Nowadays, the specific gravity is indirectly used for estimating the starch content of potatoes owing to the good correlation between the two parameters. The well-known “EU Table” or under water weight and the various numerical methods developed by different authors in different parts of the world, for example: Simmonds, 1977; Vakis, 1978; Whittenberger, 1951; Wilson and Lindsay, 1969 (Zerom, 2011). In Europe, the International Starch Institute releases a table for determining the percentage of starch in a given mass of potatoes. The tuber starch content was determined using the Commission Regulation (EC) No 97/95 of 17 January 1995 ‘EU Table’ recommends the underwater weight of 5000 g (dry) or 5050 g (wet) potatoes be used as an input to get the starch content in percent (European Committee, 1995) .

2.5.2. Tuber classification

The harvested potato tubers were graded and sized into the following three class sizes for medium size is class: the diameter of tuber is greater than 3.5 cm and less than 6.5 cm; large size is class: the diameter is greater or equal to 6.5 cm; and small size is class: smaller or equal to 3.5 cm tuber in diameter. Marketable yield was calculated as the yield of tubers within class medium and large (European Committee, 2006), excluding decayed, green, misshapen, scabby, or growth cracked tubers.

2.5.3. Tuber External and Internal Quality

The culls of potato tuber yield (growth cracked, misshaped, green and rotten tubers) were removed and weighed before analyses, while medium and large size classes were separated. Non-marketable yield were tubers of class 3 and those that were decayed, green, misshapen, scabby, with secondary growth, or cracked tubers. A 2 kg of tuber sub-sample from each plot within each block were cut into quarters and rated for internal quality. Rated disorders included infections with diseases like potato virus Y (PVY), corky ring spot (CRS), common scab (CS), and wireworm.

2.5.4. Determination of tuber nitrate nitrogen content

Potato tubers for tuber nitrate nitrogen concentration analyze were sampled at harvest, 142 days after planting (DAP) in 2010 and 150 DAP in 2011. The nitrate nitrogen content was analyzed from 2 kg middle size tubers using a Nitracheck-13 tester (Reflectoquant method) for the determination of nitrate (NO^-_3) in foodstuffs and other materials. The potato samples were minced and homogenized for test. Exactly weigh approx. 5 g sample material into a 100 ml beaker and added approx. 60 ml hot distillated water (approx. 70°C) and incubated in water bath with shaker at 60–70°C for 15 min. Strongly colored samples with a high content of starch, treated additionally with Carrez reagents (*Carrez-I-solution (potassium hexacyanoferrate(II) (ferro-cyanide),* 85 mM = 3.60 g $K_4[Fe(CN)_6] \times 3\ H_2O$/100 ml*); Carrez-II solution (zinc sulfate,* 250 mM = 7.20 g $ZnSO_4 \times 7\ H_2O$/100 ml)). Adjust to pH 7.5-8.5 with sodium hydroxide (0.1 M; e.g. 10 ml) and mixed after each addition. Then full the volumetric flask to the mark; soundly mixed and filtered. The cool extraction approx. 20-25°C transferred into a 100 ml volumetric flask. Full up to the mark with distillated water and filtered. For the assay was taken 0.100-1.000 ml of the filtrate (Boenhringer-Mannheim, 1994) (IFÖL labor, 2011).

2.6. Nitrogen use efficiency

Nitrogen use efficiency (NUE) and /or fertilizer recovery in crop production systems can be calculated using many different methods (Moll et al., 1982). The calculation of NUE parameters in potatoes is more complex than cereals due to senescence of the potato plant biomass material prior to harvest. Definitions and N equations for calculating N use efficiencies are given in Table 2. Nitrogen use efficiency (kg DM kg $^{-1}$ N) in this trial was calculated as a ratio of tuber dry matter yield (kg ha^{-1}) to the total N applied as catch crop green manure or cattle manure (kg N ha^{-1}). Tuber nitrogen uptake (kg N ha^{-1}) was calculated by multiplying the tuber DM yield (kg ha^{-1}) by the tuber N content (g N kg^{-1}).

Table 2: Nitrogen Use Efficiency (NUE) Components, Ratio, Description and Reference Source

Components	Ratio	Definition	Reference Source
Nitrogen use efficiency	NUEcc = $\frac{DMY_{cc+} - DMY_{cc-}}{NI_{cc}}$ or NUEm = $\frac{DMY_{m+} - DMY_{m-}}{NA_m}$	The amount of accumulated tuber dry matter yield per kg of applied N	(Eleanor Y Swain et al., 2014)
Apparent Nitrogen Recovery, (%)	ANRcc = $\frac{(NU_{cc+} - NU_{cc-})}{NI_{cc}} * 100$ or ANRm = $\frac{(NU_{m+} - NU_{m-})}{NA_m} * 100$	The percentage of total applied N transferred into tubers	(www.nue.okstate.edu, 1991)

NUEcc or NUEm: Nitrogen use efficiency of N applied with cover crops or manure by the potato crop, DMY_{cc+} or DMY_{cc-}: Tuber dry matter yield in treatments with or without catch crops, NI_{cc}: N input by catch crop amendment, NA_m: N applied with manure, NU_{cc+} or NU_{cc-}: Tuber N uptake in treatments with or without catch crops, NU_{m+} or NU_{m-}: Tuber N uptake in treatments with or without manure application. ANRcc or ANRm: Apparent nitrogen recovery of N applied with cover crop or manure by the potato crop.

Data obtained on potato N uptake in 2010 and 2011 were used to determine apparent N recovery for organic N amendments. The apparent nitrogen recovery (ANR) was calculated following the method used by Varvel and Peterson (1990) (Table 2).

2.7. Statistical analysis

Data for each parameter were evaluated by analysis of variance (ANOVA) based on a Split Plot design with the main factor pre-crop (PC) and the sub factors catch crop (CC) and manure (M) using a General Linear Model of the statistical software SPSS (Version 18.0). The replication (Rep) was considered as random effect. The fixed effects of growing year, previous crop, catch crop, and manure application on soil water content, inorganic nitrogen (NO^{-}_{3}-N and NH^{+}_{4}-N) and on potato yield (total, marketable, DM), tuber size distribution, proportion of discarded tubers (green, cracked, malformed, blighted, affected with common scab or corky ring), tuber nitrate and starch concentrations were assessed. The significance of the differences for the main effect of pre-crop treatments was verified with the Tukey's test at $\alpha = 0.01$. After ANOVA examination, the means with significant interaction effects ($\alpha = 0.01$) were separated by Least Significant Difference (LSD) test at 5 % level of probability among individual treatments.

Original values were logarithmically transformed if necessary to fulfill the homogeneity of variance and ANOVA was then performed on log-transformed values.

Chapter 3: Results

This experiment was designed to find a suitable preceding crop, with and without catch crop and manure combination to enhance soil water and mineral nitrogen availability in organic potato production. Moreover, the effect of pre-crops, catch crops and farmyard manure application on following potato tuber yield and quality throughout the two subsequent growing seasons 2009-2010 and 2010-2011 has been assessed.

3.1. Seasonal rainfall and temperature

Monthly weather data was obtained from a station Standort Schwechat 8.3 km from the fields of experimental research station of the University of Natural Resources and Life Sciences, Vienna for the three cropping seasons. The amount of precipitation and the average temperatures between April and November during 2009-2010 are displayed in Figure 1. The accumulated precipitation and the maximum and minimum average temperatures above mentioned growing seasons were 526.4 mm, 20.5°C and 10.3°C in 2009; 659.2 mm, 18.2°C and 9.3°C in 2010, respectively. The amount of recorded precipitations in 2009 represented over 70 mm more than the long-term mean value of 453.2 mm. The average temperature was 15.5^{o}C in the same vegetation period, which was around 1^{o}C higher than the long-term mean value of 14.6^{o}C. In April 2009 the lowest number of precipitations (3 mm) occurred. Moreover, in June and July the amount was approximately twice (124 mm and 125 mm) of the mean value 70 and 68 mm, respectively. In general, the periods from April through May also in September were drier and warmer than usual.

The growth period from spring 2010 started with better moisture conditions in the soil as compared to 2009. In 2010, 676 mm of rain fell at Gross-Enzersdorf during the 8 months period (April to November) and it was approximately 200 mm more than the long-term mean value of 453.2 mm (the average of 30 years). In the same vegetation period the average air temperature was 13.8^{o}C, which is represented nearly 1^{o}C lower than the long-term mean value of 14.6^{o}C. Furthermore, the moisture in 2010 was characterized by more rainfall during April, May, July and August, nearby many years average rainfall in June. The amount of precipitation and the average temperatures between April and August during 2010-2011 are shown in Figure 2.

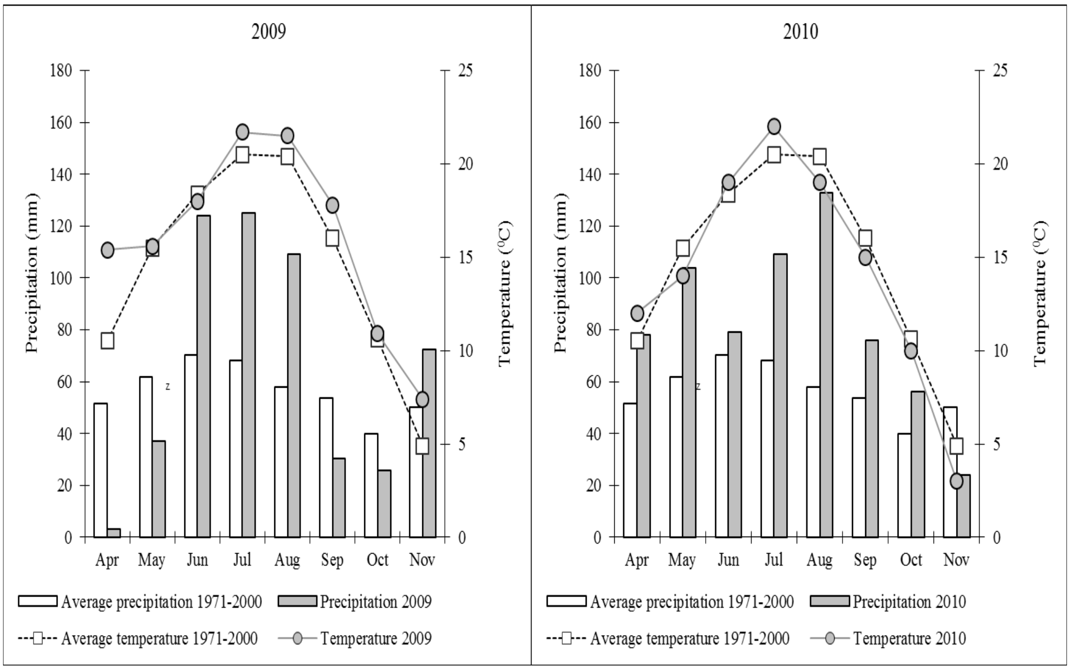


Figure 1: Monthly air temperature and precipitation for 2009 - 2010 and average of 1971 - 2000 (ZAMG, 2001)

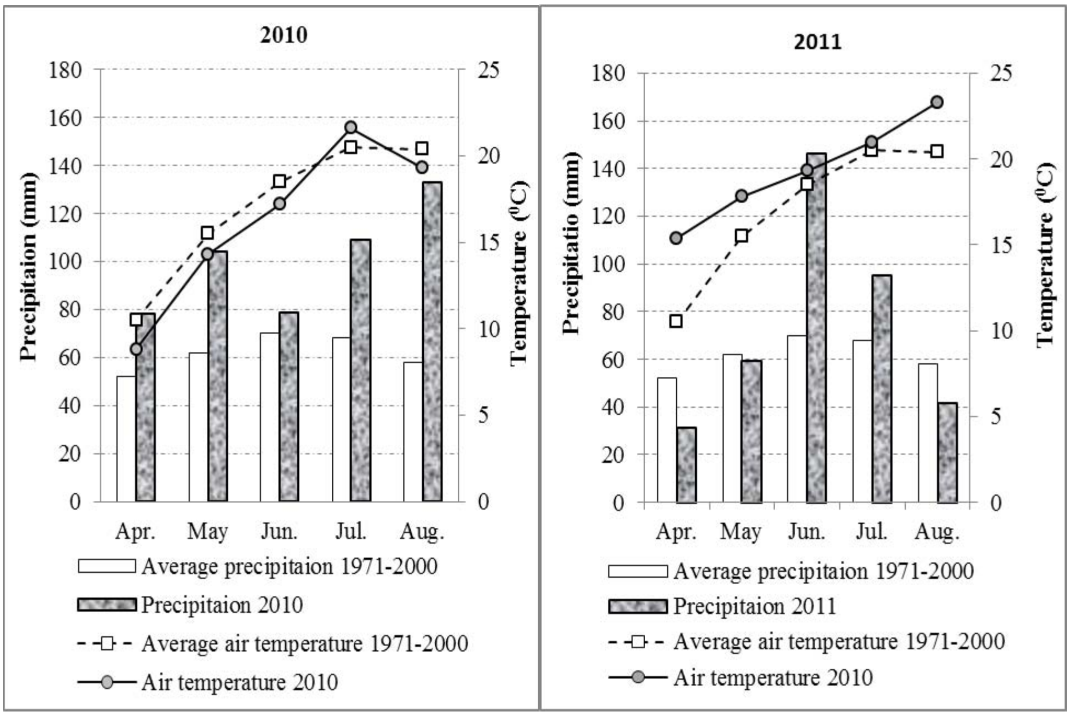


Figure 2: Monthly air temperature and precipitation for 2010 - 2011 and average of 1971 - 2000 (ZAMG, 2001)

In 2010, 503 mm of rain fell at the experimental field during the 5-month period (April to August), which represented approximately 1.6 times much than of the 30-year average of 310 mm distributed well across all 5 months.

In 2011, 374 mm of precipitation fell during the same period. Weather conditions differed between the potatoes growing seasons as well; May 2010 was much cooler than May 2011 and also cooler than the average value of 30 years and during the growth stages had extreme high precipitation than average rainfall. Because some of precipitation deficit (24 mm) occurred during the first 2 months (April and May) in early season of 2011 was a drier than average value of many years. The 2011 season was characterized by a more uniform pattern of rainfall, but with less rainfall in April and more in June. The rainfall from April 1st to August 31st was almost twice as much as the thirty-year average, while the total rainfall for 2011 was close to the average.

Average monthly temperatures, except in July (21.6 ^{0}C) were 1.1 ^{0}C higher than the 30-year average for this location. However, the monthly average temperatures were slightly lower than those from the 30-year average for the remainder of the season.

3.2. Plant numbers of pre-crops

Based on the averages of two years, shoot numbers were in the range of 300-550 m^{-2} in lucerne, 90-130 m^{-2} in field pea and 280-380 m^{-2} in spring barley. Differences between the years were found significant ($P < 0.05$) and overall shoot numbers were usually higher in 2010 in comparison to 2009 in all pre-crops species. The target plant density was 430 lucerne plants, 110 pea plants and 320 barley plants m^{-2} (Data not shown).

3.3 Total aboveground dry matter yield of different pre-crops and catch crops

Based on the results of two years average, the aboveground dry matter yield of preceding crop differed significantly ($P < 0.01$) due to the different crop species (Table 3). The highest SDMY was found in field pea (8.2 tones ha^{-1}) and lowest in lucerne (4.7 tones ha^{-1}) (Table 4). In catch crop species, the similar amounts of shoot biomass were measured following preceding crops in both years, whereas for summary of non-legume catch crop and field pea was found significantly higher SDMY than others (Table 4).

3.3.1. Total aboveground dry matter yield of pre-crops

Based on the two experimental years averages, shoot dry matter yields varied from 1.0 to 7.5 tones ha^{-1} on lucerne, from 3.7 to 9.0 tones ha^{-1} on field pea and from 2.3 to 4.8 tones ha^{-1} on spring barley (Table 4). The shoot biomass of Lucerne was highly variable between the years because in 2009 the plant density of lucerne was too sparse. A comprehensive summary of findings for different traits based on the average of two experimental years is presented in Table 3 and Table 4. There was a significant difference between the years 2009 and 2010 for the shoot dry matter yields of preceding crops at harvest. Significant differences ($P < 0.01$) were found in pre-crop species for their average shoot dry matter yields in both years. At harvest, a significantly ($P < 0.01$) higher aboveground DM yield was measured for field pea as compared to other two preceding crops (Table 4).

Table 3: Significance levels for fixed factors and their interaction for shoot and grain dry matter yields of preceding crops and shoot dry matter yield of catch crops, average of two years (2009 - 2010)

Parameter	Dry matter yield		
Effect	PC	CC	PC + CC
Y	**	**	+
PC	**	**	**
PC*Y	**	**	**

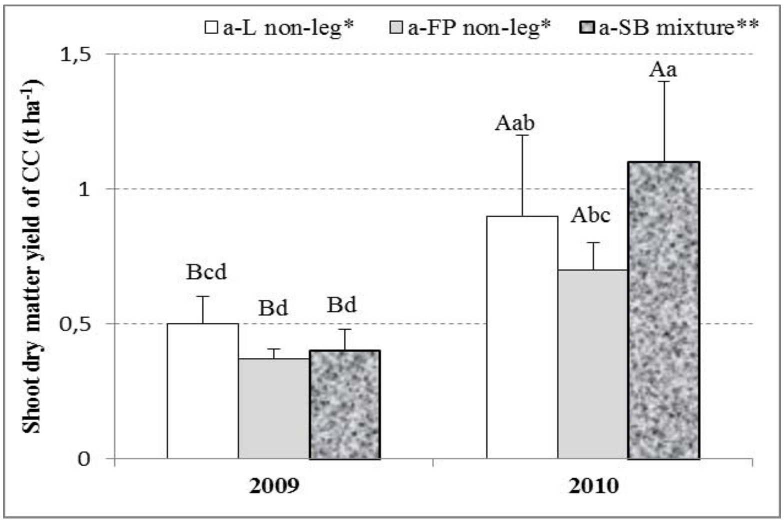
Y: year; PC: preceding crop; CC: Catch crop; PC*Y: interaction between year and pre-crop; Treatment effects labeled with “ns” are not significant; **: significant at 1 % level of probability; +: significant trend at 10 % level of probability.

The Table 3 shows also the treatment effects for the total amount of aboveground dry matter yield of pre-crop and catch crop and their combinations (PC + CC) and the interaction effects between preceding crops and growing years on dry matter yields. Significant ($P < 0.01$) interactions were established for preceding crops and year (PC*Y) on aboveground dry matter yield (Table 3). The SDMY of the preceding crops lucerne and DM yield of spring barley differed between the two growing years. In 2009, the highest DM yield was reached by PC spring barley and lowest by lucerne, but in 2010, the highest DM yield was observed for lucerne and lowest DM yield for spring barley (Table 4). Based on the two years averages, the mean values of aboveground DM yield were recorded as 6.3 tones ha^{-1} for field pea, 4.2 tones ha^{-1} for lucerne and 3.5 tones ha^{-1} for spring barley (Table 4). In 2009, spring barley (4.8 tones ha^{-1}) and field pea (3.7 tones ha^{-1}) had higher aboveground dry matter yields than lucerne (1.0 tones ha^{-1}), whereas in 2010, the aboveground DM yield of preceding crops were the highest on field pea (9.0 tones ha^{-1}), followed by lucerne (7.5 tones ha^{-1}), and lowest on spring barley (2.3 tones ha^{-1}). In 2010, early growing season was more suitable for plant growth; particularly appropriate soil moisture content and air temperature not only for pre-crops so forth to weed spread also. Therefore the barley crops have been incurred relatively high depression by weed due to their straw and grain yielded a lowest DM yield in second (2010) growing year.

In spring 2009, lack of precipitation during crop establishment probably slowed the emergence of lucerne and stimulated weed growth. During the growing season in 2009, lucerne did not grow successful due to dense weed and sparse main crops.

3.3.2. Shoot dry matter yield of catch crops

The shoot dry matter yield (SDMY) of catch crops varied from 0.4 to 0.5 tones ha^{-1} in 2009 and from 0.7 to 1.1 tones ha^{-1} in 2010 (Table 4). Significant (P < 0.01) differences were found between the two growing years for the SDMY of catch crops (Table 3 and Figure 3). The data in Table 4 are presented as means of the entire shoot and grain dry matter yield of preceding crops, SDMY of catch crops and their total amount. The highest SDMY (0.9 tones ha^{-1}) of non-legume catch crops following lucerne was recorded in 2010 and lowest value (0.4 tones ha^{-1}) was in 2009 (Table 4). Likewise, SDMY of mixture catch crops after spring barley well recorded in 2010 than 2009. There was also significant (P < 0.01) pre-crop treatment effect on SDMY of catch crops (Table 3). The year effect significantly (P < 0.01) interacted with the pre-crop effect (Y*PC) for SDMY of catch crops (Table 3).



CC: catch crop; a - L: catch crop after lucerne; a - FP: after field pea; a - SB: after spring barley. *non-leg: oil radish + phacelia; **mixture: oil radish + phacelia + common vetch + field peas. Error bars indicate standard deviations. Different capital and small letters indicate significant differences among years and treatments, respectively.

Figure 3: Shoot dry matter yield of catch crops as affected by preceding crops and years

Based on the results from the harvest 2009, the non-leg* catch crop after lucerne had the highest biomass of 0.5 tones ha^{-1}, followed by the mixture** catch crop after spring barley of 0.4 tones ha^{-1} and the non-leg* catch crop after field pea of 0.4 kg ha^{-1} (Table 4).

Table 4: Aboveground dry matter yield by pre-crop species and catch crops (measured at harvest)

Parameters / Year	2009	2010	Mean ± standard deviation
	(tones ha^{-1})		
PC: Lucerne (shoot)	1.0.^{f}	7.5^{b}	4.2 ± 3.4^{b}
Field pea (grain + straw)	3.7^{d}	9.0^{a}	6.3 ± 2.9^{a}
Spring barley (grain + straw)	4.8^{c}	2.3^{e}	3.5 ± 1.3^{c}
CC: non-leg*: following Lucerne (shoot)	0.5^{cd}	0.9^{ab}	0.70 ± 0.3^{a}
non-leg*: following field peas (shoot)	0.4^{d}	0.7^{bc}	0.54 ± 0.2^{a}
mixture**: following spring barley (shoot)	0.4^{d}	1.1^{a}	0.74 ± 0.4^{a}
PC+CC: Lucerne + non-legume*	1.5^{d}	8.6^{a}	5.0 ± 3.8^{b}
Field peas + non-legume*	4.1^{bc}	9.3^{a}	6.7 ± 2.9^{a}
Spring barley + mixture**	5.1^{b}	3.4^{c}	4.2 ± 1.1^{b}

PC: preceding crop; CC: catch crop. Mean values with the same letters within a column are not significantly different (P < 0.01) between preceding crops in two years, between catch crops in two years or total amount of PC and CC treatments in two growing years, respectively; *non-leg: oil radish + phacelia; **mixture:.

