Eesti Maaülikool
Estonian University of Life Sciences

THE EFFECT OF DIFFERENT FARMING SYSTEMS ON POTATO TUBER YIELD AND QUALITY

VILJELUSSÜSTEEMIDE MÕJU KARTULI MUGULASAAGILE JA KVALITEEDILE

BERIT TEIN

A Thesis
for applying for the degree of Doctor of Philosophy in
Agriculture

Väitekiri
Filosoofiadoktori kraadi taotlemiseks põllumajanduse erialal

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following papers, which are referred to by their Roman numbers (I–IV in the text). All papers are reproduced with due permission from the publishers.

I Tein, B., Kauer, K., Eremeev, V., Luik, A., Selge, A., Loit, E. 2014. Farming systems affect potato (*Solanum tuberosum* L.) tuber and soil quality. Field Crops Research, 156, 1–11.

II Runno-Paurson, E., Hansen, M., **Tein, B.**, Loit, K., Jõgi, K., Luik, A., Metspalu, L., Eremeev, V., Williams, I.H., Mänd, M. 2014. Cultivation technology influences the occurrence of potato early blight in an organic farming system. Zemdirbyste-Agriculture, 101(2), 199–204.

III Tein, B., Kauer, K., Runno-Paurson, E., Eremeev, V., Luik, A., Selge, A., Loit, E. 2015. The potato tuber disease occurrence as affected by conventional and organic farming systems. American Journal of Potato Research (accepted for publication)

IV Eremeev, V., Keres, I., **Tein, B.**, Lääniste, P., Selge, A., Luik, A. 2009. Effect of different farming systems on yield and quality of potato. Agronomy Research, 7(special issue 1), 245–250.

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Data analysis	**BT**, VE, KK	ERP	**BT**, VE, KK	**BT**, VE
Preparation of manuscript	All	All	All	All

BT – Berit Tein; VE – Viacheslav Eremeev; KK – Karin Kauer; ERP – Eve Runno-Paurson; All – all authors of the paper

ABBREVIATIONS

Ca	calcium
Ca_{tot}	total calcium
CC	catch crop
C_{org}	organic carbon
C_{tot}	total carbon
DM	dry matter
FS	farming system
K	potassium
K_{tot}	total potassium
M	manure
Mg	magnesium
Mg_{tot}	total magnesium
N	nitrogen
NO_3^-	nitrate
N_{tot}	total nitrogen
P	phosphorus
P_{tot}	total phosphorus
vs	versus

1. INTRODUCTION

The world's population is estimated to exceed over 9 billion people by 2050 (FAO, 2013), thus the demand for high yielding, good quality crops as well as the "challenges for the sustainability of the ecosystems" increases (Somers and Savard, 2015). Proper crop management is a key element in achieving high yields of good quality. Crop rotation, animal manures, and winter cover crops as catch crops (CC) play important roles in sustainable plant production systems because they provide nutrients for the system (Stark and Porter, 2005). CC and animal manures are mainly used by organic producers, because these are the main nutrient-rich sources for organic crop production. Animal manures are used by conventional producers only if, in addition to crop production, they have also livestock. Conventional producers, who grow only crops, largely depend on mineral fertilizers and different synthetic agrochemicals. According to Luik et al. (2008) conventional systems might not be sustainable in the long term, because they tend to be oversimplified and maximally intensified. But Edwards-Jones and Howells (2001) claimed that neither conventional nor organic farming systems (FS) are sustainable because both of them require inputs from non-renewable resources and, one way or another, they both impact on the environment. For organic producers there are also two main challenges, such as managing diseases and nutrients since nutrient availability is limited and there are only a few effective pesticides available that are allowed for use (Finckh et al., 2006). Also, Nelson et al. (2009) confirm that in organic systems nutrient transformations almost exclusively relyon soil. In conventional systems, if there are problems with diseases or pest and with plant malnutrition, synthetic agrochemicals and mineral fertilizers can be provided throughout almost the entire growing season. Despite some limitations in organic farming, organic agriculture is based on its own self-regulating production system, and the concept of a farm is as an agro-ecosystem (Lammerts van Bueren et al., 2002). But organic agriculture alone does not provide a sufficient amount of food for the growing population (Oliver and Gregory, 2015). In contrast, conventional agriculture depends mainly on external inputs, which makes it somewhat more vulnerable. To consider farming systems to be sustainable they must be "productive and maintain their contribution to society in the long term" (Gadanakis et al., 2015). In general, the demand for agricultural practices and food security that are more environment-friendly is increasing rapidly, which favours the development of new integrated farming systems (Duc et al., 2015). Such farming systems that use integrated management practices, such as crop rotations and organic (green manure crops, leguminous crops, CC) and inorganic fertilizers, will maintain soil as well as human health (Marsh, 2000; Oliver and Gregory, 2015). Future agriculture must also evolve towards climate-smart agriculture technologies, which are more adaptive to climate change by improving resource use efficiency and ensuring food security (Zhang et al., 2015). Achieving food security does not only mean an adequate food supply but it also means that the food must be nutritious, of good quality (Wei et al., 2015).

The potato is one of the most important crops worldwide, ranking fourth in annual production (Fernie and Willmitzer, 2001). The potato can be grown in harsher climates, and it is able to give, relatively quickly, high nutritious yields compared to any of the other major food crops (Lutaladio and Castaldi, 2009). However, to be productive, the potato needs significant nutrient inputs to maintain its productiveness and quality. Crop management is the main factor that influences crop production and disease resistance (Larkin and Halloran, 2014; Olanya et al., 2014). Previous research has shown that FS affect tuber quality characteristics such as tuber nutrients (Järvan and Edesi, 2009) as well as starch and dry matter (DM) contents (Roinila et al., 2003). Plant nutrition is an important factor that influences natural disease resistance. If there is a deficiency of essential elements susceptibility to potato diseases increases (Czajkowski et al., 2011), because the plant's natural ability to fight them is lowered (Mulder and Turkensteen, 2005). Nutrients affect the plant physiology and thus potential for infection with pathogens (Dordas, 2008). At the European Association for Potato Research (EAPR, 2014) conference last year it was concluded that the agronomy side of potato production has gained too little attention over the past years and needs to regain its importance, because the agronomic side of potato production determines the potato performance parameters.

Potato is a crop that has been studied in Estonia extensively because of its importance in Estonians everyday diet. The first true Estonian potato scientist was Julius Aamisepp who promoted the cultivation of potato and its research. The first fertilization experiments were conducted by Arnold Piho in 1960–1980 which also included the potato crop. The latest potato fertilization research has been made by Kuldkepp et al.

(1999), by Astover and Roostalu (2003), by Järvan and Edesi (2009), by Toomsoo and Leedu (2002), by Toomsoo et al. (2009; 2012). However, such complex potato fertilization research (under different organic and conventional farming systems) presented in current thesis has not been made before in Estonia. Earlier potato research has had mainly domestic importance. In the past, besides potato fertilization, the effect of different potato pre-planting thermal treatments on the tuber yield formation has been studied by Viacheslav Eremeev. Also there has been some potato disease related research by Mati Koppel who studied the potato soft rot (*Erwinia/Pectobacterium* spp.) disease and by Eve Runno-Paurson who investigated the potato late blight (*Phytophthora infestans*). The potato meristem multiplication has been studied by Viive Rosenberg and Marje Särekanno. Potato research related to plant breeding has been conducted by Aide Tsahkna and Mati Koppel. There are many other great potato researchers in Estonia who are a true experts in their field of study.

Crop rotations are important tools that affect potato productivity (Carter et al., 2003) and diseases (Peters et al., 2004). Catch crops are essential to avoid nutrient losses (Stark and Porter, 2005). *Brassica* crops used as CC have, furthermore, been found to have a disease suppressing effect (Cohen et al., 2005). Since the potato is a high nutrient demanding crop, additional mineral or organic fertilizers must be provided. Despite nitrogen (N) being a basic potato nutrient, the selection of its appropriate application rate for the potato is quite difficult, due to significant variation (Zebarth et al., 2009). The appropriate N demand can vary among many factors such as climatic conditions during the growth period, crop management practices the previous crops cultivated. Addressing all the aforementioned factors should ensure high potato yields of good quality.

Currently, these are the following gaps in our knowledge: (i) how the yield increase through different agronomic practices affects the potato tuber mineral elements concentrations (which are considered tuber nutrients) (White et al., 2009) and overall crop quality (Wang et al., 2008), (ii) how crop rotations influence tuber quality parameters (Mohr et al., 2011), and (iii) how the plant nutrition and crop rotations together affect the occurrence of tuber diseases (VanderZaag, 2010). The focus of much research tends to be on organic or conventional management systems separately, it is important to investigate their influence together comparatively (Bernard et al., 2014). Thus, the overall aim of this thesis is to investigate how different organic and conventional management practices under the same crop rotation influence tuber quality characteristics as well as yield.

2. REVIEW OF THE LITERATURE

2.1. The potato crop

The potato is the most important non-grain food crop in the world, and its importance is growing rapidly (Fiers et al., 2012). Nutrient-rich potatoes contribute to improved human diets and are able to reduce malnutrition (Lutaladio and Castaldi, 2009). Because the potato is a crop that does not need any special growing conditions it is a major food crop in temperate areas, and its importance is also increasing in warmer regions (Haverkort, 1990). However, the ideal soils for potato production are well-drained with a sandy loam texture (Moulin et al., 2011) such as *Stagnic Luvisols* (Reintam et al., 2000; Mazare et al., 2012). Moreover, because of its high starch content, large quantities of potatoes are used in the food processing industry (Högy and Fangmeier, 2009). The potato can be highly productive if managed properly, but a lack of knowledge into how to use management practices correctly is one of the main causes for why potato yields in some cases remain low (Zubarev et al., 2008). Such knowledge is achieved only through experimental research. Demand for organically produced potato tubers is also increasing fast (Willer and Youssefi, 2007). For the majority of organic producers, the potato is the most important vegetable food crop from economic and agronomic points of view (Haase et al., 2007a).

2.2. Potato quality characteristics

Potato plants require more than 13 mineral elements (Harris, 1992), which include macronutrients (N, P, K, Ca, Mg, S) as well as trace elements (Cl, Fe, Mn, B, Zn, Cu, Mo). Three of them – N, phosphorus (P) and potassium (K), are the top elements that determine crop yields (Dreyer, 2014). Certain mineral nutrition limits must be maintained for adequate nutrition, and to avoid mineral toxicities, because insufficient nutrients concentrations limit potato growth and therefore can affect tuber quality, but an excess of nutrient concentrations inhibit growth through toxicity (White et al., 2007). Adequate N nutrition results in high yields of good quality (Gianquinto et al., 2004). The nutritional status of the potato also determines the ability of the plant to protect itself against attack from pathogens (Agrios, 2005), which is one of the main quality characteristics next to overall nutritional condition.

2.2.1. Potato tuber nutrients, dry matter and starch

A balanced nutrient supply is the main factor that helps to maintain crop health (Klikocka et al., 2005). Both low and high tuber N concentrations affect the tubers;: if the tuber N concentrations are very low then the DM contents in tubers are also low (Sowokinos and Preston, 1988), but conversely if the N concentrations are very high then DM contents tend to be lower, and the tubers are more prone to bruising, damage and pathogens (Dean and Thornton, 1992). However, according to findings by Woltz and Engelhar (1973) high levels of N have an inhibiting effect on some dry-rot causing species. Nitrogen is also important for plant cell maintenance and construction (Abenavoli et al., 2005).

Phosphorus is a nutrient that is involved in energy transfer processes (Westermann, 2005). A deficiency in P decreases tuber growth rates (McCollum, 1987). Higher P concentrations in tubers result in a thicker tuber skin, which makes the tubers more resistant to pathogens, and it also has a positive effect on tuber starch quality (Mulder and Turkensteen, 2005).

Potassium is a vital element for overall plant growth, for yield and quality and for stress resistance of crops. It plays an important role in crop physiological processes (Zörb et al., 2014), improves cooking and processing qualities (Marschner, 1995), makes the tubers resistant to bruising (Panique et al., 1997) and also influences the DM percentage (Imas and Basal, 1999). Higher levels of tuber K help to thicken the cell walls of epidermal cells, which helps to prevent pathogen attack (Dordas, 2008). High tuber K levels have also been found to have an effect of reducing *Fusarium* (Srihuttanum and Sivasithamparam, 1991) which causes disease.

Calcium (Ca) is a nutrient that helps to strengthen and thicken the cell walls, which makes the tubers more resistant to pathogenic organisms (Easterwood, 2002; Palta, 2010). Calcium is also responsible for maintaining tissue regulatory functions (Lambert et al., 2005) and freezing tolerance (Vega et al., 1996). High tuber Ca concentrations have been found to make plants resistant to soft rot (*Pectobacterium/Erwinia* spp.) and to dry rot (*Fusarium* spp.) pathogens (Kelman et al., 1989; Huber, 1994).

Magnesium (Mg) plays an important role in tuber disease resistance as does Ca. Magnesium affects physiological processes in plants, thus influencing the status of a plant's overall health and its susceptibility to various potato diseases (Huber and Jones, 2013). Higher Mg concentrations in tubers have been found to have a soft rot reducing effect on tubers, however Ca has a greater impact on soft rot incidence than Mg (McGuire and Kelman, 1986).

Tuber DM content affects potato cooking quality. Higher tuber DM (>20%) contents improve the appearance and texture of the cooked tubers (Blumenthal et al., 2008) making DM one of the most important quality parameters for the potato processing industry (Storey and Davies, 1992).

About 66–80 % of potato DM is its starch content (Li et al., 2006). Starch in tubers is responsible for potato sensory, cooking and processing properties (Singh et al., 2008). The mash quality, the mealiness and texture of cooked potatoes are affected by the tuber starch content (van Eck, 2007). The starch content in tubers also affects tuber bruise susceptibility, which in turn depends on the size of the starch cells (Storey, 2007). For the processing industry, it is considered that the optimal tuber starch content should be around 15% (Eilers and Hanf, 1999).

Potato tubers also contain nitrates (NO_3^-) which are natural components of plants (Rogozińska et al., 2005) that are involved in physiological and biochemical processes (Cieslik and Sikora, 1998). Nitrates are considered to be unhealthy for humans if their concentrations are high, but according to Schuddeboom (1993) potato is classified as a vegetable crop that contains low amounts of NO_3^-, which means the potato is a safe crop to consume for humans.

2.2.2. Potato tuber diseases

Diseases are a major problem in the potato industry which lower the yields and quality of harvested tubers. There are more than a hundred diseases that affect potato tubers (Hide and Lapwood, 1992) and annually approximately 22% of the global potato yield is lost due to various diseases and pests (Ross, 1986). Even nowdays potato diseases remain one of the biggest factors responsible for low yields and quality (Olanya et al., 2014). If the growing conditions are favourable for diseases to develop, and if no crop protective practices are used, then tuber diseases can cause enormous yield and quality losses that can be economically destructive. Unfortunately for potato production there are still no efficient control strategies available to fight against potato tuber pathogens that cause various diseases (Lazarovits et al., 2008). Tuber diseases remain a recurrent and persistent problem in the potato industry (Larkin and Tavantzis, 2013) against which sustainable and integrated control options are needed (Larkin, 2008).

In this research four of the potato tuber diseases – two bacterial and two fungal diseases are investigated. Two of them, such as common scab and silver scurf, are the most dominant diseases in the experiment. Dry rot and soft rot were investigated because of their overall importance in the potato industry as they not only reduce tuber quality but they may also cause enormous yield losses.

One of the most prevalent disease that lowers the tuber quality, and is found all over the world, is common scab caused by pathogenic *Streptomyces* spp., which are bacterial species, most commonly *Streptomyces scabiei* (Thaxter (Lambert & Loria)). No common scab resistant cultivars exist, but some cultivars have higher resistance against that disease (Haynes et al., 2009). Common scab is a soil-borne disease that infects the immature tubers and, as the tubers grow, so do the lesions expand (Hosaka et al., 2000). Common scab lesions can be deep-pitted, shallow or raised (Goyer et al., 1996) and they have a corky looking appearance (Lebecka et al., 2006). Common scab impairs the visual appearance of the tubers, which is highly important for the consumers, and therefore the potato marketability is affected (VanderZaag, 2010). According to the findings of Conn and Lazarovits (1999) common scab disease can infect and thereby reduce the quality of an entire harvested yield, but such high infection rates occur only in extreme cases. Because the common scab pathogen is viable on plant residues, or in the soil, for many years (Kritzman and Grinstein, 1991), and there are no strategies available to control the disease (Abbasi et al., 2006), it is important to use crop management practices that reduce the occurrence of common scab.

Silver scurf is caused by the fungus *Helminthosporium solani* (Durieu & Montagne) affects the periderm of tubers causing its metallic discoloration (Secor and Gudmestad, 1999). In very severe cases the tubers will eventually shrink and lose weight because of the water losses caused by silver scurf (Platt and Peters, 2006). Due to shrinkage and water loss the overall tuber yield decreases causing economic problems. The tubers are already infected in a field but major silver scurf outbreaks usually occur during the storage period (Olivier et al., 1998) thus it is also considered to be a storage disease. Silver scurf disease is a rapidly emerging problem because, over recent years, the disease's incidence has dramatically increased because cultural as well as chemical practices are very difficult to solve the problem as the silver scurf pathogen has developed resistance to some of the fungicides used (Errampalli et al., 2001). The silver scurf pathogen has been found to infect up to 90% of the yield (Frazier et al., 1998). Therefore it is a serious need to investigate which agronomic practices favour the disease incidence, since there are no silver scurf resistant cultivars available (Lebecka et al., 2006).

Dry rot is a fungal disease that is caused by *Fusarium* spp.. Dry rot is a post-harvest disease, but the pathogen may also affect seed tubers after they are planted (Xiao-Juan et al., 2008). The pathogen enters into tubers mainly through wounds inflicted when the tubers are harvested. Dry rot yield losses have been estimated to be 6% or even up to 25% of the harvested yield (Chelkowski, 1989; Stevenson et al., 2001; Singh and Sharma, 2007) and more than 60% of the tubers may be further infested during storage (Wharton et al., 2006). According to Lui and Kushalappa (2002) the disease symptoms are the following: the first symptom of dry rot infections is that dark depressions occurr on the surface of the tubers. In later stages the tuber skin becomes wrinkly and internal tissues become dry, dark, and cavities may occur. If the tubers are fully rotted then they eventually become shrivelled and mummified (Bojanowski et al., 2013). Dry rot is considered to be one of the most important potato storage diseases, and because there are no dry rot resistant cultivars available (D'Ippólito et al., 2010), much attention must be paid to crop management practices such as effective weed control (Carnegie et al., 2001), avoiding damaging the tubers during harvest (Secor and Salas, 2001), and most importantly growing potatoes in long crop rotations (Platt and Peters, 2006). The application of fertilizers also increases the tolerance of plants to overall pathogens (Huber et al., 2012). In some cases, once the tubers are already infected with dry rot then soft rot (*Pectobacterium*/*Erwinia* spp.) infections occur in combination with dry rot (Davis et al., 1983; Corsini and Pavek, 1986), especially under humid storage conditions or if the tubers are wet (Howard et al., 1994; Stevenson et al., 2001).

Soft rot caused by *Pectobacterium* (*Erwinia*) spp. bacteria species causes significant yield decreases which result in major economic losses. The pathogen enters the tubers through natural openings (Lyon, 1989) or through wounds caused while harvesting the tubers. Yield and quality losses due to soft rot may reach, in very severe cases, up to 100% of the total yield (Elphinstone, 1987). As the disease name indicates, the diseased tissues are wet and soft with a slightly granular consistency, and in colour they are cream to tan (Tweddell et al., 2003). Despite tubers contaminated already in the soil, major disease outbreaks occur when the tubers are stored. The pathogen spreads rapidly in storage with the fluids from rotting tubers making the disease highly infectious. Soft rot is also one of the most important quality and yield lowering potato diseases because there are no efficient control methods available against soft rot pathogen virulence (Latour et al., 2008). According to a review by Czajkowski et al. (2011) there is only one previous research article from 1966 by Graham and Harper who studied the effect of N levels on the incidence of soft rot, and found that increased levels of N had the effect of reducing the incidence of soft rot. Thus, studies such as those described in this thesis, are extremely important and have a high value for the potato industry.

2.3. The factors affecting potato tuber yield and quality

According to Vos (1997) it is very important to study how potato responds to N continuously because of the environmental issues which require agriculture producers to reassess N inputs and manage the nutrient flows. Contemporary data is needed all the time because production factors, pests and disease are changing, and relying only on older data is not sustainable (Padmos, 1986) since current technologies are constantly changing (de Wit, 1992). Vos (2009) confirmed this; as potato average yields have enormously increased recently due to improved crop management practices, new experiments are needed since older data and recommendations are becoming obsolete. Vos (2009) also claimed that, since the potato industry has developed tuber quality parameters, there is need for research about the role of mineral nutrition as this is the main factor that determines the quality characteristics of the tubers. Overall, excess or inadequate amounts of fertilizers reduce potato tuber yields and potato quality (Öztürk et al., 2010). Moreover, there are many controversies when comparing conventional and organic crop quality characteristics (Maggio et al., 2008), thus further experiments are required to clear the missing link between FS and the quality of the crops (Bourn and Prescott, 2002).

2.3.1. The effect of farming systems on tuber yield and quality

Conventional FS mainly rely on mineral fertilization because it is much easier to control the amounts of nutrients applied using mineral fertilizers than when using manure or leguminous crops in rotation. Mineral fertilizers are more easlily available for the plants to use. They are also more easily accessible for producers. Mineral crop nutrition has also an impact on plant stress tolerance by improving it (Klikocka et al., 2005). Manure is mainly used in organic farming to improve plant productivity and soil fertility (Schröder, 2005) by providing nutrients. Rodrigues et al. (2006) stated that organic amendments used in organic farming may not always ensure the crop N demand from available N sources. The nutrient availability from leguminous crops and manure can be highly variable in a given year and in a given field (Zebarth and Rosen, 2007) because the bedding material used or manure composition may be different, and also there are uncertainties in ammonia volatilization losses (Smith and Chambers, 1993). According to Haase et al. (2007b), even in systems in which cattle manure is available for use, organic fertilizers are very limited and serious nutrient availability problems may still occur. Furthermore, the aim for conventional farming is to provide as many mineral nutrients as the plants need to gain maximal outcome. But organic farming aims to minimize the environmental impact of agricultural production by recycling plant nutrients and organic matter (Dalgaard et al., 2002) within the system. With improved N use efficiency the crop yield and quality are also increased (Stockdale et al., 1997). Disease outbreaks in conventional system are also easier to control because conventional systems can use many of the various synthetic agrochemicals which use in organic farming is prohibited. Organic farming is much more affected by environmental factors such as disease and climate pressure than conventional farming (Hagman et al., 2009). The use of agro-chemicals in conventional farming has various beneficial effects such as increasing crop yields, food safety, environmental degradation and energy use, (Cooper and Dobson, 2007).

Errebhi et al. (1998) stated that potatoes respond to N fertilization very well and that N is usually the most limiting essential nutrient for potato growth for both conventional and organic producers (Vos, 1995; Finckh et al., 2006). However, it is highly important that the producers should not over supply with N fertilizers because studies by Silva et al. (1991) and Westermann et al. (1994) have found that a surplus of N can actually decrease yields not to mention the greater environmental pollution over fertilization may cause. Moreover, potato has a low N use efficiency, so only 50–60% of applied N is used (Dilz, 1987). Nitrogen fertilization also affects indirectly affects crop damage and susceptibility to pests, diseases and weeds (Jørnsgård et al., 1996), which indicates that optimizing the nutrient management in FS, especially N management, is extremely important for the yield and quality of potato tubers (Joern and Vitosh, 1995). Despite that manure is one of the main nutrient sources in organic farming, its impact on soil pathogenic organisms and their effects on plants have been overlooked for a long time (Conn and Lazarovits, 1999) because it is very complicated to replace the use of it with other sources which would have the same nutritional value for the crop.

There are a range of different results about how potato N fertilization affects yields, its components and quality characteristics (Table 1). It is confirmed that the application of K might also have a significant effect of increasing tuber NO_3^- concentrations. There has also been found a strong relationship between tuber N and NO_3^- concentrations (Bélanger et al., 2002).

Fertilization regimes also have an effect on potato tuber diseases. According to Khomyakov and Kostin (1981) site specific fertilization allows the crops to grow strong and healthy, by making the plants less sensitive to pathogenic organisms.

Table 1. Overview of previous research on some tuber yield and quality parameters.

Fertilization	Parameter	The influence on studied parameter	Authors
Excess supply of N	Size of the tubers, tuber DM and starch content, tuber maturity, common scab	Increases the number of very large tubers, lowers DM and starch content, delays tuber maturity, incidences of common scab reduced	O’Beirne et al., 1990; Riley, 2000; Lin et al., 2004, Laboski and Kelling, 2007; Goffart et al., 2008
Increasing use of N	Tuber DM, N and NO_3^- concentrations	Increasing/no effect on tuber DM, increasing tuber N and NO_3^- concentrations,	White and Sanderson, 1983; Millard, 1986; Muller and Hippe 1987; Sylvester-Bradley and Chambers, 1992; Vogtmann et al., 1993; Eppendorfer et al., 1996; Mäck and Schoerring, 2002; Rogozińska et al., 2001; Tadesse et al., 2001
Low supply of N	Yield, tuber size	Lower yields, smaller amount of marketable tubers	Fontes et al.,2010
Organic vs conventional	Tuber P, Mg and K concentrations, overall diseases	Tuber P, Mg and K concentrations and diseases higher in organic potatoes, only tuber P concentrations higher in organic farming	Warman and Havard 1998; Wszelaki et al., 2005; Fiers et al., 2012; Smith-Spangler et al., 2012

However, the fertilization may contrarily also have a disease favouring effect by enhancing foliar development which is responsible for retaining high humidity, which is needed for the growth of soft rot bacteria for example (Rousselle et al., 1996). Despite some studies that have been made there are still many unanswered questions and controversies between them that need clarification.