The amounts of SDMY of preceding crops and catch crops ranged from 4.2 (PC + CC: SB + mixture CC) to 6.7 tones ha^{-1} (PC + CC: P + non-legume CC). There was a significant (P < 0.01) difference on SDMY in PC + CC combinations. Resulted on the two years averages, non-legume catch crops after field pea (0.54 tones ha^{-1}) produced lower amount of SDMY than mixture catch crops following spring barley (0.74 tones ha^{-1}) and non-legume catch crops following lucerne (0.70 tones ha^{-1}) (Table 4). However, there was found non-significant different between pre-crops for SDMY of catch crops. Differences between preceding crops for SDMY of catch crops were found significant (P < 0.01) in both years. The shoot dry matter yield of non-legume catch crop following Lucerne was higher (0.48 t ha^{-1}) as compared to SDMY of CC after field pea (0.4 t ha^{-1}) in 2009. Whereas, the higher SDMY recorded by mixture catch crop following spring barley (1.1 t ha^{-1}) as compared to SDMY of non-legume CC after field pea (0.7 t ha^{-1}) in 2010 (Table 4).

3.4. Nitrogen and carbon uptake by pre-crop and catch crop shoots

Based on the results of two years average, the shoot total nitrogen and total carbon (C) content by pre-crop and catch crop differed significantly (P < 0.01) (Table 5). The shoot nitrogen and carbon yield of pre-crops and catch crops (2009 and 2010) are summarized in Table 6. There were lowest N and C contents observed either in lucerne or spring barley in 2009 and in 2010, respectively, whereas field pea had the highest total nitrogen (269 kg ha^{-1}) in grain (Table 6).

3.4.1. Nitrogen and carbon yield of the pre-crop shoots

Nitrogen content and yield: The total nitrogen concentration in the shoots of different preceding crops ranged from 1.89 % (spring barley) to 3.56 % (lucerne) N and from 1.87 % to 3.41 % N in 2009 and 2010, respectively. The spring barley generally had the lowest concentration of nitrogen averaging 1.9 % throughout those two years; the lucerne had the highest concentration of nitrogen 3.4% in their shoot (Data not shown). The shoot biomass or grain nitrogen yield of three different pre-crops at harvest time ranged from 42 kg ha^{-1} (spring barley) to 178 kg N ha^{-1} (field pea) over two years. The Table 5 shows the significant levels for fixed factors and their interactions for shoot N and C yields of pre-crops. Significant differences (P < 0.01) among preceding crops (crop species) were found for total shoot N yield as determined at harvest. Growing years or extreme weather condition and plant species affected the crop N and C yields, although significant interactions between pre-crops and year were observed. The significantly higher amount of shoot N yield was recorded with 190 kg ha^{-1} in growing season 2010 and lowest value of shoot N was with 54 kg ha^{-1} in 2009 (Table 6).

Table 5: Significance levels for fixed factors and their interaction for nitrogen and carbon yield in shoot and grain of preceding crops, average of two years (2009 - 2010)

Parameter/ Effect	Nitrogen yield	Carbon yield
	in shoot and shoot + grain of PC	
Y	**	ns
PC	**	**
PC*Y	**	**

See Table 3; N and C yields were measured in shoot of lucerne and in shoot + grain for field pea and in grain of spring barley.

Averaged over two years, in legume crops resulted in a total shoot N yield of lucerne 145.3 kg ha^{-1} and N yield of field pea 177.7 kg ha^{-1}, which were significantly (P < 0.01) higher than cereal crop spring barley with a shoot N yield of 42.0 kg ha^{-1} in the spring barley (Data not shown). In 2009, the nitrogen yield of preceding crops showed a minimum values for grain of spring barley (40.6 kg N ha^{-1}) and for shoot of lucerne (33.9 kg N ha^{-1}); in 2010, the minimum value of nitrogen yield of pre-crop recorded for grain of spring barley (43.4 kg N ha^{-1}) (Table 6).

Carbon content and yield: In both years carbon concentration in pre-crops varied in a narrow range from 41.1 – 41.8 % in shoot of Lucerne, from 39.5 to 39.9 % in field peas and 39.9 % in seed of spring barley. Interestingly, there was not significant difference on carbon concentration between the two years while there was a significant difference in nitrogen concentration (Data not shown). Based on the two years average, the shoot total carbon amounted to significantly (P < 0.01) high yield of 2506 kg ha^{-1} in field pea followed by lucerne 1766 kg ha^{-1}, and lowest value of 893 kg ha^{-1} in spring barley (Data not shown). It is obvious that the effect of the interaction between the preceding crops and years were significant (P < 0.01) for carbon yield by pre-crop shoot (Table 5).

Table 6: Nitrogen and carbon yields of the preceding crops in 2009 - 2010

Year	Pre-crop		N, (kg ha^{-1})	C, (kg ha^{-1})
2009	Lucerne	shoot	33.9^{c}	396.6^{e}
	Field pea	grain + straw	86.1^{b}	1470.4^{c}
	Spring barley	grain	40.6^{c}	859.1^{d}
2010	Lucerne	shoot	256.6^{a}	3135.6^{b}
	Field pea	grain	269.3^{a}	3542.0^{a}
	Spring barley	grain	43.4^{c}	927.8^{d}
Year			**N, (kg ha^{-1})**	**C, (kg ha^{-1})**
2009			54^{B}	909^{B}
2010			190^{A}	2535^{A}

The values with the same small and capital letters within a column are not significantly different (P < 0.01).

Table 6 also presents the average values of total C yield in the three preceding crop species over two years. The low amount of shoot C yield was observed with 396.6 kg ha^{-1} by lucerne in 2009 and with 927.8 kg ha^{-1} by spring barley in 2010. The highest C yield was recorded for field peas at 1470.4 kg ha^{-1} in 2009 and at 3542.0 kg ha^{-1} in 2010 (Table 6).

3.4.2. Nitrogen and carbon yield of the catch crop shoots

Nitrogen yield: In the present study, the mean annual nitrogen uptake by shoot of catch crops varied from 26.0 to 43.4 kg N ha^{-1} for the non-legume catch crop after lucerne, from 18.7 to 36.1 kg N ha^{-1} non-legume catch crop after field pea and from 17.6 to 49.1 kg N ha^{-1} for the mixture catch crop after spring barley (Table 8). The Table 7 indicates those significance levels for preceding crop and year, as well as their interaction for the shoot N and C yields of the catch crops. Years significantly (P < 0.01) affected carbon yield in catch crop shoot (Table 7). The shoot N yield of catch crops did not significantly differ by pre-crop effect; whereas, years significantly affected it. Moreover, a significant interaction of pre-crop with the year was established for catch crop shoot N yield (Table 7).

Table 7: Significance levels for fixed factors and their interaction for catch crops shoot nitrogen and carbon, average of two years (2009 - 2010)

Parameter/ Effect	N yield	C yield
	in shoot of catch crop	
Y	**	**
PC	ns	**
PC*Y	**	**

See Table 3.

Carbon yield: The organic carbon yield of catch crop shoots varied from 164.6 to 329.2 kg ha^{-1} for the non-legume crop after lucerne, from 127.4 to 255.2 kg ha^{-1} for the non-legume crop after field pea and from 133.0 to 399.6 kg ha^{-1} for the mixture catch crop after spring barley (Table 8). However, catch crops did not differ for their shoot N content after three different preceding crops, but significant differences (P < 0.01) were found between catch crops for their shoot carbon yield (Table 7). The shoot of catch crop which is including a mixture of oil radish, common vetch, and field pea was significantly (P < 0.01) highest carbon content (399.6 kg ha^{-1}) than non-legume (127.4 kg ha^{-1}) catch crop (Table 8).

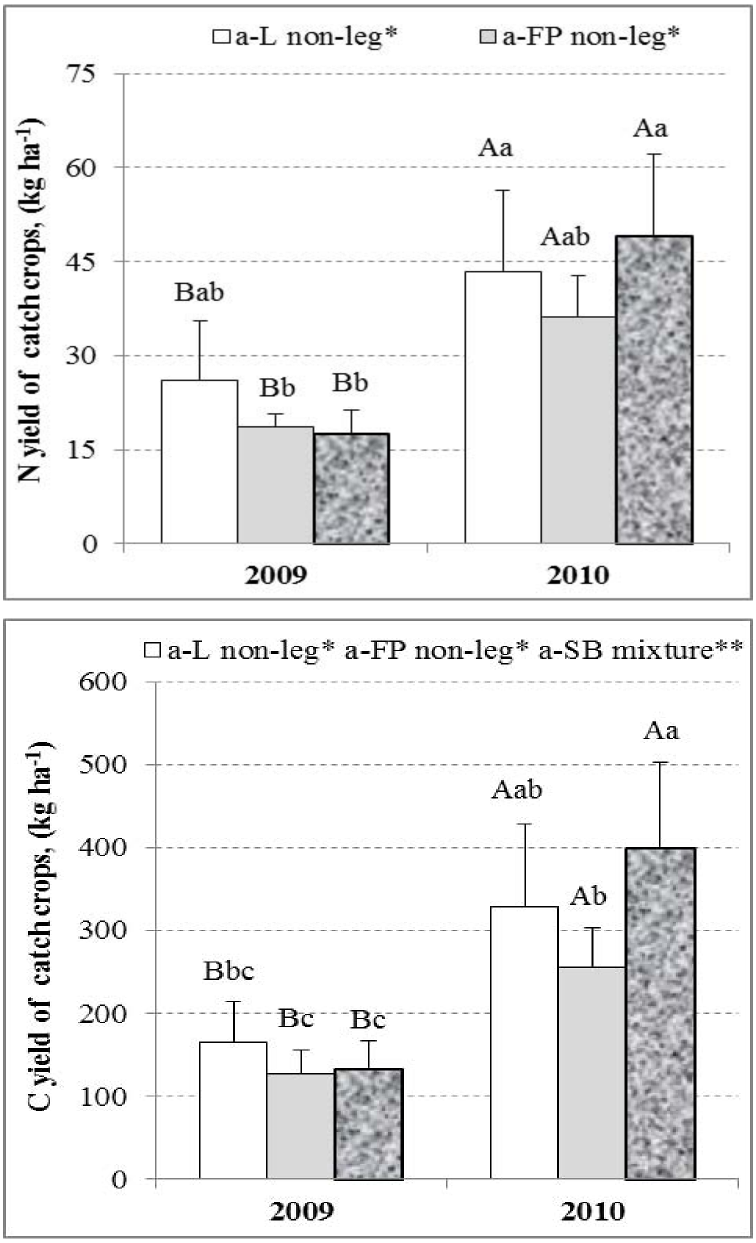
Table 8: Nitrogen and carbon yields in shoot of catch crops

Year	Pre-crop	Catch crop	N, (kg ha^{-1})	C, (kg ha^{-1})
2009	Lucerne	Non-leg*	26.0^{ab}	164.6^{bc}
	Field pea	Non-leg*	18.7^{b}	127.4^{c}
	Spring barley	Mixture**	17.6^{b}	133.0^{c}
2010	Lucerne	Non-leg*	43.4^{a}	329.2^{ab}
	Field pea	Non-leg*	36.1^{ab}	255.2^{bc}
	Spring barley	Mixture**	49.1^{a}	399.6^{a}

Year	N, (kg ha^{-1})	C, (kg ha^{-1})
2009	21^{B}	142^{B}
2010	42^{A}	328^{A}

The values with the same small and capital letters within a column are not significantly different (P < 0.05). *non-leg: oil radish + phacelia; **mixture: oil radish + phacelia + common vetch + field peas.

The interaction effects between experimental years and preceding crops for shoot N and C yields of catch crops are shown in Figure 4. The mixture catch crops following spring barley accumulated significantly higher carbon than non-legume catch crops following field pea only in 2010.



a - L: catch crop after lucerne; a - FP: after field pea; a - SB: after spring barley. *non-leg: oil radish + phacelia; **mixture: oil radish + phacelia + common vetch + field peas. Error bars indicate standard deviations. Different capital and small letters indicate significant differences among years and treatments, respectively.

Figure 4: Nitrogen and carbon yield of catch crops as affected by pre-crops and year

The pre-crop had influence on the shoot N and C yield of preceding crop and catch crop combinations. The non-legume catch crop after field pea recorded a significantly ($P < 0.01$) higher amount of N content than after lucerne and mixture catch crop following spring barley (Data not shown).

3.5. The early soil water content and nitrogen availability

Influence of three different pre-crops, non-legume (oil radish + phacelia) and mixture (oil radish + phacelia + common vetch + field peas) catch crops following pre-crop, farmyard manure and their interactions were investigated for soil water content (WC) and soil inorganic nitrogen (N_{min}) availability in three different soil profiles up to 90 cm on silty loam soil. Soil moisture in the 0 - 90 cm soil profile did not differ between field plots after pre-crops and between the plots planted with catch crop and bare fallow, between the plots manure applied and bare fallow at two sampling date (Table 9). Soil water content prior to planting and early growing period varied from 97 to 100 mm and from 86 to 100 mm, respectively in 0 – 30 cm soil profile (Table 10). In this study, soil inorganic nitrogen (NO_3^--N + NH_4^+-N) contents in 0 - 30 cm soil depth at pre-planting and during growing period (vegetative growth stage of main crop potato) were highly variable among years (Table 12). Soil NO_3^--N content differed by year in 0-30cm soil depth at pre-plant in Mid. March and growing period in Mid. June. Based on two years average, a relatively high (> 100 kg N ha^{-1}) amount of soil NO_3^--N content was measured in top soil, but decreased substantially in early growing period (Table 14). The soil NO_3^--N content is described more detail than soil NH_4^+-N content in this part, because the NO_3^--N largely partake of soil inorganic nitrogen content.

3.5.1. Soil water content

Averaged on over two years, at pre-planting time the soil water content in the 0-30 cm and 0-90 cm soil depths ranged from 98 mm to 99 mm and 287 - 290 mm, respectively (Table 10). The soil water content in 2010 and 2011 were statistically non- significant in prior potato planting (in March) up to 90 cm soil depths (Table 9). Also, there were no significant differences between main factors pre-crops, catch crop, manure application, and their interactions in the mean values of soil water content.

Table 9: Significance levels for fixed factors and their interactions on soil water content in March and June samples of two years (2010 - 2011)

Parameter/ Depth, (cm)	Effect	March				June
		0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
Soil water content , (mm)	Y	ns	ns	ns	ns	**
	PC	ns	ns	ns	ns	ns
	CC	ns	**	ns	ns	ns
	M	ns	ns	ns	ns	ns
	PC*Y	ns	ns	ns	ns	ns
	CC*M	ns	ns	+	ns	ns
	CC*Y	ns	ns	ns	ns	ns
	PC*CC	ns	ns	ns	ns	ns
	M*Y	ns	ns	ns	ns	ns
	PC*M	ns	ns	ns	ns	ns
	PC*CC*Y	ns	ns	ns	ns	ns
	PC*M*Y	ns	ns	ns	ns	ns
	CC*M*Y	**	ns	ns	ns	ns
	PC*CC*M	ns	ns	ns	ns	ns
	PC*CC*M*Y	ns	ns	ns	ns	ns

Y: year; PC: preceding crop; CC: catch crop; M: manure; PC*Y, CC*M, PC*CC, M*Y, PC*M: two-way interactions between fixed factors; PC*CC*Y, PC*M*Y, CC*M*Y: three-way interactions between fixed factors; PC*CC*M*Y: complete interaction between fixed factors; Treatment effects labeled with "ns" are not significant; **: significant at 1 % level of probability; *: significant at 5 % level of probability; +: significant trend at 10 % level of probability.

Generally, during the first part of the growing season until June, the soil water supply showed no changes after various preceding crops to 90 cm soil profile. There were similar values of soil water content following pre-crops in potato plant rooting depth in March. However, significant three-way interaction effect between year, catch crop, and manure (Y*CC*M) had detected on water content in 0 – 30 cm soil depths (Table 9 and Table 10). Moreover, a significant differences were found between with and without catch crop treatments in 30-60 cm soil profile (Table 9), the significantly (P < 0.01) lowest soil water content (97.2 mm) was found with catch crop plot and the highest (101.7 mm) was at bare fallow plots in March (Table 10).

Years significantly (P < 0.05) affected on soil moisture in 0-30 cm soil depth only for June samples (Table 9). During the first part of the growing season in 2011, slightly higher (100 mm) amount of soil water was stored in the top soil layer compared to soil water from the growing season in 2010 (86 mm) (Table 10).

Table 10: Soil water content in 0 - 90 cm depth of soil for potato fields as influenced by main effect catch crop, manure application and growing years

Sampling date		Water content, (mm) March				June
Effect		0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
CC	-	*98.7 ± 3.8^{a}	101.7 ± 6.0^{a}	92.9 ± 9.4^{a}	246 ± 75^{a}	93 ± 3.8^{a}
	+	97.9 ± 3.9^{a}	97.2 ± 6.9^{b}	90.0± 13.6^{a}	247 ± 89^{a}	93 ± 3.9^{a}
Y	2010	98 ± 3.7^{a}	102 ± 6.8^{a}	93 ± 14.7^{a}	292 ± 19^{a}	102 ± 6.8^{a}
	2011	99 ± 4.3^{a}	97 ± 5.5^{a}	102 ± 6.8^{a}	287 ± 94^{a}	86 ± 5.5^{b}

CC	M	2010	2011	2010	2011
		0-30 cm in March		0-30 cm in June	
-	-	99.5^{ab}	99.1^{ab}	99.5^{a}	99.5^{a}
	+	97.0^{ab}	99.3^{ab}	97.0^{a}	97.0^{a}
+	-	96.8^{b}	100.2^{a}	96.8^{a}	96.8^{a}
	+	97.5^{ab}	97.2^{ab}	97.5^{a}	97.5^{a}

CC: catch crop; M: manure. –: without, +: with CC or M; *: mean ± standard deviation. Mean values with the same letters for individual treatments (upper part) and for interactions (lower part) within a column are not significantly different (P < 0.05).

Based on two years averages, differences were non-significant between pre-crops, catch crops and manure main factors, likewise no interaction effects were found for soil water content in top layer in June (Table 9). There were not statistical significant differences between main factors for the soil water content on the top layers in March.

The same amounts of soil water content were stored in March and no in response to both catch crops and manure application (Table 10).

3.5.2. Inorganic soil nitrogen (N_{min}) content

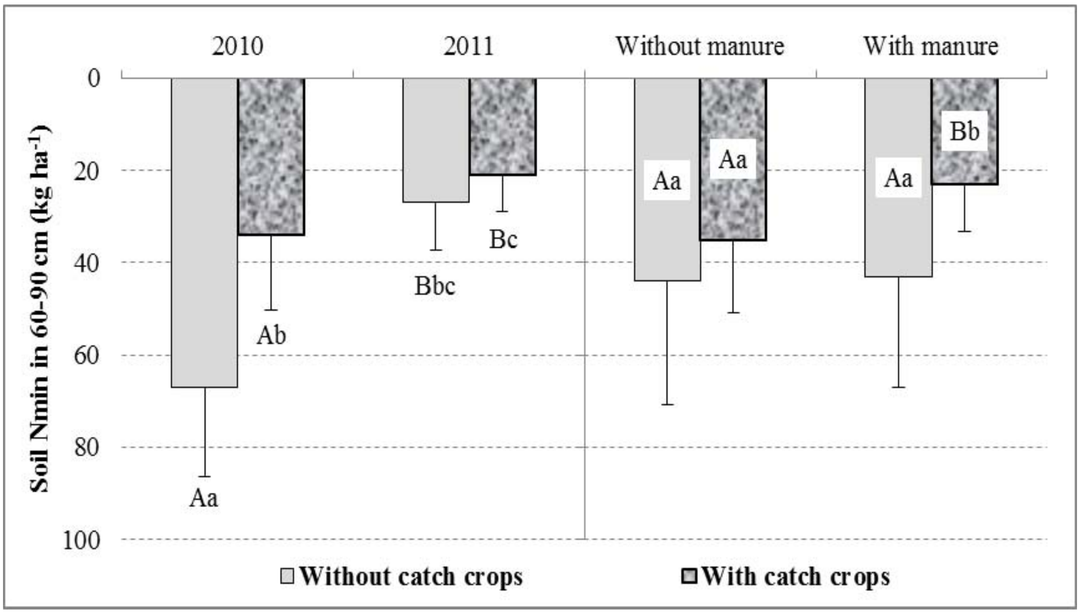
ANOVA table (Table 11) shows that the main differences of soil inorganic nitrogen contents in March sampling up to 90 cm and in June sampling to 30 cm soil profiles. Under the following potatoes, the early spring soil mineral N content was unaffected by the preceding crops. The inorganic nitrogen contents in the soil profile (0-90 cm) at pre-planting (Mid. March) varied from 216 - 260 kg N ha^{-1} for all treatments and there were no significant differences between other main factorial treatments (CC and M) in both years (Table 11 and Table 12).

Table 11: Significance levels for fixed factors and their interactions for soil inorganic nitrogen contents in March and June samples in 2010 - 2011

Effect	March				June
Depth	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30cm
Y	**	ns	**	**	**
PC	ns	**	+	ns	ns
PC*Y	ns	ns	ns	ns	ns
CC	ns	ns	**	ns	ns
M	ns	ns	**	ns	ns
CC*M	ns	ns	**	ns	ns
CC*Y	ns	ns	**	ns	ns
PC*CC	ns	ns	ns	ns	ns
M*Y	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns
PC*CC*Y	ns	ns	+	ns	ns
PC*M*Y	ns	ns	ns	ns	ns
CC*M*Y	ns	+	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns
PC*CC*M*Y	ns	ns	ns	ns	ns

See Table 9.

Variation in soil mineral N content under the main crop potato between cropping seasons indicated a greater influence of regional climatic conditions. There were mainly differences between the years (2010 and 2011) in 0-30 cm, and 0-90 soil profiles, moreover, some significant differences were found only in soil below layer (60-90 cm) for CC and M treatments. Furthermore, there were significant ($P < 0.01$) differences between the levels of soil inorganic nitrogen contents in treatments with catch crop or manure application in 60 - 90 cm soil profile (Table 11). Catch crops significantly decreased the soil inorganic nitrogen content in 60 - 90 cm soil profile for March sampling (Figure 5).



Error bars indicate standard deviations. Different capital and small letters below of the shapes indicate significant differences ($P < 0.05$) among years and catch crop treatments, respectively; Different capital and small letters inside of the shapes indicate significant differences ($P < 0.05$) among manure and catch crop treatments, respectively.

Figure 5: Catch crop*year and catch crop*manure interaction for soil inorganic nitrogen content in subsoils (60 - 90 cm depth) in March

Although, soil inorganic nitrogen content (NO_3^--N + NH_4^+-N) did not significant differ between pre-crop, catch crop and manure treatments in top soil (to 30 cm) and to 90 cm soil depths, therefore there had not their interaction effects. Significant two-way interaction effect ($P < 0.01$) occurred for catch crop*manure (CC*M) and catch crop*year (CC*Y) combinations on soil inorganic nitrogen in 60 - 90 cm soil profile only (Table 11 and Figure 5). This experiment shows that both the significant ($P < 0.01$) differences were found between the years on inorganic nitrogen content of the lower soil layers both in the without and with catch crop treatments. The soil mineral nitrogen content in subsoil was not influenced by catch crop treatment in without manure plot to the same extent as the manure applied plots. In March 2011, values in widely excess of 100 kg N ha^{-1} were found in top layer of the soil (Table 12).

Table 12: Soil N_{min} (NO_3^--N + NH_4^+-N) content in 0 - 90 cm depth of soil for potato fields as influenced by main effect preceding crop, catch crop, manure, and their interaction effects in two years

Sampling date	Effect	N_{min} content , (kg N ha^{-1}) March				June
		0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
PC	Lucerne	*111 ± 62^a	60 ± 23^{ab}	34 ± 16^a	239 ± 88 ^{a}	64 ± 22^a
	Field pea	106 ± 66^a	81 ± 51^a	42 ± 22^a	260 ± 117^a	62 ± 26^a
	Spring barley	105 ± 56^a	47 ± 17^b	32 ± 25^a	216 ± 77^a	69 ± 24^a
CC	-	103 ±58^a	65 ± 35^a	44 ± 25 ^{a}	242 ± 79^a	65 ± 24^a
	+	112 ± 64^a	61 ± 39^a	29 ± 14 ^{b}	234 ± 113^a	63 ± 24^a
M	-	105 ± 64^a	66 ± 42^a	40 ± 22^a	244 ± 105^a	65 ± 23^a
	+	110 ± 58^a	60 ± 31^a	34 ± 21^b	233 ± 88^a	65 ± 26^a
Y	2010	69 ± 18^b	64 ± 25^a	51 ± 24^a	168 ± 45^b	49 ± 18^b
	2011	146 ± 64^a	62 ± 43^a	26 ± 11^b	234 ± 93^a	82 ± 17^a
Y	CC					
2010	-	64^b	72^a	65.9^a	212^a	48^b
	+	73^b	56^a	35.6^b	165^a	48^b
2011	-	142^a	60^a	26.6^{bc}	228^a	83^a
	+	151^a	64^a	25.4^c	221^a	82^a
M	CC					
-	-	99^a	62^a	47.5^a	214^a	67^a
	+	110^a	70^a	35.7^b	229^a	63^a
+	-	107^a	68^a	46.3^a	228^a	64^a
	+	114^a	52^a	25.4^c	194^a	67^a

PC: preceding crop; CC: catch crop; M: manure. –: without, +: with CC or M; *: mean ± standard deviation. Mean values with the same letters for individual treatments (upper part) and for interactions (middle and lower part) within a column are not significantly different (P < 0.05).

There were almost similar results in 0 - 90 cm soil layer both catch crop or manure fertilized plots of 234 kg N ha^{-1} - 242 kg N ha^{-1} and 233 kg N ha^{-1} - 244 kg N ha^{-1}, accordingly. In addition, catch crop and manure application tended to reduce the soil mineral nitrogen content in deep soil (60 - 90 cm) layers (Table 12).

3.5.3. Soil nitrate nitrogen (NO_3^--N) content

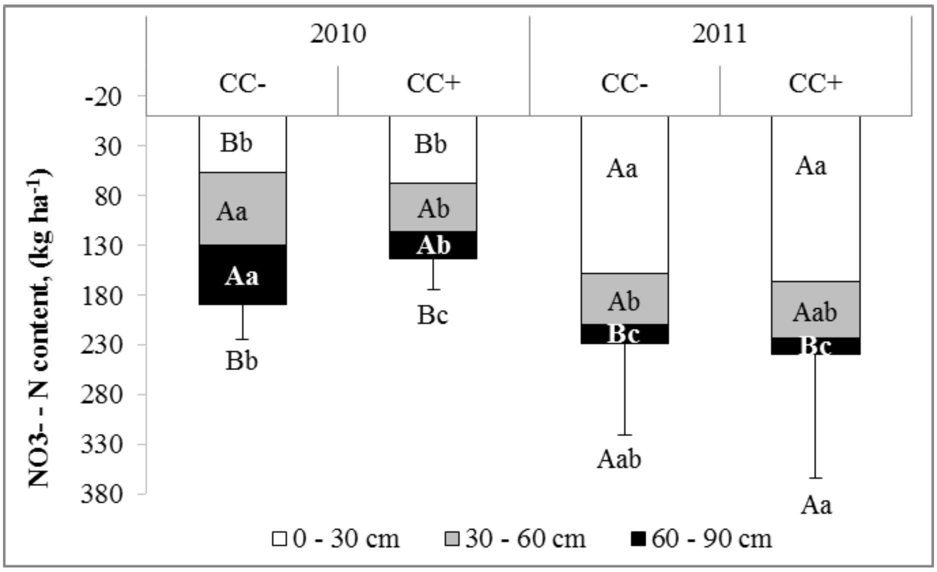
Based on two years average values, soil NO_3^--N content ranged from 196 to 236 kg N ha^{-1} in 0 – 90 cm soil profile in March. Table 13 shows the significance levels for fixed factors and their interactions for soil nitrate (NO_3^--N) nitrogen contents to 90 cm soil profiles on March and June sampling. Analysis of variance showed significant differences at 0-30 cm between years, but no significant interaction between catch crop and year (Table 13).

Table 13: Significance levels for fixed factors and their interactions for NO_3^--N content in March and June samples of two years (2010 - 2011)

Effect / Depth	2010-2011				
	March				June
	0-30cm	30-60cm	60-90cm	0-90cm	0-30cm
Y	**	+	**	ns	**
PC	ns	**	**	ns	ns
CC	+	**	**	**	ns
M	ns	ns	*	ns	ns
PC*Y	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	ns	ns
CC*Y	ns	**	**	**	ns
PC*CC	ns	ns	ns	ns	ns
M*Y	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns
PC*CC*Y	ns	ns	**	ns	ns
PC*M*Y	ns	ns	+	ns	+
CC*M*Y	ns	+	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns
PC*CC*M*Y	ns	ns	ns	ns	ns

See Table 9.

There were no pre-crop and manure treatment effect for the soil NO_3^--N content in the 0 - 90 cm soil profile. Just as with the soil NO_3^--N, the subsequent crop response to preceding crop was negligible. In top layer, the effect of the preceding crop on soil NO_3^--N was consistent for experimental two years, values of soil NO_3^--N varied closely for a given preceding crop in each year. There was significant (*P* < 0.01) difference between two catch crop levels; significantly lower soil nitrate nitrogen content was recorded in with catch plot than without catch crop in 0 - 90 cm depth (Table 13). Interaction effect between Y and CC was found for soil NO_3^--N content in 30 - 60 cm, 60 - 90 cm, and 0 - 90 cm soil profiles (Table 13). With a preceding crop field pea, soil $N0_3^-$-N content was a bite-size more than other two crops only in 2010. Nitrate N content of soil was varying greatly with depth. Upper soil layers (0 - 30 cm) usually had higher nitrate N content than lower soil layers (30 - 90 cm) (Table 13). The soil NO_3^--N content in 0 - 90 cm of soil profile varied from 142 to 190 kg ha^{-1} and from 212 to 262 kg ha^{-1} in 2010 and 2011, respectively (Table 5.2 in the annex), at pre-planting time in March. Generally, the catch crop decreased the level of soil nitrate nitrogen content to 90 cm soil depth at pre-planting time. There was significant interaction between catch crop and year on NO_3^--N content in 30 - 60 cm and 60 - 90 cm soil depths (Table 13 and Figure 6).



-CC: without catch crop; +CC: with catch crop. Error bars indicate standard deviations. Different capital and small letters indicate significant differences among years and treatments, respectively.

Figure 6: Catch crop and year interaction for NO_3^--N content in 0 - 90 cm soil profile in March

Significant (*P* < 0.01) differences between with and without catch crop plots for nitrate nitrogen were found in the lower soil profile depths (30 - 60 cm and 60 - 90 cm) in March. There was an interacting effect of pre-crop, catch crop and year on NO_3^--N content 60 - 90 cm depth (Table 13). The soil nitrate N remained significantly (*P* < 0.01) less in 2010 compared to 2011; the highest soil content reached to 162 kg N ha^{-1} in 0 - 30 cm soil depth in 2011, the lowest NO_3^--N content (62 kg N ha^{-1}) was measured in 2010 (Figure 6 and Table 14).This result relieved that the soil nitrate nitrogen content from 30 to 90 cm soil profile decreased by the catch crops in 2010 but not in 2011 (Figure 6). On the other hand, there was no significant effect found for soil nitrate N content in 0 – 30 cm soil profile in June. In 2011, overall of the top soils nitrate nitrogen contents were higher (over 100 kg N ha^{-1}) than in 2010 (Figure 6).

Table 14: Soil NO_3^--N content in 0 - 90 cm depth of potato fields as influenced by preceding crop, catch crop and manure application; average of two years (2010 - 2011)

Sampling date	Effect	NO_3^--N content , (kg N ha^{-1})				
		March				June
		0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
PC	Lucerne	*116 ± 76.4^{a}	52 ± 21^{ab}	28 ± 17^{ab}	216 ± 71^{a}	64 ± 22^{a}
	Field pea	111 ± 79.6^{a}	76 ± 49^{a}	37 ± 21^{a}	236 ± 98^{a}	62 ± 26^{a}
	Spring barley	110 ± 70.6^{a}	44 ± 20^{b}	26± 25^{b}	196 ± 63^{a}	69 ± 24^{a}
CC	-	108 ± 72.0^{a}	63 ± 31^{a}	39 ± 25^{a}	221 ± 66^{a}	65 ± 24^{a}
	+	117 ± 78.1^{a}	52 ± 39^{b}	22 ± 13^{b}	211 ± 93^{a}	63 ± 24^{a}
M	-	110 ± 77.3^{a}	59 ± 41^{a}	34 ± 23^{a}	222 ± 88^{a}	65 ± 23^{a}
	+	114 ± 73.1^{a}	56 ± 29^{a}	28 ± 20^{b}	211 ± 73^{a}	65 ± 26^{a}
Y	2010	62 ± 16.8^{b}	61 ± 24^{a}	44 ± 22^{a}	168 ± 36^{b}	37 ± 16^{b}
	2011	162 ± 64.8^{a}	54 ± 44^{a}	17 ± 8^{b}	201 ± 94^{a}	79 ± 17^{a}
Y	CC					
2010	-	57^{b}	73.0^{a}	59.8^{a}	189.7^{b}	48^{b}
	+	67^{b}	48.8^{b}	26.9^{b}	141.8^{c}	48^{b}
2011	-	158^{a}	52.1^{b}	17.9^{c}	228.6^{ab}	83^{a}
	+	167^{a}	55.6^{ab}	16.0^{c}	238.5^{a}	82

See Table 12.

In addition, nitrate nitrogen contents (NO_3^--N) were in the range of 92 - 136 kg N ha^{-1} after spring barley, 130 - 160 kg N ha^{-1} after lucerne and 140 - 189 kg N ha^{-1} after field pea to 90 cm soil layer, respectively in 2010. In 2011, the soil nitrate nitrogen content to 90 cm soil profile ranged from 211 to 240 kg N ha^{-1} after lucerne, from 253 to 279 kg N ha^{-1} after field pea and from 193 - 231 kg N ha^{-1}

after spring barley and there was no significant difference between them (Data not shown). No statistically significant responses of soil nitrate nitrogen content were found to catch crop, manure main factors and between their interactions in 2011 (Table 5.1 in the annex). Based on results, the two experimental years strongly affected for soil nitrate N content in upper soil layer (0 - 30 cm) at pre-planting and during the growing season. Nitrate nitrogen contents in 30 - 60 and 60 - 90 cm soil layers showed a significant ($P < 0.01$) effect of preceding crops in both years. In 30 - 60 cm and in 60 - 90 cm soil profiles nitrate nitrogen content varied from 44 to 76 kg N ha^{-1} and from 22 to 39 kg N ha^{-1}, respectively (Table 14). In 2010, when seasonal soil moisture levels (after incorporation of pre-crops biomass in August and after incorporation of catch crops biomass in November) were enough, relatively high soil nitrate nitrogen content accumulated in the upper soil layer in the spring of 2011. The lower soil layers (30 -60 cm and 60 - 90 cm) in plots after field pea usually had higher nitrate nitrogen contents than the after lucerne and spring barley preceding crops (Table 14).

3.5.4. Ammonium nitrogen (NH_4^+ - N) content

Table 15 presents the significance levels and interaction effects for the soil ammonium nitrogen (NH_4^+ - N) content (kg N ha^{-1}) to 90 cm soil profiles in potato fields as influenced by preceding crop, catch crop and manure application in 2010 - 2011.Years significantly ($P < 0.01$) affected for soil ammonium nitrogen content in 0- 30 cm soil depth in June (Table 15). On average, significantly higher ($P < 0.01$) soil ammonium N was occurred in 2010 in top (0 - 30 cm) soil depth with the amount of 11.5 kg N ha^{-1} (Data not shown). In this study, soil NH_4^+-N content at pre-planting (in March) and during of growing season (in June) were lightly variable among factorial treatments and years, with 0 - 30 cm soil profile having values of 6.6 - 7.8 kg N ha^{-1} at pre-planting and 3.5 - 13.6 kg N ha^{-1} at planting time (Data not shown). Mean soil (NH_4^+-N) contents were similar values among years; there was also no significant effect of preceding crop, catch crop, and manure on soil NH_4^+ - N content at pre-planting and at growing period in 2010 or 2011 (Table 6.1 in the annex). Although, subsoil profiles (from 30 cm to 90 cm) did not show any significant effects by factorial treatments and their interactions for NH_4^+-N content (Table 15).

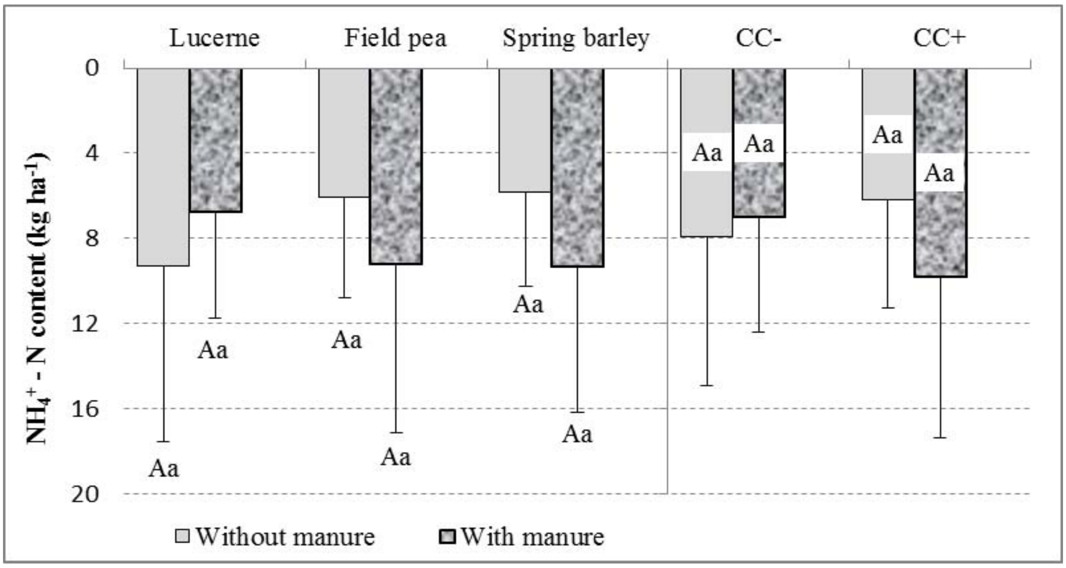
Table 15: Significance levels for fixed factors and their interactions for NH_4^+ - N content and soil inorganic nitrogen contents in March and June samples of two years average

Effect / Depth	March				June
	0-30cm	30-60cm	60-90cm	0-90cm	0-30cm
Y	ns	ns	ns	ns	**
PC	ns	ns	ns	ns	ns
PC*Y	ns	ns	ns	ns	ns
CC	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns
CC*M	+	ns	+	ns	ns
CC*Y	ns	ns	ns	ns	ns
PC*CC	ns	ns	ns	ns	ns
M*Y	ns	ns	+	ns	ns
PC*M	+	ns	ns	ns	ns
PC*CC*Y	ns	ns	ns	ns	ns
PC*M*Y	ns	ns	ns	ns	ns
CC*M*Y	ns	ns	ns	ns	ns
PC*CC*M	ns	+	ns	ns	ns
PC*CC*M*Y	ns	ns	ns	ns	ns

See Table 9.

A trends of interaction effects between manure and catch crop, between manure and previous crop occurred in 0 - 30 cm soil depth for soil ammonium N content in March sampling (Table 15), while soil ammonium N content of manure fertilized plots following field pea and spring barley was greater (approx. 30 %) than following lucerne (5.9 t ha^{-1}).

Figure 7 shows that soil NH_4^+ - N contents were lower following pea (6.2 t N ha^{-1}) and spring barley (5.3 t N ha^{-1}) in unfertilized plot than manured plots (9.2 - 9.3 6.2 t N ha^{-1}). However, that result shows only a trend at 10 % level of probability. Soil ammonium N content was greater within catch crop (9.1 t ha^{-1}) as compared to without catch crops treatment (6.4 t ha^{-1}) in manured plot.



-CC: without catch crop; +CC: with catch crop. Error bars indicate standard deviations. Different capital and small letters below the shapes indicate significant differences among pre-crop and manure treatments, respectively; Different capital and small letters center of the shapes indicate significant differences ($P < 0.01$) among manure and catch crop treatments, respectively.

Figure 7: Ammonium nitrogen content in 0 - 30 cm soil depth affected by manure, catch crops and previous crops in March

Therewith, soil NH_4^+ - N was unaffected by catch crop and the result shown in the opposite trend in un-manured treatment.

3.6. The effects of preceding crop, catch crop and manure on tuber yield and quality of main crop potatoes

Potato yield, size distribution, and grade were not significantly affected by pre-crop treatments with "Ditta" cultivar tested over the two experimental years. Table 16 shows preceding crop, catch crop and manure main effects in 2010 - 2011 for tuber total, marketable fresh matter and dry matter yields at harvest timing. The experimental year had a significant effect on total tuber (TT) fresh matter yield. The preceding crop, catch crop and manure application had no significant effect on tuber fresh matter and marketable (MT) yields. Total and marketable tuber fresh matter and tuber dry matter yields in 2011 differed significantly ($P < 0.01$) from the yields in 2010. Tuber size, shape, appearance, absence of diseases or defects, and ingredient contributed to potato quality (Table 17 - Table 20). The tubers contained very few internal defects in the two experimental years (2010 and 2011) (data not shown). Differences between preceding crops as regards percentage of potato virus Y, common scab in the tuber yield did not reach statistical significances. However, growing years significantly affected the percentage of tubers with potato virus Y (Table 19). The value of tubers, which is detected virus Y was significantly (P < 0.05) greater (2.5 % of total tuber yield) in growing season 2011 than in 2010 (Table 20). In addition, the tuber wireworm was observed (1.7 - 2.9 %; data not shown) only in 2011; in case non-significant treatment effects were found for percentage of wireworm in total tuber fresh matter yield. Year effect had influence on external tuber quality such as green tubers, malformed tubers, and total culls in the total tuber yield.

3.6.1. Total and marketable tuber fresh matter yield

The significance levels of the main factors preceding crop, catch crop and manure, their interaction effects on potato total tuber yield of two years average values (2010 - 2011) are presented in Table 16. Tuber initiation occurred in late June and early July in both seasons (2010 & 2011). The growing years significantly (P < 0.01) affected total tuber fresh matter yield. A relatively higher tuber total fresh matter production was recorded in 2011 (43.3 tones ha^{-1}) than in 2010 (26.0 tones ha^{-1}) (Table 17). The main reason the yields were much less in 2010 than 2011 may be the soil inorganic nitrogen availability in top soil during the early growing season (Table 17 and Table 12).

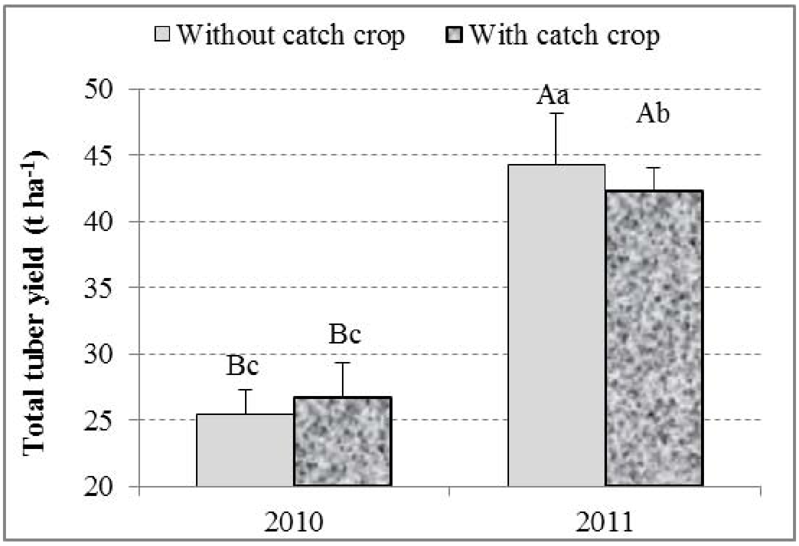
Total fresh tuber yield: Total tuber fresh matter yield varied from 25.0 to 26.8 and from 40.8 - 43.4 tones ha^{-1} in 2010 and in 2011, respectively (Table 7.2 in the annex). Total yield was significantly greater with high soil N availability in 2011 than with low soil N in 2010. Over 100 kg N ha^{-1} soil nitrate N content in the main plant rooting zone of soil (0 - 30 cm) was preferable for potato tuber yields, while the total tuber and MT yield were relatively great due to high (163 kg N ha^{-1}) soil NO_3^--N content (Table 14) in 2011. The total fresh tuber yields after three different pre-crops and two levels of catch crop were statistically non-significant (P > 0.05). A significant (P < 0.01) interaction between catch crop and year was observed on total tuber yield; while yield of potatoes in 2010 was greater following green manure catch crop than bare fallow, yield was unaffected by catch crop in 2011 (Table 17 and Figure 8). Also, no significant difference was observed among manure treatments for potato fresh tuber yields at the harvest (Table 16).

Table 16: Significance levels for fixed factors and their interactions for potato tuber yield, tuber DM content and tuber nitrate N uptake average of two years (2010 - 2011)

Parameters/ effects	TTY ($t\ ha^{-1}$)	MTY ($t\ ha^{-1}$)	DMY ($t\ ha^{-1}$)	DM content (%)	NO_3^- uptake (tones ha^{-1})
Y	**	**	**	**	+
PC	ns	ns	ns	ns	+
CC	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns
PC*Y	ns	ns	ns	+	ns
CC*M	ns	ns	ns	ns	ns
CC*Y	**	+	**	ns	ns
PC*CC	ns	ns	ns	ns	ns
M*Y	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	**	ns
PC*CC*Y	ns	ns	ns	ns	ns
PC*M*Y	ns	ns	ns	ns	ns
CC*M*Y	ns	ns	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns
PC*CC*M*Y	**	ns	+	ns	+

TTY: total tuber yield; MTY: marketable yield; DMY: dry matter yield; DM conc.: DM concentration; see Table 9.