There are no unanimous recommendations regarding the suggested nutrients amounts for the potato. According to Roy et al. (2006) the potato requires, in temperate growing regions, as much as 200–300 kg of N ha^{-1}, 100–300 kg of P_2O_5 (44–132 kg P ha^{-1},) ha^{-1}, and 60–300 (50–249 kg K ha^{-1}) kg of K_2O ha^{-1}. Another study (White et al., 2007) claims that on most soils potato requires 150–250 kg of N ha^{-1} and 170–210 kg of K ha^{-1} to achieve maximum yields. Kanger et al. (2014) have stated that potato requires (depending on soil nutritional status) 70–150 kg ha^{-1} of N, 25–90 kg ha^{-1} of P and 55–240 kg ha^{-1} of K. The ratio of the main potato nutrients amounts is recommended to be 1:0.3:1.8 (N:P:K) (Mengel et al., 2001), however the specific nutrients amounts and ratios required by the potato are mainly dependent on soil type, farming system, climatic conditions and growing season.

2.3.2. The effect of crop rotations and catch crops on tuber yield and quality

Long crop rotations (over four years) with various crops in rotation are essential to control diseases and pests, to optimize the crop productivity and reduce production costs by optimizing the sustainability of agro-ecosystems (Olanya et al., 2006). Tuber soil-borne diseases have most often been controlled and managed with the use of various crop rotations (Honeycutt et al., 1996; Larkin and Honeycutt, 2002). It has been found that longer rotations are more effective at controlling tuber soil-borne diseases than short-term rotations (Carter and Sanderson, 2003; Peters et al., 2003). Effective rotations also have a positive impact on soil parameters by altering the soil biological, chemical and physical characteristics (Karlen et al., 1992; Magdoff, 2000; Ball et al., 2005; Magdoff and van Es, 2009) which in turn affect the tuber nutritional status and thus tuber resistance to diseases.

Because of environmental impacts, and due to high fertilizer prices, there has been an increasing interest towards leguminous crops as N sources in rotation (Sharifi et al., 2009). Legumes must satisfy firstly their own N needs, but additionally they must also supply enough N for the succeeding crop (Rodrigues et al., 2006). Leguminous crops in rotation are known to increase the soil N supply (Stark and Porter, 2005) and availability, thus improving tuber yield and quality, and they have even the ability to suppress potato soil-borne diseases (Sanderson et al., 1999). Legumes are a rich source of N, containing approximately 100–250 kg N ha^{-1} (Mohr et al., 1999). However, if the potato is grown after leguminous crops then its N uptake is usually much higher compared to when potato is grown after cereals (Zebarth et al., 2005). Cereal crops in potato rotation help to interrupt the life cycles of potato pathogens thereby decreasing disease pressure and inoculum load (Peters et al., 2008).

CC are capable of helping to reduce N losses from FS during the surplus precipitation of the autumn-winter period, by absorbing N from the soil and then carrying-over to a succeeding main crop (Vos and van der Putten, 2001). The use of CC after the main crop also helps to reduce NO_3^- concentrations in the leachate (Shepherd, 1999; Vos and van der Putten, 2004) which otherwise would reach the groundwater reservoirs.

The use of *Brassica* crops in rotation or as CC is highly valuable for producers because they have many beneficial effects for the following crop. According to much previous research *Brassicaceous* species, as CC, have been found to have profound effects on potato tuber soil-borne diseases (Larkin and Honeycutt, 2006; Larkin et al., 2010; Lazarovits, 2010; Larkin et al., 2011a; Larkin et al., 2011b), but no tuber yield increase has been found to be associated with those species (Campiglia et al., 2009). *Brassica* crops have also been found to suppress weed (Boydston and Hang, 1995) and nematodes (Buskov et al., 2002) populations.

Previous research has tended to focus on specific practices or rotations, but there is a lack of studies that focus on multiple aspects at the same time, and such interactions need to be assessed to help to gain high yielding healthy crops (Larkin et al., 2011a).

2.3.3. The effect of climatic conditions on tuber yield and quality

The long days during the growing period and moderate temperatures in temperate regions allow the potato to photosynthesize for a longer period, which is necessary for the nutrients to translocate from the leaves to the tubers (Iwama and Yamaguchi, 2006). According to Hammes and Jager (1990) the optimal temperatures for photosynthesis in potato range from 16–25 °C. If the temperatures are abnormal compared to the average for the growing season, the photosynthesizing processes are disturbed which in turn may result in abnormalities in potato nutrients translocation. Tuber growth performance is disturbed and decreases when the average daily temperatures are higher than 19 °C (Van Dam et al., 1996), but according to Timlin et al. (2006) the optimal temperature for yield formation is between 14–22 °C, however Wheeler et al. (1986) specify that for long day areas this should be 16 °C. Thus, the optimal temperatures for the potato are very site specific.

Drought and high temperatures reduce the starch content (Krauss and Marschner, 1984) and DM (Jefferies, 1995), as well as tuber growth and yield (Iwama et al., 1999). Therefore the potato is very sensitive to dry weather conditions. If there is no rainfall, then even in a moist temperate climate the soil water potential reaches a critical level within three days (Burton, 1981), which in turn begins to affect potato growth. A water shortage at the beginning of growing season before tuber initiation (Shock et al., 1992), as well as in the middle of tuber initiation (Deblonde and Ledent, 2001), influences negatively the number of tubers, which also determines the final tuber yield. However, if drought conditions occur during the tuber initiation stage then average tuber size is larger, but if drought occurs after the tuber initiation then the average size of the tubers is smaller (Fabeiro et al., 2001). Therefore, drought affects the total and marketable yields differently – the total yields may be lower, but the portion of marketable yield may be higher. An excess of rainfall during potato growth may also decrease and reduce tuber yield (van Oort et al., 2012), because the effects of excess rainfall and fertilizers applied may cancel each other out (Ferreira and Carr, 2002), which similarly leads to lower yields. There are different published recommended water amounts for the potato. For instance, Haverkort (1982) recommends that potato needs 400–800 mm, Dimitrov (1983) claims that potato needs 380–450 mm, Paul et al. (1996) noted that potato need 252 mm, and Paningrahi et al. (2001) stated that potato needs 247–297 mm of water during the growing season to gain highest yields of good quality. Thus, the amount of water potato needs is very location specific and no uniform recommendations can be given.

The climatic conditions affect also the severity of disease occurrence. The common scab pathogen prefers warm (soil temperature over 22 °C) and a dry season, and under those conditions even resistant cultivars become infected (Loria, 2001). According to Lebecka et al. (2006) the optimal air temperature for the common scab bacteria is 30 °C. The silver scurf pathogen prefers moist conditions (Platt and Peters, 2006) and its optimal temperature range is very wide 15–32 °C (Adams et al., 1987; Errampalli, 2001). Wet soil also creates beneficial conditions for the tuber-rotting pathogens (Pereira and Shock, 2006). Dry rot pathogens favour temperatures between 3–25 °C (Errampalli, 2001; Kong et al., 2006) and disease development is more rapid at higher temperatures (Platt and Peters, 2006). Irregular rainfall and high temperatures also create a beneficial environment for the soft rot bacteria (Haverkort and Verhagen, 2008). Optimal temperatures for soft rot bacteria to spread are 15–35 °C (Helias, 2008; Latour et al., 2008). According to those authors the silver scurf, dry and soft rot pathogens spread well under humid conditions.

3. HYPOTHESIS AND AIMS OF THE STUDY

The concentrations of tuber nutrients, nitrates, starch contents and DM, as well as the incidence of tuber diseases all depend on the FS, rotation crops, and on soil and climatic conditions. There is lack of knowledge and comparative analyses regarding how conventional and organic FS under the same crop rotation influence the tuber quality parameters, and are therefore in need of further research. Thus this is the first study that focuses on comparing the systems as a whole and their effects on tuber quality characteristics.

Hypotheses:

- Tubers under conventional fertilized FS have higher nutrients concentrations, starch and DM contents than tubers grown under organic FS because of the additional mineral fertilizers provided that are more easily available for the potato to use.
- The infection of potato tubers with pathogens is significantly affected by the FS, due to the various sources and amounts of nutrients that have an impact on the disease susceptibility of potato.

The aims of the study were:

1. To assess the effect of FS on tuber yield differences (I, II, IV).
2. To investigate how different FS influence the tuber macronutrient concentrations as well as starch and DM contents (I).
3. To investigate how different FS affect the incidence of potato tuber diseases such as common scab, silver scurf, dry rot and soft rot (III).

4. MATERIALS AND METHODS

In this thesis, the term farming system (FS) is used to refer to a system as a whole that consists of all the elements of a specific farming system such as rotation crops fertilization regimes (mineral and organic as well as overall fertilizer amounts and their availability) and strategies (1–3 applications of fertilizers with different nutrient amounts), means of plant protection (the use of agrochemicals versus natural resistance and means to help cope with unfavourable organisms), the use of CC also determines the soil cultivation and disturbance intensity and the interaction of all the aforementioned elements together. The term tuber quality is used to characterize the tuber nutrient concentrations, nitrates, starch and dry matter contents which are considered to be the basic quality characteristics which also determine the quality of other quality parameters. Potato diseases are considered as a quality parameter as well because they have a very strong influence on yields as well as damaging the visual appearance of the tubers; overall they cause enormous yield losses.

4.1. Experimental site and design

In 2008 a five crops rotation experiment was established at the Estonian University of Life Sciences on an experimental field in Eerika (58°22'N, 26°40'E), located near to Tartu in Estonia. At the beginning of the experiment there were four conventional and one organic FS. Starting from 2009 one more organic system was added. The experiment was laid out in four replications, with each plot in a systematic block design. Randomization between plots was fixed every year in all replications and FS. The size of each plot was 60 m^2 – 6 meters wide and 10 meters long. For potato there were eight rows in one plot. Between organic and conventional plots there was an 18 meters long separation area with a mixture of grasses to avoid any contamination and mixing of organic and conventional systems. The organic systems were also separated with a 10 meters long protective area by potatoes to avoid the spread of manure to other organic plots. There was no separation between conventional systems and replications. However, between conventional systems there was a 6 m^2 (1 m long and 6 m wide) transition area where no samples were taken for analyses. Based on the World Reference Base classification (FAO, 2006) the soil of the experimental field was a *Stagnic Luvisol* with a sandy loam texture (humus layer 20–30 cm), which is highly suitable for potato production. At the beginning of the experiment the soil humus layer characteristics were the following: pH_{KCl} 5.9, C_{org} 1.38%, N_{tot} 0.14%, plant available $P_{(avail)}$ 112.6 mg kg^{-1}, K_{avail} 168.1 mg kg^{-1}, Ca_{avail} 1185 mg kg^{-1}, Mg_{avail} 188.7 mg kg^{-1}. During the years 2008–2011 different potato parameters were monitored.

Potato was part of a five crops rotation experiment where red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.), potato and barley (*Hordeum vulgare* L.) undersown (us) with red clover followed each other in this sequence in each year (Table 2). In 2008 there were altogether 100 plots in one field. After modifications in 2009 the number of plots increased to 120.

Table 2. Five crops rotation in 2008–2011.

Year	Crop				
2008	barley us red clover	**potato**	pea	winter wheat	red clover
2009	red clover	barley us red clover	**potato**	pea	winter wheat
2010	winter wheat	red clover	barley us red clover	**potato**	pea
2011	pea	winter wheat	red clover	barley us red clover	**potato**

4.2. Management of farming systems

4.2.1. Management of organic systems

In 2008 there was only one organic FS in which fully composted cattle manure was used. There were no CC between 2007–2008 autumn-winter. When the main crops were harvested in 2008 CC (Table 3) were sown and the organic part was divided into two systems. Starting from the autumn of 2008 in both organic FS the previous CC (Organic CC) before potato was winter oilseed rape (*Brassica napus* L. ssp. *oleifera biennis*) which was sown after the pea harvest. When potato was harvested following CC, winter rye *(Secale cereale* L.) was sown. After the harvest of winter wheat perennial ryegrass (*Lolium perenne* L.) was sown. The CC were ploughed into the soil one or two weeks before the planting/sowing of the main crop in the spring. In the second organic FS, potato received fully composted cattle manure (Organic CC+M) at the amount of 40 t ha^{-1}, which contained on average N_{tot} 9.7 g kg^{-1} (174 kg ha^{-1}), P_{tot} 4.6 g kg^{-1} (82 kg ha^{-1}), K_{tot} 8.6 g kg^{-1} (154 kg ha^{-1}), C_{tot} 138 g kg^{-1} (2473 kg ha^{-1}), and DM 44.8% (17920 kg ha^{-1}). In 2008 and 2009 the manure was added in the autumn of the previous year and then ploughed into the soil before sowing the CC (2009). Starting from 2010 the manure was added in spring and then ploughed into soil with previous CC. Manure was added only to potato. Other crops' Organic CC+M system followed the manure after-effect from potato. The years before 2011 were a period of conversion to organic, but starting from 2011 the organic systems were completely converted into organic. Although the years 2008–2010 were conversion years to organic, the term 'Organic' has been used for better data monitoring. Similarly the term 'Organic CC+M' is used for the year 2008, although no CC were used. For ease of understanding, it will be noted under those tables in which the year 2008 is also monitored.

Table 3. Catch crops in organic systems.

Catch crop	Cultivar	Sowing rate kg ha^{-1}
Winter oilseed rape	'Banjo'	6
Ryegrass	'Talvike'	25
Winter rye	'Tulvi'	220

4.2.2. Management of conventional systems

The conventional FS were the same in all years. No mineral fertilizers were used in the conventional control system (N0). The other three conventional systems differed regarding the added mineral N: $N_{50}P_{25}K_{95}$ (N_{low}) (ratio 1:0.5:1.9), $N_{100}P_{25}K_{95}$ ($N_{average}$) (ratio 1:0.25:0.95) and $N_{150}P_{25}K_{95}$ (N_{high}) (ratio 1:0.17:0.63). All the conventional systems which were fertilized received NPK fertilizers during planting at the rate of 20:25:95 kg ha^{-1}. During the potato growth one or two subsequent N supplements were added during the growth depending on the system – N_{low} = 30 kg ha^{-1}; $N_{average}$ = 60+20 kg ha^{-1}; and N_{high} = 90+40 kg ha^{-1}. Also, synthetic agrochemicals were used in conventional systems. In 2008 insecticide was used only once. During the first experimental year the main focus was on fertilization, thus the crop protection practices were retained. In the following years pesticides (Table 4) were used several times during the growth period.

Table 4. Synthetic agrochemicals used in potato conventional systems during potato growth.

Product name	Active ingredient	Quantity used	Category
Fastac 50	alpha-cypermethrin (50 g l^{-1})	0.15–0.3 l ha^{-1}	Insecticide
Decis EC	deltamethrin (27.5 g l^{-1})	0.2 l ha^{-1}	Herbicide
Titus 25 DF	rimsulfuron (250 g kg$^{-1)}$	40–50 g ha^{-1}	
Ridomil Gold MZ 68 WG	metalaxyl (40 g kg^{-1}), mancoceb (640 g kg^{-1}	1.25–2.5 kg ha^{-1}	Fungicide
Shirlan	fluazinam (500 g l^{-1})	0.4 l ha^{-1}	
Revus 250 SC	mandipropamid (250 g l^{-1})	0.6 l ha^{-1}	
Ranman 400 SC	cyazofamid (400 g l^{-1})	0.15–0.2 l ha^{-1}	

Herbicides were used one-two, insecticides two-three, fungicides three-four times during the potato vegetation period depending on the need. The other main crops received mineral N fertilizers as follows: Winter wheat conventional FS were fertilized with the same amount of fertilizers as potato. Pea, as it is a leguminous crop, received mineral fertilizers N0 (control), $N_{low\text{-}high}$ – $N_{20}P_{25}K_{95}$. Barley undersown with red clover received mineral fertilizers: N0 (control); N_{low} – $N_{40}P_{25}K_{95;}$ $N_{average}$ – $N_{80}P_{25}K_{95;}$ N_{high} – $N_{120}P_{25}K_{95}$. Red clover as a main crop was not fertilized. After the potato was harvested the plots were treated with glyphosate (4 l ha^{-1}). After the winter wheat, pea and potato in conventional systems were harvested, the soil remained untouched until the end of October when the fields were ploughed.

4.3. Planting and harvesting

Before planting, the seed tubers were kept for 35–38 days in a humid (80–85%) and illuminated room at 12–15 °C. The diameter of seed tubers used for planting was 35–55 mm. The tubers were planted at the beginning of May with the norm of 2.7–3.0 t ha^{-1}. The distance between rows was 70 cm and the distance between tubers was 27 cm. Approximately 52,910 tubers were planted per hectare. In 2008 the cultivar used was 'Ants', which is late maturing. From 2009 'Ants' was replaced with 'Reet', which is an early to medium maturing cultivar. Both cultivars used were developed in Estonia at the Jõgeva Plant Breeding Institute. According to the breeders, the yielding ability for cultivars 'Ants' and 'Reet' are similar and comparable (Tsahkna and Tähtjärv, 2008).

Potato was harvested at the end of August or at the beginning of September depending on the year. The tubers were hand-picked after the rows were opened using a two-row elevator-picker machine.

4.4. Measurements, analyses and calculations

4.4.1. Tuber yield analyses

To measure total and marketable yields (tuber diameter >35 mm) ten consecutive plants in a row were taken directly before the harvest of potato and from these the yields were determined.

4.4.2. Tuber nutrients, dry matter, starch and cattle manure analyses

After the potato was harvested six tubers (with a diameter of 35–55 mm) from each replication were sampled to measure tuber nutrient concetnrations and DM content. Starch contents in tubers were measured using Parov's weight. To measure DM tubers were washed, cut into strips and then dried for 48 h at a temperature of 80 ºC. The samples of manure were taken before it was applied onto the field. N_{tot} concentrations in tubers and manure, as well as C_{tot} in manure, were analysed by the dry combustion method in a varioMAX CNS elemental analyser (ELEMENTAR, Germany). Acid digestion by sulphuric acid solution (Methods of Soil and Plant Analysis, 1986) was used to determine tuber P_{tot}, K_{tot}, Ca_{tot} and Mg_{tot} concentrations, as well as cattle manure P_{tot} and K_{tot} concentrations. NO_3^- concentrations in tubers were measured using the cadmium (Cd) column method (Houba et al., 1989).

4.4.3. Tuber disease analyses

One hundred tubers from each replication were randomly selected after the tubers were harvested to characterize the marketable yield. Tubers were placed into wooden boxes (33x38x10 cm). There were three layers of tubers in each box. Tubers were stored in a dark room at a temperature of 4 ºC. Storage room air humidity was 80–85 %. In total there were two disease measurements during the storage period. One day before the first disease measurement the tubers were washed to better evaluate the disease incidences and severity. The first measurement was three months after harvest and the second was seven months after harvest. During the first measurement common scab (*Streptomyces* spp.), silver scurf (*Helminthosporium solani*), dry rot (*Fusarium* spp.) and soft rot (*Pectobacterium* spp.) infections were determined visually. Visual disease assesment is approved and has also been used in other studies previously (Bernard et al. 2014; Larkin and Halloran, 2014). Depending on the severity of the common scab infections the infected tubers were divided into four groups – (1) 4–15% of tuber surface infected, (2) 16–30% of tuber surface infected, (3) 31–45% of tuber surface infected, (4) >45% of tuber surface infected (Estonian Plant Production Inspectorate, 2001). Thereafter the number of tubers from each group was counted, and the percentages of infected tubers were calculated. If the severity of surface infections was less than 4% then the tubers were not grouped, because the infection was not that severe. At the same time silver scurf, dry rot and soft rot infections were also counted and the percentages of infected tubers were subsequently calculated. During the first measurement, tubers infected with soft rot were removed to avoid further infection from already infected tubers. The same tubers were used in the second measurement as in the first. Only dry rot and soft rot were measured during the second measurement to see new disease developments. The disease assessments were made by the same person on all occasions. Altogether 400 tubers characterized one FS.

4.4.4. Soil analyses

Soil samples were taken once in a year in mid-April, before the start of any field operations. The samples were taken from each plot at a depth of 0–25 cm. Eight samples were taken from one plot and combined to get one average sample. Air-dried soil samples were sieved through a 2 mm sieve and used to determine soil reaction (pH) in 1M KCl 1:2.5 solution. C_{org} was measured after the method of Tjurin (Soil Survey Laboratory Staff, 1996) and N_{tot} concentration after Kjeldahl (van Reeuwijk, 1995). The concentrations of plant available nutrients P, K, Ca and Mg in the soil were determined by the ammonium lactate (AL) method (Egnér et al., 1960).

4.4.5. Weather conditions during the potato growing period

Metos Model MCR300 (Pessl Instruments GmbH, Weiz, Austria) electronic weather station was used to monitor weather during the potato growing period. The weather station automatically calculates the average daily temperatures and the sum of precipitation. The daily average temperatures were averaged over 10 days (referred as decade) to obtain the decade average of daily average temperatures.

The average temperature in 1969–2011 during the potato growing period (May-September) was 14.5 °C (Table 5). In 2008 the average May-September temperatures were 0.8 °C lower than the average of many years (1969–2011) making it the coldest of the years studied. In 2009 the potato growing period was the most similar to the average of many years. The difference was only 0.2 °C, making the year studied optimal for the growing area. The last two experimental years were much warmer compared to the average of 1969–2011. The temperatures in these years were 1.3 or 1.0 °C warmer in 2010 and 2011 respectively.

Table 5. Average monthly temperatures (°C) during the potato growing period in the Eerika experimental field.

Month	Decade[1]	Temperatures (°C)				
		2008	2009	2010	2011	1969–2011
May	I	11.1	10.9	7.3	8.0	9.7
	II	8.8	9.3	16.7	11.8	11.4
	III	12.0	14.1	12.4	13.0	12.8
June	I	15.4	11.7	13.3	19.7	14.9
	II	14.1	13.1	13.6	15.9	15.1
	III	13.9	16.7	15.9	16.2	16.2
July	I	15.1	15.6	19.9	20.0	17.3
	II	16.6	17.9	22.9	18.6	17.4
	III	16.5	17.2	22.4	21.0	17.8
August	I	15.4	16.3	20.9	16.1	17.6
	II	18.0	15.1	19.1	15.6	16.2
	III	13.9	14.8	13.7	15.8	14.6
September	I	13.4	15.7	10.4	13.0	12.7
	II	7.1	11.8	12.1	12.2	10.6
May-September	I–III	13.7	14.3	15.8	15.5	14.5

[1] Period of 10 days

The precipitation sum in May-September as a long-term average in a growing area was 331.4 mm (Table 6). In 2008 and 2010 the precipitation sums during the potato growing period were 13.8 and 129.8 mm higher, respectively, compared to the long-term average for precipitation. In 2009 and 2011 the precipitation sums were lower compared to the long-term average. In 2009 there was 9.6 mm, and in 2011 74.4 mm, less precipitation than on average.

Table 6. Precipitation (mm) during the potato growing period.

Month	Decade[1]	Precipitation (mm)				
		2008	2009	2010	2011	1969–2011
May	I	16.6	3.2	39.2	0.2	12.9
	II	10.6	7.6	44.6	46.6	20.9
	III	0.2	2.6	13.6	11.6	22.8
June	I	1.0	86.6	41.4	0.0	20.9
	II	76.4	34.0	17.8	24.8	26.9
	III	33.2	16.8	38.8	10.4	28.0
July	I	28.8	10.4	11.6	9.2	19.3
	II	16.0	21.4	3.0	30.4	24.8
	III	9.0	22.8	23.8	8.6	26.5
August	I	74.0	4.6	18.2	16.2	33.3
	II	22.6	54.2	74.6	17.0	28.5
	III	21.2	30.4	55.6	21.4	28.0
September	I	35.2	16.0	32.6	32.2	20.3
	II	0.4	11.2	46.4	28.4	18.3
May-September	I–III	345.2	321.8	461.2	257.0	331.4

[1] Period of 10 days

The year 2008 can be characterized as cold, but with quite similar rainfall to the average of many years (1969–2011). In 2009 the weather conditions were the most similar to the long-term average, making this studied year optimal. In 2010 the weather was very warm and there were problems with excessive moisture during the growing period. In 2011 the weather was also warmer but very dry, but with high air humidity in mid-August (data not presented). The potato growing periods studied therefore differed substantially.

4.5. Statistical analyses

Statistica version 11.0 (StatSoft Inc.) software package was used for statistical analyses. Factorial analysis of variance (ANOVA) was used to test the effect of different FS on tuber yield and quality parameters. Least significant difference (Fisher's LSD) test for homogenous groups was used to test for significant differences between FS, experimental year, time of measurement (tuber diseases) and their interaction. Means followed with different capital letters within each column in tables, or on top of the bars in figures, indicate a significant influence ($P<0.05$) of FS, and means followed by different small letters within each table row indicate a significant influence ($P<0.05$) of year, if it is not written otherwise. Data in tables also represent mean±95% confidence limits.

RESULTS

5.1. Tuber total and marketable yield

Tuber total and marketable yields were significantly influenced by FS, experimental year, and their interactions (Table 7, 8; Figure 1, 2) (**I**, **II**, **IV**). Fertilization with mineral N fertilizers gave, on average, higher ($P<0.05$) total yields (Figure 1) as well as marketable yields (Figure 2), however the total yield differences between mineral fertilized systems were not significant ($P>0.05$). The marketable yields were different ($P<0.05$) between studied mineral fertilized systems. The N_{high} system increased ($P<0.05$), average marketable yield compared to N_{low} system. Both total and marketable yields remained ($P<0.05$ or $P>0.05$) lower in 2010 (except in the Organic CC system). The only significant ($P<0.05$) differences between organic systems occurred in 2011 with total yields (Table 6). Organic CC+M systems gave higher ($P<0.05$) total yields compared to the Organic CC system.

Table 7. Average tuber total yields, t ha^{-1}.

Farming system	Total yield (t ha^{-1})			
	2008	2009	2010	2011
Organic CC	–[1]	$21.6^{Aa}\pm14.6$	$15.8^{Aa}\pm4.9$	$23.0^{Aa}\pm7.0$
Organic CC+M	$20.1^{A2a3}\pm6.9^{4}$	$28.7^{Ab}\pm12.7$	$19.0^{ABa}\pm8.0$	$32.9^{Bb}\pm5.7$
$N_0P_0K_0$ (control)	$24.8^{Ab}\pm7.1$	$29.7^{Abc}\pm10.4$	$15.9^{Aa}\pm3.9$	$32.8^{Bc}\pm6.2$
$N_{50}P_{25}K_{95}$ (N_{low})	$34.2^{Bab}\pm11.7$	$48.1^{Bc}\pm18.3$	$22.9^{BCa}\pm5.4$	$37.7^{BCbc}\pm10.5$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	$38.7^{Bb}\pm11.4$	$52.4^{Bc}\pm17.8$	$26.4^{CDa}\pm3.9$	$43.1^{Cbc}\pm11.6$
$N_{150}P_{25}K_{95}$ (N_{high})	$38.0^{Bab}\pm6.7$	$57.5^{Bc}\pm20.2$	$29.0^{Da}\pm2.1$	$45.8^{Cbc}\pm11.7$

[1] – no data.