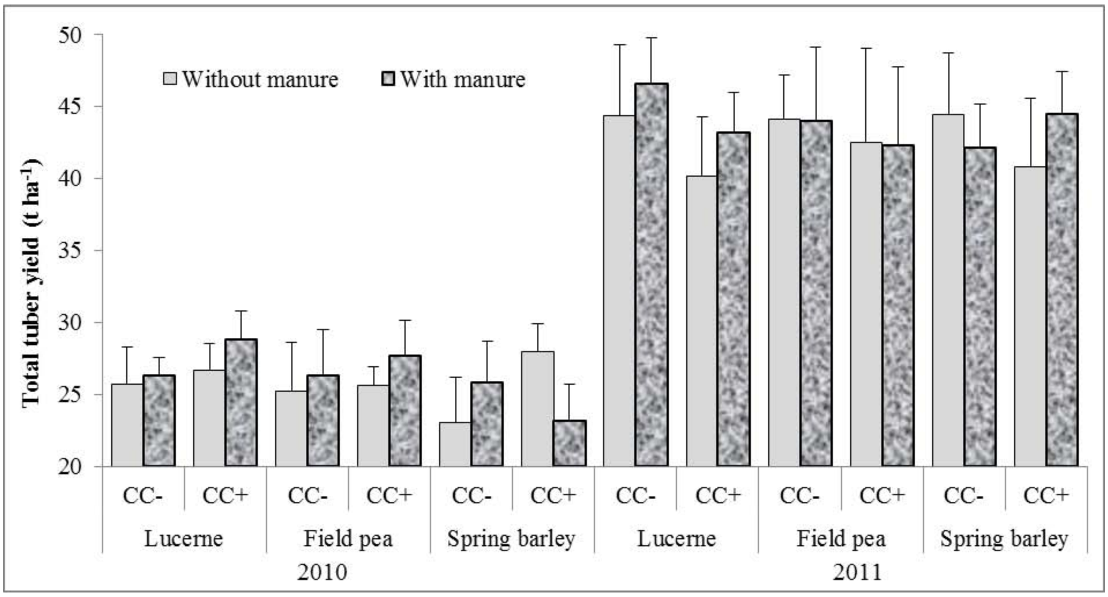
Interaction effect among year and catch crops were found non-significant at harvests on tuber marketable yield. Thereat, a positive trend occurred on catch crop treatment for marketable tuber yield in 2010 only, whereas did not any influence observed on catch crop treatment in 2011 (Table 16). Besides, a significant four-way interaction effect was found for PC*CC*M*Y on tuber total fresh matter yield at harvests in both years (Table 16 and Figure 9).



Error bars indicate standard deviations. Different capital letters indicate significant differences among years. The same small letters indicate not significant differences ($P < 0.01$).

Figure 8: Potato total tuber yield affected by catch crop and year

The significant four-way interaction effect (PC*CC*M*Y) is complex and difficult to interpret. Figure 9 shows that potato total tuber yield was significantly increased in plots, which were amended with the combination of catch crop and manure application following lucerne and field pea crops in 2010, but no such influence in 2011.



CC-: without catch crop; CC+: with catch crop. Error bars indicate standard deviations.

Figure 9: Potato tuber total yield affected by preceding crop, catch crop, manure and year

Therewith, manure had a positive effect on total tuber yield after spring barley in "without catch crop" treatment in 2010 and negative effect in 2011.

Marketable tuber yield: The marketable tuber yield ranged from 19.5 to 23.8 tones ha^{-1} and from 30.5 to 38.3 tones ha^{-1} in 2010 and in 2011, respectively (Table 7.3 in the annex). The marketable tuber yield was significantly influenced (P > 0.01) by year also. The significantly higher marketable tuber yield was produced (34.0 tones ha^{-1}) in 2011 than 2010 (21.5 tones ha^{-1}) (Table 17).

On averages, the catch crops and manure application did not affect potato marketable fresh matter tuber yields (Table 16). In 2010, there was found only a positive trend for catch crop treatment, which slightly increased total tuber yield from 25.4 tones ha^{-1} to 26.6 tones ha^{-1}, on the contrary the total tuber yield was not positively affected by catch crop in 2011 (Table 17). In addition, a significant interaction among preceding crop, catch crop and manure was found on tuber total and marketable yield in 2010 only (Table 7.1 in the annex). In green and farmyard manure applied plots, a total tuber yield was significantly higher after lucerne pre-crop (28.8 tones ha^{-1}) than following spring barley (23.1 tones ha^{-1}) in 2010 (Table 7.3 in the annex). The tuber yields of main crop following lucerne, field pea and spring barley preceding crops showed similar results by two years mean (Table 17).

Table 17: Effect of manure and growing years on potato tuber yield and some interaction effects between experimental factors

Parameters/ effects		TTY	MTY	DMY	DM content
		(tones ha^{-1})			(%)
Year	2010	*26.0 ± 2.7^{b}	21.5 ± 2.6^{b}	5.1 ± 0.6^{b}	19.5 ± 1.7^{a}
	2011	43.3 ± 4.4^{a}	34.0 ± 4.5^{a}	8.0 ± 1.0^{a}	18.0 ± 1.0^{b}
Y	CC	TTY	MTY	DMY	DM content
2010	-	25.4^{c}	21.1	4.9^{c}	19.3
	+	26.7^{c}	21.8	5.2^{c}	19.7
2011	-	44.3^{a}	35.1	8.3^{a}	18.4
	+	42.3^{b}	33.0	7.8^{b}	18.7

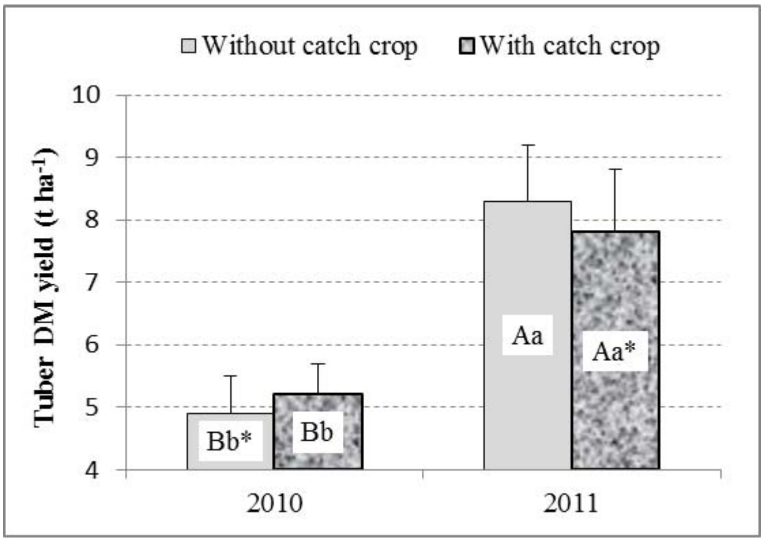
See Table 16; Y: year; CC: catch crop; *: mean ± standard deviation. Mean values with the same letters for individual treatments (upper part) and for interactions (lower part) within a column are not significantly different ($P < 0.05$).

The marketable tuber yield varied from 26.6 to 28.5 tones ha^{-1}, following various preceding crops (Table 7.3 in the annex). In individual years (2010 and 2011), the tuber yields were similar amount of fresh matter in plots with and without catch crop. The pre-crop spring barley showed an opposite effect on total tuber yield in the above mentioned plots in both years. Detailed results of studies on tuber yield from both years at harvest are presented in tables 7.1 -7.3 (see the in annex).

3.6.2. Tuber dry matter content and DM yield

Tuber dry matter content: The potato tuber dry matter concentration and yield varied from 18.0 to 19.5 % and 5.1 to 8.0 tones ha^{-1}, respectively, in the trail treatments (Table 17). Years significantly ($P < 0.01$) affected on tuber DM content and DM yield. A significant two-way interaction effect between pre-crop and manure application was detected in the dry matter content of potato tubers (Table 16). Interaction among preceding crop, catch crop and manure were non-significant at harvests however, an interaction trend ($P < 0.10$) was observed between preceding crop and year on tuber DM content in this study (Table 16). A higher tuber dry matter content was found in 2010 (19.5 %) than in 2011 (18.0 %), however a significantly ($P < 0.01$) higher DM yield accumulated during the 2011 growing season than in 2010, which had 8.0 tones ha^{-1} and 5.1 tones ha^{-1}, respectively. The tubers with manure treatments had slightly higher DM content than without manure treatments (Table 17).

Tuber dry matter yield: In the present study, the catch crop and manure effect on potato tuber dry matter yield had been well recorded only in 2010, when high soil NO_3^--N availability was reduced by catch crop in 0 - 30 cm soil depth (Table 7.1 and 7.2 in the annex). While the residual effects of catch crop and manure applications significantly increased tuber DM yield in 2010, they did not significantly affect tuber yields in 2011. There were similar values of DM yield measured for pre-crops lucerne, field pea and spring barley. The data of two years average showed that catch crops had non-significant effect on the tuber dry matter productivity. The mean yields interacted by catch crop and growing years are shown in Table 17**.** The year alone significantly affected on tuber dry matter yield, on the assumption the interaction between the year and catch crop treatment had a significant effect on DM yield. Furthermore, manure effect also no influenced for the tuber DM yield over the two seasons (Table 16). Figure 10 displays above mentioned significant two-way interaction effect on potato tuber dry matter yield.



Error bars indicated standard deviations. Different capital and small etters indicate significant differences ($P < 0.01$) among years, small letters with and without * indicate interaction trend at 10 % level of probability, respectively.

Figure 10: Potato tuber dry matter yield affected by catch crop and year

The catch crop treatment had no significant effect on tuber DM yield at harvest in 2011, however indicating a significant CC*Y interaction (Table 16 and Figure 10). Tuber dry matter yield showed a significant advantage of manure treatments only in 2010 (table 7.2 in the annex). The tuber dry matter yield significantly ($P < 0.05$) increased by catch crop, but it was occurred in 2010 (Figure 10) there was a higher value (5.2 tones ha^{-1}) within catch crop treatment and a lower (4.9 tones ha^{-1}) in without catch crop plot (Table 7.2 in the annex). In 2011, factorial treatments for tuber DM yield did not differ significantly. On averages over two years, the manure application had no significant impacts on tuber dry matter yield (Table 16). 6.8 tones ha^{-1} and 6.4 tones ha^{-1} of tuber dry matter yields were produced in the manure applied and un-manured plots, respectively. Applied manure gave tuber dry matter yield increases in 2010 but no significant DM yield increases in 2011 (Table 7.2 in the annex).

3.6.3. Tuber size distribution

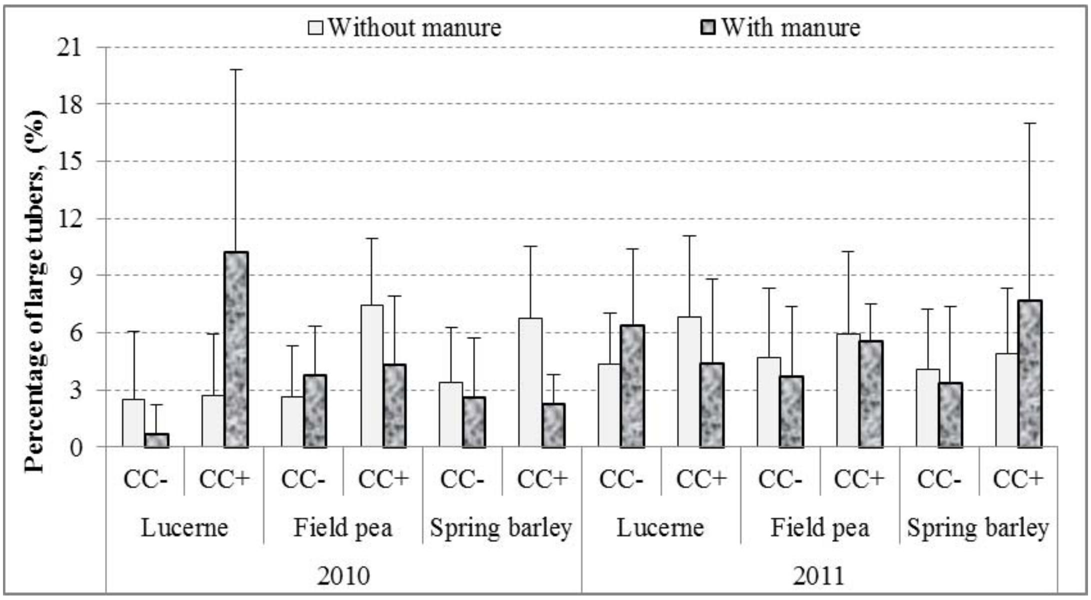
The percentage of tuber yield in diameter less than 35 mm size class, in diameter between 35 mm and 65 mm size class and in diameter more than 65 mm size class ranged from 3.5 to 27.7 %, from 66.0 to 93.0 %, and from 0.4 to 9.8 %, respectively. The year and catch crop effects significantly ($P < 0.01$) influenced tuber size classes.

Table 18: Significance levels for fixed factors and their interactions for potato tuber size classes; average of two years (2010 - 2011)

Parameters/ effects	Ø < 35	Ø 35 - 65 mm, (%)	Ø > 65	Ø < 35	Ø 35 - 65 mm, (t ha^{-1})	Ø > 65
Y	**	**	ns	**	**	ns
PC	ns	ns	ns	ns	ns	ns
CC	ns	**	**	ns	ns	**
M	ns	ns	ns	ns	ns	ns
PC*Y	ns	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	ns	ns	ns
CC*Y	**	ns	ns	**	**	ns
PC*CC	ns	ns	ns	ns	ns	ns
M*Y	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns	ns
PC*CC*Y	ns	ns	ns	ns	**	ns
PC*M*Y	+	ns	ns	ns	ns	ns
CC*M*Y	ns	ns	ns	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns	ns
PC*CC*M*Y	ns	ns	**	ns	ns	**

Ø: tuber diameter; see Table 9.

Differences among years were significant for small (Ø < 35 mm) and medium sized (Ø = 35 - 65 mm) tubers (Table 18). Percentage of small tubers (< 35 mm in diameter) was measurably increased in 2011 (25.6 %) compared with 2010 (4.7 %). In this study, the percentage of small sized tubers and total yield increased as soil inorganic nitrogen increased. Also, significant ($P < 0.01$) differences were found between without catch crop (81.8 %) and with catch crop treatment (78.7 %) for percentage of medium sized tubers (Ø 35 - 65 mm in diameter), while tuber grades did not differ depending on manure application. A higher percentage of large tubers (> 65 mm in diameter) was recorded in with catch crop treatment (5.7 %) compared to without catch crop treatment (3.5 %). There were no significant differences of three size classes on the tuber grade after various preceding crops. Nevertheless, statistically significant response of large sized tubers was found to complete interactions between main factors (Table 18 and Figure 11).



CC-: without catch crop; CC+: with catch crop. Error bars indicate standard deviations.

Figure 11: Rate of large sized potato tubers yield affected by preceding crops, catch crop, manure and year

The percentage of large tubers increased by catch crop and manure combination following lucerne crop, also that effectuality observed by catch crops following field pea and spring barley pre-crops in 2010, but those influences did not occurred in 2011 (Figure 11). The applied manure had no significant effect on the yield of tuber size grades at harvest in both years. There was also non-significant manure effect for percentage of medium tuber yield in both years (Table 18). In summary, for the average of 2010 and 2011, green manure catch crop contributed higher to higher tuber quality (large tubers) than potatoes following a bare fallow system. There was a significant interaction effect between year and catch crop for the tuber size class less than 35 mm in diameter (Table 18 and Table 15). The only significant treatment effect for percentage of small-sized tubers was observed in 2010 when non-legume/mixture was included as a catch crop. There occurred no noticeable differences between with and without catch crop treatments in 2011 (Table 18 and Figure 11). On averages, the non-significant two-way interaction effects PC*CC, PC*M and CC*M were for medium and large sized tubers at harvests in both years (Table 18). Table 19 shows the potato tuber size class distribution on the average of two years (2010 - 2011) after various preceding and catch crops, also with manure l

Percentages of small tubers (< 35 mm in diameter), which averaged 15.7 % following lucerne, 14.8 % after field pea, and 15.0 % after spring barley, were not influenced by preceding crop in each year.

Table 19: Effect of experimental factor catch crop and growing years on potato tuber size classes and CC*Y interaction effect

Parameters/ effects		Ø ≤ 35 mm	Ø 35 - 65 mm	Ø ≥ 65 mm
		(%)		
Year	2010	*4.7 ± 1.4[b]	91 ± 4.1[a]	4 ± 4.4[a]
	2011	25.6 ± 4.8[a]	69 ± 5.2[b]	5 ± 4.4[a]
CC	-	15 ± 10.1[a]	81.8 ± 11.2[a]	3.5 ± 3.1[b]
	+	16 ± 12.1[a]	78.7 ± 12.8[b]	5.7 ± 5.2[a]
Year	**Catch crop**	**Ø ≤ 35 mm**	**Ø 35 - 65 mm**	**Ø ≥ 65 mm**
2010	-	5.1[c]	92.3[a]	2.6[b]
	+	4.2[c]	90.4[a]	5.4[a]
2011	-	24.2[b]	71.4[b]	4.4[ab]
	+	27.0[a]	67.2[c]	5.9[a]

Ø: Tuber diameter; *: mean ± standard deviation. Mean values with the same letters for individual treatments (upper part) and for interactions (lower part) within a column are not significantly different ($P < 0.05$).

The preceding crops also led to similar effects on percentage medium (tuber size class in diameter 35 - 65 mm) and of large tubers (> 65 mm in diameter) of potato tuber yield by 79.6 - 80.8 % and 4.2 - 4.8 %, accordingly (Data not shown).There were recorded no significant effect for the percentage of tuber size class in diameter < 35 mm, which averaged 14.7 % following without CC and 15.6 % with catch crop treatments (Table 19). The percentage of large tubers was influenced by catch crop, with a significantly greater percentage (5.7 %) of tubers for within catch crop, compared to the without CC (3.5 %) treatment (Table 19). In 2010, the percentage of small (< 35 mm in diameter) tubers in the catch crop treatment had a significantly lower value (4.2 %) compared with percentage of tubers in this size class in without catch crop treatment (5.1 %), there almost similar values were in 2011 (Table 19).

3.6.4. Tuber specific gravity

Specific gravity of potatoes is an important determinant of harvest quality. Specific gravity, which averaged 0.991 g cm^{-3} for after lucerne, 0.994 g cm^{-3} for after field pea and 0.996 g cm^{-3} for after spring barley, that was not influenced by preceding crop. Similar findings occurred for catch crop and manure application, there was only a positive trend ($P < 0.10$) found by catch crop and M (Results not shown).

3.6.5. Potato virus Y

The main effects for potato tuber virus disease (PVY), growth cracked tubers, malformed, green and misshapen tubers on total yield in both years are presented in Table 20. The effects of preceding crop, catch crop, manure application on tuber quality, namely, on the percentage of PVY, varied from 0.2 to 3.1 % in total tuber yield over the two years (Table 21). The proportion of damaged tubers was relatively low in both years, but the tuber PVY significantly affected by growing season, in particular, the percentage of potato virus Y significantly increased in 2011, presumably attributable to increased average air temperature during the whole growing season (Table 1 in the annex). PC, CC and manure treatments did not have a significant effect; therefore non - significant interaction was among the main factors for potato virus Y in both years.

3.6.6. Common scab

Based on two years average, the percentage of common scab (CS) varied from 0.02 to 0.09 % (data not shown). There were no differences among preceding crops, with and without catch crop treatments also manured and un-manure treatments for potato CS in both years (Table 20). Interactions between pre-crop and catch crop (PC*CC) or between pre-crop and manure (PC*M) were found non - significant. There were no interaction effects between year and main factors, also.

3.6.7. Corky ring spot

In both years, no statistically significant differences occurred in the percentage of tubers with corky ring spot (CRS) according to the three different preceding crops. There were no differences among with and without catch crop or manure treatments for potato CRS in any year (data not shown).

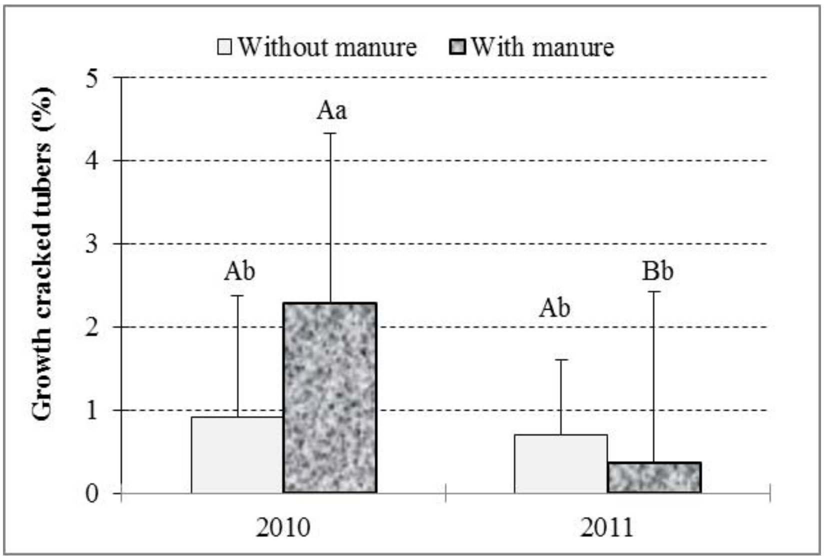
Table 20: Significance levels for fixed factors and their interactions for potato tuber virus disease (PVY), common scab, growth cracked, malformed, green tubers and total culls

Parameters/ effects	PVY, (%)	Common scab, (%)	MF tubers, (%)	Green tubers, (%)	GC tubers, (%)	Total culls, (%)
Y	**	+	*	**	**	**
PC	ns	ns	ns	ns	ns	ns
CC	ns	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	+	ns
PC*Y	ns	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	*	ns	ns
CC*Y	ns	ns	ns	ns	ns	ns
PC*CC	ns	ns	+	ns	ns	ns
M*Y	ns	ns	ns	ns	**	ns
PC*M	ns	ns	ns	ns	ns	ns
PC*CC*Y	ns	ns	ns	ns	ns	ns
PC*M*Y	ns	ns	ns	ns	ns	+
CC*M*Y	ns	ns	*	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns	**
PC*CC*Y*M	ns	ns	ns	ns	ns	ns

PVY: potato virus Y; MF: malformed; GC: growth cracked; see Table 9.

3.6.8. Growth cracked tubers

The percentage of growth cracked tubers in total tuber yield varied from 0.4 to 2.5 % over two years (Table 21). Growth cracked tuber was slightly influenced by manure application, there was only significant (P < 0.10) trend observed (Table 20). The significant two-way interactions were detected between year and manure application in the proportion of growth cracked tubers (Table 20 and Figure 12). Manure treatments differed significantly (P < 0.05) in producing growth cracked tubers in 2010, but not in 2011.



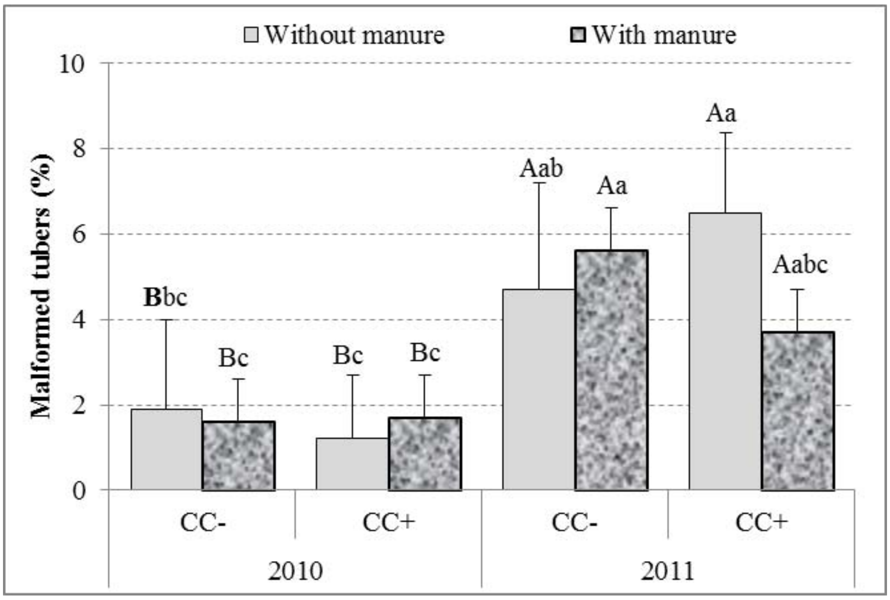
Legend: Error bars indicated standard deviations. Different capital and small letters indicate significant differences (P < 0.05) among years and treatments, respectively.

Figure 12: Potato growth cracked tubers affected by manure treatment and year

In the manured plots 2.3 % of growth cracked tubers were observed, which was significantly more than as compared to the growth cracked tuber percentage of 0.9 % without manure treatment in 2010 (Figure 12).

3.6.9. Malformed tubers

The percentage of malformed tubers was increased in 2011 compared with 2010 (Table 21). It could be explain that, applying a moisture stress to potato plants during the tuber maturity set period (in August, 2011; Figure 2) increased the percentage of malformed tubers with bottlenecks shapes. Based on two years' average, the significant three-way interaction effect was found between catch crop, manure and year (P < 0.01) for malformed tubers (Table 20 and Figure 13). In 2011, tuber quality such as malformed tubers responded to manure treatment compared to without manure. In this year (2011), with manure plots had a positive impact on tuber quality, when a catch crop incorporated as green manure, but in bare fallow system not (Figure 13).



-CC: without catch crop; +CC: with catch crop. Error bars indicated standard deviations. Different capital and small letters indicate significant differences (P < 0.05) among years and treatments, respectively.

Figure 13: The percentage of malformed tubers affected by year, catch crop and manure

In 2010, percentage of malformed tubers in total tuber yield was relatively low approximately less than 2 % in overall (Figure 13 and Table 21).

3.6.10. Green tubers

Based on two years average, percentage of green tubers ranged from 4.1 (after barley) to 5.7 % (after field pea). Differences among pre-crop, catch crop and manure treatments were found non-significant for green tubers in both years (Table 20). Significantly highest percentage of the green tubers was recorded with 7.7 % in 2011, whereas the lowest percentage of green tubers of 0.8 % was found in 2010 (Table 21). Averaged on results, the significant (P < 0.05) two-way interaction effect was between catch crop and manure main factors (CC*M) for the percentage of green tuber (Table 20).

The catch crop effect slightly increased the green tubers in the without manure treatment only; other words, a negative manure effect occurred on tuber quality in the manure applied treatment. The data in the Table 21 shows that in 2010, the percentage of green tubers was lowest (0.8 % of total tuber yield) and comparatively increased in 2011 (7.7 %). There were no other noticeable differences in external quality between the treatments.

Table 21: Effect of some experimental factors and their interaction effects on tuber quality

Parameter/		Effect	PVY (%)	MF tuber (%)	Green tuber (%)	GC. tuber (%)
Y		2010	*0.4 ± 1.9^{b}	1.6 ± 1.4^{b}	0.8± 0.9^{b}	1.6 ± 1.9^{a}
		2011	2.5 ± 0.8^{a}	5.1 ± 3.3^{a}	7.7 ± 4.4^{a}	0.5 ± 0.8^{b}
Y		M				
2010		-	0.4^{b}	1.5^{b}	0.8^{b}	0.9^{b}
		+	0.5^{b}	1.6^{b}	0.9^{b}	2.3^{a}
2011		-	2.6^{a}	5.6^{a}	7.1^{a}	0.7^{b}
		+	2.4^{a}	4.6^{a}	8.3^{a}	0.4^{b}
Y	CC	M				
2010	-	-	0.2^{b}	1.9^{bc}	0.7^{b}	1.4^{ab}
		+	0.4^{b}	1.6^{c}	1.0^{b}	2.5^{a}
	+	-	0.5^{b}	1.2^{c}	1.0^{b}	0.4^{b}
		+	0.6^{b}	0.8^{c}	0.8^{b}	2.1^{a}
2011	-	-	2.2^{a}	4.7^{ab}	6.4^{a}	0.5^{b}
		+	2.0^{a}	5.6^{a}	8.4^{a}	0.4^{b}
	+	-	3.1^{a}	6.5^{a}	7.7^{a}	0.9^{ab}
		+	2.8^{a}	3.7^{abc}	8.2^{a}	0.4^{b}

See Table 10 and Table 20; Mean values with the same letters for individual years (upper part) and for interactions (middle and lower part) within a column are not significantly different ($P < 0.05$).

3.6.11. Total culling

Reduction in marketable yields from total tubers varied substantially between years, with losses more apparent in 2011 than 2010. The percentage of tubers with potato virus Y, common scab, malformation, growth cracks and greening was reduced in 2010. In the manured plots 2.28% of growth cracked tubers were observed, which was significantly ($P < 0.01$) more than as compared to the growth cracked tuber percentage of 0.98 % without manure. The interaction terms for the pre-crop, catch crop and manure main effects were significant differed ($P < 0.01$) for total culling (Table 20 and Table 22).

Tubers contained very few internal defects in both years. There was a non-significant tuber discard by preceding crop, catch crop and manure application effects on yield (Table 20). Hugely, the growing seasons significantly influenced the incidence of total cull. The percentage of total culls was significantly (P < 0.01) higher in 2011 (21.5 %) compared with 2010 (13.2%) growing season (Table 22).
Generally, percentage of total culls for tuber yield was no influenced by legume lucerne and field pea or cereal spring barley pre-crops.

Table 22: Interaction effect of some experimental factors and effect of growing years on total cull of tuber yield

Parameter/ Effect			Total cull on the tuber yield (%)	
			Without catch crop	With catch crop
Pre-crop:	Lucerne	Without manure	21.6^{a}	17.5^{ab}
		With manure	13.1^{b}	21.1^{a}
	Field pea	Without manure	15.2^{ab}	19.1^{ab}
		With manure	20.0^{a}	15.1^{ab}
	Spring barley	Without manure	13.5^{b}	17.4^{ab}
		With manure	16.0^{ab}	16.9^{ab}
Year			2010	2011
Mean ± standard deviation			13.2 ± 5.3^{B}	21.5 ± 7.8^{A}

The values with the same letters within a column are not significantly different (P < 0.05). The values with the different capital letters within a row are significantly different (P < 0.05).

The catch crop and manure treatments together slightly enhanced the total tuber culling following lucerne; however that amount reduced in manure plots following field pea. But, as figured above, the increases in total culling were accompanied by increases in with manure treatment after field pea and spring barley. In without catch crop plot after lucerne, tuber total culls (21.6 %, on average across treatment) were 29.6 % - 37.5 % higher than average values in the after filed pea and spring barley plots, respectively (Table 22).

3.7. Effects of preceding crop, catch crop and manure on potato starch content, nitrate uptake, nitrogen use efficiency and apparent nitrogen recovery

Tuber nitrate N uptake during the two growing seasons as well as apparent N recovery (ANR) and N use efficiency (NUE) were used to compare the final performance of catch crops or manure application and control treatments (without CC and without M) after three different pre-crops in the field trail (Table 25). There were generally no consistent tuber yield benefits from N in catch crop and manure in both years. The effect of main factors on subsequence crop potato tuber N content was described in Table 24. The effect of legume pre-crops on tuber N concentration and N accumulation were statistically non-significant at harvest maturity. Catch crop for green manure and farmyard manure in both years had no influence on potato tuber yield after preceding crops (Table 24).

3.7.1. Tuber starch content

Growing years significantly ($P < 0.05$) affected potato tuber starch content (Table 24). A statistically higher value was observed in 2011 with 18.6 % compared to 14.7 % in 2010 (**Error! Reference source not found.**). No effect of preceding crop and no consistent effect of catch crop and manure on tuber starch content were established; also no significant interactions between main effects (PC, CC, M) and year were found (Table 24).

3.7.2. Tuber Nitrate N content and N accumulation

The significantly ($P < 0.01$) highest nitrate nitrogen uptake by tubers was found in 2010, and the lowest was recorded in 2011. The accumulated nitrate N (dry weight) during the growing period represented 955 mg kg^{-1} and 469 mg kg^{-1} in 2010 and 2011, respectively.

Table 23: Potato tuber starch content and tuber NO_3^--N uptake in both years

Parameters/ Effect	Starch content (%)	NO_3–N concentration (mg N kg^{-1})	NO_3–N accumulation (mg N kg^{-1})
Year: 2010	14.7 ± 0.7^b	190 ± 188^a	955 ± 260^a
2011	18.8 ± 1.0^a	91 ± 49^b	469 ± 252^b

The nitrate N content of potato tuber was measured once after harvest; See Table 22.

The data in the Table 23 indicates that the catch crop and manure main effects did not influence tuber nitrate nitrogen concentration and nitrate N accumulation by tubers. However, the growing years affected tuber nitrate N accumulation.

Pre-crop main effect: Nitrate nitrogen content of harvested tubers was not influenced by preceding crops (Table 24). There was tuber nitrate N content slightly increased (although not significantly) for lucerne pre-crop. Nitrate nitrogen accumulation by tubers was the highest after legume lucerne (751 mg kg^{-1}), followed by field pea and the lowest after spring barley (650 mg kg^{-1}).

Table 24: Significance level for fixed factors and their interactions for starch content, potato tuber nitrate - N content (fresh weight), nitrate - N accumulation (dry weight), NUE and ANR of catch crops or manure (average of two years)

Parameters/ effects	Starch content	NO_3–N content	NO_3–N accumulation	NUEcc	NUEm	ANRcc	ANRm
	(%)	(mg kg $^{-}$	(mg kg^{-1})	(kg DM (kg N) $^{-1}$)		%	
Y	**	**	+	+	ns	ns	ns
PC	ns	+	+	-	-	-	-
CC	ns	ns	ns	-	ns	-	ns
M	ns	ns	ns	ns	-	ns	-
PC*Y	ns	ns	+	ns	ns	ns	ns
CC*M	ns	ns	ns	-	-	-	-
CC*Y	ns	ns	ns	-	+	-	ns
PC*CC	ns	ns	ns	-	ns	-	ns
M*Y	ns	ns	ns	+	-	ns	-
PC*M	ns	ns	ns	ns	-	ns	-
PC*CC*Y	ns	ns	ns	-	**	-	ns
PC*M*Y	ns	ns	ns	**	-	ns	-
CC*M*Y	ns	ns	ns	-	-	-	-
PC*CC*M	ns	ns	ns	-	-	-	-
PC*CC*M*Y	ns	ns	ns	-	-	-	-

NUEcc or NUEm: Nitrogen use efficiency of N applied with cover crops or manure by the potato crop; ANRcc or ANRm: Apparent nitrogen recovery of N applied with cover crop or manure by the potato crop; see Table 9.

The ANOVA table (Table 24) indicates that the catch crop and manure main effects did not influence tuber nitrate nitrogen concentration and nitrate N accumulation by tubers.

Main effect interaction: There were no interactions of treatment factors on tuber nitrate N accumulation (Table 23).

3.7.3. Nitrogen use efficiency and apparent N recovery

Nitrogen use efficiency (NUE) was calculated as the tuber dry matter productivity per unit N applied by manure or N input by catch crop during the growing season period. Nitrogen use efficiency of the potato crop was not significantly affected by year in treatments with catch crop and manure N input (Table 24). The NUE of catch crop N by the potato crop reached 68.5 kg DM (kg N)$^{-1}$ after spring barley, whereas, after lucerne and after field pea -21.5 kg DM (kg N)$^{-1}$ and -13.8 kg DM (kg N)$^{-1}$ were recorded, respectively. The highest and lowest NUEcc of the potato crop were observed in 2010 (27.6 kg DM (kg N) $^{-1}$) and in 2011 (7.3 kg DM (kg N) $^{-1}$), respectively, and there were similar results for NUEm in both years (Table 25).

Table 25: Nitrogen use efficiency and apparent nitrogen recovery of potatoes

Effect		NUEcc			NUEm
Pre-crop	M	(kg DM (kg N)$^{-1}$)	Pre-crop	CC	(kg DM (kg N)$^{-1}$)
		2010			
Lucerne	without	5.8^{ab}	Lucerne	without	-0.3^{ab}
	with	22.0^{ab}		with	2.8^{ab}
Field pea	without	9.5^{ab}	Field pea	without	1.5^{ab}
	with	20.8^{ab}		with	2.3^{ab}
Spring	without	68.5^{a}	Spring	without	5.0^{a}
	with	-47.3^{b}		with	-3.5^{b}
		2011			
Lucerne	without	-13.8^{ab}	Lucerne	without	2.0^{ab}
	with	-14.3^{ab}		with	2.8^{ab}
Field pea	without	-21.5^{ab}	Field pea	without	-1.8^{b}
	with	-15.5^{ab}		with	-1.0^{b}
Spring	without	-20.3^{ab}	Spring	without	-5.3^{b}
	with	14.0^{ab}		with	6.0^{a}
Mean		1.3			21.3

See Table 24.

Although the nitrogen use efficiency was unaffected by the preceding crop, catch crop and manure application, interaction effects were significant between pre-crop, manure and year on NUE of catch crop - N, and also three-way interaction effect was found between pre-crop, catch crop and year for manure - N (Table 24). The potato NUE of manure N ranged from -2.3 kg DM (kg N)$^{-1}$ to 7.0 kg DM (kg N)$^{-1}$ (Table 25).The apparent recovery was calculated from the N uptake in tubers and the total N supplied. Apparent N recoveries in the trial were 17.3 % and 1.6 % in catch crop and manure plots, respectively. There were no significant differences in ANRcc or ANRm (Table 25).

Chapter 4: Discussion

The findings from this study shows that soil water content and amount of soil inorganic nitrogen may be not influenced by some organic amendments, like farmyard or green manure following different preceding crops in early growing season on a more fertile soil. Since all main factors in the experiments indicate no significant effect on the tuber productivity, starch content, specific gravity, tuber external and internal quality, tuber nitrate nitrogen accumulation, moreover no influence for NUE and ANR of potato crop in both years. Likewise, Rinnofner et al. (2008) found no benefit of green manure crop effects for the first following crop potato at dry weather conditions on the same site. One reason, according to Griffin and Hestermann (1991), could be that N from the catch crop residue was released too late in the development of the potatoes to provide any yield benefit. On the other hand, perhaps some of the inorganic N in the cattle manure may have been immobilized (Paul and Beauchamp, 1994) as evidenced by the very low values (0.4 – 2.1%) of apparent recovery of manure inorganic N and the lower inorganic N content in manured subsoil than the N_{min} in un-amended soil. Honeycutt et al. (2005) reported that soil with higher clay and silt contents showed greater N immobilization when amended with dairy manure compared to the other soils. The year of the study was significant as a main effect with higher soil inorganic N content, tuber yields and starch content in 2011, while tuber N content and percentage of standard tubers were higher in 2010. The main reason that the yields were much less in 2010 than in 2011 may be the extreme weather conditions during the growing period. Van Oort et al. (2012) investigated which weather extremes have the strongest impacts on potato yields, and they found that the most influential factor is excessive wetness during the growth period, which decreases yields. The main factors investigated, such as the growth of pre-crops and catch crops as well as the application of farmyard manure, did not lead to significant residual effects on potato tuber N uptake, apparent N recovery or nitrogen use efficiency in the both years.

4.1. Pre-crop and catch crop performance

The dry matter yields, nitrogen and carbon accumulations in shoot and grain of preceding crops differed significantly ($P < 0.01$) due to the different crop species and differed among two growing years. Lucerne aboveground dry matter yield increased from the first (2009) to the second (2010) growing year of the experiment, whereas spring barley yield decreased. Lucerne shoot DM yield can be affected by climate condition of these experimental years. Weather condition in early season of 2009 was considerably drier and hotter than long term average values (Figure 1). This led to greater water stress and weaker growth of the lucerne in 2009 compared to 2010. That was confirmed by a study of Hakl et al., (2014) who found that the climate condition (regions) strongly impacts the lucerne yield. However, compared to other reports on dry matter yield of lucerne shoots, the average lucerne DM production found in the present study was similar with the result of Pietsch et.al (2007) and lower than previously reported studies by Hakl et al.(2014), Ali Moghaddam et al. (2015) and Raza et al. (2014) in the rain-fed condition. The field pea yield obtained in the present study can be considered as high for legumes grown as a preceding crop, though fresh tuber and DM production of following potato was not significantly affected by preceding crop. This observation agreed with the results of other authors Wilczewskia et al. (2014) and Hauggaard-Nielsen et al. (2009b) who found that more N accumulation of pea crop in grain and subsequent crop response to preceding crop were negligible. The nitrogen and carbon contents in shoots were differently ranked among pre-crop species.

The two year of the catch crop study differed in terms of climatic condition in 2009 were much hotter days in July - August and much drier in September – October than normal, whereas more typical growing conditions were in 2010. The lower catch crop yields produced in 2009 compared to 2010 can be related to a long hot period immediately after catch crop sowing and insufficient amount of precipitation during the growth , which delayed the crop emergence and early plant development, similar to findings of a previous study (Möller and Reents, 2009). This is also consistent with previous report by Bodner (2007) who found that, catch crop growth is mainly influenced by rainfall distribution over the vegetation period.

4.2. Soil water availability

Years of the study had a slight effect on soil moisture in 0-30 cm and a strong effect on soil total inorganic nitrogen and nitrate N content in 0-90 cm depth; the difference was possibly caused by weather conditions, water consumptions of preceding crops and catch crops, N mineralization from crop residues and soil type. In the present study, soil moisture to 90 cm soil depth was not affected by different pre-crops in early spring of the experimental years. However, several researchers, Nulsen and Baxter (2004), Whitfield et al. (1992), noted that lucerne had more water consumption than pea and barley. There perhaps was a residual contribution to water conservation, e.g., through reduced evaporation, during the off-season. Catch crop treatments had no effect on soil water content up to 30 cm depth in March and in June. Thus, our finding is consistent with that reported by van Donk et al. (2010), where at the beginning of the growing season (in March), soil water content was very similar in the bare-soil and the catch crop plots in top soils. That result matches the findings of Farthofer et al. (2004), who found soil moisture in the Ap horizon did not differ between green manure and bare fallow. The soil water content was significantly lower in catch crop plots than in bare fallow plots in the subsoil (30-60 cm) in March. This can be explained by the catch crops water consumption.

4.3. Soil inorganic nitrogen availability

The main differences of soil inorganic nitrogen contents in March, sampling up to 90, cm and in June, and sampling to 30 cm, were found between the two experimental years. In the present study, the non-significant differences between pre-crop species and between catch crop treatments for soil mineral N from 0 to 90 cm soil depth at the time before spring sowing, possibly were a result of excessive N availability in the Chernozem soil. This finding suggests that soil inorganic N may be not significantly increased after legume preceding crops or the incorporation of non-legume and mixture catch crops in more fertile soil to the next spring. Similar results have been observed by Hauggaard-Nielsen et al. (2009b) in previous study, who found that no clear difference among different preceding crops for soil inorganic nitrogen content. Therefore, the soil inorganic nitrogen content was greatly influenced by year condition on upper soil layers in March, in agreement with reports by Moeller and Reents (2009). Jensen (1991) reported that grain legumes, such as field peas (*Pisum sativum* L.), can leave relatively higher inorganic nitrogen contents in the soil profile compared to cereals after harvest. This present study confirms that only in deeper soil layers (30 – 60 cm) higher NO_3^--N content occurred after pre-crop pea than barley (Table 14). Since, these results match the findings of Haase et al. (2007b) who found higher nitrate-N (NO_3^--N) contents in the 30-60 cm soil profile after pea than after cereal grain. For various preceding crops, Millburn et al. (1990) measured spring soil NO_3^--N contents to 60 cm depth ranging from 40 to177 kg N ha^{-1}. The comparatively higher nitrate N content of soil in early spring after field pea was possibly caused by their relatively high shoot biomass (Table 4) and N yield (Table 6).

According to Wilczewski et al. (2014) the soil with a catch crop contained significantly higher mineral nitrogen in the topsoil during the following crop than control soil (without catch crop). This could not be confirmed in the present experiments, perhaps due to the rather early sampling just before sowing. Significantly lower soil inorganic nitrogen content occurred with catch crop treatment in the 30 - 60 cm and 60 - 90 cm soil layers in March, perhaps reflecting a reduction of soil N_{min} content caused by catch crop roots which reach the deep soil layers early. This agrees with findings by Thorup-Kristensen (2001). The top soil, the zone into which most of the fertilizer is placed and most crop residues are incorporated, often has much higher levels of nitrogen than the soil below; the soil nitrate nitrogen content decreased with increasing soil depth in the profile within all treatments (Table 13). Nitrate nitrogen content tended to decline with increasing soil depth in the profile for plots with catch crops.

On silty loam, there was no effect of manure application on soil inorganic nitrogen content (NO_3^--N + NH_4^+-N) to 90 cm soil depths in early spring. This is consistent with previous report by Leif-Nett (2012), who found that the fertilization rate of 60 tones ha^{-1} $year^{-1}$ manure had no significant effect compared to the non-fertilized treatment on total tuber yield and on soil N availability. Furthermore, Miller and Miller (2000) highlighted that organic material application to cropland could affect soil properties, but the effects generally may not be apparent over a short time period.