[2] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[3] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[4] Data represents mean±95% confidence limits.

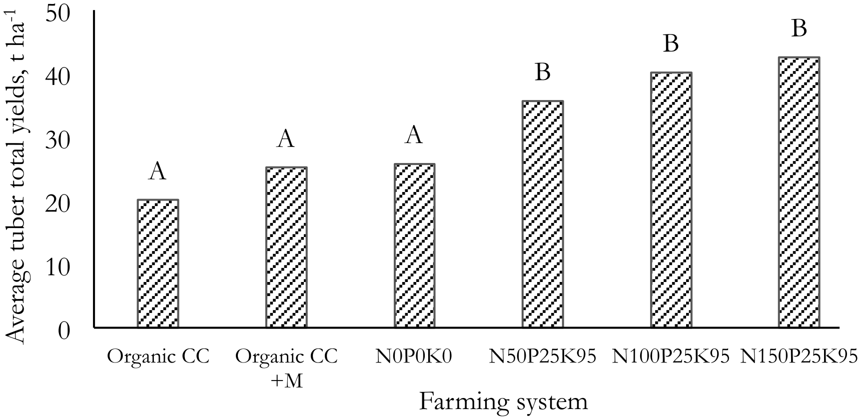

Figure 1. Four year (2008–2011) average tuber total yields depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), t ha^{-1}. Different capital letters on top of the bars indicate significant influence (P<0.05) of FS.

Table 8. Average tuber marketable yields, t ha^{-1}.

Farming system	Marketable yield (t ha^{-1})			
	2008	2009	2010	2011
Organic CC	–[1]	$19.2^{Aa}\pm12.7$	$14.0^{Aa}\pm3.9$	$19.2^{Aa}\pm6.6$
Organic CC+M	17.4^{A}[2]^{a}[3]±6.3[4]	$26.3^{Ab}\pm11.3$	$17.1^{ABa}\pm8.1$	$26.9^{ABb}\pm4.2$
$N_0P_0K_0$ (control)	$21.7^{Ab}\pm6.7$	$27.4^{Abc}\pm9.8$	$14.3^{Aa}\pm3.9$	$29.0^{BCc}\pm4.7$
$N_{50}P_{25}K_{95}$ (N_{low})	$31.7^{Bab}\pm11.5$	$46.1^{Bc}\pm17.0$	$21.3^{BCa}\pm6.4$	$35.1^{CDbc}\pm10.5$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	$36.6^{Bb}\pm11.0$	$50.1^{Bc}\pm16.9$	$24.4^{CDa}\pm3.7$	$40.9^{DEbc}\pm11.0$
$N_{150}P_{25}K_{95}$ (N_{high})	$36.0^{Bab}\pm6.5$	$55.1^{Bc}\pm19.0$	$26.6^{Da}\pm1.0$	$43.2^{Eb}\pm11.5$

[1] – no data.

[2] Means followed by a different capital letters within each column indicate significant influence (P<0.05) of farming systems (FS).

[3] Means followed by a different small letters within each row indicate significant influence (P<0.05) of year.

[4] Data represents mean±95% confidence limits.

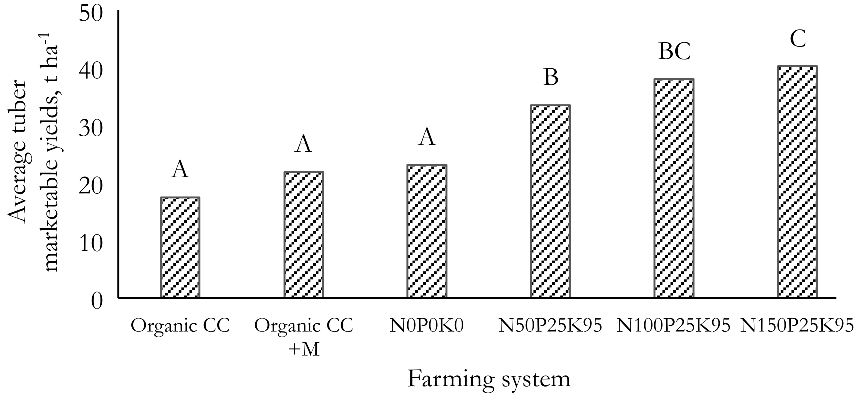

Figure 2. Four year (2008–2011) average tuber marketable yields depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), t ha^{-1}. Different capital letters on top of the bars indicate significant influence (P<0.05) of FS.

5.2. Tuber nutrients

N_{tot} concentrations in tubers were influenced (P<0.001) by all of the factors (**I**). Conventional FS with higher inputs of mineral N fertilizers increased tuber N_{tot} concentrations (Table 9). N_{tot} concentrations in tubers were, on average, higher in $N_{average-high}$ systems compared to the Organic CC and conventional control systems (Figure 3).

Table 9. Average N_{tot} concentrations in potato tubers, %.

Farming system	N_{tot} (%)		
	2009	2010	2011
Organic CC	$1.01^{B1a2}\pm0.03^{3}$	$1.30^{Ab}\pm0.04$	$1.30^{Ab}\pm0.08$
Organic CC+M	$1.04^{Ba}\pm0.05$	$1.36^{ABb}\pm0.12$	$1.35^{Ab}\pm0.09$
$N_0P_0K_0$ (control)	$0.94^{Aa}\pm0.02$	$1.47^{ABCc}\pm0.15$	$1.25^{Ab}\pm0.09$
$N_{50}P_{25}K_{95}$ (N_{low})	$1.01^{Ba}\pm0.01$	$1.53^{BCc}\pm0.19$	$1.26^{Ab}\pm0.13$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	$1.28^{Ca}\pm0.05$	$1.52^{BCa}\pm0.37$	$1.33^{Aba}\pm0.21$
$N_{150}P_{25}K_{95}$ (N_{high})	$1.41^{Da}\pm0.06$	$1.60^{Cb}\pm0.22$	$1.42^{Ba}\pm0.09$

[1] Means followed by a different capital letters within each column indicate significant influence (P<0.05) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence (P<0.05) of year.

[3] Data represents mean±95% confidence limits.

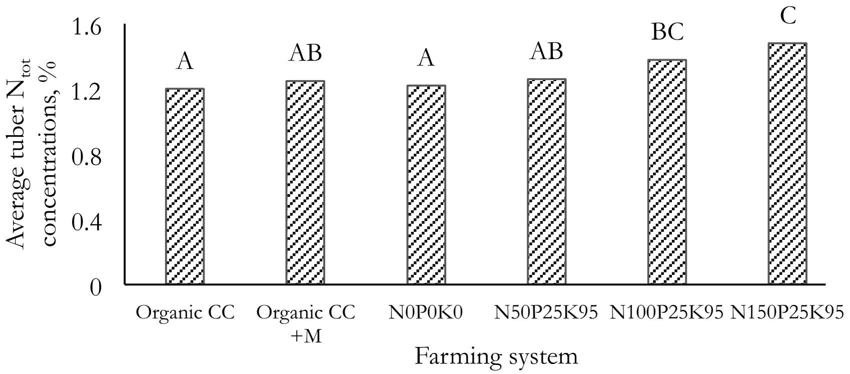

Figure 3. Three year (2009–2011) average tuber N_{tot} concentrations depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence (P<0.05) of FS.

The P_{tot} concentrations in tubers were affected by FS (P<0.001) and year interaction with FS (**I**). Year alone had a non-significant (P>0.05) effect on P_{tot} concentrations. P_{tot} concentrations were, on average, higher (P<0.05) in the organic and conventional control systems (Table 10; Figure 4) compared to mineral fertilized systems.

Table 10. Average P_{tot} and K_{tot} concentrations in potato tubers, %.

Farming system	P_{tot} (%)			K_{tot} (%)		
	2009	2010	2011	2009	2010	2011
Organic CC	0.22^{B1a2} ±0.01^{3}	0.23^{Aa} ±0.04	0.29^{Cb} ±0.02	1.78^{Aa} ±0.12	2.28^{ABb} ±0.15	2.34^{Ab} ±0.28
Organic CC+M	0.28^{Db} ±0.02	0.21^{Aa} ±0.04	0.22^{Ba} ±0.05	1.79^{Aa} ±0.12	2.24^{ABb} ±0.24	2.52^{Ac} ±0.15
$N_0P_0K_0$ (control)	0.24^{Ca} ±0.02	0.24^{Aa} ±0.08	0.22^{Ba} ±0.03	1.77^{Aa} ±0.06	2.12^{Ab} ±0.29	2.36^{Ac} ±0.08
$N_{50}P_{25}K_{95}$ (N_{low})	0.19^{Aa} ±0.01	0.24^{Aa} ±0.07	0.20^{ABa} ±0.04	1.74^{Aa} ±0.04	2.41^{Bb} ±0.44	2.42^{Ab} ±0.11
$N_{100}P_{25}K_{95}$ ($N_{average}$)	0.21^{Ba} ±0.01	0.21^{Aa} ±0.04	0.19^{Aa} ±0.04	1.75^{Aa} ±0.14	2.38^{ABb} ±0.20	2.41^{Ab} ±0.28
$N_{150}P_{25}K_{95}$ (N_{high})	0.19^{Aa} ±0.01	0.20^{Aa} ±0.03	0.19^{ABa} ±0.03	1.82^{Aa} ±0.12	2.33^{ABb} ±0.38	2.51^{Ab} ±0.38

[1] Means followed by a different capital letters within each column indicate significant influence (P<0.05) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence (P<0.05) of year.

[3] Data represents mean±95% confidence limits.

In contrast, the K_{tot} concentrations in tubers were influenced only by experimental year ($P<0.001$) (**I**) and, on average, no differences ($P>0.05$) were found between FS for tuber K_{tot} concentrations (Figure 5). In 2010 and 2011 the K_{tot} concentrations in tubers were higher ($P<0.05$) than in 2009 (Table 10).

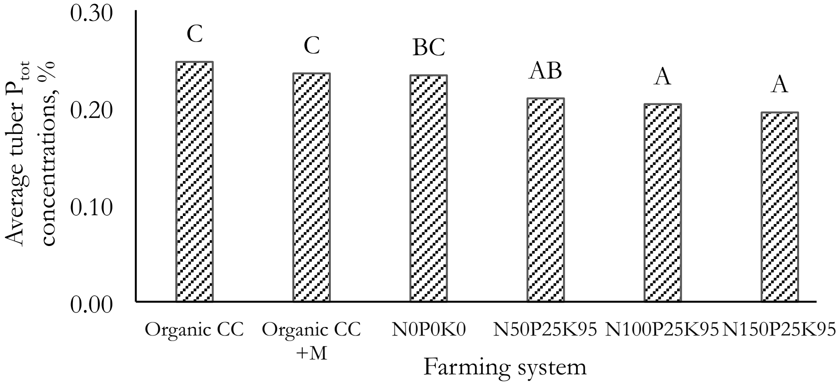

Figure 4. Three year (2009–2011) average tuber P_{tot} concentrations depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

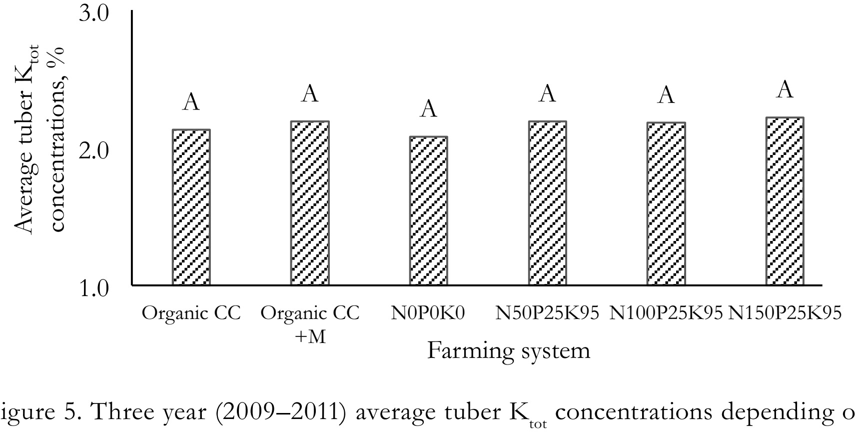

Figure 5. Three year (2009–2011) average tuber K_{tot} concentrations depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

Tuber Ca_{tot} concentrations were influenced by experimental year and year interaction with FS ($P<0.001$) (**I**). Mg_{tot} concentrations in tubers were affected by all the factors ($P<0.05$) (**I**). Ca_{tot} concentrations were higher ($P<0.05$) in 2010 and 2011 compared to 2009 (Table 11 (including Mg_{tot}). FS had, on average, no influence ($P>0.05$) on tuber Ca_{tot} concentration (Figure 6). Mg_{tot} concentrations in tubers were significantly (organic systems and conventional control system) or non-significantly (conventional fertilized systems) lower in 2011 (Table 11).

On average, the Mg_{tot} concentrations in tubers were significantly different ($P<0.05$) only between Organic CC+M and $N_{average}$ systems (Figure 7). However, organic systems and conventional control systems tended to have higher Mg_{tot} concentrations in tubers compared to other FS.

Table 11. Average Ca_{tot} and Mg_{tot} concentrations in potato tubers, %.

Farming system	Ca_{tot} (%)			Mg_{tot} (%)		
	2009	2010	2011	2009	2010	2011
Organic CC	0.05^{B1a2} $\pm0.00^{3}$	0.09^{Bb} ±0.01	0.14^{BCc} ±0.02	0.13^{Bb} ±0.01	0.16^{Ac} ±0.03	0.11^{ABCa} ±0.01
Organic CC+M	0.05^{Ba} ±0.01	0.07^{Aa} ±0.02	0.17^{Cb} ±0.06	0.14^{Cb} ±0.01	0.14^{Ab} ±0.02	0.11^{Ca} ±0.01
$N_0P_0K_0$ (control)	0.06^{Ca} ±0.01	0.10^{BCb} ±0.02	0.14^{BCc} ±0.02	0.12^{Bab} ±0.01	0.15^{Ab} ±0.04	0.11^{BCa} ±0.01
$N_{50}P_{25}K_{95}$ (N_{low})	0.08^{Da} ±0.01	0.09^{Ba} ±0.01	0.19^{ABb} ±0.04	0.10^{Aa} ±0.01	0.15^{Ab} ±0.02	0.10^{ABCa} ±0.01
$N_{100}P_{25}K_{95}$ ($N_{average}$)	0.08^{Ea} ±0.01	0.11^{Cb} ±0.02	0.10^{Aab} ±0.03	0.10^{Aa} ±0.01	0.14^{Ab} ±0.02	0.10^{ABa} ±0.02
$N_{150}P_{25}K_{95}$ (N_{high})	0.04^{Aa} ±0.00	0.09^{Bb} ±0.01	0.11^{ABc} ±0.028	0.10^{Aa} ±0.01	0.15^{Ab} ±0.03	0.10^{Aa} ±0.01

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

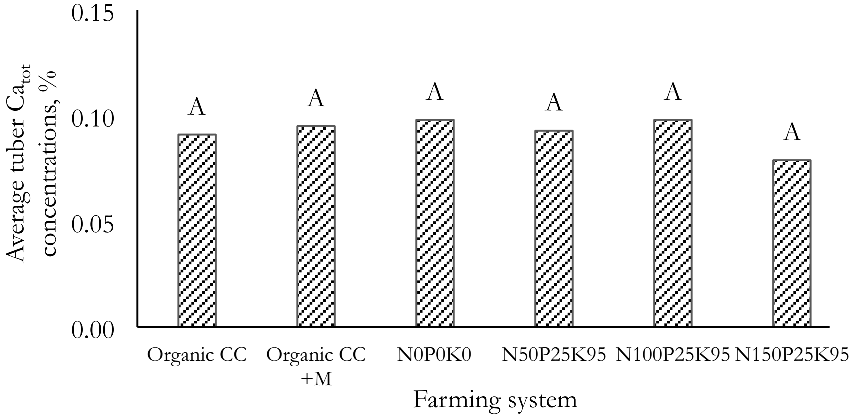

Figure 6. Three year (2009–2011) average tuber Ca_{tot} concentrations depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

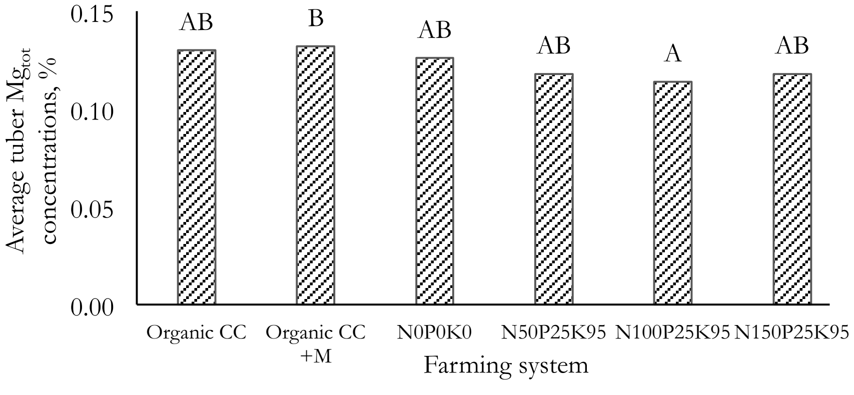

Figure 7. Three year (2009–2011) average tuber Mg_{tot} concentrations depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

Tuber NO_3^- concentrations were, similarly to tuber N_{tot} concentrations, influenced by all the factors ($P<0.001$) (**I**). NO_3^- concentrations in tubers were, in 2010 and 2011, approximately twice those in 2009 (Table 12). In conventional systems in which $N_{average\text{-}high}$ amounts of mineral N fertilizers were used had, on average, much higher ($P<0.05$) tuber NO_3^- concentrations compared to the other FS (Figure 8).

Table 12. Average NO_3^- concentrations in potato tubers, mg kg^{-1}.

Farming system	NO_3^- (mg kg^{-1})		
	2009	2010	2011
Organic CC	$6.2^{A1a2} \pm 1.2^{3}$	$60.0^{Ac} \pm 26.6$	$43.7^{Ab} \pm 5.7$
Organic CC+M	$24.2^{BCa} \pm 1.0$	$71.5^{Ab} \pm 59.6$	$50.2^{Aab} \pm 17.5$
$N_0P_0K_0$ (control)	$22.0^{BCa} \pm 1.6$	$58.0^{Ac} \pm 10.1$	$41.3^{Ab} \pm 18.4$
$N_{50}P_{25}K_{95}$ (N_{low})	$25.0^{Ca} \pm 1.2$	$96.2^{Ab} \pm 63.5$	$50.6^{Aa} \pm 21.3$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	$61.9^{Ea} \pm 5.6$	$195.1^{Bb} \pm 68.9$	$110.8^{Ba} \pm 63.4$
$N_{150}P_{25}K_{95}$ (N_{high})	$39.7^{Da} \pm 3.5$	$182.4^{Bc} \pm 14.1$	$149.8^{Cb} \pm 49.9$

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

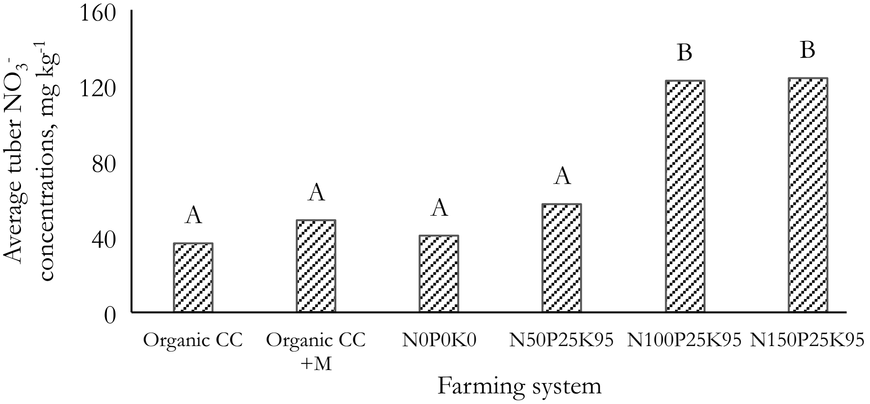

Figure 8. Three year (2009–2011) average tuber NO_3^- concentrations depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), mg kg^{-1}. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

5.3. Tuber dry matter and starch

Year, and year interaction with FS, had an influence ($P<0.001$) on tuber DM and starch contents (**I**). Dry matter and starch contents in tubers were mostly and statistically higher in 2009 and 2011 compared to 2009

(Table 13). But, on average, FS alone had no significant ($P<0.05$) influence on tuber DM (Figure 9) or starch content (Figure 10).

Table 13. Average potato tuber dry matter and starch contents, %.

Farming system	DM (%)			Starch (%)		
	2009	2010	2011	2009	2010	2011
Organic CC	25.0^{C}[1]$^{\mathrm{b}}$[2] ±0.4[3]	21.4^{ABa} ±1.2	22.0^{Aa} ±0.5	17.6^{Cb} ±0.2	16.1^{Ba} ±0.5	15.9^{Aa} ±0.6
Organic CC+M	24.9^{Cb} ±0.6	22.9^{Ba} ±0.9	21.9^{Aa} ±1.2	16.5^{Ab} ±0.3	16.7^{Cb} ±0.5	15.8^{Aa} ±0.6
$N_0P_0K_0$ (control)	25.5^{Cb} ±1.1	20.9^{ABa} ±4.1	22.8^{ABab} ±2.2	17.9^{Cc} ±0.9	14.9^{Aa} ±0.3	16.6^{Bb} ±0.4
$N_{50}P_{25}K_{95}$ (N_{low})	25.1^{Cc} ±0.3	21.3^{ABa} ±1.4	23.7^{BCb} ±0.8	17.3^{BCc} ±0.3	14.9^{Aa} ±0.5	16.7^{Bb} ±0.4
$N_{100}P_{25}K_{95}$ ($N_{average}$)	22.6^{Ab} ±0.6	20.1^{Aa} ±2.3	23.3^{BCb} ±1.9	17.0^{ABb} ±1.1	15.0^{Aa} ±0.3	16.9^{Bb} ±0.2
$N_{150}P_{25}K_{95}$ (N_{high})	23.7^{Bb} ±0.4	20.7^{Aa} ±1.8	24.4^{Cb} ±0.5	16.6^{Ab} ±0.4	14.7^{Aa} ±0.2	16.8^{Bb} ±0.4

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

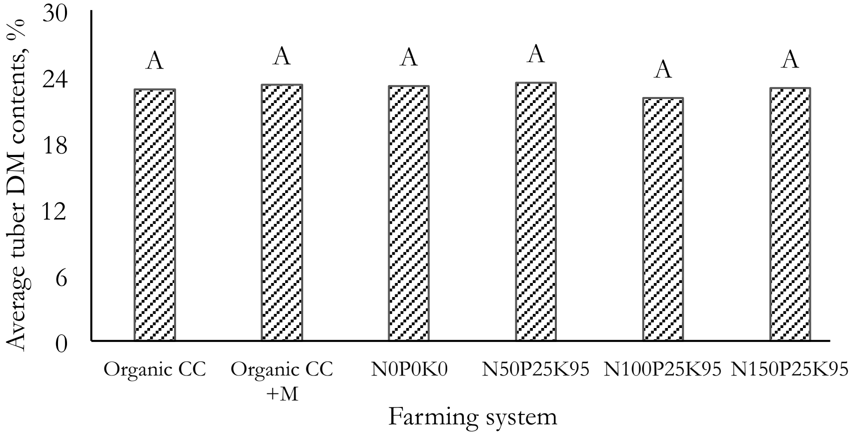

Figure 9. Three year (2009–2011) average tuber dry matter (DM) contents depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

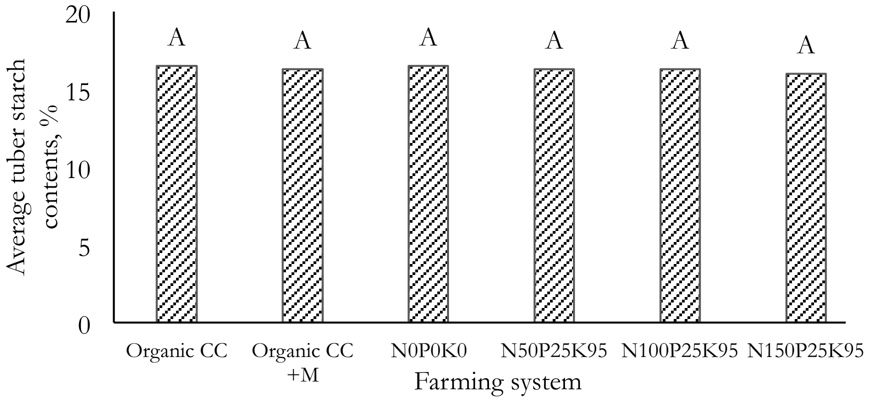

Figure 10. Three year (2009–2011) average tuber starch contents depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

5.4. Tuber diseases

5.4.1. Tuber bacterial diseases

The total percentage of tubers infected with common scab were influenced by experimental year and its interactions with FS (**III**). When comparing experimental years, then organic systems had greater ($P<0.05$) total percentages of tubers infected with common scab in the last two experimental years, but in conventional systems only in the last experimental year (Table 14). In 2010, tubers grown under conventional systems had significantly fewer tubers infected with common scab than in organic systems. FS alone had, on average, no influence ($P>0.05$) on the total percentage of tubers infected with common scab (Figure 11).

Table 14. Total percentage of tubers infected with common scab from marketable yield, %.

Farming system	Yield with common scab (%)		
	2009	2010	2011
Organic CC	10.5^{A}[1]^{a}[2]±6.6[3]	63.3^{Bb}±2.7	58.8^{Ab}±16.5
Organic CC+M	15.3^{Aa}±8.4	77.8^{Bb}±14.7	71.8^{Ab}±7.0
$N_0P_0K_0$ (control)	9.3^{Aa}±6.1	34.0^{Aab}±26.5	60.3^{Ab}±39.9
$N_{50}P_{25}K_{95}$ (N_{low})	14.3^{Aa}±14.1	32.3^{Aa}±16.8	61.5^{Ab}±42.5
$N_{100}P_{25}K_{95}$ ($N_{average}$)	15.3^{Aa}±16.0	25.0^{Aa}±15.6	60.5^{Ab}±46.5
$N_{150}P_{25}K_{95}$ (N_{high})	8.0^{Aa}±5.7	30.8^{Aa}±18.1	66.5^{Ab}±35.3

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

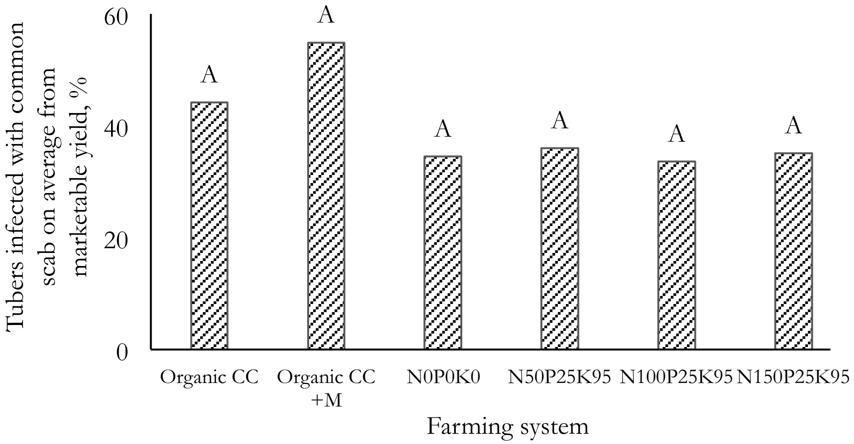

Figure 11. Three year (2009–2011) average percentage of tubers infected with common scab from marketable yield depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

When the common scab infection severities were divided into four groups, then some differences between FS were found. The percentage of tubers in groups 1 and 2 were significantly influenced by all the factors (**III**). The percentage of tubers in groups 1 and 2 were lower ($P<0.05$ (except $N_{low\text{-}average}$)) in 2009 (Table 15). In group 1 the conventional systems had, on average, fewer ($P<0.05$) tubers infected with common scab compared to organic systems (Figure 12). In group 2 the differences ($P<0.05$) were found only between organic systems (Figure 13). In the organic system in which CC were used together with manure a statistically higher ($P<0.05$) percentage of tubers were in group 2 compared to organic systems in which only CC were used. Tubers in group 3 were influenced only by year, but tubers in group 4 were not influenced by any of the factors (**III**).

Table 15. The percentage of tubers infected with common scab from marketable yield (4–15% and 16–30% of tuber surface infected), %.

Farming system	Common scab (distribution of tubers with surface area lesion coverage)					
	(1) 4–15% (%)			(2) 16–30% (%)		
	2009	2010	2011	2009	2010	2011
Organic CC	10.5^{A1a2} ±6.6^{3}	55.8^{Bb} ±5.4	51.8^{Bb} ±9.9	0^{Aa}	6.8^{Ab} ±2.7	5.5^{Ab} ±7.4
Organic CC+M	15.0^{Aa} ±8.7	55.0^{Bb} ±17.2	47.5^{ABb} ±9.9	0.3^{Aa} ±0.8	19.3^{Bb} ±19.0	19.8^{Ab} ±2.4
$N_0P_0K_0$ (control)	9.3^{Aa} ±6.1	28.3^{Ab} ±23.6	37.8^{Ab} ±11.9	0^{Aa}	4.0^{Aab} ±3.9	16.8^{Ab} ±22.7
$N_{50}P_{25}K_{95}$ (N_{low})	13.3^{Aa} ±12.4	22.5^{Aa} ±8.9	40.0^{Ab} ±11.3	1.0^{Aa} ±2.3	8.0^{Aa} ±17.1	16.8^{Aa} ±28.8
$N_{100}P_{25}K_{95}$ ($N_{average}$)	13.8^{Aa} ±13.5	21.3^{Aa} ±9.8	40.0^{Ab} ±12.9	1.5^{Aa} ±3.0	3.0^{Aa} ±4.7	16.3^{Aa} ±26.6
$N_{150}P_{25}K_{95}$ (N_{high})	7.3^{Aa} ±4.2	26.5^{Ab} ±18.1	41.8^{ABc} ±10.5	0.5^{Aa} ±1.6	3.8^{Aa} ±5.4	20.3^{Ab} ±21.6

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

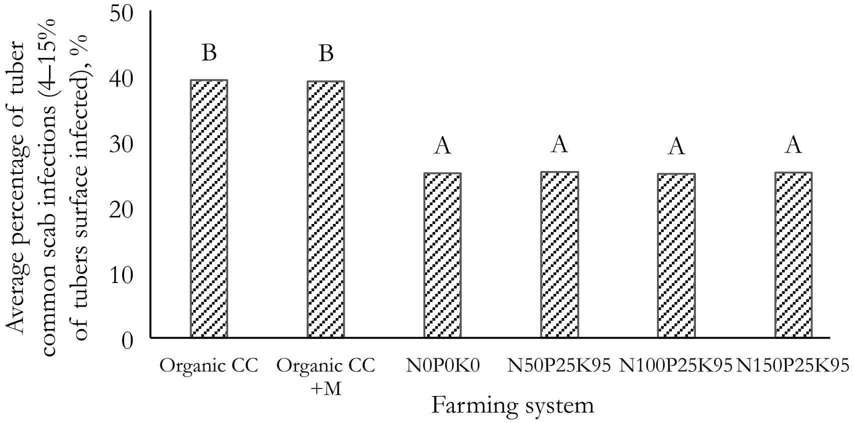

Figure 12. Three year (2009–2011) average percentage of tubers infected with common scab from marketable yield depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}) (4–15% of tuber surface infected), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

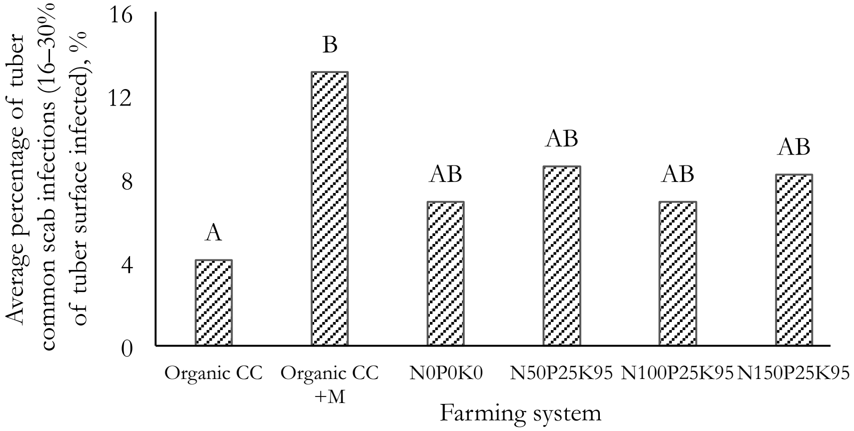

Figure 13. Three year (2009–2011) average percentage of tubers infected with common scab from marketable yield depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}) (16–30% of tuber surface infected), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

Tuber soft rot infections were influenced by year, time of disease measurement and their interaction (**III**). Soft rot infections were found only in 2011 during the first disease measurement. In 2011, soft rot occurrence was much higher ($P<0.05$) in the Organic CC+M system compared to the conventional control, N_{low} and N_{high} systems (Table 16). FS alone had no effect ($P>0.05$), on average, on tuber soft rot incidence (Figure 14).

Table 16. Total percentage of tubers infected with soft rot from marketable yield, %.

Farming system	Soft rot (%)		
	Autumn		
	2009	2010	2011
Organic CC	0^{a2}	0^{a}	$2.0^{AB1b}\pm3.7^{3}$
Organic CC+M	0^{a}	0^{a}	$3.5^{Bb}\pm3.8$
$N_0P_0K_0$ (control)	0^{a}	0^{a}	$1.0^{Aa}\pm3.2$
$N_{50}P_{25}K_{95}$ (N_{low})	0^{a}	0^{a}	$0.8^{Aa}\pm1.5$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	0^{a}	0^{a}	$1.3^{ABb}\pm0.8$
$N_{150}P_{25}K_{95}$ (N_{high})	0^{a}	0^{a}	$0.5^{Aa}\pm0.9$

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

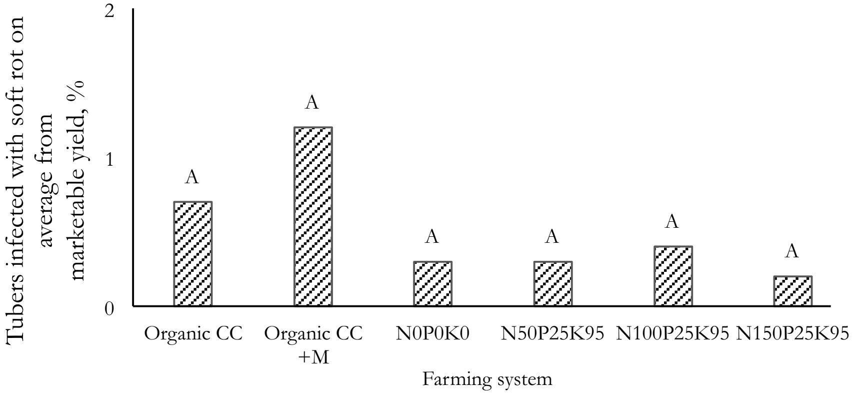

Figure 14. Three year (2009–2011) average percentage of tubers infected with soft rot from marketable yield depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

5.4.2. Tuber fungal diseases

The occurrence of silver scurf was influenced only by FS (Table 17) (**III**). On average, silver scurf incidence increased with the use of mineral N, however the increase was significant ($P<0.05$) only when comparing organic systems with the N_{high} system or Organic CC system with the conventional control and $N_{average-high}$ systems (Figure 15).

Table 17. Total percentage of tubers infected with silver scurf from marketable yield.

Farming system	Silver scurf (%)	
	2009	2011
Organic CC	8.3^{A}[1]^{a}[2]±9.1[3]	12.8^{Aa}±10.9
Organic CC+M	10.0^{ABa}±3.4	15.5^{ABa}±8.4
$N_0P_0K_0$ (control)	17.5^{ABa}±10.8	21.8^{BCa}±8.0
$N_{50}P_{25}K_{95}$ (N_{low})	11.0^{ABa}±15.6	24.5^{Ca}±9.2
$N_{100}P_{25}K_{95}$ ($N_{average}$)	16.5^{ABa}±19.4	23.5^{BCa}±11.4
$N_{150}P_{25}K_{95}$ (N_{high})	21.5^{Ba}±12.5	25.3^{Ca}±7.8

[1] Means followed by a different capital letters within each column indicate significant influence ($P<0.05$) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence ($P<0.05$) of year.

[3] Data represents mean±95% confidence limits.

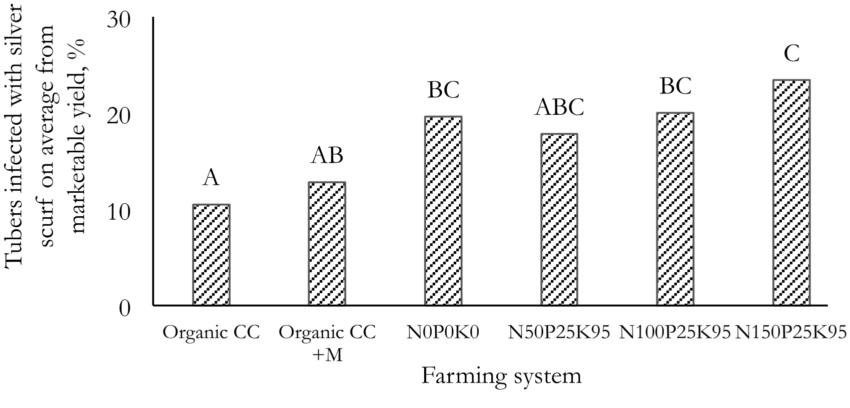

Figure 15. Two year (2009, 2011) average percentage of tubers infected with silver scurf from marketable yield depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters on top of the bars indicate significant influence ($P<0.05$) of FS.

The incidence of tuber dry rot was affected by FS, year, time of disease measurement, year interaction with time of measurement and FS interactions with time of measurement (**III**). In 2010 there were significantly fewer tubers infected with dry rot in 2010 compared other years (Table 18).

During the first measurement there were significantly more tubers, on average, infected with dry rot in the N_{low} system compared to the Organic CC and N_{high} systems (Figure 16). The same trend also occurred after the second disease measurement. During the experimental years only three significant dry rot increases occurred between two measurement times: In 2009 in the conventional N_{low} and N_{high} systems, and in 2010 in the N_{low} system.

Table 18. Total percentage of tubers infected with dry rot from total yield.

	Dry rot (%)		
Farming system	Autumn		
	2009	2010	2011
Organic CC	1.3^{A}[1]^{a}[2]±2.4[3]	$0.3^{Aa}\pm0.8$	$1.0^{Aa}\pm1.8$
Organic CC+M	$2.8^{BCb}\pm0.8$	$0.5^{Ba}\pm0.9$	$1.5^{Aab}\pm2.8$
$N_0P_0K_0$ (control)	$3.3^{Cb}\pm0.8$	0^{Aa}	$1.0^{Aa}\pm1.8$
$N_{50}P_{25}K_{95}$ (N_{low})	$2.8^{BCb}\pm2.4$	0^{Aa}	$2.5^{Aab}\pm3.8$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	$2.8^{BCc}\pm0.8$	0^{Aa}	$1.0^{Ab}\pm1.3$
$N_{150}P_{25}K_{95}$ (N_{high})	$0.8^{Aa}\pm1.5$	0^{Aa}	$0.8^{Aa}\pm2.4$
	Spring		
	2010	2011	2012
Organic CC	$1.5^{Aa}\pm2.1$	$0.3^{Aa}\pm0.8$	$1.0^{Aa}\pm1.8$
Organic CC+M	$3.0^{ABCb}\pm0$	$0.5^{Aa}\pm0.9$	$1.8^{Aab}\pm2.7$
$N_0P_0K_0$ (control)	$4.3^{BCb}\pm1.5$	0^{Aa}	$2.5^{Ab}\pm2.8$
$N_{50}P_{25}K_{95}$ (N_{low})	4.8^{Cb*}[4]±3.3	$1.0^{Aa*}\pm2.3$	$3.3^{Aab}\pm4.2$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	$3.8^{BCb}\pm2.0$	$0.3^{Aa}\pm0.8$	$1.5^{Aa}\pm2.8$
$N_{150}P_{25}K_{95}$ (N_{high})	$2.5^{ABb*}\pm2.8$	0^{Aa}	$1.8^{Aab}\pm1.5$

[1] Means followed by a different capital letters within each column indicate significant influence (P<0.05) of farming systems (FS).

[2] Means followed by a different small letters within each row indicate significant influence (P<0.05) of year.

[3] Data represents mean±95% confidence limits.

[4] Means followed by a * indicate significant difference (P<0.05) between values during autumn and spring measuring times.

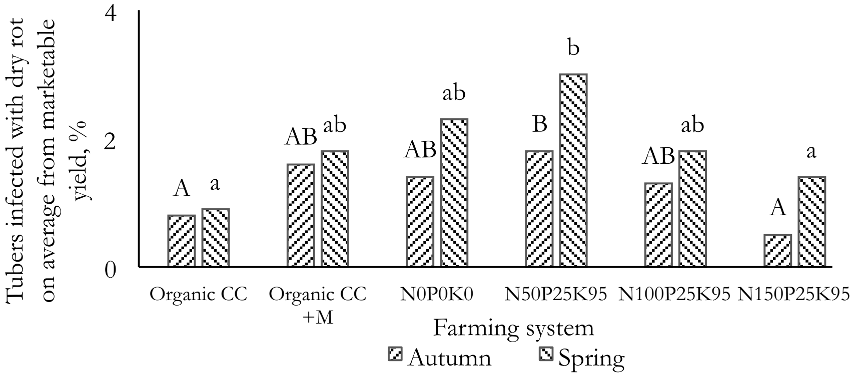

Figure 16. Three year (2009–2011) average percentage of tubers infected with dry rot from marketable yield depending on farming systems (FS) (Organic CC – organic catch crops, Organic CC+M – organic catch crops+manure, $N_0P_0K_0$ – conventional control, $N_{50}P_{25}K_{95}$ – N_{low}, $N_{100}P_{25}K_{95}$ – $N_{average}$, $N_{150}P_{25}K_{95}$ – N_{high}), %. Different capital letters above the bars indicate a significant difference (P<0.05) of FS in autumn measuring time; small letters above the bars in the spring measuring time.

6. DISCUSSION

6.1. Tuber total and marketable yield (Papers I, II and IV)

De Ponti et al. (2012) have argued that the yields under organic production are on average 80% of those obtained from conventionally grown potatoes. In the studies of the current thesis the differences between conventional and organic systems total yields varied between years, from 48% in 2008 (**IV**) up to 62% in 2009. The difference between marketable yields varied from 47% in 2010 to 65% in 2009. Nutrients from mineral fertilizers are much more easily available for plants, thus the effect of using them is faster and more direct than using organic fertilizers (Chen, 2006). When mineral N fertilizers were used the yields were much greater, because potato responds very well to an increase of N availability (Love et al., 2005). Moreover, higher N availability helped the canopy to photosynthesize for a longer period, thus tuber growth was also maintained in the later part of the growing period (Shahnazari et al., 2008). If the growing season was optimal for the potato growth (Table 5, 6) then the yield differences between organic and conventional systems were much larger. Maggio et al. (2008) found that when potato was grown under organic farming conditions tuber marketable yield reduction was 25%. Contrary to these findings, the differences between total and marketable yields in the current research were not so drastic. Even in organic systems the marketable yields were at least 86% of those of total yields. However, the marketable yield percentages of total yields were higher in conventional fertilized systems (94–95%). The same was found by (Gao et al., 2015) that the application of mineral N improved the tuber marketable yields. If there are enough nutrients provided into the soil then the potato is able to grow larger tubers (Tein and Eremeev, 2011), thus increasing the marketable yield percentages of total yield.

In organic systems, the use of synthetic agrochemicals and mineral fertilizers is prohibited. The CC used did not add additional nutrients from the outside of plant-soil system for the potato, because CC bind nutrients from the soil. However, CC help to avoid nutrient losses during the winter period. Despite the non-significant differences found between organic systems, the organic system in which cattle manure was used had higher yields. Thus manure (at least that from cattle) had a positive effect on yields. Also, Kimpinski et al. (2003) noted that when manure or compost was used potato yields increased by 27%. Potato diseases and pests were also a problem in organic systems, which had a yield reducing effect. More recently, the Colorado potato beetle (*Leptinotarsa decemlineata*) became a problem. Also some problems with early blight (*Alternaria solani*) and late blight (*Phytophthora infestas*) occurred. Such potato diseases and pests may cause yield losses as high as 75% (Oerke, 2006). The tuber bulking period is much shorter if the canopy is destroyed earlier, which results in lower yields (Hospers-Brands et al., 2008). Despite that the Organic CC+M system had more foliage destroyed by early blight, the yield was not affected as much as in Organic CC system. Cattle manure used in the Organic CC+M system enabled higher yield growth through the supply of nutrients (**II**). Despite that the Organic CC system did not provide sufficient amounts of nutrients for the potato it still had a beneficial effect on potato production. Catch crops helped to avoid nutrient leaching, because without CC the loss of nutrients would otherwise be considerably higher (**I**). In some years (2009, 2011), and as an overall average, the yields from conventional control and Organic CC+M systems were comparable, despite no additional fertilizers having been provided in the conventional control system and no agrochemicals in the Organic CC+M systems. As mentioned earlier, in the Organic CC+M system the use of cattle manure helped to increase the yield before the canopy was destroyed, but in the conventional control system the use of different agrochemicals helped to postpone canopy disease infections, and the plants were able to photosynthesize for a longer period. Therefore, higher yields were achieved also in that system. Moreover, low chemical stress may even increase yields (Cedergreen et al., 2009). Nevertheless, and as expected, mineral fertilizers had the greatest effect on potato yields.

The main factor that influences tuber yields is weather conditions, because temperature (Kooman et al., 1996) and precipitation (Dalla Costa et al., 1997) during potato growth determine the uptake of nutrients and their use. In 2010 yields remained much lower (15.8–29.0 t ha^{-1}) compared to the other experimental years (2008: 20.1–38.7 t ha^{-1}; 2009: 21.6–57.5 t ha^{-1}; 2011: 23.0–45.8 t ha^{-1}), which was the result of extreme weather conditions; excessive moisture and very high temperatures during the potato growth period. Also, van Oort et al. (2012) confirmed in their study that the greatest impact on yields is excessive moisture during the growing season, which lowers yields, because as found by Ferreira and Carr (2002) the heavy rainfalls that cause excessive soil moisture, and the mineral N fertilizers supplied, can cancel out each other's effects on tuber yields. Study by Zarzynska and Pietraszko (2015) stated that organic systems are more easily affected by the unfavourable growing season, but no such trends were confirmed in this study, because all of the studied systems were equally affected by the growing season extremes. Optimal weather conditions (similar to the long term average) during the potato growth create favourable growing conditions for the plants, and thus higher yields are obtained.

6.2. Tuber quality characteristics (Papers I, III)

Tuber nutritional status and disease incidences are directly related to the availability of nutrients and their uptake by potato. Well maintained systems provide tubers which have high nutrient values and good overall qualities.

Because of the higher N input, the N_{tot} and NO_3^- concentrations in tubers were significantly higher under systems in which above average amounts of mineral N fertilizers were provided (Organic CC-CC+M 36.6–48.6 mg kg^{-1}, $N_{control\text{-}low}$ 40.5–57.3 mg kg^{-1} versus (vs) $N_{average\text{-}high}$ 122.6–124.0 mg kg^{-1}). This is confirmed by previous research (Eppendorfer et al., 1996; Hajšlová et al., 2005; Millard, 1986; Mäck and Schoerring, 2002; Rembialkowska, 1999; Rogozińska et al., 2001; Sylvester-Bradley and Chambers, 1992; Vogtmann et al., 1993; White and Sanderson, 1983). However, according to Santamaria (2006), potato is classified as a crop that overall contains very low amounts of NO_3^- in their tubers (<200 mg kg^{-1}), and there are no official maximum limits for potato tuber NO_3^- concentrations set by the European Union (EU) (Gorenjak et al., 2014).

Smid et al. (1993) have noted that high NO_3^- concentrations in tubers promote the soft rot multiplication and spread. Czajkowski et al. (2011) however noted, in their review, that how different N fertilization levels affect soft rot incidence has not been studied previously. In the current study it was found that higher tuber nitrate concentrations, a consequence of using higher mineral N amounts, did not result in a higher rate of soft rot infections. Even in the system in which the applied mineral N amount was the highest, and also NO_3^- concentration was one of the highest, had a low soft rot incidence (soft rot incidence in N_{high} 0.5% vs in other systems 0.8–3.5%) in 2011 compared to other systems. However, the greater mineral N fertilizer inputs and increased tuber N_{tot} concentrations had an effect on tuber silver scurf incidences, making the tubers more susceptible to the disease compared to those in organic systems (silver scurf incidence in organic systems 10.5–12.8% vs in systems $N_{average-high}$ 20.0–23.4%). Higher mineral N rates cause more vigorous vegetative growth, thus the young to mature tissue changes are more unbalanced in favour of the younger tissues, which are more prone to disease infections (Dordas, 2008). If the N availability to plants is low, then the synthesis of compounds that are related to defence mechanisms against pathogens increases, making the plants in some cases more resistant to pathogenic organisms (Herms and Mattson, 1992). Thus, in organic systems and in conventional control system, the lower N availability actually helped to reduce the incidence of silver scurf. In organic systems the CC winter oilseed rape also had a beneficial reducing effect on the incidence of silver scurf, because winter oilseed rape is a *Brassica* crop that contains glucosinolates which hydrolysation products, isothiocyanates (Sarwar et al., 1998), are highly biocidal to bacteria and fungi (Brown and Morra, 1997). Thus the use of winter oilseed rape helped to keep the silver scurf infections under control.

Tuber P_{tot} concentrations were, on average, much higher in systems in which no mineral N fertilizers were used, and tuber N_{tot} concentrations remained lower (in Organic CC system 0.247% to 0.195% in N_{high} system). Likewise Curless et al. (2004), Smith-Spangler et al. (2012), and Šrek et al. (2010) have confirmed that organic fertilizers have an increasing effect of tuber P_{tot} concentrations. According to Rosen and Bierman (2008) the use of additional mineral P fertilizers should also increase the tuber P_{tot} concentration which, however, was not confirmed by the current research. The most significant influence on tuber P_{tot} concentration was mineral N fertilization: studies by Augustin (1975) and Maier et al. (1994) claimed that tuber P concentrations may decrease when mineral N fertilizers are used. The same relationship was found in this study, that when the mineral N amount increased the tuber P_{tot} concentration decreased. The reason why P_{tot} concentration decreases when using higher N fertilizer amounts is because N reduces the overall uptake of P by the plant, which leads to a lower plant P concentration (Ranade-Malvi, 2011). Despite the tuber P_{tot} concentrations remaining low in conventional fertilized systems, there were no problems found with with overall P_{tot} concentrations, as they were found to be in accord with those of other studies (Mkhabela and Warman, 2005; Alvarez-Sánchez et al., 2008). The availability of P also affects the marketable yields, because the number of marketable tubers decreases when the P is highly available for the plants to use (Rosen and Bierman, 2008). Thus, one of the reasons why the marketable yields were lower in the organic systems was also because of the high P_{tot} concentrations and availability, due to which the tubers remained generally smaller. According to research which was based on the same experiment, by Tein and Eremeev (2011), it was confirmed that tubers under organic FS remaine smaller than the tubers from conventional fertilized systems.