4.4. Total, marketable and DM tuber yield

Research suggests that relatively warm temperature and abundant soil water and mineral N availabilities (2011) may have a beneficial effect on the potato production, resulting in tuber yield, increased total, marketable, dry matter yields and starch content. It can be explained by the relatively warmer start and end of growing season that forwarded for emergence and maturity in that year as potato crop growth proceeded without water stress. Furthermore, the higher spring soil nitrate N content in rooting zone (163 kg ha^{-1} in March samples) in 2011 (Table 14) is perhaps reflected in the higher yields compared to 2010 (Table 17). The wetter and warmer conditions in spring 2011may have been conducive to improved N supply from mineralized organic matter which resulted in the higher levels of soil inorganic N content at early growing season. In previous studies, Costa et al. (1997) recorded that the variability in potato yield is caused by rainfall and Kooman et al. (1996) explained that reason by temperature. This present study suggests that both quantity and quality of potato yield influenced by weather conditions of growing years, it could be caused that relatively high soil temperature influenced to strongly release N from organic amendments or from soil organic matter to subsequent potato (in 2011), other one possibility is may be great amount of soil nitrate N leaching to subsoils (in 2010) by strongly rainfall. That result matches with previous study by Macak et al. (2012), who found that a highly significant differences between certain years (weather condition) in potato tuber yield and quality parameters.

Several authors reported that the potential benefits of growing legumes prior to potatoes (Reents and Möller, 2000, Amir Ali Najm. et al., 2013, Haase et al., 2007b, Essah et al., 2012, Henriksen et al., 2007). This was not found in the present study; our finding indicates that catch crop treatment had no effect for tuber yield, whereas manure treatment increased a negligible amount for tuber DM yield (Table 17). According to Macák et al. (2012) green manure management did not influence potato yields significantly, that is also in agreement with our results, it could therefore be hypothesized that N in farmyard manure may be released too late to be fully utilized by the potato crop (Larrson et al., 2010).

Moreover, Lynch et al. (2012) found that an incorporated green manure or farmyard manure treatments increased a subsequent potato tuber yield by 22-25%, rather to combine of those two amendments, which increased a potato yield by 43%. That previous result did not verify in the present study, namely the combination of catch crop and manure application following different preceding crops had no such influence on tuber yield. It may be caused by the great N immobilization in manured soil, which consists high clay and silt contents, observed by Honeycutt et al. (2005).

In addition, Bath et al. (2006) found the combination of a green manure pre-crop and fermented manure slurry increasing organic potato yields by approximately 40%, on a site with poorer soil but not on a site with more fertile soil. The results of this study such as quantitative parameters were more or less on the same level in the different treatments.

4.5. Tuber quality

Tuber quality (standard tubers with less external and internal defects) was generally higher in 2010 compared with 2011; the percentage of tubers with common scab, malformation and greening was less in 2010 than in 2011. Contribution of growth cracked tubers may be greater under conditions with excess of water during the tuber development period in 2010. The percentage of potato virus Y in tuber yield also significantly increased in 2011, presumably attributable to increased average temperature during the whole growing season, particularly during the tuber growing phase. This discard generally occurs in year with higher yield (e.g. 2011), possibly due to the higher percentage of small tuber per unit. Reductions in marketable yields from total tubers were primarily due to amount of misshapen, malformed and green tubers averaging ~16 % and other defects accounting for less than 3% of tubers in 2011 (Table 8.1 in the annex). When the quality of tubers (larger tubers) following cereal spring barley was compared to the quality of the tubers following legume crops lucerne and field peas, it was found that all preceding crop species contributed to similar percentages of total and larger tubers. In both years, percentage of tuber size > 65 mm (with larger tubers being considered of better quality) in diameter was only influenced by catch crop, significantly higher percentage of large tubers occurred in catch crop plots, in comparison to bare fallow plots (Table 19). The same findings by Essah et al. (2012) reported that cover crops have the potential to increase potato tuber yield and quality, as measured by tuber size (larger tubers) and appearance (e.g., tubers with reduced defects such as cracks, knobs, and misshapes). Small sized tubers tended to be significantly higher in 2011, perhaps due to delayed plant maturity and tuber fill as an excessive soil N availability. Resent research suggests that farmyard manure does not consistently enhance the risk of diseases such as common scab and may occasionally suppress it (Conn and Lazarovits, 1999, Snapp et al., 2003).

The starch content determined in potato tubers was lower in 2010 than 2011, it may be the case that abundant rainfall occurred during the vegetation period in 2010 (especially in growth stages of tuber bulking and maturating). Previous researchers noted that the quality of agricultural products is highly dependent on the soil properties and on the meteorological conditions (Eleanor Y Swain et al., 2014, Bakšiene et al., 2014). Also, Belinger et al. (2002) reported that the risks of low specific gravity and high tuber NO_3^--N concentration are greater when fertilization exceeds the N requirements to reach maximum tuber yield. Interestingly, our result did not confirmed that or even tuber nitrate nitrogen accumulation decreased by abundant soil nitrate nitrogen content in organic potato farming.

4.6. Main crop nitrogen uptake, apparent nitrogen recovery and nitrogen use efficiency

This present study did not find a first year after-effect of catch crops on potato tuber N uptake. This confirms results by Rinnofner et al. (2008) who reported that an additional amount of N was conserved by the green manure crops compared to bare fallow but N was not used for conversion into yield by the first subsequent crop. The current study shows that the tuber nitrate N accumulation in amended and un-amended soils appeared more or less on the same level, which are lower values compared to the finding of Lynch et al. (2008) but similar to the values found in other experiments by Van Delden (2001), Vos and van der Putten (2001) for organic potato. The positive influence of the N-supply caused by catch crop legumes or legume mixtures on the N-uptake of the subsequent crops has been described by several authors (Muller and Sundman, 1988, Smith and Sharpley, 1993). Although, there was no any evidence of a statistically significant effect of catch crops on the tuber N uptake. Nonetheless, there was a pronounced trend for the tuber nitrate N uptake after different previous crops; tuber nitrate N content from the following legume lucerne plots was greater than following spring barley plots.

Overall, potato NUEcc was significantly higher in 2010 compared to 2011. Somewhat interestingly, the pattern of results for potato NUE of catch crop and manure-applied N compared to unfertilized control treatments were very similar and negative values appeared more common on the potato NUE of manures. This finding reflects that an additional N from catch crop as green manure and manure application were inefficient on NUE of potato in a highly fertile soil. Swain et al. (2014) found that the use of organic fertility sources resulted in lower NUE.

The results of low apparent N recoveries of catch crop N in potato have also been found in previous studies: according to Vos and van der Putten (2001) the average recovery in potato of incorporated catch crop N was low.

Chapter 5: Conclusions

On the basis of the results it can be concluded:

- The greatest amount of plant residues was left in the soil after the cultivation of field pea (8.2 tones ha^{-1} DM), which is 1.7 and 1.4 times higher than after spring-sown lucerne and spring barley, respectively. The contents of carbon and total nitrogen in the dry matter were significantly affected by the plant species. Shoot biomass of pea used as preceding crop was rich in nitrogen and carbon. Field pea increased the soil N availability for the next early season in 30-60 and 60-90 cm depths.
- Overall, the experiments showed that nitrogen stress was not a yield limiting factors on organic potato crops at this study site; e.g. leguminous pre-crops such as lucerne and field peas did not significantly increase the tuber yield in comparison to the non-legume pre-crop barley.
- Results show clearly that catch crop and farmyard manure did not consistently enhance the potato tuber yield and quality in a soil with high fertility during a wet year. Potato size distribution in both years was related to the cultivation of catch crops, the large potato size was positively affected by the catch crop treatment and the small sized (non-marketable) tubers increased in numbers. The percentage of large and small tubers could be increased by applying catch crops as green manure.
- Higher mineral soil nitrogen availability resulted in higher marketable potato tuber yield (31.1 tones ha^{-1}) and dry matter yield (7.7 tones ha^{-1}) in 2011, as compared to the plots which were supplied with less soil N in 2010, after three different preceding crop-catch crop combinations and manure application.
- During the first year of potato growing (2010), the monthly average air temperature was lower by 1.2^{o} – 1.7 ^{o}C than normal at the experimental site at the start of the vegetation period (April to June), which is extremely cool compared to the long-term average values, causing a negative influence on the yield. The second year (2011) was characterized by a relatively warmer season, thereby causing positive conditions for a higher potato yield. Precipitation distribution and temperature fluctuation in the growing season

might have limited the use of soil mineral nitrogen for potato tuber yield and quality, because yield varied from season to season.

- Results gave evidence that significantly lower soil nitrate nitrogen content occurred in the treatment with catch crops than in the treatment without catch crops in subsoils (30 - 60 and 60 - 90 cm soil layers). As a consequence, catch crops may lower the risk of N movement or loss from the plant rooting zone into sub soils.
- Furthermore, it was found that abundant soil inorganic N content, continuously higher air temperature and wet conditions in 2011 deteriorated tuber quality. The percentage of non-standard tubers e.g. malformed and sunburned tubers were increased 3.2 and 9.6 times, respectively in 2011 compared with 2010.
- The high level of tuber N uptake even in unfertilized plots showed that the Chernozem soil has a high potential to supply N from its reserves.
- For potatoes, nitrogen use efficiency and apparent N recovery of the nitrogen applied with organic sources was low both in catch crop and in manure treatments.
- Results suggest that any further work in this area could include a second or third year of study of organic manures as well as long-term N balance studies in field experiments to assess nitrogen use efficiency in the organic potato production. The present short term approach to address subsequent crop effects seems too simple for an appropriate evaluation of preceding cropping and manuring effects.

References

ALI MOGHADDAM, AMIR RAZA, JOHANN VOLLMANN, M. REZA ARDAKANI, WOLFGANG WANEK, GABRIELLE GOLLNER & FRIEDEL, J. K. 2015. Biological nitrogen fixation and biomass production stability in alfalfa (Medicago sativa L.) genotypes under organic management conditions. Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, 31, 177-192.

ALVA, A., FAN, M., QING, C., ROSEN, C. & REN, H. 2011. Improving nutrient-use efficiency in Chinese potato production: experiences from the United States. J. Crop improvement, 25, 46 - 85.

AMIR ALI NAJM., MOHAMMAD REZA HAJ SEYED HADI., MOHAMMAD TAGHI DARZI. & FAZELI., F. 2013. Influence of nitrogen fertilizer and cattle manure on the vegetative growth and tuber production of potato International Journal of Agriculture and Crop Sciences, 5, 147-154.

BAKŠIENE, E., RAZUKAS, A., ROMANOVSKAJA, D., TITOVA, J. & TRIPOLSKAJA, L. 2014. Research of plant production and quality on different farming systems. Journal of Food, Agriculture and Environment, 12, 296-301.

BATH, B., EKBLADH, G., ASCARD, J., OLSSON, K. & ANDERSSON, B. 2006. Yield and nitrogen uptake in organic potato production with green manures as pre-crop and the effect of supplementary fertilization with fermented slurry. Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, 24, 135-148

BÉLANGER G., WALSH J.R., RICHARDS J.E., MILBURN P.H. & N., Z. 2002. Nitrogen fertilization and irrigation affects tuber characteristics of two potato cultivars. American Journal of Potato Research, 79, 269-279.

BODNER, G. 2007. Cover cropping in water limited environments. Dr. nat. techn., University of Natural Resources and Applied Life Sciences BOKU, Vienna.

BODNER, G., HIMMELBAUER, M. & LOISKANDL, W. 2010. Improved evaluation of cover crop species by growth and root factors. Agronomy for Sustainable Development, 30, 455-464.

CAMPIGLIA, E., PAOLINI, R., COLLA, G. & MANCINELLI, R. 2009. The effects of cover cropping on yield and weed control of potato in a transitional system. Field Crops Research, 112, 16-23.

CARTER, M., SANDERSON, J. & MACLEOD, J. 2004. Influence of compost on the physical properties and organic matter fractions of a fine sandy loam throughout the cycle of a potato rotation. Canadian Journal of Soil Science, 84, 211-218.

CONN, K. L. & LAZAROVITS, G. 1999. Impact of animal manures on verticilllium wilt, potato scab and soil microbial populations. Can. J. Plant Pathol., 21, 81-92.

COSTA, L. D., VEDOVE, G. D., GIANQUINTO, G., GIOVANARDI, R. & PERESSOTTI, A. 1997. Yield, water use efficiency and nitrogen uptake in potato: influence of drought stress. Potato Res., 40, 19-34.

DAVIS, J., HUISMAN, O., EVERSON. DO., NOLTE, P., SORENSEN, L. & SCHNEIDER, A. 2010. Ecological relationships of verticillium wilt suppression of potato by green manures. American Journal of Potato Research, 87, 315-326.

ELEANOR Y SWAIN, LEONIDAS REMPELOS, CAROLINE H. ORR, GAVIN HALL, RACHEL CHAPMAN, MFTAH ALMADNI, ELIZABETH A. STOCKDALE, JONATHAN KIDD, CARLO LEIFERT & COOPER, J. M. 2014. Optimizing nitrogen use efficiency in wheat and potatoes interactions between genotypes and agronomic practices. Euphytica, 199, 119-136.

ESSAH, S., DELGADO, J., DILLON, M. & SPARKS, R. 2012. Cover crops can improve potato tuber yield and quality. HortTechnology, 22, 185-195.

EUROPEAN COMMISSION, E. 1991. Organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs. In: EC (ed.) Official Journal of the European Communities.

EUROPEAN COMMITTEE, E. 1995. The Commission Regulation (EC) No 97/95. Official Journal of European Union.

EUROPEAN COMMITTEE, R. 2006. Rules and Practices of the Inte-rEuropean Trade in Potatoes: RUCIP Rules and Practices (Usage), Rules for Expert Asse. n: Committee, R.U.C.I.P.E. (Ed.).

FAO 1998. World Reference Base for Soil Resources. In: FAO/ISRIC/ISSS (ed.) World Soil Resources Report. Rome.

FAOSTAT 2014. Food and Agricultural commodities production. 23 October 2014 ed.: FAO, Statistics Division.

FARTHOFER, R., FRIEDEL JK., PIETSCH G., RINNOFNER, T., W. LOISKANDL. & B., F. Plant biomass nitrogen and effects on the risk of nitrate leaching of intercrops under organic farming in Eastern Austria. EUROSOIL 2004, 2004 Freiburg, Germany.

FINCKH, R., SCHULTE-GELDERMAN, E. & BRUNS, C. 2006. Challenges to organic potato farming: disease and nutrient management. Potato Research, 49, 27-42.

FREYER, B. 2003. Crop rotation, Stuttgart, Eugen Ulmer.

FREYER, B., PIETSCH, G., FRIEDEL, K. J. & STARZ, W. 2006. Biological nitrogen fixation of different legume species under water stress. Final report of BIOfix project, component B field trail. Case study in Austria. Vienna: University of natural resources and life sciences, Vienna.

GALLANDT, R. E., MALLORY, B. E., AFFORD, R. A., DRUMMOND, A. F., GRODEN, E., LIEBMAN, M., MARRA, C. M., MCBURNIE, C. J. & PORTER, A. G. 1998. Comparison of alternative pest and soil management strategies for Maine potato production systems. American Journal of Alternative Agriculture, 13, 146-161.

GILLER, E. 2004. Emerging technologies to increase the efficiency of use of fertilizer nitrogen. Agriculture and the nitrogen cycle. Washington DC: Island Press.

GOFFART, J., OLIVIER, M. & FRANKINET , M. 2008. Potato Crop Nitrogen Status Assessment to Improve N Fertilization Management and Efficiency: Past–Present–Future. Potato Research, 51 355 - 383.

GRIFFIN, T. & HESTERMANN, B. 1991. Potato response to legume and fertilizer nitrogen sources. J. Agron., 83, 1004-1012.

HAASE, N. U. 2003. Estimation of dry matter and starch concentration in potatoes by determination of under-water weight and near infrared spectroscopy. Potato Res., 46 (2003/4): 117-127.

HAASE, T., SCHÜLER, C., HAASE, U. & HEB, J. 2007a. Suitability of organic potatoes for industial processing: Effect of agronomic measures on selected quality parameters at harvest and after storage. Potato Research, 50, 115-141.

HAASE, T., SCHÜLER, C., PIEPO, H.-P., THÖNI, H. & HEB, J. 2007b. The effect of preceding crop and pre-sprouting on crop growth, N use and tuber yield of main crop potatoes processing under conditions of N stress. Agronomy and Crop Science, 193, 270 - 291.

HAKL, J., FUKSA, P., KONECNÁ, J., PACEK, L. & TLUSTOS, P. 2014. Effect of applied cultivation technology and environmental conditions on lucerne farm yield in the Central Europe. Plant Soil Environment, 60, 475-480.

HAUGGAARD-NIELSEN, H., GOODING, M., AMBUS, P., CORRE-HELLOU, G., CROZAT, Y., DAHLMANN, C., DIBET, A., VON FRAGSTEIN, A., PRISTERI, A., MONTI, M. & JENSEN, E. S. 2009a. Pea–barley intercropping and short-term subsequent crop effects across European organic cropping conditions. Nutr Cycl Agroecosyst., 85, 41-155.

HAUGGAARD-NIELSEN, H., MUNDUS, S. & JENSEN, E. 2009b. Nitrogen dynamics following grain legumes and subsequent catch crops and the effects on succeeding cereal crops. Nutr Cycl Agroecosyst., 84, 281-291.

HENRIKSEN, C. B., RASMUSSEN, J. & MØLGAARD, J. P. 2007. Potato tuber yield and quality and soil inorganic nitrogen as affected by timing of ridging with and without catch crops. Soil & Tillage Research 94, 36–46.

HONEYCUTT, C., GRIFFIN, T. & HE., Z. 2005. Manure nitrogen availability: dairy manure in northeast and central U.S. Soils. Biological Agriculture and Horticulture, 23, 199-214.

HONISCH, M., HELMEIR, C. & WEISS, K. 2002. Response of surface and subsurface water quality to land use changes. Geoderma, 105, 277-298.

JENSEN, E. 1991. Nitrogen accumulation and residual effects of nitrogen catch crops. Acta.Agric. Scand., 41, 333-334.

JENSEN, E. S. 1996. Compared cycling in a soil-plant system of pea and barley residue nitrogen. Plant and Soil, 182, 13-23.

JENSEN, S. L. 2013. Animal manure residue upgrading and nutrient recovery in biofertilisers. In: SVEN G. SOMMER., MORTEN L. CHRISTENSEN. & SCHMIDT., T. (eds.) Animal Manure Recycling: Treatment and Management. UK: John Wiley&Sohn.

KOOMAN, P., PAHEM, M., TEGERA, P. & HAVERKORT, A. 1996. Effects of climate on differnt potato genotypes 2. Dry matter allocation and duration of the growth cycle. Europ. J. Agronomy, 5, 207-217.

KÖPKE, U. 1995. Nutrient management in organic farming systems: the case of nitrogen. Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, 11, 15 - 29.

LAMPKIN, N. 1998. Organic farming. UK: Farming Press Books.

LARRSON, C., NILSSON, A. T. S. & SVENSSON, G. Tests of new catch crop technique in organic potato production: Acta Horti-culture (ISNS). International Symposium on Ecologically Sound Fertilization Strategies for Field Vegetable Production., 2010 Malmö, Sweden. 163-168.

LEIF-NETT. 2012. N use efficiency in field vegetable production systems - Catch crop strategies and fertilization history effects on organic fertilizer turnover. Dr. rer. agr., Humboldt-Universität zu Berlin.

LIU, K., HAMMERMEISTER, M., WARMAN, R., DRURY, F. & MARTIN, R. 2011. Assessing soil nitrogen availability in contrasting cropping systems at the end of transition to organic production. Canadian Journal of Soil Science, 91, 493 - 501.

LUPWAYI, N. & SOON, Y. 2009. Nitrogen release from field pea residues and soil inorganic N in a pea-wheat crop rotation in northwestern Canada. Canadian journal of plant Science, 89, 239-246.

LYNCH, D., SHARIFI, M., HAMMERMEISTER, A. & BURTON, D. 2012. Tuber yield and quality, crop apparent N recovery and soil mineral N as affected by rotation design and use of supplemental organic amendments. In: ZHONGQI HE., ROBERT LARKIN. & HONEYCUTT., W. (eds.) Sustainable Potato Production: Global Case Studies. Springer.

LYNCH DH., ZHIMING ZHENG., BERNIE J. ZEBARTH. & MARTIN., R. C. 2008. Organic amendment effects on tuber yield, plant N uptake and soi mineral l N under organ ic potato production. Renewable Agriculture and Food Systems, 23, 250-259.

MACÁK, M., ZAK, S. & POLLAKOVA, N. 2012. Yield and technological quality of ecological and low-input production of potatoes. Journal of Central European Agriculture, 13, 588-603.

MILLBURN, P., RICHARDS, J., GARTLEY, C., POLLOCK, T., ONELL, H. & BAILEY, H. 1990. Nitrate leaching from systematicaly tiled potato fields in New Brunswick. Canadian J. Environ. Qual., 13, 448-454.

MILLER, D. & MILLER, W. 2000. Land application of wastes. In: SUMNER, M. (ed.) Handbook of soil science. CRC Press.

MOLL, R. H., KAMPRATH, E. J. & JACKSON, W. A. 1982. Analysis and interpretation of factors which contribute to efficiency to nitrogen utilization. Agron. J., 74, 562-564.

MÖLLER, K. & REENTS, H. 2009. Effects of various cover crops after peas on nitrate leaching and nitrogen. J. Plant Nutr. Soil Sci., 172, 277-287.

MULLER, M. & SUNDMAN, V. 1988. The fate of nitrogen released from different plant materials during decomposition under field conditions. Plant and Soil, 105, 133-139.

MÜLLER, T. & THORUP-KRISTENSEN, K. 2001. N-fixation of selected green manure plants in an organic crop rotation. Biology, Agric. Hortic. J, 18, 345-363.

NEUHOFF, D. & KÖPKE, U. 2002. Potato Production in Organic Farming: Effects of Increased Manure Application and Different Cultivars on Tuber Yield and Quality Pflanzenbauwissenschaften, 6, 49 - 56.

NULSEN, R. & BAXTER, I. 2004. Water use by some crops and pastures in the southern agricultural areas of Western Australia. Resource Management Technical Report No.32. Department of Agriculture Western Australia.

OLESEN, J. E., ASKEGAARD, M. & RASMUSSEN, I. A. 2009. Winter cereal yields as affected by animal manure and green manure in organic arable farming. European J. Agron., 30, 119-128.

OPENA, G. & PORTER, G. 1999. Soil Management and Supplemental Irrigation Effects on Potato: II. Root Growth. Agron. J., 91, 426 - 431.

OSTERREICHISCHES NORMUNGSINTITUT, W. 1999. Chemische Bodenuntersuchungen - Bestimmung von mineralischem Stickstoff - Nmin-Methode. Austrian Standards. Wien.: Osterreichisches Normungsintitut, Wien.

PANG, X. & LETEY, J. 2000. Organic farming: Challenge of timing nitrogen availability to crop nitrogen requirements. Soil Science Society of America Journal, 64, 247 - 253.

PAUL, J. W. & BEAUCHAMP, E. G. 1994. Short-term nitrogen dynamics in soil amended with fresh and composted cattle manures. Canadian Journal of Soil Science, 74, 147-155.

PAUL, U. & VIGIL, M. 1998. Cover crop effects on soil water relatioships. Soil and Water Conservation, 53, 200 - 207.