On average, K_{tot} concentrations in tubers were not influenced by FS, and compared to research by Trehan and Sharma (2002), the K_{tot} concentrations in this study were relatively low. Also Haase et al. (2007b) affirmed that cattle manure and mineral K fertilizers are able to increase the K availability equally. Therefore, as presented in this study, the use of mineral K fertilizers and cattle manure resulted in similar tuber K_{tot} concentrations. In addition, there has been found to be antagonism (a negative effect between nutrients) between tuber K_{tot} and other nutrient concentrations. MacKay et al. (1987) have stated that between tuber P and K there can be antagonism. Rhue et al. (1986) claimed that there are also antagonistic relationships between tuber K_{tot}, Ca_{tot} and Mg_{tot} concentrations. This study found that K_{tot} concentrations had no antagonism between P_{tot} and Ca_{tot} concentrations. However, some antagonistic relationships were found with Mg_{tot} concentrations (although only in 2011) when higher K_{tot} concentrations resulted in lower Mg_{tot} concentrations. In 2011, Ca_{tot} and Mg_{tot} concentrations also showed antagonistic relationships between each other; higher Ca_{tot} concentrations resulted in lower Mg_{tot} concentrations. This indicates that growing conditions have a great impact on relationships between tuber nutrients (Westermann, 2005). If plants suffer from stress caused by a water deficit (Dalla Costa et al., 1997) some tuber nutrients may become antagonistic to each other. A study by Warman and Havard (1998) found that tuber Ca concentrations are influenced by neither organic nor conventional production systems, but Mg concentrations in tubers were higher in potatoes that were grown organically. In the present study we also found that none of the FS differed, on average, from the others, despite some changes in tuber Mg_{tot} concentrations occurring. No differences between systems, on average, for tuber Ca_{tot} concentrations were found either.

Tuber Ca_{tot} concentrations were higher when the conditions in the potato growth period were arid and significantly warmer than usual. Contrarily, Mg_{tot} concentrations were higher in a growing season which was also very warm but extremely wet.

Dry rot species infect the tubers through wounds (Mecteau et al., 2002), thus it is highly important that the tubers should be resistant to damage. According to Bergmann (1992), K deficiency leads to thinner cell walls, which makes the tubers more susceptible to potato diseases. As revealed from this study, tuber K_{tot} concentrations had a significant effect on the occurrence of dry rot infections. In 2009, when the tuber K_{tot} concentrations were the lowest, dry rot infections were the severest. Therefore, low tuber K_{tot} concentrations may result in a higher rate of dry rot infections, because tuber resistance to wounds is lower, which makes the tubers weaker and more susceptible to dry rot which enters mainly into tubers through wounds. Despite the fact that the growing season for potato growth was optimal it was also optimal for dry rot. In order to develop, the pathogen must also experience optimal growing conditions (Fiers et al., 2012); usually, if the growing season is ideal for crops to grow then it is also favourable for pathogens. Many *Fusarium* species favour cooler growth conditions (Platt and Peters, 2006), which is also a reason why dry rot infections were the severest in 2009. However, in order to infect healthy well maintained plants there must be some disorder that would make the plants susceptible to pathogens. In this case, K_{tot} concentrations were the limiting factor for dry rot resistance. On average of the years studied, the CC in the organic CC system helped to keep the dry rot infections relatively low, which can be explained by the positive biocidal effect of the CC winter oilseed rape used on dry rot pathogen. The lower occurrence of dry rot in N_{high} system was because of the presence of a high level of N, that has a reducing effect on *Fusarium* species (Dordas et al., 2008). N delays plant senescence and metabolic activites, which may increase resistance to some pathogenic organsims such as *Fusarium* species (Agrios, 2005). The incidences might have been lower also due to an overall poorer soil microbial quality which can be caused by using higher amounts of mineral N (Drinkwater et al., 1996; Gunapala and Scow, 1998). Study by Zou et al., (2015) stated similarly that higher availability of soluble N may contribute to low relative abundance of various *Fusarium* species. But to confirm this theory, further research is needed.

High Ca concentrations make the plants more resistant to bacterial diseases (McGuire and Kelman, 1986; Berry et al., 1988; Palta, 1996). However, tuber Ca_{tot} concentrations had no effect on soft rot or common scab incidence in this study. In fact in 2011, when the tuber Ca_{tot} concentrations were the highest, common scab incidences were also one of the highest, and soft rot infections also occurred. Neither of the two other studied years had problems with soft rot. However, higher tuber Ca and K concentrations were associated with lower tuber Mg concentrations in 2011. If there are problems with Mg deficiency then plants tend to be weaker (Mulder and Turkensteen, 2005). The unfavourable growing season in 2011, together with low Mg_{tot} concentrations, made the tubers more susceptible to soft rot. Also the incidence of common scab was significantly (except in organic systems) one of the highest in 2011.

Overall, FS had an effect, on the incidence of common scab, observed when the tubers were grouped into four groups based on the severity of infections. Huber and Haneklaus (2007) has reported that ammonia based fertilizers have a common scab reducing effect. This was also confirmed by the current study; in group 1 the conventional systems had significantly fewer tubers infected with common scab compared to the organic systems. However, studies by Conn and Lazarovits (1999) and Larkin and Griffin (2007) found that animal manures and green manure organic fertilizers had a disease reducing effect. Only rarely have they been found to have a stimulating effect for potato diseases (Termorshuizen et al., 2006). However, in group 2, the use of CC helped to keep the common scab severity the least, which indicates that winter oilseed rape as a previous CC can help to keep the disease severity under control, even if it does not fully prevent the disease. Cattle manure used together with CC had no such reduction effect on common scab, indicating that cattle manure has a very strong influence on common scab incidence. Despite some research confirming that manure does not increase the incidence of tuber diseases, others (Bailey and Lazarovits, 2003; Bernard et al., 2014) have found the same as was found in the current study, that manure has the effect of increasing common scab as well as soft rot (at least in 2011). Furthermore, Moore et al. (2011) proposed that manure is suspected of creating optimal conditions for the development of the common scab pathogen.

Soft rot infections were found only in 2011. As discussed earlier, tuber nutritional quality had no influence on soft rot incidence. Because the soft rot pathogen is viable in a soil for only a few months (Pérombelon and Kelman, 1987), the only way bacteria can enter soil is through cross-contamination by machinery or with infected seed tubers. In another potato experiment (Tein et al., 2014), in which the same machinery was used, there were no soft rot infections, in this case the only possible way the soft rot bacteria could have got into soil was through the seed tubers used. According to Lebecka et al. (2006) there might be no visual symptoms on seed tubers that the tubers are contaminated with the soft rot pathogen because it can survive latent in tubers. However, if there are favourable conditions for the pathogen to develop then the symptoms may develop and become visible. The extreme weather conditions during the growth period in 2011 made the tubers highly susceptible to soft rot. Margquez-Villavicencio et al. (2011) stated that the size and maturity of the tubers are important factors influencing soft rot incidence. They claimed that mature and large tubers are much most susceptible to soft rot. Tubers under conventional systems are larger (Tein and Eremeev, 2011). In organic systems however, the tubers were not able to reach maturity due to suboptimal growth conditions (**I**). Because the periderm of immature tubers is weaker then such tubers are more easily infected by pathogens. Also, the high humidity at the end of the growing season promoted the spread of soft rot. Pérombelon (2000) claimed that if the tubers are exposed to humid conditions for long enough, the spread of bacteria is ensured. According to Sicilia et al. (2002) the presence of late blight also favours the infection of tubers with soft rot, especially under high humidity conditions. The only year in which soft rot infected tubers were found in this study there were also some problems with late blight, because such weather conditions also promote the spread of late blight. All these factors together made the tubers highly susceptible to soft rot in 2011. After the infected tubers were removed from storage, when they were inspected the first time, no new lesions were found. This demonstrates that disease development can be stopped when the infected tubers are removed from storage to avoid further infections from the already infected tubers. Under the right storage conditions tubers are even able to heal themselves.

According to Kolbe and Stephan-Beckmann (1997) DM and starch contents are generally lower in very small or large tubers. Hajšlová et al. (2005) stated that tuber DM and starch contents are negatively correlated with the amount of N applied. The current study however revealed that there were, on average, no significant differences between FS for tuber DM and starch contents. Differences between systems were found only when the years studied were monitored separately. In all FS the DM and starch contents were higher in 2009 (in Organic CC+M system starch also in 2010), which had the most similar growing season to the long-term average, thus making it the optimal. The conventional and organic systems differed from each other in 2010 and 2011. In 2010 organic systems had significantly higher starch and DM contents. However, overall starch and DM contents in conventional systems remained the lowest in 2010, which was the warmest and rainiest year. In 2011, in contrast to 2010, the conventional systems had higher DM and starch contents than the organic systems. This was caused by the very warm and arid growing conditions in that year. Dalla Costa et al. (1997) reported that water deficit causes the plants to suffer stress. Thus the aboveground biomass in organic systems suffered from a water deficit that caused them to die earlier than usual, before the tubers were able to reach maturity. This caused lower DM and starch contents in organic systems. In conventional systems, the agrochemicals and mineral fertilizers used helped the plants to grow for a longer time, thus the tubers were able to mature before the above-ground biomass died off, which also resulted in higher DM and starch contents.

Relationships have been found between tuber P_{tot} concentrations and starch contents, tuber starch contents and soft rot occurrences, and between tuber K_{tot} and DM contents. Jacobsen et al. (1998) reported that higher tuber P concentrations may result in higher starch contents. Zimnoch-Guzowska and Lojkowska (1993) stated that resistance to soft rot pathogens increased when tubers had higher starch contents. Higher tuber K concentrations may have a negative effect on tuber DM contents (Haase et al., 2007a; Kumar et al., 2007). In the current study no relationships between tuber P_{tot} concentrations and starch contents were found; year had no effect of tuber P_{tot} concentrations, but starch contents were significantly affected by year. Also, on average, starch contents did not differ between different FS, but the P_{tot} concentrations did. Starch contents also had no effect on tuber soft rot incidence; there were no differences between different FS in terms of starch contents and soft rot incidence. Even if the years were monitored separately it was not possible to report that higher starch contents reduce the incidence of soft rot, even though in 2009, in which the starch contents were the highest, no soft rot was discovered. Indeed in 2010, which had overall one of the lowest starch contents (in conventional systems), no soft rot was discovered. Tuber DM contents were also not found to be affected, as an average, by K_{tot} concentrations. However, if the years were monitored separately, some antagonistic relationships were found between tuber K_{tot} concentrations and DM contents. In 2009, in which the K_{tot} concentrations were the lowest, DM contents were the highest. In 2010 and 2011 the K_{tot} concentrations were higher, which had a reduction effect on DM contents. Bergmann (1992) claimed that when the tuber K_{tot} concentrations are over 2% (as was found in 2010 and 2011) then the water content in tubers increased above normal, which resulted in a lower DM. This is because the K influences the plasma volume water content, which in turn affects the water content of the storage tissues, are fleshy, as tubers are (Bergmann, 1992; Imas and Bansal, 1999). Van Eck (2007) has reported that tuber starch content largely determines the tuber DM content. The current study confirms that tuber DM and starch contents are associated. If the starch contents were high, as in 2009, then the DM contents were also high. By contrast, if the starch contents are lower (2010) then also DM contents remained lower.

Fungal pathogens allow entry by bacterial pathogens (van der Wolf and De Boer, 2007), thus dry rot infected tubers are sometimes further infected with soft rot bacteria (Platt and Peters, 2006), especially under high relative humidity conditions and temperatures (Sicilia et al., 2002). In 2009, dry rot occurrences were the highest, but no soft rot incidences were discovered. The soft rot infections occurred only in 2011, in which dry rot infections were also found. Hence some of the findings by Platt and Peters (2006) were confirmed. However, as mentioned earlier, soft rot infections occurred mainly because of the coincidence of several factors together. It has been found (Haas and Défago, 2005; Weller et al., 2002) that some bacterial species are naturally suppressive against fungal pathogens. The results from the current study showed that if dry rot (fungi) infections in studied year were low then common scab (bacteria) incidences were high. But when the common scab occurrences were low then dry rot incidences were high. Also, when monitoring common scab and soft rot (bacteria) infections as on average over the years studied, then despite no significant differences and only tendencies were found, the silver scurf (fungi) occurrences were higher when the soft rot and common scab infections were lower. On average, where soft rot and common scab infections were numerically higher in organic systems and lower in conventional ones, then silver scurf infections were higher in conventional systems and lower in organic systems. According to Edesi (2015) the more bacteria there are in the soil the more yeasts there are, thus higher yeast and bacteria concentrations result in lower *Fusarium* species occurrences. The same might be possible to assume to be so for other fungal pathogens.

CONCLUSIONS

- The tuber total and marketable yields depended on a FS and the amounts of nutrients provided into the system. Higher nutrient inputs into the system resulted in higher total and marketable yields. Therefore, in conventional systems in which more than 50 kg of N ha^{-1} were applied there were significantly higher yields.
- On average over the years studied, FS had a significant effect on tuber N_{tot}, NO_3^-, P_{tot} and Mg_{tot} concentrations, indicating that there were yield differences between systems, FS supply of nutrients or their source may have a great influence on some tuber nutritional quality parameters.
- No significant effect of FS were found, on average over the years studied, on tuber K_{tot} and Ca_{tot} concentrations, and on DM and starch contents indicating that these studied parameters are not influenced by yield differences between systems, FS supply of nutrients or their source on some tuber quality parameters when the effect of growing season is excluded.
- Farming systems influenced the incidence of tuber silver scurf, dry rot and common scab (with low infection severities). The silver scurf incidences increased with the increasing amounts of mineral N provided to the system. The use of CC without cattle manure helped to keep the common scab severity under control. The incidences of dry rot remained the lowest in Organic CC system and in a system which received 150 kg of N ha $^{-1}$.
- The impact of FS on potato quality characteristics is affected by the climatic environment of the specific growing season.
- Tuber nutrients and diseases may have additive or antagonistic impacts on each other.

Issues requiring further research

In the present study the results from the first four years of the first rotation were investigated. It would be highly valuable to monitor the potato results after a higher number of rotations, because the changes in soil as a primary nutrient resource occur slowly and it takes time for systems to fully develop their inner nutrients cycling. Because the years investigated had very different weather conditions during the potato growing period it would be highly valuable to compare the quality parameters in more similar growing seasons.

Catch crops were used only in organic systems. In future, CC could also be used in conventional systems to provide a better understanding of how synthetic agrochemicals and mineral fertilizers might influence the potato, as well as soil quality parameters, when they are used together with CC.

In this study, fully composted cattle manure was used as a nutrient source in one of the organic systems. It would be necessary to investigate how other animal manures, as well as other forms of cattle manures, influence potato quality characteristics, as well as soil nutrient balance and cycling.

Since the potato plant development and life cycle in conventional and organic systems differ due to the use of synthetic agrochemicals and fertilizers, it is important to further study potato plant nutrient partitioning in different plant parts to better understand the yield formation, stress tolerance under different growing conditions, and how it affects tuber quality traits.

In the present study potato tuber pathogens of the *Fusarium* spp. and *Pectobacterium* spp. were investigated, but the exact species causing the tuber diseases were not determined. Thus, in further research, DNA analyses could be made to better understand which pathogen species are dominating and causing tuber diseases under different FS.

Different microorganisms should simultaneously be studied in the soil to monitor (i) different pathogenic and antagonistic species, (ii) how their activity and biomass change over time, and (iii) how the crops, in rotation together with FS, affect the occurrence of different pathogenic and antagonistic microorganisms.

Finally, a Life Cycle Assessment (LCA) of different FS, especially for potato as a high nutrient demanding and using crop, would give a better understanding of their environmental impact, and thus the longer sustainability of the systems.

Application of the research results

Poor potato nutrition is the main yield and quality limiting factor. If the main aim is to achieve higher yields, the potato should receive mineral fertilizers with a N amount of at least 50 kg ha^{-1}. But care should be taken not to oversupply the N as was also shown from the study, with the N_{high} system in which the highest amount of mineral N fertilizers was used was one of the most soil exhausting systems next to the negative control (N0). Therefore, over a longer period when high amounts of mineral N are used, the soil may become poorer in nutrients because potato tends to overuse the nutrients if they are easily available in large quantities. Monitoring the weather conditions during potato growth is also extremely important. As shown from this study, if the growing season is very wet and higher external amounts of mineral fertilizers are provided, the yield increase will be small because extreme moisture and mineral fertilizers may cancel out each other's effects. There is a small yield increase comparing organic systems and conventional non-fertilized systems if mineral fertilizers are used, but eventually it not be economically beneficial, since the expenses tend to be higher than gained income. For organic producers it is recommended to use additional organic fertilizers, such as cattle manure, if the main aim is to get higher yields. However, as shown in this study, cattle manure creates a beneficial environment for some of the pathogenic organisms that affect the quality and marketability of the tubers, and may eventually cause major storage losses, which could be economically devastating.

As shown, tuber nutritional status and diseases are in many cases related. If there are problems with some tuber nutrients then tubers are more easily infected with diseases. Also, antagonistic relationships between tuber nutrients can occur. Therefore, a balanced fertilization system, in which none of the nutrients are oversupplied, is a key element in achieving high quality yields.

The use of long crop rotations is a basic tool for sustainable crop production. They help to reduce production costs and optimize crop productivity. For sustainable potato production the rotations must be as long and diverse as possible to help to control and manage diseases and pests, and also to keep the soil fertile after heavy disturbance by potato.

The use of CC in organic farming is mandatory to avoid nutrient losses during the winter period. It is highly recommended to use CC in conventional systems as well, because they help to reduce mineral fertilizer costs. *Brassicaceous* crops especially have beneficial effects on reducing some soil-borne tuber diseases, which are equally important for conventional and organic farmers.

In summary, the author of this thesis suggests combining various positive aspects of conventional and organic farming systems together. To grow high yielding potato of good quality it is recommended to use cattle manure to provide organic material, CC for nutrient cycling and mineral fertilizers at an amount between 50–100 kg N ha^{-1} to provide sufficient amount of mineral fertilizers for potato growth. This should ensure a well-functioning potato farming system.

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SUMMARY IN ESTONIAN

VILJELUSSÜSTEEMIDE MÕJU KARTULI MUGULASAAGILE JA KVALITEEDILE

Sissejuhatus

Maailma rahvastiku pidev kasv suurendab järjest nõudlust kõrgekvaliteetsete suuresaagiliste põllukultuuride järele (FAO, 2013). Peamine viis, kuidas tagada hea kvaliteediga suuri saake, on põllukultuuride nõuetekohane ja jätkusuutlik majandamine. Selle väljundiks on külvikordade rakendamine, erinevate väetamissüsteemide ning väetiste kasutamine, sügis-talviste vahekultuuride kasvatamine jne. Need tagavad tootmissüsteemides toitainetega varustatuse. Kasutusel on mitmed erinevad viljelussüsteemid. Üheks neist on maheviljelus, mida käsitletakse kui tervikut, mille tagab isereguleeriv tootmissüsteem (Lammerts van Bueren et al., 2002). Üldtuntud on tavaviljeluslik tootmine, mis sõltub peamiselt välistest sisenditest ning seetõttu seda tootmist peetakse isegi liiga sõltuvaks ja haavatavaks. Mõlemal tootmisviisil on nii positiivseid kui negatiivseid omadusi, nende tundmaõppimine ning oskuslik rakendamine aitab tagada jätkusuutlikku taimekasvatust ja kõrgeid ning kvaliteetseid saake.

Kartul (*Solanum tuberosum* L.) on üks tähtsamaid toidukultuure, mis kogutoodangult on maailmas neljandal kohal (Fernie and Willmitzer, 2001). Seda kultuuri on võimalik kasvatada ka põhjapoolsetes regioonides ja saada seal teiste sealsete põllukultuuridega võrreldes võrdlemisi kiiresti suurt toiteaineterikast saaki (Lutaladio and Castaldi, 2009). Selleks aga, et anda küllaldasel määral kvaliteetset saaki, vajab kartul kasvuperioodil suurtes kogustes toitaineid, samuti on äärmiselt olulised nõuetekohased kasvatusvõtted. Need kõik kokku mõjutavad tootlikkust ja haiguskindlust (Larkin and Halloran, 2014). Järvani ja Edesi (2009) andmeil mõjutavad nii viljelusviisid kui -süsteemid kartulimugulate toitainetesisaldust ning Roinila ja tema kaastöötajad (2003) leidsid positiivse seose viljelusviiside ning kuivaine ja tärklisesisalduse vahel. Kuivõrd taimetoitained mõjutavad taimede füsioloogiat (Dordas, 2008), siis nende nappus või madal kvaliteet võivad suurendada vastuvõtlikkust haigustekitajatele (Czajkowski et al., 2011), kuna taime loomulik vastupanuvõime väheneb (Mulder and Turkensteen, 2005).

Külvikord kartulikasvatuses on üks olulisemaid võtteid, mis mõjutab kartuli produktiivsust (Carter et al., 2003) ja haiguste esinemist (Peters et al., 2004). Samuti on oluliseks osutunud sügis-talviste vahekultuuride kasutamine, kuna need aitavad vähendada toitainete kadusid mullast (Stark and Porter, 2005). Ristõielised vahekultuuridena aitavad alla suruda ka mitmeid haigusi (Cohen et al., 2005). Kuna kartul on kultuur, mis vajab rohkesti toitaineid, on äärmiselt oluline kasutada täiendavaid mineraalseid ja/või orgaanilisi väetisi. Vaatamata sellele, et lämmastik (N) on peamine kartuli toiteelement, on temale sobilike koguste valimine äärmiselt keeruline (Zebarth et al., 2009), sest tema vajadust mõjutavad mitmed faktorid: kasvuperioodi klimaatilised tingimused, viljelusvõtted, kartuli eelkultuur, jne. Nimetatud tegurite kartulile soodsa seisu korral peaks olema tagatud suur ning kõrge kvaliteediga mugulasaak.

Vaatamata sellele, et kartul on üks olulisemaid toidukultuure, on selle kasvatamisel siiski veel mitmeid lahendamata või väheuuritud probleeme. Näiteks ei ole teada, kas ja kuidas muutub mugulate mineraalsete elementide sisaldus, kui kasutatakse erinevaid agronoomilisi võtteid. Milline mõju on erinevatel külvikordadel mugulate kvaliteedile? Vähe on uuritud erinevate külvikordade, kartuli toitumise ning kartulihaiguste vahelisi kolmiksuhteid ning toimeid. Kuivõrd varasemad uuringud on keskendunud kas tava- või maheviljeluse uurimisele, siis äärmiselt oluline oli uurida erinevaid viljelussüsteeme ühel ja samal ajal sarnastes külvikordades ning näitajaid omavahel võrrelda. Antud teadustöö eesmärgiks oligi võrrelda ühesuguses külvikorras tava- ja maheviljeluse tingimustes kasvatatud kartulite mugulate kvaliteedinäitajaid ning saagikust, käsitledes viljelussüsteeme kui tervikuid.

Töö peamine hüpotees: mugulate toitainete, nitraatide, kuivaine ja tärklise sisaldus ning mugulahaiguste esinemine sõltub viljelussüsteemist, külvikorrakultuuridest ja ilmastikutingimustest.

Uurimustöö eesmärgid:

- Hinnata viljelussüsteemi mõju kartuli saagile.
- Uurida erinevate viljelussüsteemide mõju mugulate makrotoitainete kontsentratsioonile ning kuivaine ja tärklisesisaldusele.
- Selgitada, kas erinevad viljelussüsteemid mõjutavad peamiste mugulahaiguste – hariliku kärna, hõbekärna, kuivmädaniku ja märgmädaniku esinemist.

Metoodika

Antud töös kasutatakse mõistet *viljelussüsteem*, mis käsitleb süsteemi kui tervikut. See sisaldab konkreetse viljelussüsteemi osi – külvikorra kultuuride väetusrežiim ja -strateegia, taimekaitselised võtted, vahekultuuride kasutamine mullaharimise intensiivsus ja kõikide nende osade koosmõju. Üldist mõistet *mugulate kvaliteet* kasutatakse mugulate toitainete (N_{tot}, P_{tot}, K_{tot}, Ca_{tot}, Mg_{tot}), nitraatide (NO_3^-), tärklise ja kuivaine sisalduse iseloomustamiseks. Mugulahaigusi käsitletakse samuti kui kvaliteedinäitajaid, sest neil on väga suur mõju saagikusele ning ühtlasi vähendavad nad ka mugulate visuaalset välimust, mis kõik toob kaasa suure majandusliku kahju.

Uurimaks erinevate viljelussüsteemide mõju kartuli mugulasaagile ja selle mõningastele kvaliteedinäitajatele, rajati 2008. aastal Eesti Maaülikooli Eerika katsepõllule 5-väljaline külvikord, kus kartul oli üheks külvikorralüliks. Külvikord: punane ristik (*Trifolium pratense* L.), talinisu (*Triticum aestivum* L.), hernes (*Pisum sativum* L.), kartul ja oder (*Hordeum vulgare* L.) punase ristiku allakülviga. Antud uurimus keskendus kartulikasvatusele.

Katses oli kokku 6 viljelussüsteemi. Tavaviljeluses oli kartulikatses neli süsteemi. 1. Kontroll, kus (N0) mineraalseid väetisi ei kasutatud. Teised kolm tavaviljeluse süsteemi erinesid üksteisest kasutatud mineraalse lämmastikväetise koguse poolest: 2. $N_{50}P_{25}K_{95}$ (N_{low}), 3. $N_{100}P_{25}K_{95}$ ($N_{average}$) ja 4. $N_{150}P_{25}K_{95}$ (N_{high}). Teised külvikorras olevad kultuurid said tavaviljeluses mineraalset lämmastikväetist järgnevalt: talinisu väetati sarnaselt kartuliga, hernes liblikõielise kultuurina sai mineraalset väetist N0 (control), $N_{low\text{-}high}$ – $N_{20}P_{25}K_{95}$. Oder allakülviga sai väetist N0 (control); N_{low} – $N_{40}P_{25}K_{95;}$ $N_{average}$ – $N_{80}P_{25}K_{95;}$ N_{high} – $N_{120}P_{25}K_{95}$. Punast ristikut iseseisva kultuurina ei väetatud. Tavaviljeluses tehti ka taimekaitsetöid erinevate agrokemikaalidega, mida kasutati vastavalt vajadusele.

Maheviljeluses oli kartulikatses kaks süsteemi. Esimesse neist külvati pärast põhikultuuride koristust sügis-talviseks perioodiks vahekultuurid (Organic CC). Teises süsteemis manustati kartulile täiendavalt täielikult komposteerunud veisesõnnikut (Organic CC+M) normiga 40 t ha^{-1}, mis sisaldas keskmiselt N_{tot} 9.7 g kg^{-1} (174 kg ha^{-1}), P_{tot} 4.6 g kg^{-1} (82 kg ha^{-1}), K_{tot} 8.6 g kg^{-1} (154 kg ha^{-1}), C_{tot} 138 g kg^{-1} (2473 kg ha^{-1}) ja kuivainet 44.8% (17920 kg ha^{-1}).

Maheviljeluse külvikorras kasutati järgmisi vahekultuure: talinisule järgnes ühe-aastane raihein (*Lolium perenne* L.), hernele järgnes taliraps (*Brassica napus* L. ssp. *oleifera biennis*) ning kartulile järgnes talirukis (*Secale cereale* L.). Tavaviljeluse süsteemides vahekultuure ei kasvatatud. Kõik katsed olid neljas korduses.

Eelidandatud mugulad pandi maha mai alguses ning sortideks oli 2008. aastal 'Ants' ning alates 2009. aastast sort 'Maret'. Saagikuste poolest on need sordid omavahel sarnased ja seetõttu on näitajad võrreldavad (Tsahkna and Tähtjärv, 2008). Sõltuvalt kasvuaastast koristati kartul augusti lõpus või septembri alguses.

Mugulasaakide määramiseks (2008–2011) võeti vahetult enne koristust iga süsteemi kõikidest kordustest 10 järjestikust taime, mille alusel määrati kogusaagid ja kaubanduslikud saagid (mugulad mille diameter >35 mm). Mugulate kvaliteedinäitajatest (2009–2011) toitainete (N_{tot}, P_{tot}, K_{tot}, Ca_{tot}, Mg_{tot}), nitraatide (NO_3^-), tärklise ja kuivaine sisalduse ning haiguste määramine toimus pärast saagikoristust. Haiguste määramiseks võeti süsteemide igast kordusest 400 mugulat ja määrati hariliku kärna (*Streptomyces* spp.), hõbekärna (*Helminthosporium solani* (Durieu & Montagne)), kuivmädaniku (*Fusarium* spp.) ja märgmädaniku (*Pectobacterium* spp.) esinemissagedus. Harilikku kärna nakatunud mugulad jagati täiendavalt erinevatesse kategooriatesse tuginedes nakkuse tugevuse astmele – (1) 4–15%, (2) 16–30%, (3) 31–45%, (4) >45% mugula pinnast oli nakatunud hariliku kärnaga. Esimene haiguste määramine toimus 3 kuud (kõik haigused) ja teine määramine 7 kuud (mädanikud) pärast saagikoristust.

Tulemused ja arutelu

Mugulate saagikus (artiklid I, II ja IV)

Antud tööst selgus, et mugulate kogusaagid olid maheviljeluse süsteemis küllalt madalad, moodustades tavaviljelusega võrreldes 2008 aastal 48% ning 2009 aastal kuni 62%. Samuti olid maheviljeluses kaubanduslikud saagid madalamad, moodustades 2010 aastal 47% ning 2009 a. kuni 65% tavaviljeluse saagist. Üldiselt on leitud, et maheviljeluses võivad kartulisaagid moodustada kuni 80% tavaviljeluses toodetud kartuli saakidest (de Ponti et al., 2012). Meie katses tavaviljeluse süsteemis saadud kõrgemate saakide üheks põhjuseks oli see, et seal kasutati lämmastikku sisaldavaid mineraalväetisi. Teatavasti reageerib kartul lämmastikule positiivselt (Love et al., 2005), samuti on mineraalsete väetiste kasutamisel taimel toitainete omastamine lihtsam ja nende mõju taimes kiirem kui orgaaniliste väetiste kasutamisel (Chen, 2006).

Kogusaagid jäid madalaimaks 2010 aastal (20.1–38.7 t ha^{-1}), mil peaaegu kogu kasvuperiood, võrreldes paljude aastate keskmisega, oli oluliselt sademeterohkem ning temperatuurid tavatult kõrged. Vegetatsiooniperioodi ilmastikul on äärmiselt oluline roll mugulasaakide kujunemisel, sest kasvuperioodi temperatuurid (Kooman et al., 1996) ja sademete hulk (Dalla Costa et al., 1997) määravad toitainete omastamise ja nende kasutamise taime poolt. Kõige suuremat negatiivset mõju saagikustele avaldabki just see kui kasvuperiood on sademeterohke (Oort et al., 2012), sest pikaajalised, tugevate vihmasadudega perioodid võivad mineraalsete lämmastikväetiste mõju mugulasaakidele tühistada (Ferreira and Carr, 2002). Üldiselt on teada, et mida lähemal on antud piirkonnas konkreetse aasta kartuli kasvuperioodi ilmastikunäitajad paljude aastate keskmistega, seda suuremaid saake on võimalik saada, sest siis on kasvutingimused kartulile kõige optimaalsemad. Antud katses oli 2009 aasta kõige optimaalsemate kasvutingimustega, mil kartuli kogusaagid olid 21.6–57.5 t ha^{-1}.

Mugulate kvaliteet (artiklid I ja III)

Käesolevast tööst selgus, et nii mugulate üldlämmastiku (N_{tot}) kui ka nitraatide (NO_3^-) sisaldus oli oluliselt suurem neis tavaviljeluse süsteemides, kus manustati mineraalset lämmastikku üle 100 kg ha^{-1} (nitraatide sisaldus süsteemides Organic CC-CC+M 36.6–48.6 mg kg^{-1}, $N_{control\text{-}low}$ 40.5–57.3 mg kg^{-1} versus (vs) $N_{average\text{-}high}$ 122.6–124.0 mg kg^{-1}). Seega, mida rohkem oli taimedele vabalt kättesaadavat lämmastikku, seda suurem oli ka mugulate N_{tot} ja NO_3^- sisaldus.

Tööst selgus, et lämmastikväetise koguste suurendamine ning sellega kaasnev mugulate N_{tot} sisalduse tõus tõid kaasa mugulate intensiivsema hõbekärnaga nakatumise (mahesüsteemides 10.5–12.8% vs $N_{average\text{-}high}$ süsteemides 20.0–23.4%). Kuivõrd kõrged mineraalse N kogused suurendavad taimede vegetatiivset kasvu ning tõstavad nooremate kudede osakaalu, toob see kaasa erinevate haigustekitajate suhtes vastuvõtlikkuse suurenemise (Dordas, 2008). Kui aga taimede N kättesaadavus on madal, siis aktiviseeruvad patogeenide vastased kaitsemehhanismid, muutes taime patogeenide suhtes resistentsemaks (Herms and Mattson, 1992). Meie tulemused ühtisid nende varem saadud tulemustega nii mahe- kui ka tavaviljeluse kontrollsüsteemides. Hõbekärna nakatumine oli seal madal. Suure tõenäosusega aitas maheviljeluses hõbekärnaga nakatumist vähendada ka eelnevalt vahekultuurina kasvatatud taliraps. See taim sisaldab glükosinolaate (Sarwar et al., 1998) ning tema hüdrolüüsiproduktid on bakteritele ja seentele äärmiselt biotsiidse toimega (Brown and Morra, 1997).

Mugulate üldfosfori (P_{tot}) sisaldus oli oluliselt suurem neis süsteemides, kus mineraalset lämmastikväetist ei kasutatud (süsteemis Organic CC 0.247% kuni 0.195% süsteemis N_{high}). Meie katses sõltusid P sisaldused manustatud lämmastikväetiste kogustest ning mugulate P_{tot} sisaldus oli madalam tavaviljeluse süsteemides. Kirjanduse andmeil on lämmastiku koguste ning P sisalduse vahel negatiivne seos. Mida suuremad on mulda viidavad mineraalse N väetise kogused, seda väiksem on mugulates P_{tot} sisaldust (Augustin, 1975; Maier et al., 1994), sest N vähendab taimede P omastamise võimet (Ranade-Malvi, 2011). Kui P kättesaadavus taimedele on suur võib see põhjustada kaubandusliku saagi languse, kuna kogusaagis väheneb kaubanduslike mugulate osakaal (Rosen and Bierman, 2008). Antud töös olid maheviljeluses kaubanduslikud saagid väiksemad, kui tavaviljeluse väetatud süsteemides.

Tulemustest selgus, et mugulate üldkaaliumi (K_{tot}) sisaldus ei olnud viljelussüsteemide võrdluses usaldusväärselt erinev. Haase jt. (2007b) andmeil võivad nii mineraalne väetamine kui ka sõnniku kasutamine tagada K kättesaadavuse kartulile võrdlemisi sarnaselt. Antud uurimusest selgus, et kui mugulate K_{tot} sisaldus oli kõrge (eriti 2011. aastal), siis jäi mugulate üldmagneesiumi (Mg_{tot}) sisaldus tunduvalt madalamateks kui madala K sisalduse puhul. Kirjanduse andmeil on kaalium toiteelement, millel võivad olla mõne teise toiteelemendiga antagonistlikud suhted (Rhue et al., 1986; MacKay et al., 1987). Nagu ka K_{tot} sisalduste puhul, ei avaldanud viljelussüsteemid aastate keskmisena usutavat mõju ka mugulate Ca_{tot} sisaldustele. Väikesi erinevusi mugulate Mg_{tot} sisaldustes küll ilmnes, kuid need ei olnud usaldusväärsed. Ilmnes, et mugulate Ca_{tot} sisaldus oli suurem siis, kui kasvuperiood oli kuiv ja soe, Mg_{tot} sisaldus oli suurem siis, kui kasvuperiood oli küll soe, kuid äärmiselt niiske. Antagonistlikke suhteid täheldati ka teiste elementide puhul. Näiteks oli antagonistlik suhe mugulate üldkaltsiumi (Ca_{tot}) ja Mg_{tot} vahel, kus kõrge

Ca_{tot} sisaldus vähendas mugulates Mg_{tot} sisaldust. Kirjanduse andmeil avaldavad kasvutingimused suurt mõju toitainete omavahelistele suhetele (Westermann, 2005). Oluliselt mõjutas meie katses elementide omavahelisi suhteid ka niiskuse sisaldus. Kui taimed kannatasid veepuuduse all (2011. aastal), hakkasid mõned toiteelemendid pärssima üksteise omastamist.

Mugulate K_{tot} sisaldus avaldas olulist mõju mugulate kuivmädanikuga nakatumisele. Kuivmädanikku nakatumine oli suurim 2009. aastal, mil mugulate K_{tot} sisaldus oli madalaim. Bergmanni (1992) andmeil sõltub mugulate vastuvõtlikkus välismõjutustele nende K_{tot} sisaldusest, kui see on madal on mugulad erinevatele vigastustele vastuvõtlikumad, kuna rakuseinad on õhemad. Kuivmädaniku tekitaja aga siseneb mugulatesse esmajoones just vigastuste kaudu (Mecteau et al., 2002). Vaatamata sellele, et 2009. katseaasta oli kartuli kasvuks soodsaim, oli see ilmselt optimaalseim ka kuivmädaniku tekitajale. Nagu taim, nii vajab ka patogeen elutegevuseks ja nakatamiseks optimaalseid tingimusi (Fiers et al., 2012). Samuti eelistavad mitmed kuivmädaniku tekitaja liigid just jahedamaid kasvutingimusi (Platt and Peters, 2006). Nimetatud tingimustele vastas meil 2009. aasta. Siiski, et nakatuda, peab taimel esinema teatud häireid. Antud juhul oli selleks nähtavasti mugulate madal K_{tot} sisaldus. Katse tulemustest selgus, et taliraps vahekultuurina aitas mahesüsteemis Organic CC hoida mugulate kuivmädanikku nakatumist madalal tasemel, mõjudes nähtavasti kuivmädaniku tekitajale biotsiidselt. Vähene kuivmädanikku nakatumine tavaviljeluse N_{high} oli nähtavasti tingitud sellest, et kõrge lämmastikusisaldus mõjub osadele kuivmädaniku liikidele pärssivalt. Selle kohta on kirjanduses andmeid. Lämmastik, lükates edasi taimede valmimist ja ainevahetustegevust, võib suurendada taime resistentsust mõne patogeeni, kaasa arvatud kuivmädaniku suhtes (Agrios, 2005; Dordas et al., 2008).

Mugulate harilikku kärna nakatumise intensiivsus oli erinevates viljelussüsteemide erinev. Tavaviljeluses oli mugulate harilikku kärna nakatumine grupis 1 (4–15% mugula pinnast nakatunud) oluliselt madalam kui maheviljeluses. Ka varasemalt on leitud, et ammooniumipõhistel väetistel on harilikku kärna vähendav efekt (Huber and Haneklaus). Grupis 2 (16–30% mugula pinnast nakatunud) esines harilikku kärna kõige vähem selles maheviljeluse süsteemis, kus kasutati vahekultuure (Organic CC). Sellest järeldub, et taliraps vahekultuurina aitab hoida hariliku kärna edasist nakatumise laienemist kontrolli all. Sõnnikuga väetamine suurendas nii harilikku kärna nakatumist kui ka nakatumise tõsidust.

Katsetest järeldub, et kolme aasta keskmisena erinevad viljelussüsteemid mugulate märgmädanikku nakatumist ei mõjutanud. Seda mõjutas aga konkreetse katseaasta ilmastik. Kui ilm oli kartuli kasvuperioodi lõpus (vahetult enne koristust) väga soe ning samal ajal kõrge õhuniiskusega nagu seda oli 2011. aastal, esines ka mugulate märgmädanikku nakatumist, sest stressis taimed olid märgmädaniku tekitajale vastuvõtlikumad.

Tööst selgus, et viljelussüsteemid kolme aasta keskmisena arvestatult, ei avaldanud mõju mugulate tärklise ja kuivaine (DM) sisaldustele. Need tulemused on vastuolus Hajšlová et al. (2005) uuringuga, milles leiti, et mugulate tärklise ja DM sisaldused olid negatiivses korrelatsioonis manustatava N kogusega. Meie leiame, et antud uuritavad parameetrid sõltuvad siiski eelkõige kasvuaasta ilmastikust ning selle mõjust viljelussüsteemile. Lisaks selgus antud uurimusest, et mugulate K_{tot} ja DM sisalduste vahel võivad esineda antagonistlikud suhted. Kui mugulate DM sisaldus oli suur (2009. aastal) oli mugulate K_{tot} sisaldus madalam ning mugulate kõrgeima K_{tot} sisalduse korral oli mugulate DM sisaldus madalaim (2010. ja 2011. aastal). Kui mugulate K_{tot} sisaldus oli üle 2% (2010. ja 2011. aastal), siis sellistes mugulates oli vee sisaldus ebaharilikult kõrge, mis nähtavasti vähendaski mugulate DM sisaldust. Täiendavalt leiti, et mugulate tärklise ja DM sisalduste vahel oli seos. Suur tärklisesisaldus mugulates tagas suure DM sisalduse mugulates. Tulemus ühtib kirjanduse (van Eck, 2007) andmetega, kus leiti, et mugulate tärklisesisaldus määrab mugulate DM sisalduse.

Üldiselt arvatakse, et lisaks toiteelementide vahelistele antagonistlikele suhetele esineb vastandlikke suhteid ka haigustekitajate vahel. See leidis tõestuse ka antud uurimuses. Kuivmädaniku (seenhaigus) vähese esinemise korral esines rohkem harilikku kärna (bakteriaalne haigus) ning vastupidi kui harilikku kärna esines mugulatel vähem, siis oli kuivmädanikku nakatunud mugulaid rohkem. Samuti ilmnes aastate keskmisena tendents, et kui hõbekärna oli palju, siis oli vähem harilikku kärna ja märgmädanikku. Selgus, et hõbekärna nakatunud mugulaid esines tavaviljeluse väetatud süsteemides rohkem kui harilikku kärna. Märgmädanikku esines tavaviljeluses vähem võrreldes maheviljelusega. Varasematest uuringutest on teada, et mida rohkem on mullas baktereid seda rohkem on ka pärme, mille tulemusena esineb vähem *Fusariumi* liike (sh kartuli kuivmädaniku tekitajad) (Edesi, 2015). Arvame, et selline seos peaks kehtima ka teiste seenhaigustekitajate puhul.

Kokkuvõte

Mugulate kogusaak ja kaubanduslik saak sõltusid nii viljelussüsteemist (FS) tervikuna kui ka toitainete kogusest, mida süsteemile manustati. Süsteemilt, millele manustati suuremates kogustes toitaineid, saadi ka suuremad kogu- ja kaubanduslikud saagid. Süsteemidelt, millele manustati vähemalt 50 kg N ha^{-1}, saadi usutavalt suuremad saagid.

Katseaastate (2009–2011) keskmisena avaldasid viljelussüsteemid usutavat mõju mugulate üldlämmastiku (N_{tot}), nitraatide (NO_3^-), üldfosfori (P_{tot}) ja üldmagneesiumi (Mg_{tot}) sisaldustele. Järelikult võivad saagikuste erinevused avaldada mõningast mõju ka mugulate toitainete sisaldusega seotud kvaliteedinäitajatele.

Viljelussüsteemide võrdlusel ei leitud katseaastate keskmisena erinevusi mugulate üldkaaliumi (K_{tot}), üldkaltsiumi (Ca_{tot}), kuivaine (DM) ja tärklise sisaldustes. Seega, kui välistada kasvuaasta mõju, siis neid omadusi ei mõjuta saagikuse suurus ega süsteemide toitainetega varustatus kui ka nende allikas.

Mugulate harilikku kärna nakatumine sõltus viljelussüsteemist siis, kui mugulate kärnasus jäi vahemikku 4–30% kogu mugulapinnast. Samuti sõltus viljelusviisist mugulate nakatumine hõbekärna ja kuivmädanikku. Hõbekärna nakatumine kasvas koos suureneva mineraalse N väetise kogusega. Vahekultuuri kasutamine ilma veisesõnniuta aitas harilikku kärna nakatumise tõsidust kontrolli all hoida. Kuivmädanikku nakatumine oli madalaim süsteemis Organic CC ja tavaviljeluse süsteemis, millele manustati 150 kg N ha^{-1}.

Üksikute aastate näitajate võrdlustest selgus, et viljelussüsteemid avaldasid mitmel juhul mõju uuritavatele kvaliteedinäitajatele, eriti mugulate toitainete sisaldusele. Sellest järeldub, et see, kuidas teatud kindel süsteem mõjutab mugulate kvaliteediomadusi, sõltub otseselt konkreetse kasvuperioodi keskkonnatingimustest.

Uurimustööst selgus, et mugulate toitainete sisaldus ja haigused võivad üksteist mõjutada. Nii võis ühe toitaine liig vähendada teise toitaine sisaldust mugulates. See omakorda avaldas mõju mugulate haiguskindlusele. Samuti leiti, et on haigused võivad mõjutada üksteise esinemist ning intensiivsust.

Edasist uurimist vajavad teemad

Käesolevas töös uuriti, kuidas külvikorra esimese rotatsiooni neli esimest aastat avaldasid mõju kartuli erinevatele kvaliteedinäitajatele. Äärmiselt oluline on jätkata seda uurimistööd ning uurida ja võrrelda neid näitajaid ka pärast mitme rotatsiooni läbimist. Mullas toimuvad muutused väga aeglaselt, mistõttu võtab süsteemi kui terviku toimima hakkamine kaua aega ning külvikorra positiivsed mõjud hakkavad ilmnema alles pikema perioodi jooksul.

Vahekultuure (CC) kasutatakse praegu ainult mahesüsteemides. Tulevikus tuleks neid kasutada ka tavasüsteemides. See annaks uusi teadmisi sellest, kuidas sünteetilised taimekaitsevahendid ja mineraalväetised koos vahekultuuridega mõjutavad nii kartuli kui ka mulla kvaliteedinäitajaid.

Antud katses kasutati ühes mahesüsteemis (Organic CC+M) toitaineteallikana täielikult komposteerunud allapanuga veisesõnnikut. Vajalik oleks uurida, kas ja kuidas teised loomset päritolu orgaanilised väetised sh ka teist tüüpi veisesõnnik mõjutavad kartuli kvaliteedinäitajaid kui ka mulla toitainetega varustatust ja ringlust.

Kuna kartulitaime areng ja elutsükkel tavasüsteemides erineb mahesüsteemidest sünteetiliste taimekaitsevahendite ja erinevate väetiste kasutamise tõttu, siis oleks edaspidi vajalik uurida, kuidas toimub antud süsteemides toitainete jagunemine eri taimeosade vahel. See võimaldaks paremini aru saada saagikujunemise protsessidest, stressitaluvusest ning kuidas kõik see omakorda avaldab mõju mugulate kvaliteedinäitajatele.

Katseaastate ilmastik oli väga varieeruv, seepärast tuleks edasiste uuringutega selgitada, kas samad trendid esineksid tulemustes ka siis kui aastad oleks ilmastiku poolest sarnasemad.

Uurimustöös määrati erinevaid mugulahaigusi, mis pärinesid *Fusarium* spp. ja *Pectobacterium* spp. perekondadest, kuid kindlaks ei määratud konkreetseid liike. Seetõttu edaspidises töös oleks vaja DNA analüüsidega kindlaks määrata patogeenide liigid, saamaks teada, millised liigid meil esinevad ja millised neist on domineerivad ning kuidas nad reageerivad erinevatele viljelussüsteemidele.

Katseala kõikidelt lappidelt oleks vaja kevadel enne põllutööde algust ja vahetult enne või pärast põhikultuuride saagikoristust võtta täiendavaid mullaproove. See võimaldaks jälgida erinevate patogeensete ja antagonistlike organismide liigilist koosseisu, nende aktiivsust ja biomassi muutusi ajas ja ruumis ning selgitada, kuidas erinevad kultuurid külvikorras ja süsteemis kui tervikus mõjutavad erinevate patogeensete ja antagonistilike mikroorganismide esinemissagedust ning arvukust.

Erinevate viljelussüsteemide elutsüklianalüüs (Life Cycle Assessment) annaks kartuli kui palju toitaineid vajava ja tarbiva kultuuri kohta ülevaate ja arusaama sellest, kuidas erinevad viljelussüsteemid ja -viisid mõjutavad keskkonda ning sellest lähtuvalt ka süsteemi jätkusuutlikkust pikemas perspektiivis.

Uurimustöö tulemuste kasutamine

Tähtsaim faktor, mis langetab mugulate saagikust ja kvaliteeti on taime ebarahuldav toitumine. Kui põhimiseks eesmärgiks on saada suuri saake, vajab kartul selliseid mineraalseid väetisi, mille puhul mulda viidavad lämmastikukogused oleks vähemalt 50 kg ha^{-1}. Kuid samas tuleb kartulit väetades olla ettevaatlik, et lämmastikuga üle ei väetataks. Uurimusest selgus, et (**I**) N_{high} süsteem, kus kasutati mineraalset lämmastikväetist 150 kg ha^{-1} ning tavaviljeluse kontrollsüsteem (N0), kus lämmastikväetist üldse ei kasutatud olid kõige mulda kurnavamad süsteemid. Pikemas perspektiivis, kui jätkuvalt kasutatakse kõrgeid lämmastikväetise norme, hakkab kartul toitaineid liigtarbima kuna need on suurtes kogustes kergesti kättesaadavad ning muld muutub toitainetevaeseks. Samuti on äärmiselt oluline väetamisel jälgida ilmastikutingimusi. Tulemustest järeldub, et kui kasvuperiood on väga niiske ning kartulile manustatakse samal ajal suurtes kogustes mineraalseid lämmastikväetisi, võib saagikuse tõus olla väga väike, sest liigniiskus ja mineraalsed väetised võivad sõna otseses mõttes üksteise mõju tühistada. Kuna mahetootjad soovivad saada suuremaid saake, siis tuleks neil kindlasti kasutada täiendava toitaineteallikana orgaanilisi väetisi, näiteks sõnnikut. Sõnnikuga väetamisel tuleb siiski olla ettevaatlik, sest nagu uurimusest selgus loob sõnnik patogeensetele mikroorganismidele arenguks soodsa keskkonna. Haigused aga mõjutavad kartuli kvaliteeti ja selle kaudu kaubalisust ning võivad põhjustada kartuli säilitamisel suuri saagikadusid, mille tagajärjeks on majanduslik kahju.

Kartulimugulate toitumuslik seisund ja mugulahaigused on sageli omavahel seotud. Mõne toiteelemendi puudusel võivad mugulad nakatuda kergemini mitmetesse haigustesse. Kuna toitainete vahel võib esineda ka antagonistlikke suhteid, on suurte ja kvaliteetsete saakide saamise aluseks tasakaalustatud väetamine.

Vahekultuuride kasutamine mahepõllumajanduses on kohustuslik hoidmaks ära toitainete kadu mullast sügis-talvisel perioodil. Ristõieliste kultuuride kasutamine vahekultuuridena aitab vähendada mõningaid mullakaudseid mugulahaiguseid, mis on ühtemoodi oluline nii tava- kui maheviljelejatele.

Antud doktoritöö autor soovitab kombineerida erinevaid positiivseid aspekte nii tava- kui maheviljelusest. Suurte kõrgekvaliteediliste saakide saamiseks on soovitatav kasutada veisesõnnikut, mis tagab mulda orgaanilise aine, vahekultuure, et tagada toitainete ringlus ning samuti manustada mineraalset väetist lämmastiknormiga 50–100 kg ha^{-1}. See peaks tagama hästitoimiva kartulikasvatuse süsteemi.