PETTYGROVE, G. S., HEINRICH, A. L. & CROHN, D. M. 2009. Manure Nitrogen Mineralization University of California.

PIETSCH, G., FRIEDEL, J. K. & FREYER.B 2007. Lucerne management in an organic farming system under dry site conditions. Field Crop Research, 102, 104-118.

PRATT, P. F. & CASTELLANOS, J. Z. 1981. Available nitrogen from animal manures. University of California, Riverside: .

RAZA, A. 2010. Water relations of Lucerne (Medicago sativa L.) under organic farming conditions. Dissertation in the Department of Sustainable Agricultural systems, University of Natural Resources and Life Sciences, Vienna.

RAZA, A., BODNER, G., MOGHADDAM, A., ARDAKANI, M., LOISKANDL, W., HIMMELBAUER, M., GOLLNER, G., WANEK, W. & FRIEDEL, J. 2014. Assessing the effect of lucerne utilization systems in the Pannonian region of Austria. Arch. Agron. Soil Sci.. , 60, 297-311.

REENTS, H. & MÖLLER, K. Effects of different green manure catch crops grown after peas on nitrate dynamics in soils and on yield and quality of subsequent potatoes and wheat. In: ALFÖLDI, T., LOCKERETZ, W. &

NIGGLI, U., eds. 13th International IFOAM Scientific Conference 2000 Zürich, Switzerland. IFOAM, 73 - 75.

RINNOFNER, T., FRIEDEL, J., DE KRUIFF, R., PIETSCH, G. & FREYER, B. 2008. Effect of catch crops on N dynamics and following crops in organic farming. J. Agron. Sustain. Dev., 28, 551-558.

RODRIGUES, M. A., PEREIRA, A., CABANAS, J. E., DIAS, L., PIRES, J. & ARROBAS, M. 2006. Crops use-efficiency of nitrogen from manures permitted in organic farming. Europ. J. Agronomy 25, 328-335.

SMITH, S. & SHARPLEY, A. 1993. Nitrogen availability from surface-applied and soil-incorporated crop residues. J. Agron., 85, 776-778.

SNAPP, S. S., NYIRANEZA, J., OTTO, M. & KIRK, W. W. 2003. Managing Manure in Potato and Vegetable Systems. Extension Bulletin. MICHIGAN STATE U N I V E R S I T Y EXTENSION.

TALGRE, L., LAURINGSON, E., ROOSTALU, H., ASTOVER, A. & MAKKE, A. 2012. Green manure as a nutrient source for succeeding crops. Plant Soil Environ., 58, 275 - 281.

THORUP-KRISTENSEN, K. 2001. Are differences in root growth of nitrogen catch crops important for their ability to reduce soil nitrate-N content, and how can this be measured? Plant and Soil, 230, 185-195.

THORUP-KRISTENSEN., MAGID, K. & JENSEN, S. 2003. Catch crop and green manures as biological tools in nitrogen management in temperate zones. Adv.Agron., 69, 79 - 118.

TISCHLER, K. & RECH, T. 2009. Organic farming in Austria. Federal Ministry of Agriculture, Forestry, Environment and Water Management.

VAN DELDEN, A. 2001. Yield and growth components of potato and wheat under organic nitrogen management. J. Agron., 93, 1370 - 1385.

VAN DONK, S., MARTIN, D., IRMAK, S., MELVIN, S., ., PETERSEN, J. & DAVISON, D. 2010. Crop residue cover effects on evaporation, soil weter content, and yield of defficit-irrigated corn in west-central nebraska. American Society of Agricultural and Biological Engineers, 53.

VAN OORT, P., TIMMERMANS, B., MEINKE, H. & VAN ITTERSUM, M. 2012. Key weather extremes affecting potato production in The Netherlands. European Journal of Agronomy, 37, 11–22.

VOS, J. 1995. Foliar development of the potato plant and modulations by environmental factors. In: KABAT, P. (ed.) Modeling and parameterization of the soil-plant-atmosphere system: A comparison of potato growth models. Wageningen, the Netherlands: Wageningen Pers.

VOS, J. 2009. Nitrogen Responses and Nitrogen Management in Potato. Potato Res., 52, 305-317.

VOS, J. & VAN DER PUTTEN, P. 2001. Field observations on nitrogen catch crops. III. Transfer of nitrogen to the succeeding main crop. Plant & Soil. J., 263-273.

WALKER, T., SCHMIEDICHER, P. & HIJMANS, R. 1999. World trends and patterns in the potato crop: An economic and geographic survey. Potato Research, 42, 241 - 264.

WHITFIELD, D., NEWTON, P. & MANTELL, A. Comparative water use of dryland crop and pasture species. 6th Australian Agronomy Conference 1992 Armidale, New South Wales.: The University of New England.

WILCZEWSKIA, E., PIOTROWSKA-DŁUGOSZB, A. & LEMAŃCZYKC, G. 2014. Influence of catch crop on soil properties and yield of spring barley. International Journal of Plant Production, 8.

WWW.NUE.OKSTATE.EDU. 1991. Nitrogen Use Efficiency Definitions [Online]. Department of Plant and Soil Sciences Oklahoma State University Driving Directions to OSU.

ZEROM, H. H. 2011. Estimation of Mesh Size and Starch Content of Potato by Machine Vision Application. Master, Wageningen University.

Curriculum vitae TSOLMON NYAMDAVAA

Personal Profile

Father's name	Nyamdavaa
Date of birth	22 January 1971
Nationality	Mongolian
Religion	Buddha
Postal address	Hohenauergasse 9/21, 1190, Vienna, Austria
Phone	00436603585789
E-mail address	agrotsolmon@yahoo.com

Academic record

Feb.2002 – Apr. 2004	Institute of Finance and Economics (Mongolia) Bachelor program: Risk management
Sept.1996 - Feb. 1999	Mongolian State university of Agriculture, Ulaanbaatar Master study: Crop Science and Plant Nutrition
Sept. 1989 – Feb. 1994	Mongolian State university of Agriculture Bachelor program: Agronomy
Sept. 1979 – Jun. 1989	Secondary school Selenge Orkhontuul, Mongolia

Professional Career:

Mar. 1994 – Aug. 1996	General agronomist, "Khugjil" company Ltd, Selenge, Mongolia
Sept. 1996 – Mar. 2008	Lecturer, Mongolian State university of Agriculture (MSUA)
Mar. 2008 – Apr. 2009	Head of experimental station of MSUA at Agropark, Ulaanbaatar
Apr. 2009 – to date	PhD Project: Organic Potato Farming at University of Natural Resources and Life Sciences, Vienna, Austria

Annexure

Table 1: Monthly air temperature and rainfall for the study period in comparison to the long-term (1971-2000) average (ZAMG)

Year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Mean monthly air temperature (^{0}C)								
2009	15.4	15.6	18.0	21.7	21.5	17.8	10.9	6.4
2010	8.8	14.3	17.2	21.6	19.3	14.6	7.6	7.0
2011	15.1	17.8	19.3	21.0	23.3	-	-	-
1971-2000	10.5	15.5	18.5	20.5	20.4	16.0	10.6	5.0
Rainfall (mm)								
2009	3	37.1	124	125	109.1	30.2	25.6	72.4
2010	78.5	104	78.7	109	133	76	56	24
2011	31.5	59.5	146.4	95.1	41.6	-	-	-
1971-2000	52	62	70	68	58	54	40	50

Table 2: SDMY, total N and C yield in the pre-crop species treatments measured at harvest time

Year	Parameter/ DM yield (t ha^{-1})		N yield (kg ha^{-1})	C yield (kg ha^{-1})
2009				
PC: Lucerne (shoot)	*0.96 ± 0.18 c	Lucerne (shoot)	33.9 ± 5.9 b	396.9 ± 93
Field pea (straw + grain)	3.70 ± 1.16 b	Field pea (straw + grain)	86.1 ± 27.2 a	1470.4 ± 451
Spring barley (straw + grain)	4.75 ± 0.42 a	Spring barley (grain)	40.6 ± 5.1 b	859.1 ± 112
	SDMY (t ha^{-1})		N yield (kg ha^{-1})	C yield (kg ha^{-1})
CC: non-leg after lucerne	0.48 ± 0.1		26 ± 9.6	165 ± 50
non-leg after field pea	0.37 ± 0.04		19 ± 2 .0	127 ± 24
mixture after spring barley	0.39 ± 0.08		18 ± 3.7	133 ± 34
2010				
PC: Lucerne (shoot)	7.5 ± 1.0 b		257 ± 41	3136 ± 408
Field pea (grain)	9.0 ± 1.3 a		269 ± 37	3542 ± 527
Spring barley (grain)	2.3 ± 0.6 c		46 ± 14	928 ± 242
CC: non-leg afterlicerne	0.92 ± 0.3		43 ± 13	329 ± 100
non-leg after peas	0.71 ± 0.1		36 ± 6.7	255 ± 48
mixture after barley	1.09 ± 0.3		49 ± 13	399 ± 103

DM: dry matter; SDMY: shoot dry matter yield; N: nitrogen; C: Carbon; PC: preceding crop; CC: catch crop; *: mean ± standard deviation

Table 3.1: Significance levels for fixed factors and their interactions for soil water content (2010 & 2011)

Year	2010					2011				
	March				June	March				June
Depth / Effect	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
PC	ns	ns	ns	ns	ns	ns	ns	**	ns	ns
CC	ns	ns	ns	ns	ns	ns	**	ns	ns	ns
M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PC*B	ns	ns	ns	ns	ns	ns	ns	ns	**	ns
PC*CC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	ns	+	ns	ns	**	ns	+
PC*CC*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

See table 2; ns: non-significant; **: significant at 1 % level of probability; +: significant trend at 10 % level of probability.

Table 3.2: Soil water (WC) content (kg ha^{-1}) in both years

Parameter/ Effect	March								June	
	0-30cm		30-60cm		60-90cm		0-90cm		0-30cm	
	WC	St.D.	WC	St.D.	WC	St.D.	WC	St.D.	WC	St.D
Pre-crop:	2010									
Lucerne	98 a	±4.5	102 a	±6.5	95 a	±11	295 a	±16	101 a	±2
Field pea	96 a	±3.4	101 a	±7.9	89 a	±13	286 a	±19	100 a	±4
Barley	99 a	±2.7	103 a	±6.2	97 a	±19	298 a	±20	99 a	±3
Catch crop:										
Without	98 a	±4.2	103 a	±5.7	96 a	±10	296 a	±14	100 a	±3
With	97 a	±3.1	101 a	±7.7	92 a	±18	289 a	±23	99 a	±3
Manure:										
Without	98 a	±4.4	101 a	±7.1	92 a	±12	290 a	±18	100 a	±3
With	98 a	±2.8	103 a	±6.5	96 a	±17	296 a	±20	99 a	±3
Pre-crop:	2011									
Lucerne	99 a	±4.2	96 a	±4.3	90 a	±6.3	286 a	±88	87 a	±6
Field pea	98 a	±4.0	99 a	±5.1	92 a	±7.1	288 a	±12	85 a	±8
Barley	100 a	±3.6	98 a	±6.8	88 a	±7.3	282 a	±65	87 a	±7
Catch crop:										
Without	99 a	±3.4	99 b	±5.6	91 a	±8.3	284 a	±80	86 a	±6
With	99 a	±4.4	96 a	±5.0	89 a	±6.7	288 a	±10	87 a	±5
Manure:										
Without	99 a	±4.5	97 a	±5.8	90 a	±9.1	286 a	±10	86 a	±5
With	99 a	±3.3	97 a	±5.3	90 a	±5.9	285 a	±83	86 a	±6

WC: water content; St.D: standard deviation.

Table 4.1: Significance levels for fixed factors and their interactions for soil N_{min}

Year	2010					2011				
	March				June	March				June
Depth Effect	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
PC	ns	ns	*	ns	ns	ns	*	ns	ns	ns
CC	+	**	**	**	ns	ns	**	ns	ns	ns
M	+	**	ns	ns	ns	ns	**	+	ns	ns
PC*CC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

See table 3.1.

Table 4.2: Soil Nmin content (kg ha^{-1}) in both years

Parameter/ Effect	March				June
	0-30cm	30-60cm	60-90cm	0-90cm	0-30cm
	Nmin ± St.D	Nmin ± St.D	Nmin ± St.D	Nmin ± St.D	Nmin ± St.D
	2010				
Pre-crop:					
Lucerne	63.8 ± 13.4a	62.8 ± 16.7a	39.3 ± 13.7a	192.8 ± 25.8a	49.9 ± 16.8a
Field pea	56.0 ± 17.5a	76.0 ± 20.5a	53.8 ± 21.5a	207.4 ± 36.1a	41.2 ± 14.5a
Spring barley	54.5 ± 12.5a	54.9 ± 27.5a	45.5 ± 28.5a	169.7 ± 58.1a	53.7 ± 19.6a
Catch crop:					
Without	54.4 ± 12.2a	73.0± 19.9a	59.7 ± 17.7a	211.7 ± 33.7a	48.4 ± 16.2a
With	61.8 ± 16.6a	56.2± 25.0b	31.4 ± 15.3b	168.2 ± 39.1b	48.1 ± 19.1a
Manure:					
Without	54.5± 16.4a	71.5± 21.6a	48.4 ± 22.6a	196.1 ± 40.7a	49.4 ± 15.7a
With	61.5 ± 12.4a	57.6± 24.0b	42.7 ± 22.3a	183.8 ± 48.1a	47.1 ± 19.5a
	2011				
Pre-crop:					
Lucerne	147 ± 71.0a	56.2 ± 24.2ab	26.3± 39.8ab	229.0 ± 85.5a	78.2 ± 18.2a
Field pea	147 ± 70.6a	81.7 ± 64.1a	29.7 ± 39.8a	258.1 ± 123.2a	83.2 ± 16.3a
Spring barley	145 ± 53.6a	47.6 ± 18.9b	21.8 ± 39.8b	214.4 ± 61.4 a	85.1 ± 17.5a
Catch crop:					
Without	142 ± 59.9a	60.0 ± 39.8a	26.5 ± 39.8a	228.1 ± 81.3a	82.5 ± 18.1a
With	151 ± 69.2a	63.6 ± 46.3a	25.3 ± 39.8a	239.5 ±105.5a	81.8 ± 16.6a
Manure:					
Without	145 ± 69.0a	63.7± 49.9a	28.6 ± 39.8a	237.0 ± 105.8a	81.1 ± 17.1a
With	148 ± 60.4a	59.9 ± 35.1a	23.3 ± 39.8a	230.6 ± 81.3a	83.3 ± 17.6a

Nmin: mineral nitrogen; See table 3.2.

Table 5.1: Significance levels for fixed factors and their interactions for soil NO^{-}_{3}-N

Year	2010					2011				
	March				June	March				June
Depth / Effect	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm	0-30 cm	30-60 cm	60-90 cm	0-90 cm	0-30 cm
PC	ns	ns	ns	ns	ns	ns	**	**	ns	ns
CC	**	**	**	**	ns	ns	ns	ns	ns	ns
M	ns	ns	**	ns	ns	ns	ns	ns	ns	ns
PC*CC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns	ns	+	**	ns	ns
CC*M	ns	+	ns	ns	ns	ns	ns	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

See table 3.1.

Table 5.2: Soil NO_3^--N (nitrate nitrogen) content (kg ha^{-1}) in both years

Parameter/ Effect	March				June
	0-30cm	30-60cm	60-90cm	0-90cm	0-30cm
	NO_3^- ± St.D.	NO_3^- ± St.D.	NO_3^- ± St.D.	NO_3^- ± St.D.	NO_3^- ± St.D.
Pre-crop:			2010		
Lucerne	69 ± 14a	58 ±19a	42 ± 16a	164 ± 27b	42 ± 19a
Field pea	60 ± 20a	76 ±24b	51 ± 20 a	186 ± 32a	38 ± 16a
Barley	57 ± 13a	49 ±21a	41 ± 29 a	147 ± 41 c	47 ± 21a
CC: Without	57 ± 14b	73 ± 21a	60 ± 17b	190 ± 30 a	44 ± 19a
With	67 ± 18a	49 ± 20b	28 ± 15a	142 ± 27 b	41 ± 19a
M: Without	58 ± 18a	64 ± 23a	48 ± 23a	170 ± 34 a	45 ± 18a
With	65 ± 15a	58 ± 25a	39 ± 21b	162 ± 38a	40 ± 19a
Pre-crop:			2011		
Lucerne	163 ± 84a	47 ± 22ab	16 ± 6a	226 ± 102a	82 ± 17a
Field pea	163 ± 83a	77 ± 66b	23 ± 9 a	262 ± 139a	91 ± 18a
Barley	162 ± 66a	38 ± 18a	12 ± 6a	212 ± 77a	94 ± 21a
CC: Without	159 ± 71a	52 ± 35a	18 ± 9a	229 ± 93a	92 ± 20a
With	161 ± 76a	48 ± 13a	16 ± 10a	238 ± 125a	90 ± 19a
M: Without	162 ± 80a	55 ± 53a	18 ±10 a	234 ± 122a	90 ± 19a
With	164 ± 75a	53 ± 33 a	16 ±7 a	233 ± 97a	92 ± 20a

See tables 3.1 and 3.2.

Table 6.1: Significance levels for fixed factors and their interactions for soil ammonium nitrogen content (2010 & 2011)

Parameter/ Depth	Effect	2010 March 0-30 cm	2010 June 0-30 cm	2011 March 0-30 cm	2011 March 30-60 cm	2011 March 60-90 cm	2011 June 0-30 cm
NH_4-N content (kg ha^{-1})	PC	ns	ns	ns	ns	ns	ns
	CC	ns	ns	ns	ns	ns	ns
	M	ns	ns	ns	ns	ns	ns
	PC*B	ns	ns	ns	ns	ns	ns
	PC*CC	ns	ns	ns	ns	ns	+
	PC*M	ns	ns	+	ns	ns	ns
	CC*M	ns	ns	ns	ns	**	ns
	PC*CC*M	ns	ns	ns	+	ns	ns

See table 3.1.

Table 6.2: Soil NH_4^+ - N (ammonium nitrogen) content (kg ha^{-1}) in both years for June sampling

Parameter	NH_4^+ - N ± St.D.	NH_4^+ - N ± St.D.	NH_4^+ - N ± St.D.
Effect	2010	2011	2010 - 2011
Pre-crop:			
Lucerne	13.6 ±11.6a	2.9 ± 3.1a	8.3 ± 10.0a
Field pea	8.2 ± 4.8a	4.0 ± 3.4a	6.1 ± 4.6a
Barley	12.8 ± 10.4a	2.8 ± 1.7a	7.8 ± 8.9a
Catch crop:			
Without	10.3 ± 6.9a	2.5 ± 2.0a	6.4 ± 6.4 a
With	10.8 ± 11.6a	4.0 ± 3.3	8.4 ± 9.5a
Manure:			
Without	10.7 ± 7.9a	2.9 ± 2.8a	6.8 ± 7.1a
With	12.4 ± 11.0a	3.5 ± 2.9a	8.0 ± 9.1a
Year:			
2010	-	-	11.5 ± 9.5b
2011	-	-	3.2 ± 2.8a

See table 3.1.

Table 6.3: Soil NH_4-N (ammonium nitrogen) content (kg ha^{-1}) in both years

Sampling date Parameter/ effect	March 0-30cm		30-60cm		60-90cm		0-90cm	
	NH_4^+-N	St.D.	NH_4^+-N	St.D.	NH_4^+-N	St.D.	NH_4^+-N	St.D.
Pre-crop:	2010							
Lucerne	7.0 ± 5.1a		7.0 ± 4.5a		11.6 ± 10.0a		22.9 ± 11.8a	
Field pea	6.6 ± 3.4a		7.8 ± 8.8a		9.6 ± 4.81a		21.8 ± 8.5a	
Spring barley	7.5 ± 4.7a		10.3 ± 8.6a		5.5 ± 2.3a		20.1 ± 8.6a	
Catch crop:								
Without	7.5 ± 4.9a		6.5 ± 4.0a		10.2 ± 6.6a		21.5 ± 7.7a	
With	6.5 ± 3.9a		10.7± 10.1a		7.1 a± 6.2		21.6 ± 11.1a	
Manure:								
Without	6.1 ± 3.8a		9.7 ± 8.1a		6.8 ± 4.3a		19.5 ±7.7a	
With	7.9 ± 4.9a		7.3 ± 7.4a		10.5± 7.7 a		23.3 ± 10.4a	
Pre-crop:	2011							
Lucerne	10.7 ± 9.8a		16.2 ± 25.2a		12.5 ± 9.8a		39.4 ± 33.2a	
Field pea	10.2 ± 10.4a		15.1 ± 19.9a		9.8 ± 6.6a		35.1 ± 19.6a	
Spring barley	9.1 ± 8.4a		15.1 ± 18.5a		12.1 ± 13.4a		36.3 ± 29.4a	
Catch crop:								
Without	8.8 ± 8.8a		15.2 ± 22.7a		11.2 ± 7.5a		35.2 ± 23.9a	
With	11.2 ± 10.8a		15.8 ± 19.5a		11.8 ± 12.5a		38.7 ± 30.6a	
Manure:								
Without	9.5 ± 9.2a		16.7 ± 22.9a		13.6 ± 12.6a		39.8 ± 32.5a	
With	10.5 ± 9.7a		14.2 ± 19.1a		9.4 ± 6.7a		34.0 ± 21.0a	
Pre-crop:	2010 - 2011							
Lucerne	7.5 ± 6.7a		11.5 ± 18.3a		11.5 ± 9.8a		30.6 ± 25.1a	
Field pea	7.1 ± 6.6a		10.7 ± 14.5a		8.6 ± 9.8a		27.1 ± 14.3a	
Spring barley	7.0 ± 5.7a		11.7 ± 13.6a		11.7 ± 13.4a		27.3± 21.8 a	
Catch crop:								
Without	6.9 ± 6.0a		10.3 ± 16.0a		9.8 ± 6.5a		27.2 ± 17.5a	
With	7.5 ± 6.7a		12.3 ± 13.7a		9.1 ± 9.7a		29.4 ± 23.4a	
Manure:								
Without	6.6 ± 6.1a		12.5 ± 13.9a		10.0 ± 9.7a		29.3 ± 24.5a	
With	7.8 ± 6.5a		10.1 ± 16.8a		9.0 ± 6.4a		27.3 ± 16.0a	
Year:								
2010	5.9 ± 3.7a		7.5 ± 6.9a		8.0 ± 5.9a		32.8 ± 24.4a	
2011	8.5 ± 7.9a		13.8 ± 18.7a		10.5 ± 9.3a		21.5 ± 9.3a	

St.D: standard deviation.

Table 7.1: Effect of experimental factors pre-crop, catch crop and manure on potato tuber virus disease (PVY, growth cracked tuber, mechanical damage, green and misshapen tuber.

Parameters/ effects	Total tuber	MT yield	DM yield	Total tuber	MT yield	DM yield
		2010			2011	
PC	ns	ns	ns	ns	ns	ns
CC	+	ns	**	ns	ns	ns
M	ns	ns	**	ns	ns	ns
PC*CC	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	ns	ns	ns
PC*CC*M	**	**	**	ns	ns	ns

See table 3.1.