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I

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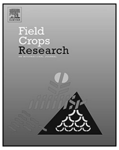

Farming systems affect potato (*Solanum tuberosum* L.) tuber and soil quality

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ABSTRACT

In organic farming, nutrient cycling is based mainly on a farm level with external inputs only when organic fertilisers are not cycled and produced, and conventional systems largely depend on external inputs. Therefore, crop rotations are important tools for maintaining soil fertility and for increasing crop yields and qualities not only in organic farming systems but also in conventional systems. Moreover, proper nutrient management is a key element for sustainable farming. To identify the farming systems that would be sustainable for a longer period, a field experiment was conducted. The aim of this study was to investigate how different farming systems influenced tuber yields and quality (N, NO_3^-, P, K, Ca, Mg, dry matter and starch concentrations) of potato as well as how potato cultivation within a crop rotation under different farming systems affects soil quality (pH, N_{tot}, C_{org}, plant available P, K, Ca and Mg concentrations). Potato (*Solanum tuberosum* L.) was part of a five crop rotation experiment in which red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), peas (*Pisum sativum* L.), potato and barley (*Hordeum vulgare* L.) followed each other simultaneously on a same field. Data presented in this paper concerned the first 3 years of the rotation during 2009–2011. The experiment was performed with six different farming systems as follows: two organic and four conventional. In both organic farming systems, catch crops (Organic CC) were used to provide organic green manure. In the second organic system, fully composted cattle manure (Organic CC + M) at a rate of 40 t ha^{-1} was also added as a fertiliser. The four conventional farming systems differed in the amounts of mineral fertilisers used as follows: $N_0P_0K_0$ (control), $N_{50}P_{25}K_{95}$ (low), $N_{100}P_{25}K_{95}$ (average), or $N_{150}P_{25}K_{95}$ (high). The average yield as well as tuber N, NO_3^- and Mg concentrations were significantly influenced by farming systems, year and their interaction. Fresh tuber yields were significantly higher under conventional systems in which nitrogen fertilisers were used. The use of average and high amounts of mineral nitrogen fertilisers increased tuber nitrogen and nitrate concentrations. The use of nitrogen fertilisers slightly decreased tuber Mg concentrations. There were no significant differences among farming systems in average tuber K, Ca, dry matter and starch concentrations. Only the year and its interaction with farming systems had a significant influence on these indicators. Different farming systems had different effects on some soil quality parameters. The Organic CC system significantly decreased the average soil K concentration after potato cultivation. The other organic system, Organic CC + M, significantly increased the average soil C_{org} and P concentrations after potato cultivation. The conventional control system significantly decreased the average soil N_{tot}, K and Mg concentrations and increased the P concentration. The conventional system that received 50 kg N ha^{-1} significantly decreased the average soil N_{tot} concentration after potato cultivation. The farming system that received an average amount of mineral nitrogen fertilisers significantly increased the average soil C_{org} and P concentrations and decreased the soil pH and K after potato cultivation. The conventional system that received 150 kg N ha^{-1} significantly decreased the average soil C_{org}, K and Mg concentrations. The average plant available Ca concentrations before and after potato crops did not have statistically significant differences among systems.

1. Introduction

Potato is one of the most important crops worldwide and ranks fourth in annual production (Fernie and Willmitzer, 2001). Potato can be highly productive, but it has a relatively shallow root system

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and often requires significant nutrient input to maintain tuber productivity and quality. Thus, proper nutrient management of potato crops is extremely important (Alva et al., 2011). Research has shown that farming systems have an influence on tuber quality parameters, such as starch and dry matter concentrations (Roinila et al., 2003), as well as on tuber nutrient concentrations (Järvan and Edesi, 2009). However, there is concern that different agronomic practices have resulted in reduced concentrations of mineral elements essential to human nutrition in edible crops. Few studies have investigated if increasing yields through agronomic measures affects the concentrations of mineral elements in tubers (White et al., 2009) and the overall crop quality (Wang et al., 2008). The influence of crop rotations on tuber yields has been well studied, but the effects of rotation on tuber quality have been studied to a lesser extent (Mohr et al., 2011).

Potato is often used in crop rotations. As a crop needing intensive soil cultivation and a high amount of nutrients, crop rotation in a potato cropping system is important because it allows the system to restore soil conditions after the intense disturbance during potato cultivation (Grandy et al., 2002). Crop rotation effects can have a major effect on soil health and, therefore, through that on crop productivity due to soil ecological interactions and processes that emerge with time (Carter et al., 2003). Many soil physical, chemical and biological characteristics are influenced by some of the most important management practices, such as tillage, nitrogen fertilisation and catch crop cultivation (Sapkota et al., 2012). The soil nitrogen supply and crop nitrogen demand, as a basic nutrient, can vary among many factors, such as the previous crops cultivated, weather conditions during the plant growth, and crop management. Therefore, selection of the appropriate nitrogen fertiliser rate for potato is difficult due to significant variations (Zebarth et al., 2009). Catch crops during winter are important to reduce nutrient leaching (Stark and Porter, 2005) and to maintain soil quality, especially in organic farming systems where problems with nutrient deficiencies may occur. Healthy, fertile soil can sustain plant production (Stockdale et al., 2002). van Bruggen and Semenov (2000) considered that soil is healthy and nutritious when it is stable, resilient to stress, has high biological diversity and has a high level of internal cycling of nutrients. The aim of every grower should be to grow crops in a way that maintains or improves soil quality because rebuilding the quality of exhausted soil is a slow process.

Even though previous research has investigated soil nutritional quality parameters, it is still important to simultaneously investigate potato tuber and soil quality parameters in the same systems. We hypothesised that (1) different farming systems are significantly influencing tuber quality because the amount of nutrients provided to farming systems is different and that (2) potato as a rotation link under different farming systems significantly affects the soil quality due to the amount of nutrient use/uptake. The objectives of this study were as follows: (i) to investigate how different farming systems influence tuber yield and quality parameters as characterised by tuber nutrients, starch concentrations and dry matter concentrations; and (ii) to assess the influence of potato as a rotation link under different farming systems on soil quality as described through concentrations of plant available nutrients and organic carbon content in soil. The study was performed in a five-field crop rotation with four conventional and two organic farming systems to identify sustainable systems for potato production that ensure good quality tubers and nutritious soil.

2. Materials and methods

2.1. Experimental design and management practices

In 2008, a crop rotation experiment with two organic and four conventional farming systems was established on an experimental field in Eerika (58°22′N and 26°40′E). The field belongs to the Department of Field Crops and Grassland Husbandry of the Estonian University of Life Sciences and is located near Tartu in Estonia. The experiment was set up in four replications with each plot ($60\,m^2$) in a systematic block design. Randomisation was fixed in every year in all farming systems and replications (Suppl. Fig. 1). Each plot was 6 meters wide and 10 m long. There were 8 rows in all potato plots. Organic and conventional plots were separated with an 18 m long section of mixed grasses to avoid contamination with synthetic pesticides, mineral fertilisers and catch crops. Between organic systems, there was also a 10 m long protective area to prevent spreading cattle manure to plots where manure was not used. Conventional systems and all four replications were next to each other without separation. Between the conventional systems, there was a transition area (1 m long and 6 m wide) where no samples were taken. The soil of the experimental field is *Stagnic Luvisol* according to the World Reference Base classification (FAO, 2006), and the texture of the soil is sandy loam with a humus layer of 20–30 cm (Reintam and Köster, 2006). The data in the present study concerned 3 years of the first rotation in 2009–2011.

Potato was part of a crop rotation experiment where red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), peas (*Pisum sativum* L.), potato and barley (*Hordeum vulgare* L.) undersown with red clover followed each other in that sequence every year. Altogether, there were 120 plots in one field. In both organic farming systems, catch crops (Organic CC) for organic green manure were used. After winter wheat, ryegrass (*Lolium perenne* L.) was sown as the catch crop. Before potato in the rotation, winter oilseed rape (*Brassica napus* sp. *oleifera biennis*) was sown, and after potato in the rotation, winter rye (*Secale cereale* L.) was sown. In the second organic system, fully composted cattle manure (Organic CC + M) was added in the autumn (2009) or in the spring (2010–2011) at a rate of 40 t ha^{-1}. On average, the composted cattle manure contained 9.7 g kg^{-1} total N (N_{tot}), 4.6 g kg^{-1} P_{tot}, 8.6 g kg^{-1} K_{tot}, 138 g kg^{-1} C_{tot} and 44.8% dry matter (DM). The years of 2009 and 2010 were the second and third years, respectively, following conversion to the organic-farming system. By 2011, the organic farming systems were already fully organic. For better data monitoring, the term 'organic' is used for all experiment years in the organic farming systems. The four conventional farming systems differed in application of mineral nitrogen fertilisers. The conventional control system (N0) had no fertilisers added. The other three systems, namely N_{low}, $N_{average}$, and N_{high}, had differing levels of fertilisers added (50, 100, and 150 kg N ha^{-1}, respectively). All mineral fertilised systems had NPK fertilisers added at planting at the rate of 20:25:95 kg ha^{-1}. One and/or two subsequent N supplements were added during growth (N_{low} = 30 kg ha^{-1}; $N_{average}$ = 60 + 20 kg ha^{-1}; and N_{high} = 90 + 40 kg ha^{-1}). Conventional systems were treated with several synthetic pesticides. Herbicides were used one to two times, insecticides were used two to three times and fungicides were used three to four times during the potato growth period as necessary. In the organic systems, weeds were removed by hand, and no chemical plant protection was used. The preceding crop of winter wheat received mineral fertilisers in the same amount in all systems as potato. The pea crop received mineral fertilisers as either N0 (control) or $N_{average\text{-}high}$ ($N_{20}P_{25}K_{95}$). Because pea is a leguminous crop, the N rate was not increased. Barley undersown with red clover received mineral fertilisers as N0 (control), N_{low} ($N_{40}P_{25}K_{95}$), $N_{average}$ ($N_{80}P_{25}K_{95}$) or N_{high} ($N_{120}P_{25}K_{95}$). Red clover alone did not receive any mineral fertilisers. Only potato received composted cattle manure in a rotation, and the other Organic CC + M crops had the manure after-effect from potato.

All seed tubers were pre-sprouted. Tubers were kept for 35–38 days before planting in a sufficiently humid and lighted room at 12–15 °C in a wooden box. Seed tubers with a diameter of 35–55 mm were planted according to the norm of 2.7–3.0 t ha^{-1}

Table 1
Average monthly temperatures (°C) and precipitation (mm) during the growing period in the Eerika experimental field.

Month	Decade	Temperatures (°C)				Precipitation (mm)			
		2009	2010	2011	1969–2011	2009	2010	2011	1969–2011
May	I	10.9	7.3	8.0	9.7	3.2	39.2	0.2	12.9
	II	9.3	16.7	11.8	11.4	7.6	44.6	46.6	20.9
	III	14.1	12.4	13.0	12.8	2.6	13.6	11.6	22.8
June	I	11.7	13.3	19.7	14.9	86.6	41.4	0.0	20.9
	II	13.1	13.6	15.9	15.1	34.0	17.8	24.8	26.9
	III	16.7	15.9	16.2	16.2	16.8	38.8	10.4	28.0
July	I	15.6	19.9	20.0	17.3	10.4	11.6	9.2	19.3
	II	17.9	22.9	18.6	17.4	21.4	3.0	30.4	24.8
	III	17.2	22.4	21.0	17.8	22.8	23.8	8.6	26.5
August	I	16.3	20.9	16.1	17.6	4.6	18.2	16.2	33.3
	II	15.1	19.1	15.6	16.2	54.2	74.6	17.0	28.5
	III	14.8	13.7	15.8	14.6	30.4	55.6	21.4	28.0
September	I	15.7	10.4	13.0	12.7	16.0	32.6	32.2	20.3
	II	11.8	12.1	12.2	10.6	11.2	46.4	28.4	18.3
May–September	I–III	14.3	15.8	15.2	14.5	321.8	461.2	257.0	331.4

(52,910 tubers per hectare). The distance between tubers was 27 cm, and the distance between rows 70 cm. The domestic early to medium ‘Reet’ potato cultivar was used. This cultivar is recommended for organic farming (Tsahkna and Tähtjärv, 2008), and because it is adapted to local conditions, it is able to give reasonably high yields of good quality tubers.

After harvest of the preceding main crop of pea, the soil in the organic systems was cultivated twice. The winter oilseed rape was then sown as the catch crop, which was ploughed into the soil at the end of April. After harvest of pea and potato in the conventional systems, the soil remained untouched until the end of October when the fields were ploughed. There was no winter cover in the conventional farming systems. Potato was planted at the beginning of May and harvested in August-September. After the potato crop was harvested, the field was cultivated twice to a depth of 12 cm, and the following catch crop of winter rye was sown in the organic systems. All other field operations with the potato crop followed normal cultivation practices.

2.2. Potato tuber and cattle manure analyses

Ten consecutive plants in a row were taken before harvest to measure total yield. After the potato was harvested, tubers were taken from each replication to measure tuber nutrients, dry matter (DM) and starch concentrations. Tubers for chemical and DM measurements were between 35 and 55 mm in diameter with 6 tubers taken from each replication. Starch contents were found using Parov’s weight. For DM, the tubers were washed, cut into strips and then dried for 48 h at the temperature of 80 °C. Samples of fully composted cattle manure were taken before the application of manure. Total nitrogen (N) concentrations in tubers and manure as well as total carbon concentration in manure were analysed by the dry combustion method in a varioMAX CNS elemental analyser (ELEMENTAR, Germany). Acid digestion by sulphuric acid solution (Agricultural Research Centre, 1986) was used to determine tuber total phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) concentrations as well as cattle manure total P and K concentrations. Nitrate ($NO_3{}^-$) concentrations in tubers were measured using the cadmium (Cd) column method (Houba et al., 1989).

2.3. Soil analysis

Once a year in mid-April before the start of field operations, soil samples were taken from a depth of 0–25 cm. Eight samples were taken from each plot to obtain the average for one plot. Air-dried soil samples were sieved through a 2 mm sieve and used to determine soil reaction (pH) in a 1 M KCl solution (1:2.5). Soil organic carbon (C_{org}) was measured using the Tjurin method (Soil Survey Laboratory Staff, 1996), and total nitrogen (N_{tot}) concentration was measured using the Kjeldahl method (van Reeuwijk, 1995). The concentrations of plant available nutrients, including P, K, Ca and Mg, in the soil were determined by the ammonium lactate (AL) method (Egnér et al., 1960).

2.4. Weather conditions

The weather during the experiment period was monitored with a Metos Compact (Pessl Instruments) electronic weather station, which automatically calculates the average daily temperatures and the sum of precipitation. To obtain the decade average of daily average temperatures at the weather station, the daily temperatures were averaged over each decade.

Weather conditions during the study period (2009–2011) differed substantially (Table 1), especially the total precipitation amounts during the growing period. In 2009, the precipitation sum during the growth period was quite similar to the long-term average (1969–2011). By contrast, the precipitation in 2010 and 2011 differed considerably from the long-term average as follows: 2011 was arid with 74.5 mm less rainfall than the long-term average; and 2010 was unusually wet with 461.2 mm of rainfall.

Average temperatures showed the expected progression from low in May to high in August with a decrease in September. For the month of May the temperatures were lowest in 2011 and highest in 2010. Over the entire season, 2010 was generally the warmest, and 2009 was the coolest and had lower temperatures than the long-term average through June, July and August.

2.5. Statistical analyses

The Statistica version 11.0 (Statsoft Inc.) software package was used for all statistical analyses. Factorial analysis of variance (ANOVA) and one-way ANOVA were applied to test the effect of farming systems on tuber and soil properties. The means are presented with their confidence limits. Fisher’s least significant difference test for homogenous groups was used for testing significance differences between farming systems and experimental year. The level of statistical significance was set at $P < 0.05$ if not indicated otherwise.

Table 2
Average tuber yields depending on the farming system.

Farming system	Yield (t ha^{-1})			
	2009	2010	2011	Average
Organic CC	$21.6^{A1a2} \pm 14.6^{3}$	$15.8^{Aa} \pm 4.9$	$23.0^{Aa} \pm 7.0$	$20.1^{A} \pm 4.1$
Organic CC + M	$28.7^{Ab} \pm 12.7$	$19.0^{ABa} \pm 8.0$	$32.9^{Bb} \pm 5.7$	$26.9^{A} \pm 5.1$
$N_0P_0K_0$	$29.7^{Ab} \pm 10.4$	$15.9^{Aa} \pm 3.9$	$32.8^{Bb} \pm 6.2$	$26.1^{A} \pm 5.5$
$N_{50}P_{25}K_{95}$	$48.1^{Bb} \pm 18.3$	$22.9^{BCa} \pm 5.4$	$37.7^{BCb} \pm 10.5$	$36.2^{B} \pm 8.2$
$N_{100}P_{25}K_{95}$	$52.4^{Bb} \pm 17.8$	$26.4^{CDa} \pm 3.9$	$43.1^{Cb} \pm 11.6$	$40.6^{B} \pm 8.5$
$N_{150}P_{25}K_{95}$	$57.5^{Bb} \pm 20.2$	$29.0^{Da} \pm 2.1$	$45.8^{Cb} \pm 11.7$	$44.1^{B} \pm 9.2$

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[2] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.

[3] Data represents mean ±95% confidence limits, $n = 4$ (one year), $n = 12$ (average).

3. Results

3.1. Tuber yield

The overall yields remained significantly less in 2010 compared to 2009 and 2011, except for the fresh tuber yields in the Organic CC system where the three year yield differences were statistically non-significant ($P > 0.05$) (Table 2). Tuber fresh matter yields in 2009 and 2011 were statistically non-significant. The main reason the yields were much less in 2010 than in the other two years may be the extreme weather conditions (Table 1) during the growing period. On average, significantly higher ($P < 0.05$) yields were obtained from the conventional farming systems in which mineral nitrogen fertilisers were used with the amount of 50–150 kg N ha^{-1}, but the differences between systems where mineral nitrogen fertilisers were used were non-significant. The same result was found when comparing the control system and both organic systems where, on average, the fresh tuber yield differences were non-significant. The fresh tuber yield was significantly ($P < 0.001$) influenced by year, farming system and their interaction (Table 3).

3.2. Nutrient, starch and dry matter concentrations in potato tubers

The following concentration values were measured: total nitrogen and nitrate (Table 4); P and K (Table 5); and Ca and Mg (Table 6). A summary of the two-way analyses of variance of the effects of year and farming system as well as their interactions on each of these variables is shown in Table 3. Tuber N and nitrate concentrations were both significantly influenced by all the factors ($P < 0.001$). Conventional farming systems with higher inputs of mineral nitrogen fertilisers had increased tuber N and NO_3^-concentrations. In 2010 and 2011, the tuber nitrate concentrations were approximately twice those in 2009. The P concentrations in tubers were mostly affected by farming system ($P < 0.001$) and were, on average, higher in the organic and control systems. The year alone had a non-significant effect on P concentrations (n.s.), but the interaction between the experimental year and farming system had a significant effect on P concentrations ($P < 0.001$). In contrast to the P concentrations, the K concentrations in tubers were significantly influenced only by experimental year ($P < 0.001$). The last two experimental years had significantly higher K concentrations in tubers than in 2009. Mg concentrations in tubers were significantly affected ($P < 0.01\ldots0.001$) by all the factors and were, on average, higher in the control and organic systems. Ca concentrations as well as DM and starch contents were significantly influenced by experimental year and the interaction of year and farming systems ($P < 0.001$). Farming systems alone had a non-statistical influence on tuber Ca concentrations as well as on starch and DM contents ($P > 0.05$). Tuber starch and DM contents were mostly and significantly higher in 2009 and 2011. Ca concentrations were significantly higher in 2010 and 2011.

3.3. Soil quality

Soil pH after potato cultivation, on average, decreased significantly in the conventional system in which the used N amount was 100 kg ha^{-1} (Table 8). In both organic systems, the pH after potato cultivation increased and decreased in other conventional systems, but the changes were non-significant. The soil pH concentrations after potato cultivation were non-significantly higher in organic systems. On average, the soil C_{org} concentrations increased significantly after potato cultivation in the organic system where cattle manure was used and in the conventional system in which the nitrogen amount used was 100 kg N ha^{-1} (Table 8). Moreover, the soil C_{org} concentrations slightly increased in the Organic CC system and the conventional system in which the nitrogen amount was 50 kg N ha^{-1}, but the increases were non-significant. After potato cultivation, the soil C_{org} decreased in two conventional systems. In the conventional control system, this decrease was non-significant, but this decrease was statistically significant in the conventional system in which the nitrogen amount was 150 kg N ha^{-1}. On average, the highest non-significant C_{org} concentrations were measured before potato cultivation in both organic systems and in the conventional system with the highest nitrogen amount used. After potato cultivation, similar relations were found for both organic systems, and unlike before potato cultivation, one of the highest C_{org} concentrations after potato cultivation resulted from the conventional system in which the average amount of nitrogen fertiliser was used. On average, the N_{tot} concentrations in soil after potato cultivation significantly decreased in the control system and in the conventional system in which the nitrogen amount was 50 kg N ha^{-1} (Table 8). In the other systems, N_{tot} amounts in the soil remained the same as they were before potato cultivation. On average, the highest non-significant N_{tot} concentrations measured before and after potato cultivation were in both organic systems and in the conventional system in which the nitrogen amount used was 150 kg ha^{-1}. On average, soil plant available P increased significantly after potato cultivation in the control system, in the organic system that used cattle manure and in the conventional system in which the applied nitrogen rate was 100 kg ha^{-1} (Table 9). A non-significant increase was also measured in the conventional systems in which the nitrogen amounts used were 50 and 150 kg ha^{-1}. In the Organic CC system, a slight non-significant decrease in plant available P was noticed. Plant available P concentrations, on average, were highest before and after potato cultivation in the control conventional system and in the systems in which low and

Table 3
Analysis of variance on tuber yield, total nitrogen (N), nitrate (NO_3^-), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), dry matter (DM), and starch concentrations. (ns, statistically non-significant; *significant at 5% level of probability; **significant at 1% level of probability; and ***significant at 0.1% level of probability).

	Yield (t ha^{-1})	N (%)	NO_3^- (mg kg^{-1})	P (%)	K (%)	Ca (%)	Mg (%)	DM (%)	Starch (%)
Year (Y)	***	***	***	ns	***	***	***	***	***
Farming system (FS)	***	***	***	***	ns	ns	***	ns	ns
Y × FS	***	***	***	***	ns	***	**	***	***

Table 4
Average nitrogen (N) and nitrate (NO_3^-) concentrations in potato tubers.

Farming system	N (%)				NO_3^- (mg kg^{-1})			
	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC	$1.01^{B1a2} \pm 0.03^{3}$	$1.30^{Ab} \pm 0.04$	$1.30^{Ab} \pm 0.08$	$1.20^{A} \pm 0.09$	$6.2^{Aa} \pm 1.2$	$60.0^{Ac} \pm 26.6$	$43.7^{Ab} \pm 5.7$	$36.6^{A} \pm 16.0$
Organic CC + M	$1.04^{Ba} \pm 0.05$	$1.36^{ABb} \pm 0.12$	$1.35^{Ab} \pm 0.09$	$1.25^{AB} \pm 0.10$	$24.2^{BCa} \pm 1.0$	$71.5^{Ab} \pm 59.6$	$50.2^{Aab} \pm 17.5$	$48.6^{A} \pm 18.2$
$N_0P_0K_0$	$0.94^{Aa} \pm 0.02$	$1.47^{ABCc} \pm 0.15$	$1.25^{Ab} \pm 0.09$	$1.22^{A} \pm 0.15$	$22.0^{BCa} \pm 1.6$	$58.0^{Ac} \pm 10.1$	$41.3^{Ab} \pm 18.4$	$40.5^{A} \pm 10.7$
$N_{50}P_{25}K_{95}$	$1.01^{Ba} \pm 0.01$	$1.53^{BCc} \pm 0.19$	$1.26^{Ab} \pm 0.13$	$1.26^{AB} \pm 0.15$	$25.0^{Ca} \pm 1.2$	$96.2^{Ab} \pm 63.5$	$50.6^{Aa} \pm 21.3$	$57.3^{A} \pm 24.0$
$N_{100}P_{25}K_{95}$	$1.28^{Ca} \pm 0.05$	$1.52^{BCa} \pm 0.37$	$1.33^{Aba} \pm 0.21$	$1.38^{BC} \pm 0.11$	$61.9^{Ea} \pm 5.6$	$195.1^{Bb} \pm 68.9$	$110.8^{Ba} \pm 63.4$	$122.6^{B} \pm 41.4$
$N_{150}P_{25}K_{95}$	$1.41^{Da} \pm 0.06$	$1.60^{Cb} \pm 0.22$	$1.42^{Ba} \pm 0.09$	$1.48^{C} \pm 0.08$	$39.7^{Da} \pm 3.5$	$182.4^{Bc} \pm 14.1$	$149.8^{Cb} \pm 49.9$	$124.0^{B} \pm 41.9$

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.
[2] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.
[3] Data represents mean ±95% confidence limits, $n = 4$ (one year), $n = 12$ (average).

Table 5
Average phosphorus (P) and potassium (K) concentrations in potato tubers.