Table 7.2: Potato tuber yield and cull in both years

Treatment		Yield (t ha^{-1})							
		TT (tones ha-1)		MT (tones ha-1)		DM (tones ha-1)		Cull (%)	
2010									
PC:	Lucerne	26.8 a	±2.6	21.9 a	±2.4	5.1 a	±0.5	14.3 a	±7.0
	Field pea	26.3 a	±2.1	21.6 a	±2.6	5.1 a	±0.5	12.7 a	±3.4
	Spring barley	25.0 a	±3.2	20.9 a	±3.3	5.0 a	±0.7	12.5 a	±5.1
CC:	Without	25.4 a	±2.7	21.1 a	±2.8	**4.9 a**	±0.7	12.6 a	±4.6
	With	26.6 a	±3.3	21.8 a	±2.7	**5.2 b**	±0.5	13.8 a	±6.1
M:	Without	25.6 a	±2.7	21.4 a	±2.7	**4.9 a**	±0.6	12.7 a	±3.6
	With	26.4 a	±2.8	21.6 a	±2.8	**5.2 b**	±0.6	13.7 a	±6.7
2011									
PC:	Lucerne	43.6 a	±4.7	33.9 a	±5.7	8.1 a	±0.9	22.4 a	±9.0
	Field pea	43.3 a	±4.3	33.7 a	±4.5	8.1 a	±1.2	22.0 a	±7.6
	Spring barley	43.0 a	±3.7	34.4 a	±4.5	7.9 a	±1.0	20.0 a	±7.1
CC:	Without	41.5 a	±3.9	35.1 a	±5.4	8.3 a	±0.9	20.0 a	±9.7
	With	41.2 a	±4.3	33.0 a	±4.1	7.8 a	±1.1	22.0 a	±5.5
M:	Without	41.0 a	±4.5	33.4 a	±5.4	8.0 a	±1.1	22.2 a	±8.2
	With	41.6 a	±3.9	34.7 a	±4.2	8.1 a	±0.9	20.8 a	±7.6

TT: total tuber; MT: marketable; DM: dry matter.

Table 7.3: Potato tuber yield by individual values in both years

	PC	CC	M	Tuber yield (t ha^{-1})					
				Total		MT		DM	
2010									
1	Lucerne	without	no	25.8	±3.2	21.4	±2.4	4.9	±0.7
2			yes	26.3	±1.8	22.5	±0.7	4.9	±0.3
3		with	no	26.3	±2.7	22.6	±2.7	5.1	±0.7
4			yes	28.8	±2.8	21.2	±3.4	5.6	±0.7
5	Field pea	without	no	26.3	±4.9	20.6	±2.9	4.8	±1.1
6			yes	25.8	±4.5	20.9	±2.8	5.0	±1.0
7		with	no	25.6	±1.9	21.0	±1.8	5.0	±1.0
8			yes	27.7	±3.1	23.8	±1.8	5.4	±0.7
9	Spring	without	no	23.0	±4.5	19.5	±3.0	4.3	±1.2
10	barley		yes	25.9	±4.1	21.6	±4.4	5.6	±1.3
11		with	no	28.0	±2.8	22.8	±3.6	5.4	±0.9
12			yes	23.2	±3.6	19.7	±1.7	4.8	±0.4
2011									
1	Lucerne	without	no	44.4	±7.2	32.0	±5.9	8.3	±1.2
2			yes	46.6	±5.3	38.3	±4.3	8.6	±0.8
3		with	no	40.2	±4.0	30.5	±4.9	7.4	±1.2
4			yes	43.2	±1.6	34.0	±2.0	8.0	±0.7
5	Field pea	without	no	44.2	±5.0	35.8	±1.6	8.6	±1.1
6			yes	40.0	±3.7	32.0	±5.2	8.2	±0.9
7		with	no	42.6	±7.5	32.4	±6.5	7.9	±1.8
8			yes	42.3	±5.5	34.7	±4.2	7.6	±1.0
9	Spring	without	no	44.5	±3.4	37.6	±4.1	8.1	±0.3
10	barley		yes	42.2	±2.6	33.8	±5.6	7.8	±1.2
11		with	no	40.8	±4.9	32.2	±4.0	7.4	±1.1
12			yes	44.5	±3.4	34.2	±3.0	8.5	±1.5
2010-2011									
1	Lucerne	without	no	35.1	±10.6	26.6	±8.3	6.6	±1.9
2			yes	35.8	±10.5	30.9	±9.1	6.7	±1.9
3		with	no	33.2	±8.0	26.6	±5.1	6.3	±1.5
4			yes	36.0	±8.0	27.6	±7.5	6.8	±1.3
5	Field pea	without	no	34.7	±10.5	28.5	±8.1	6.7	±2.1
6			yes	35.2	±10.3	26.3	±7.3	6.6	±2.1
7		with	no	34.1	±10.0	26.7	±7.5	6.4	±1.9
8			yes	35.0	±8.7	29.2	±6.5	6.5	±1.5
9	Spring	without	no	33.8	±11.0	28.5	±10.2	6.2	±2.2
10	barley		yes	34.0	±9.1	27.7	±8.0	6.6	±1.3
11		with	no	34.4	±7.5	27.5	±6.4	6.4	±1.3
12			yes	33.8	±11.7	26.9	±8.1	6.7	±2.1

See tables 2 and 7.2.

Table 8.1: Effect of experimental factors pre-crop, catch crop and manure on potato tuber quality

	Parameters/ effects	PVY (%)	GC tubers (%)	G tubers, (%)	MF tubers, (%)	Total cull, (%)
2010	PC	ns	ns	ns	ns	ns
	CC	ns	ns	ns	ns	ns
	M	ns	**	ns	ns	ns
	PC*CC	ns	ns	ns	ns	ns
	PC*M	ns	ns	ns	ns	ns
	CC*M	ns	ns	ns	ns	ns
	PC*CC*M	ns	ns	ns	ns	+
2011	PC	ns	ns	ns	ns	ns
	CC	ns	ns	ns	ns	ns
	M	ns	ns	ns	ns	ns
	PC*CC	+	ns	ns	ns	ns
	PC*M	ns	ns	ns	ns	+
	CC*M	ns	**	ns	**	ns
	PC*CC*M	ns	ns	ns	ns	+

PVY: potato virus Y; GC: growth cracked; G: green; MF. malformed; See table 3.1;

Table 8.2: Some characteristics of potato tuber quality in both years

Parameter/ Effect	PVY (%)	PVY St.D.	GC tubers (%)	GC tubers St.D.	SB tubers (%)	SB tubers St.D.	MF ntubers (%)	MF ntubers St.D
	(kg N ha^{-1})							
Pre-crop:	2010							
Lucerne	0.4 a	±0.5	2.3 a	±1.9	0.9 a	±1.2	1.9 a	±1.3
Field pea	0.3 a	±0.5	1.3 a	±1.3	0.6 a	±0.6	1.3 a	±1.4
Spring barley	0.5 a	±0.7	1.2 a	±2.3	1.0 a	±0.9	1.6 a	±1.6
Catch crop:								
Without	0.3 a	±0.5	1.9 a	±2.2	0.8 a	±0.7	1.7 a	±1.6
With	0.5 a	±0.6	1.3 a	±1.5	0.9 a	±1.1	1.4 a	±1.3
Manure:								
Without	0.4 a	±0.5	0.9 a	±1.5	0.8 a	±0.8	1.5 a	±1.0
With	0.4 a	±0.6	2.3 b	±2.0	0.9 a	±1.1	1.6 a	±1.8
Pre-crop:	2011							
Lucerne	2.1 a	±2.5	0.4 a	±0.6	7.7 a	±3.2	6.4 a	±4.4
Field pea	2.9 a	±2.7	0.8 a	±1.0	8.2 a	±6.1	4.4 a	±2.1
Spring barley	2.4 a	±1.9	0.4 a	±0.7	7.1 a	±3.7	4.4 a	±2.9
Catch crop:								
Without	2.1 a	±1.7	0.4 a	±0.7	7.4 a	±5.0	5.6 a	±2.5
With	2.9 a	±2.9	0.6 a	±0.8	8.0 a	±3.8	5.0 a	±3.7
Manure:								
Without	2.6 a	±2.3	0.7 a	±0.9	7.1 a	±3.7	5.6 a	±4.1
With	2.5 a	±2.4	0.4 a	±0.6	8.3 a	±5.0	5.1 a	±3.3

See table 8.1.

Table 8.3: Some characteristics of potato tuber quality by individual values in both years

T	PC	CC	F M	Percentage of graded tubers							
				PVY		GC		SB		MF	
				%	St.D	%	St.D	%	St.D	%	St.D
2010											
1	Lucerne	without	no	0.3	±0.6	2.3	±0.6	0.7	±2.0	2.2	±0.8
2			yes	0.5	±0.9	3.3	±0.9	0.5	±2.3	1.2	±1.5
3		with	no	0.6	±2.1	1.1	±2.1	0.8	±1.7	1.8	±0.9
4			yes	0.4	±2.4	2.5	±2.4	1.6	±4.6	2.5	±2.0
5	Field pea	without	no	0.0	± 0.8	1.7	± 0.8	0.4	± 2.3	1.8	± 0.4
6			yes	0.5	±2.7	1.7	±2.7	0.9	±4.1	1.7	±2.5
7		with	no	0.6	±2.3	0.0	±2.3	0.7	±2.3	0.4	±0.5
8	Spring		yes	0.2	±1.3	1.9	±1.3	0.5	±1.3	1.2	±1.2
9	barley	without	no	0.5	±1.0	0.1	±1.0	0.9	±3.3	1.6	±1.4
10			yes	0.3	±0.7	2.4	±0.7	1.6	±0.7	1.9	±2.7
11		with	no	0.4	±1.0	0.3	±1.0	1.4	±2.7	1.4	±1.3
12			yes	0.3	±1.7	1.9	±1.7	0.2	±1.5	1.3	±1.2
2011											
1	Lucerne	without	no	1.0	±1.3	0.4	±0.4	7.0	±2.7	6.4	±4.6
2			yes	1.1	±0.9	0.2	±0.4	7.1	±4.0	6.3	±2.6
3		with	no	3.1	±3.3	0.8	±0.4	7.2	±2.6	8.6	±7.0
4			yes	3.3	±3.5	0.2	±0.3	9.7	±3.9	4.4	±2.6
5	Field pea	without	no	2.7	± 2.0	0.4	± 0.5	6.9	± 7.1	5.3	±2.8
6			yes	1.5	±1.7	1.0	±1.2	12	±8.1	5.1	±2.2
7		with	no	4.0	±3.7	1.4	±1.4	7.7	±3.8	4.6	±0.8
8	Spring		yes	3.4	±3.4	0.4	±0.5	5.8	±4.3	2.5	±1.5
9	barley	without	no	2.7	±2.0	0.6	±1.1	5.4	±3.1	2.3	±1.6
10			yes	3.3	±1.8	0.0	±0.0	5.7	±1.1	5.2	±3.3
11		with	no	2.0	±0.9	0.6	±0.9	8.3	±3.5	6.3	±4.0
12			yes	1.7	±2.9	0.4	±0.5	9.2	±5.5	3.8	±1.2
2010-2011											
1	Lucerne	without	no	0.6	±1.0	1.3	±2.0	3.8	±3.8	4.3	±3.8
2			yes	0.8	±0.8	1.8	±2.1	3.8	±4.4	3.7	±3.4
3		with	no	1.9	±2.6	0.9	±1.0	4.0	±3.9	5.2	±5.9
4			yes	1.8	±2.8	1.4	±1.6	5.6	±5.2	3.4	±2.4
5	Field pea	without	no	1.4	± 2.0	1.1	± 1.3	3.7	± 5.8	3.6	±2.6
6			yes	1.0	±1.3	1.3	±0.9	6.7	±8.2	3.5	±2.8
7		with	no	2.3	±3.1	0.7	±1.2	4.2	±4.5	2.5	±2.3
8			yes	1.8	±2.8	1.1	±1.3	3.1	±4.0	1.9	±1.5
9	Spring	without	no	1.6	±1.8	0.4	±0.8	3.2	±3.2	2.0	±1.4
10	barley		yes	1.8	±2.0	1.2	±3.0	3.6	±2.4	3.6	±3.3
11		with	no	1.1	±1.1	0.4	±0.7	4.8	±4.4	3.8	±3.8
12			yes	1.3	±1.6	1.2	±1.6	4.7	±6.0	2.6	±1.7

See table 8.1.

Table 9.1: Tuber size distribution

Parameters/ effects	Ø<35 mm	Ø=35-65 mm	Ø>65 mm	Ø<35 mm	Ø=35-65 mm	Ø>65 mm
	2010			2011		
PC	ns	ns	ns	ns	ns	ns
CC	**	+	**	ns	**	ns
M	ns	ns	ns	ns	ns	ns
PC*CC	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	+	ns	ns	ns
CC*M	ns	ns	ns	ns	ns	ns
PC*CC*M	ns	**	**	ns	ns	ns

Ø: diameter; St.D: standard deviation; See table 3.1.

Table 9.2: Potato tuber size distribution in both years

Treatment	PC	Tuber size					
		Ø < 35 mm		Ø = 35-65 mm		Ø > 65 mm	
2010			ST.D		ST.D		ST.D
Pre-crop:	Lucerne	4.7 a	±1.8	91.2 a	±5.7	4.0 a	±6.2
	Field pea	4.5 a	±1.1	90.9 a	±3.0	4.5 a	±3.4
	Spring barley	4.7 a	±1.4	91.8 a	±3.2	3.5 a	±3.4
Catch crop:	Without	5.1 b	±1.5	92.3 a	±2.8	**2.6 a**	±2.7
	With	4.2 a	±1.2	90.4 a	±5.0	**5.4 b**	±5.3
Manure:	Without	4.8 a	±1.6	91.0 a	±3.4	4.2 a	±3.6
	With	4.6 a	±1.3	91.3 a	±4.1	3.8 a	±5.2
2011							
Pre-crop:	Lucerne	26.6 a	±5.7	67.9 a	±4.5	5.5 a	±3.7
	Field pea	25.0 a	±4.1	70.0 a	±5.1	5.0 a	±3.3
	Spring barley	25.2 a	±4.7	69.8 a	±6.0	5.0 a	±6.1
Catch crop:	Without	24.2 a	±4.0	71.4 b	±4.2	4.4 a	±3.3
	With	27.0 a	±5.2	67.2 a	±5.4	5.9 a	±5.3
Manure:	Without	25.7 a	±4.5	69.2 a	±5.8	5.1 a	±4.1
	With	25.5 a	±5.2	69.3 a	±4.8	5.2 a	±4.8

See table 9.1.

Table 9.3: Potato tuber size distribution by individual values in both years

Treatment	Pre-crop	Catch crop	Manure	Percentage of graded tubers (%)					
				Ø < 35 mm		Ø = 35-65 mm		Ø > 65 mm	
					ST.D		ST.D		ST.D
2010									
1	Lucerne	without	no	6.3	±2.0	91.2	±2.9	2.5	±3.6
2			yes	4.8	±1.1	94.5	±2.6	0.7	±1.5
3		with	no	4.1	±0.8	93.2	±4.0	2.7	±3.2
4			yes	3.8	±2.2	86.0	±8.8	10.2	±9.6
5	Field pea	without	no	5.1	±1.6	93.2	±2.0	2.6	±2.7
6			yes	4.3	±1.2	91.9	±3.3	3.8	±2.6
7		with	no	4.7	±0.9	87.9	±2.6	7.4	±3.5
8			yes	4.1	±0.9	91.6	±2.8	4.3	±3.6
9	Spring	without	no	5.0	±1.9	91.6	±2.9	3.4	±2.9
10	barley		yes	5.3	±1.4	92.1	±3.6	2.6	±3.1
11		with	no	3.5	±0.6	89.7	±4.4	6.8	±3.8
12			yes	5.2	±0.9	93.6	±0.7	1.3	±1.5
2011									
1	Lucerne	without	no	26.0	±6.0	69.7	±5.5	4.3	±2.7
2			yes	24.2	±4.6	69.4	±4.6	6.4	±4.0
3		with	no	28.2	±6.8	65.0	±3.8	6.8	±4.3
4			yes	28.0	±6.7	67.6	±4.1	4.4	±4.4
5	Field pea	without	no	22.3	±3.8	73.0	±4.9	4.7	±3.6
6			yes	24.3	±1.4	72.0	±2.8	6.7	±3.6
7		with	no	26.7	±2.1	67.4	±4.0	5.9	±4.3
8			yes	26.7	±6.6	67.7	±7.1	5.5	±2.0
9	Spring	without	no	23.3	±1.2	72.7	±2.1	4.0	±3.2
10	barley		yes	25.4	±6.0	71.3	±5.8	3.3	±4.1
11		with	no	27.8	±4.1	67.3	±9.9	4.9	±7.5
12			yes	24.4	±6.4	67.9	±4.4	7.7	±9.3
2010-2011									
1	Lucerne	without	no	16.2	±11.3	80.4	±12.2	3.4	±3.1
2			yes	14.5	±10.8	81.9	±12.6	3.6	±4.1
3		with	no	16.2	±13.7	79.1	±15.5	4.7	±4.2
4			yes	15.9	±13.7	76.8	±11.7	7.3	±7.6
5	Field pea	without	no	13.7	±9.6	82.7	±10.9	3.6	±3.2
6			yes	14.3	±10.8	82.0	±11.0	3.7	±2.9
7		with	no	15.7	±11.9	77.6	±11.4	6.7	±3.7
8			yes	15.4	±12.9	79.7	±13.7	4.9	±2.8
9	Spring	without	no	14.2	±9.9	82.1	±10.4	3.7	±2.8
10	barley		yes	15.3	±11.5	81.7	±12.0	3.0	±3.4
11		with	no	15.6	±13.2	78.5	±13.9	5.8	±5.6
12			yes	14.8	±11.1	80.8	±14.0	4.5	±7.1

See table 9.1.

Table 10.1: Significance levels for fixed factors and their interactions for soil water content and soil inorganic nitrogen contents (2010 & 2011)

Parameter/ Effect	2010			2011		
	Nitrate conc. (mg kg^{-1})	N uptake by tuber (g m^{-2})	Tuber starch content (%)	Nitrate conc. (mg kg^{-1})	N uptake by tuber (g m^{-2})	Tuber starch content (%)
PC	ns	+	ns	ns	ns	ns
CC	ns	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns	ns
PC*CC	ns	ns	ns	ns	ns	ns
PC*M	ns	ns	ns	ns	ns	ns
CC*M	ns	ns	ns	ns	ns	ns
PC*CC*M	ns	ns	ns	ns	ns	ns

See table 3.1.

Table 10.2: Nitrate concentration, nitrate uptake and starch content of potato tuber

Treatment		Parameter					
		Tuber nitrate concentration (mg kg^{-1})		N uptake by tuber (kg ha^{-1})		Tuber starch content (%)	
2010			ST.D		ST.D		ST.D
Pre-crop:	Lucerne	204 a	±40.2	107	±23	14.7 a	±0.8
	Field pea	194 a	±48.1	100	±25	14.9 a	±0.3
	Spring barley	169 a	±31.2	84	±19	14.5 a	±0.8
Catch crop:	Without	188 a	±39.8	94	±23	14.6 a	±0.7
	With	189 a	±44.9	99	±27	14.8 a	±0.6
Manure:	Without	195 a	±40.4	97	±23	14.8 a	±0.5
	With	183 a	±43.5	97	±27	14.6 a	±0.8
2011							
Pre-crop:	Lucerne	98 a	±59.5	80	±52	18.6 a	±0.8
	Field pea	90 a	±44.2	72	±38	18.6 a	±1.2
	Spring barley	84 a	±41.4	65	±30	18.5 a	±0.9
Catch crop:	Without	86 a	±38.3	72	±36	18.7 a	±1.1
	With	95 a	±57.1	73	±45	18.4 a	±0.9
Manure:	Without	87 a	±42.6	66	±32	18.6 a	±1.1
	With	95 a	±54.1	79	±47	18.5 a	±0.9

See table 2.

Table 10.3: Nitrate concentration, nitrate uptake and starch content of potato tuber by individual values

Treatment	Pre-crop	Catch crop	Manure	Tuber nitrate concentration (mg kg^{-1})		N uptake by tuber (kg ha^{-1})		Tuber starch concentration (%)	
2010					ST.D		ST.D		ST.D
1	Lucerne	without	no	210	±27.5	110	±14	14.9	±0.1
2			yes	230	±22.2	114	±9	14.4	±1.0
3		with	no	210	±41.2	108	±25	15.1	±0.1
4			yes	173	±49.2	98	±36	14.4	±1.2
5	Field pea	without	no	199	± 50.8	96	±8	14.8	±0.3
6			yes	174	±60.8	91	±42	15.0	±0.2
7		with	no	204	±61.0	102	±34	15.1	±0.2
8			yes	203	±12.0	114	±21	14.7	±0.4
9	Spring	without	no	166	±21.7	71	±10	14.0	±0.7
10	barley		yes	170	±10.9	94	±10	14.5	±1.2
11		with	no	180	±33.6	97	±17	14.8	±0.3
12			yes	164	±55.2	79	±27	14.6	±0.8
2011					ST.D		ST.D		ST.D
1	Lucerne	without	no	87	±27.6	71	±22	18.7	±0.7
2			yes	96	±51.8	82	±46	18.5	±0.9
3		with	no	82	±46.2	58	±28	18.6	±1.1
4			yes	129	±101.7	111	±89	18.5	±0.5
5	Field pea	without	no	91	± 62.9	81	±64	19.4	±1.2
6			yes	88	±28.7	77	±36	18.7	±1.6
7		with	no	106	±60.5	73	±32	18.4	±1.3
8			yes	73	±25.0	57	±23	18.0	±0.8
9	Spring	without	no	67	±30.4	52	±21	18.3	±1.3
10	barley		yes	88	±37.6	69	±28	18.4	±0.9
11		with	no	88	±37.1	62	±20	18.0	±0.8
12			yes	95	±65.3	76	±50	19.0	±0.8
2010-2011					ST.D		ST.D		ST.D
1	Lucerne	without	no	139	±70.5	68	±39	16.8	±2.1
2			yes	153	±81.1	76	±34	16.4	±2.4
3		with	no	146	±79.6	65	±25	16.8	±2.0
4			yes	151	±77.6	81	±59	16.4	±2.4
5	Field pea	without	no	138	± 78.4	88	±27	17.1	±2.6
6			yes	131	±63.5	96	±37	16.8	±2.3
7		with	no	155	±79.6	83	±36	16.7	±1.9
8			yes	129	±71.9	104	±63	16.4	±1.9
9	Spring	without	no	116	±53.4	61	±18	16.2	±2.5
10	barley		yes	129	±50.5	81	±24	16.5	±2.3
11		with	no	127	±59.0	77	±25	16.4	±1.8
12			yes	128	±61.2	78	±37	16.8	±2.5

St.D: standard deviation.