Farming system	P (%)				K (%)			
	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC	$0.224^{B1a2} \pm 0.014^{3}$	$0.233^{Aa} \pm 0.043$	$0.285^{Cb} \pm 0.024$	$0.247^{C} \pm 0.021$	$1.78^{Aa} \pm 0.12$	$2.28^{ABb} \pm 0.15$	$2.34^{Ab} \pm 0.28$	$2.13^{A} \pm 0.18$
Organic CC + M	$0.280^{Db} \pm 0.015$	$0.206^{Aa} \pm 0.043$	$0.220^{Ba} \pm 0.047$	$0.235^{C} \pm 0.025$	$1.79^{Aa} \pm 0.12$	$2.24^{ABb} \pm 0.24$	$2.52^{Ac} \pm 0.15$	$2.19^{A} \pm 0.21$
$N_0P_0K_0$	$0.239^{Ca} \pm 0.022$	$0.238^{Aa} \pm 0.075$	$0.222^{Ba} \pm 0.025$	$0.233^{BC} \pm 0.018$	$1.77^{Aa} \pm 0.06$	$2.12^{Ab} \pm 0.29$	$2.36^{Ac} \pm 0.08$	$2.08^{A} \pm 0.17$
$N_{50}P_{25}K_{95}$	$0.191^{Aa} \pm 0.007$	$0.236^{Aa} \pm 0.071$	$0.200^{Aba} \pm 0.036$	$0.209^{AB} \pm 0.021$	$1.74^{Aa} \pm 0.04$	$2.41^{Bb} \pm 0.44$	$2.42^{Ab} \pm 0.11$	$2.19^{A} \pm 0.23$
$N_{100}P_{25}K_{95}$	$0.212^{Ba} \pm 0.013$	$0.213^{Aa} \pm 0.035$	$0.186^{Aa} \pm 0.042$	$0.203^{A} \pm 0.014$	$1.75^{Aa} \pm 0.14$	$2.38^{ABb} \pm 0.20$	$2.41^{Ab} \pm 0.28$	$2.18^{A} \pm 0.22$
$N_{150}P_{25}K_{95}$	$0.194^{Aa} \pm 0.007$	$0.200^{Aa} \pm 0.028$	$0.192^{ABa} \pm 0.034$	$0.195^{A} \pm 0.010$	$1.82^{Aa} \pm 0.12$	$2.33^{ABb} \pm 0.38$	$2.51^{Ab} \pm 0.38$	$2.22^{A} \pm 0.23$

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.
[2] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.
[3] Data represents mean ±95% confidence limits, $n = 4$ (one year), $n = 12$ (average).

average amounts of mineral nitrogen fertilisers were used. However, these P concentrations were not statistically significantly different from other systems. On average, the soil plant available K concentrations decreased after potato cultivation in all systems, but the decrease was statistically significant only in the Organic CC, control, $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$ systems (Table 9). Before potato cultivation, the average plant available K concentrations were non-significantly higher in systems in which the used nitrogen amounts were 50 and 100 kg ha^{-1}. Compared to the K concentrations before potato cultivation, the K concentrations were also non-significantly higher after potato cultivation in the systems that used nitrogen amounts of 50 and 100 kg ha^{-1} in addition to the Organic CC + M system. Among the farming systems, the plant available average Ca concentrations before and after potato cultivation had statistically non-significant differences (Table 9). However, a non-significant increase in Ca concentrations was measured in the organic systems after potato cultivation, and a decrease in Ca concentrations was measured in the conventional systems after potato cultivation. On average, the soil plant available Mg concentrations decreased significantly after potato cultivation in the control system and in the conventional system in which the used nitrogen rate was 150 kg ha^{-1} (Table 9). The Organic CC + M system soil Mg concentration remained the same after potato cultivation as it was before potato cultivation, but a non-significant decrease in Mg concentrations occurred in the other systems.

4. Discussion

4.1. Tuber yield

In Estonia, the average potato yield is 17.5 t ha^{-1} (including yields from organic farming), and the yield has increased by 4.0 t ha^{-1} over the past 10 years (Statistics Estonia Database, 2013). In this experiment, the average yields were much higher than the Estonian average yields (Table 2). In the organic farming systems, the yields remained, on average, approximately 45–55% lower than in the conventional systems in which nitrogen fertilisers were used. On average, organic yields were 80% less than those obtained with conventional agriculture, and this result may be due to pests, diseases and/or P limitations (de Ponti et al., 2012). As shown in Table 5, the average P concentrations in potato tubers were highest in the organic systems and in the conventional control system. However, the overall uptake of phosphorus remained less in these systems compared to the conventional systems, which received mineral nitrogen. Mineral fertilisers are used to provide enough nutrients for the potato to grow higher yields. Because P

Table 6
Average calcium (Ca) and magnesium (Mg) concentrations in potato tubers.

Farming system	Ca (%)				Mg (%)			
	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC	$0.049^{B1a2} \pm 0.003^{3}$	$0.087^{Bb} \pm 0.008$	$0.136^{BCc} \pm 0.018$	$0.091^{A} \pm 0.024$	$0.126^{Bb} \pm 0.010$	$0.155^{Ac} \pm 0.028$	$0.108^{ABCa} \pm 0.008$	$0.130^{AB} \pm 0.014$
Organic CC + M	$0.051^{Ba} \pm 0.005$	$0.065^{Aa} \pm 0.021$	$0.168^{Cb} \pm 0.060$	$0.095^{A} \pm 0.037$	$0.143^{Cb} \pm 0.007$	$0.138^{Ab} \pm 0.020$	$0.114^{Ca} \pm 0.011$	$0.132^{B} \pm 0.010$
$N_0P_0K_0$	$0.059^{Ca} \pm 0.011$	$0.095^{BCb} \pm 0.021$	$0.140^{BCc} \pm 0.020$	$0.098^{A} \pm 0.023$	$0.121^{Bab} \pm 0.009$	$0.145^{Ab} \pm 0.040$	$0.112^{BCa} \pm 0.010$	$0.126^{AB} \pm 0.013$
$N_{50}P_{25}K_{95}$	$0.075^{Da} \pm 0.009$	$0.087^{Ba} \pm 0.008$	$0.118^{ABb} \pm 0.038$	$0.093^{A} \pm 0.015$	$0.102^{Aa} \pm 0.005$	$0.147^{Ab} \pm 0.020$	$0.103^{ABCa} \pm 0.013$	$0.118^{AB} \pm 0.015$
$N_{100}P_{25}K_{95}$	$0.083^{Ea} \pm 0.007$	$0.108^{Cb} \pm 0.024$	$0.103^{Aab} \pm 0.032$	$0.098^{A} \pm 0.011$	$0.104^{Aa} \pm 0.008$	$0.138^{Ab} \pm 0.015$	$0.101^{ABa} \pm 0.017$	$0.114^{A} \pm 0.012$
$N_{150}P_{25}K_{95}$	$0.036^{Aa} \pm 0.004$	$0.090^{Bb} \pm 0.013$	$0.112^{ABc} \pm 0.028$	$0.079^{A} \pm 0.022$	$0.109^{Aa} \pm 0.005$	$0.147^{Ab} \pm 0.030$	$0.098^{Aa} \pm 0.013$	$0.118^{AB} \pm 0.016$

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.
[2] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.
[3] Data represents mean ±95% confidence limits, $n = 4$ (one year), $n = 12$ (average).

comes mainly from soil resources in the organic systems and in the conventional control system, there is a threat of P deficiencies unless cattle manure or other external fertilisers are used to supply additional P. Catch crops do not add nutrients to the soil because they bind them from soil resources. Therefore, in a longer period, soil P deficiencies may occur in the organic systems and in the conventional control system without additional fertilisers providing P or if a system inner overall P cycling is unbalanced, thereby leading to lower yields. As shown in Table 9, there were no significant problems with soil P concentrations indicating that there were other reasons why yields were lower in the organic systems and in the conventional control system. Thus, if the nutrients are insufficient in the soil, crop growth and yielding ability is limited.

In the organic systems, there were also problems with Colorado potato beetle (*Leptinotarsa decemlineata* (Say)) and minor problems with late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) because no control methods were used. These pathogens and Colorado potato beetle may cause yield losses up to 75% if no crop protection means are used (Oerke, 2006). These problems shortened the tuber growth period compared to the conventional farming systems in which synthetic pesticides were used. The duration of tuber bulking is shorter and the yield is lower if the canopy is killed early (Hospers-Brands et al., 2008). Nevertheless, the use of pesticides may also cause stress to plants (Nilsen and Orcutt, 1996), especially when plants are treated several times during the growing period. Moreover, continuous stresses inhibit yield increase. However, Cedergreen et al. (2009) found that low chemical stress may increase yield but not by all chemicals. On average, the pest and disease control helped to gain a non-significantly higher yield in the conventional control system than in the organic farming system where only catch crops were used. The potatoes in the conventional control system were able to photosynthesise for longer due to the use of pesticides resulting in a higher yield. Despite the fact that the potatoes grown in the organic farming systems had shorter photosynthetically active periods, the cattle manure supplied in one of the systems increased tuber yields because of the nutrients available from the manure. Moreover, higher mineral N availability causes a higher rate of photosynthesis maintaining tuber growth during the later part of the growing season (Shahnazari et al., 2008). As expected, mineral fertilisers with the higher N amounts increased yields substantially more than crop rotation, organic fertilisers (Tein and Eremeev, 2011) and catch crops. The maximum recommended N application rates depend on local soil and climatic conditions. If the only purpose is to obtain higher yields, potato should receive adequate amounts of fertilisers (Eremeev et al., 2009) that are suitable and recommended for the specific region taking into account all other growth conditions.

Weather conditions also play an important role in potato production. 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. This present experiment also revealed that the strongest influence on potato yields was heavy rainfall during the growth period. As shown in Table 2, the yields in 2010 were significantly lower than in the other two experimental years, except in the Organic CC system, which was the result of heavy rainfall during the growth period and higher than average temperatures (Table 1). Nitrogen fertilisers and excessive water supply can cancel out each other's effects on crop yield (Ferreira and Carr, 2002). However, if there are problems with water supply, irrigation should be considered because high water deficiency negatively influences plant nutrient uptake. When weather conditions during the plant growth period are similar to the long-term average (most optimal), higher potato yields can be achieved because of the good interaction between plant available nutrients and weather conditions.

4.2. Nutrient, starch and dry matter concentrations in potato tubers

Potato is a high nutrient-demanding crop. Therefore, the tuber nutrient concentrations are directly related with nutrient availability and uptake, which is influenced by weather conditions. However, if more nutrients than required are available, then plants generally tend to take up more than they need (Westermann, 2005). Field pea as a previous crop leaves high quantities of mineral N in the soil. Part of this nitrogen can be used by the following crop, but part of this nitrogen may also be lost through emissions (Jensen, 1997) and leaching during winter. In conventional farming systems, mineral fertilisers are used to provide nutrients for the plants, thus resulting in a less serious problem with emissions. In organic farming systems, catch crops as winter cover crops must be used to reduce nutrient losses. Well maintained soil in both farming systems is a key element for high quality yields and fertile healthy soil.

N_{tot} and nitrate concentrations are closely related. Average tuber nitrogen and nitrate concentrations were higher in farming systems in which average and high amounts of nitrogen fertilisers were applied to the soil (Table 4) because of the higher nitrogen input. It has been previously found that tuber nitrate concentrations are higher in conventionally grown tubers (Eremeev et al., 2009). When comparing the two organic systems with each other, the manure application non-significantly increased, on average, the tuber nitrate concentrations in the organic farming systems by 12 mg kg^{-1} compared to the Organic CC system. Nitrates are considered to be a health risk, and organically grown potatoes are considered to be healthier by consumers because of the lower nitrate concentrations in tubers. In 2010, it was rainy and warm during the potato growth period. Therefore, the total nitrogen concentrations in 2010 were significantly higher in the conventional control, N_{low} and N_{high} systems, and nitrate concentrations were significantly higher in all systems, except in the Organic CC + M system, than in the other two experimental years. Crop N uptake is ultimately defined by temperature, radiation and water (van Evert et al., 2012). Excessive moisture and warm weather during the growth period can increase tuber nutritional uptake.

Tuber P concentrations depended on the farming system (Table 5). In this study, the overall tuber P concentrations, on average, varied between 0.195% and 0.247%, which was average compared to the other studies (Papadopoulos, 1992; Fangmeier et al., 2002; Mkhabela and Warman, 2005; Alvarez-Sánchez et al., 2008). Both the organic farming systems and conventional control system had higher tuber P concentrations compared to the other farming systems. Curless et al. (2004), Šrek et al. (2010) found that organic fertilisers increase tuber P concentrations. Farming systems where average and high amounts of mineral nitrogen fertilisers are used have, on average, significantly lower P concentrations compared to the organic fertilisers as shown by Šrek's et al. (2010). Rosen and Bierman (2008) found that mineral P application increases tuber P concentrations. In this study, the P fertilisation rate was 25 kg ha^{-1} in all conventional systems that were fertilised, and the P concentration decreased when the N amount increased. Moreover, Augustin (1975), Maier et al. (1994) argued that the use of mineral N fertilisers can decrease tuber P concentrations. Jacobsen et al. (1998) have found that higher tuber P concentrations may result in higher starch contents. In the present study, however, higher tuber P concentrations had a non-significant effect on tuber starch contents (Table 7). Rosen and Bierman (2008) also argued that the high P availability decreases the number of marketable tubers and, therefore, the marketable yield. Previous study, based

Table 7
Average potato tuber dry matter (DM) and starch contents.

Farming system	DM (%)				Starch (%)			
	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC	$25.0^{C1b2} \pm 0.4^{3}$	$21.4^{ABa} \pm 1.2$	$22.0^{Aa} \pm 0.5$	$22.8^{A} \pm 1.1$	$17.6^{Cb} \pm 0.2$	$16.1^{Ba} \pm 0.5$	$15.9^{Aa} \pm 0.6$	$16.5^{A} \pm 0.5$
Organic CC + M	$24.9^{Cb} \pm 0.6$	$22.9^{Ba} \pm 0.9$	$21.9^{Aa} \pm 1.2$	$23.2^{A} \pm 0.9$	$16.5^{Ab} \pm 0.3$	$16.7^{Cb} \pm 0.5$	$15.8^{Aa} \pm 0.6$	$16.3^{A} \pm 0.3$
$N_0P_0K_0$	$25.5^{Cb} \pm 1.1$	$20.9^{ABa} \pm 4.1$	$22.8^{ABab} \pm 2.2$	$23.1^{A} \pm 1.6$	$17.9^{Cc} \pm 0.9$	$14.9^{Aa} \pm 0.3$	$16.6^{Bb} \pm 0.4$	$16.5^{A} \pm 0.8$
$N_{50}P_{25}K_{95}$	$25.1^{Cc} \pm 0.3$	$21.3^{ABa} \pm 1.4$	$23.7^{BCb} \pm 0.8$	$23.4^{A} \pm 1.1$	$17.3^{BCc} \pm 0.3$	$14.9^{Aa} \pm 0.5$	$16.7^{Bb} \pm 0.4$	$16.3^{A} \pm 0.7$
$N_{100}P_{25}K_{95}$	$22.6^{Ab} \pm 0.6$	$20.1^{Aa} \pm 2.3$	$23.3^{BCb} \pm 1.9$	$22.0^{A} \pm 1.1$	$17.0^{ABb} \pm 1.1$	$15.0^{Aa} \pm 0.3$	$16.9^{Bb} \pm 0.2$	$16.3^{A} \pm 0.7$
$N_{150}P_{25}K_{95}$	$23.7^{Bb} \pm 0.4$	$20.7^{Aa} \pm 1.8$	$24.4^{Cb} \pm 0.5$	$22.9^{A} \pm 1.1$	$16.6^{Ab} \pm 0.4$	$14.7^{Aa} \pm 0.2$	$16.8^{Bb} \pm 0.4$	$16.0^{A} \pm 0.6$

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.
[2] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.
[3] Data represents mean ±95% confidence limits, $n = 4$ (one year), $n = 12$ (average).

on the same experiment, found that tubers under organic farming remained smaller than tubers under conventional systems where mineral fertilisers were used (Tein and Eremeev, 2011).

Trehan and Sharma (2002) showed that K concentrations of an average cultivar range between 2.6% and 3.6%. Average tuber K concentrations in our research were relatively low ranging between 2.08% and 2.22% (Table 5), and non-significant influences of farming systems were found on tuber K concentrations. Fertilisation with K fertiliser affects tuber DM concentration, flesh colour and hollow heart disorder as found by Panique et al. (1997). Haase et al. (2007a), Kumar et al. (2007), Westermann et al. (1994) confirmed that tuber K concentrations may have a negative effect on tuber DM contents. In this study, tuber K concentrations did not affect tuber DM concentrations (Table 7) because the tuber K concentrations were not affected by farming systems. There can also be antagonism between P and K (MacKay et al., 1987). Haase et al. (2007b) noted that mineral K fertilisers and cattle manure can increase K availability equally. Therefore, tuber K concentrations can be quite similar in farming systems where mineral K fertilisers or manure are used, as demonstrated in the present study. Low K concentrations in economic products are not a desirable trait because of the reduced nutritional value for human consumption (Rengel and Damon, 2008).

Neither tuber Ca nor Mg concentrations are thought to be crucial to human nutrition because tubers are not a rich source of either, but they have an important role in the control of physiological disorders and diseases of potato (Brown et al., 2012). Palta (1996, 2010) noted that Ca decreases hollow heart, bruising, storage rot and internal brown spot what has also been confirmed by Ozgen et al. (2006). Warman and Havard (1998) found that the average Mg concentrations are higher in organically grown potatoes and that conventional nor organic production does not influence tuber Ca concentrations. In our study, we found that none of the systems clearly differed from the others even though there were some differences in tuber Mg concentrations (Table 6). Farming systems also had a non-significant effect on tuber Ca concentrations (Table 6) as found in previous research. The tuber Ca concentration was most affected by year. In 2011, when the growth period was relatively dry, tuber Ca concentrations increased significantly, except in the $N_{average}$ system. Mg concentrations in tubers were also significantly influenced by year, and most of the systems had the highest Mg concentrations in 2010. Therefore, Ca concentrations in tubers increased when the growing season was warm and arid, and tuber fresh matter yields were the highest next to 2009. In contrast to Ca concentrations in tubers, Mg concentrations were principally higher in 2010 when the growing season was also warm but wet, and the tuber fresh matter yields were significantly lower in 2010 (except in Organic CC system) compared to the other experimental years. Rhue et al. (1986) noted that when K concentrations increase, the Ca and Mg concentrations typically decrease. This study found no effect of K on tuber Mg and Ca concentrations because the farming systems had no effect on tuber K.

Climate, cultivar and crop management determine the DM production of potato (Geremew et al., 2007). DM and starch contents also depend on the size of tubers, but they are also affected by climate. Large tubers generally have low DM and starch contents, but small tubers usually also contain the lowest contents of DM and starch (Kolbe and Stephan-Beckmann, 1997). Therefore, tubers grown under conventional farming systems that receive nitrogen should have lower DM and starch contents because their tubers grow larger resulting in lower DM and starch contents. In organic systems, the nitrogen supply is lower, so the tubers remain a bit smaller resulting in larger DM and starch concentrations. This same trend was found with the starch results in 2010 (Table 7). Hajšlová et al. (2005) confirmed that the amount of nitrogen applied is negatively correlated with starch and DM contents. In the present study, different farming systems had, on average, a non-significant effect on tuber starch and DM contents. The experimental year had a significant influence on the tuber DM and starch results. In the organic systems, the tuber DM contents were significantly higher in 2011 when the growing period temperatures and precipitation were most similar to the average of many years. Starch contents were also significantly higher in the Organic CC system in 2009 as well as in the Organic CC + M system in 2009 and 2010. Conventional systems that were fertilised had lowest DM and starch contents in tubers in 2010 when the growing season was warm and wet. Thus, nitrogen fertilisers together with an unfavourable growing period resulted in decreased tuber DM and starch contents. In 2011, the lower DM and starch contents in the organic farming systems compared to the nitrogen fertiliser systems were apparently caused by the weather conditions because 2011 was a relatively dry year with high temperatures (Table 1). The aboveground biomass suffered from drought and died earlier, but the tubers were not fully mature causing lower tuber DM and starch contents. The use of pesticides and mineral fertilisers in the conventional farming systems helped the plants to grow longer and therefore the tubers were able to reach maturity which resulted in higher DM and starch contents.

In 2009, most of the tuber macronutrient concentrations (except Mg) remained lower than in the other two experimental years, but the yields were one of the highest next to 2011. If during the potato growing period weather conditions are near optimal in a specific location, the potato uses nutrients more efficiently. Therefore, weather has an enormous effect on yields and qualities with crop rotation and farming systems.

4.3. *Soil quality*

Potato cultivation within a crop rotation link had various effects on soil C_{org} and N_{tot} depending on the farming systems (Table 8). C_{org} decreased in the conventional farming system with the highest amount of mineral fertilisers used due to the high amount of mineral N, which may cause extensive soil organic matter mineralisation and, therefore, a decrease in C_{org}. N_{tot} decreased in

Table 8
Soil pH, organic carbon (C_{org}) concentration and total nitrogen (N_{tot}) concentration before and after potato planting.

Farming system	pH				C_{org} (%)				N_{tot} (%)			
	Before potato											
	2009	2010	2011	Average	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC	6.0^{A1}	5.9^{A}	5.9^{AB}	5.9^{AB}	1.41^{AB}	1.46^{B}	1.46^{B}	1.44^{C}	0.13^{A}	0.13^{AB}	0.16^{B}	0.14^{BC}
Organic CC + M	6.1^{A}	6.0^{A}	6.2^{B}	6.1^{B}	1.44^{B}	1.43^{AB}	1.36^{AB}	1.41^{BC}	0.14^{A}	0.15^{B}	0.15^{AB}	0.14^{C}
$N_0P_0K_0$	5.9^{A}	6.0^{A}	5.8^{AB}	5.9^{AB}	1.40^{AB}	1.22^{AB}	1.09^{A}	1.24^{A}	0.13^{A}	0.12^{A}	0.14^{A}	0.13^{AB}
$N_{50}P_{25}K_{95}$	6.1^{A}	5.8^{A}	5.6^{A}	5.8^{AB}	1.19^{A}	1.17^{A}	1.39^{B}	1.25^{A}	0.13^{A}	0.13^{AB}	0.14^{A}	0.13^{AB}
$N_{100}P_{25}K_{95}$	6.0^{A}	5.7^{A}	5.7^{A}	5.8^{A}	1.18^{A}	1.30^{AB}	1.37^{AB}	1.28^{AB}	0.12^{A}	0.13^{AB}	0.14^{A}	0.13^{A}
$N_{150}P_{25}K_{95}$	5.9^{A}	5.7^{A}	5.6^{A}	5.7^{A}	1.48^{B}	1.34^{AB}	1.40^{B}	1.41^{BC}	0.13^{A}	0.13^{AB}	0.14^{A}	0.13^{ABC}
	Year after potato											
	2010	2011	2012	Average	2010	2011	2012	Average	2010	2011	2012	Average
Organic CC	6.0^{A}	6.0^{A}	5.9^{A}	6.0^{BC}	1.42^{AB}	1.31^{AB*}	1.60^{BC*}	1.45^{BC}	0.12^{AB*}	0.15^{B*}	0.15^{C*}	0.14^{CD}
Organic CC + M	6.0^{A}	6.2^{A*2}	6.4^{B*}	6.2^{C}	1.52^{B*}	1.40^{B}	1.69^{C*}	1.54^{C*}	0.15^{B*}	0.14^{AB*}	0.14^{C}	0.14^{D}
$N_0P_0K_0$	5.9^{A}	5.9^{A}	5.8^{A}	5.8^{AB}	1.17^{A*}	1.04^{A*}	1.24^{A*}	1.15^{A}	0.12^{A*}	0.12^{A}	0.12^{A*}	0.12^{A*}
$N_{50}P_{25}K_{95}$	5.9^{A}	5.8^{A}	5.5^{A}	5.7^{AB}	1.24^{AB}	1.29^{AB}	1.34^{AB}	1.29^{AB}	0.13^{AB}	0.12^{A*}	0.13^{AB*}	0.13^{AB*}
$N_{100}P_{25}K_{95}$	5.9^{A}	5.6^{A}	5.5^{A*}	5.6^{A*}	1.42^{AB*}	1.37^{B}	1.38^{AB}	1.39^{BC*}	0.14^{AB*}	0.13^{AB}	0.13^{AB*}	0.13^{ABC}
$N_{150}P_{25}K_{95}$	5.7^{A}	5.6^{A}	5.5^{A}	5.6^{A}	1.40^{AB*}	1.22^{AB*}	1.40^{AB}	1.34^{B*}	0.13^{AB}	0.13^{AB}	0.14^{BC}	0.13^{BCD}

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[2] Means followed by a * indicate significant difference ($P < 0.05$) between values before and after potato.

the conventional farming system without mineral fertilisers and in the system in which a low amount of mineral fertilisers was used because the input of organic matter into soil was significantly less than the soil organic matter mineralisation. The C_{org} concentration in the $N_0P_0K_0$ farming system decreased after 2009 and 2010 but increased after 2011 because the soil organic matter input was higher compared to previous years (unpublished data) and the weather was unfavourable for organic matter decomposition. After potato cultivation in this study, C_{org} and N_{tot} were higher in the organic farming systems in which catch crops were used and in the conventional farming system in which the used nitrogen amount was 100 kg ha^{-1}. The amount of C input into soil and the content of C_{org} in soil are positively correlated (Parton et al., 1995; Karlen and Cambardella, 1996). Generally, the input of organic matter into the soil was greater in the conventional farming systems with mineral fertilisers than in the organic farming systems. In the organic systems, the soil C_{org} increased because the soil decomposition of ploughed catch crops and nutrient mineralisation during potato growth were inhibited, which was confirmed by the lower potato yield in the organic farming system in which only catch crops were used, thereby resulting in accumulation of C_{org} in the soil. The use of manure further increased the soil C_{org}. In the conventional $N_{average}$ system, the soil C_{org} increased because the soil organic matter input amount exceeded the amount of organic matter decomposition. In the N_{high} system, the soil organic matter input amount was similar to the amount of the $N_{average}$ system, but the higher amount of nitrogen added favoured the soil organic matter mineralisation, thereby resulting in a decrease of soil C_{org} instead of an increase.

The soil pH ranged between 5.7 and 6.1 before potato cultivation and between 5.6 and 6.2 after potato cultivation (Table 8). Potato cultivation had some effect on soil pH values, but the changes were not major enough to cause problems with soil pH. Some significant differences between farming systems were visible after potato cultivation. In the organic systems, the pH was significantly higher compared to the conventional systems in which average and high amounts of nitrogen fertilisers were used. The lower pH in conventional systems was due to the use of ammonium saltpetre (34.4% N) several times during the growing period to provide extra nitrogen for plants. Catch crops and manure may increase soil pH, and the soil pH increase with manure can be attributed to cattle diets (Eghball, 1999). In this study, there were no problems with soil pH concentrations, but soils in the conventional systems might become more acidic and soils in organic systems might become more alkaline if the same trend continues.

The average plant available P concentrations after potato cultivation were 103–125 mg kg^{-1} (Table 9). Potato cultivation within a crop rotation in the different farming systems mainly increased available P concentrations in the soil, except in the organic farming system lacking manure usage in which a non-significant decrease in soil P was measured. Previous studies have confirmed that the use of manure (Mozaffari and Sims, 1994) and fertilisers (Motavalli and Miles, 2002) increases soil P pools and that the P from animal manure can be as available as that supplied by mineral fertilisers (Gale et al., 2000). If the soil P pools are in good condition and there is enough P provided with fertilisers or the system inner P cycle is functioning, then potato cultivation may even increase the P concentration in soil for the following crops because it uses less P than provided as shown by the present study.

Potato cultivation greatly influences soil K pools. In this study, the average soil K concentrations before and after potato cultivation were 161–188 and 138–170 mg kg^{-1}, respectively (Table 9), which suggested that potato cultivation within a crop rotation removed high amounts of K from the soil under all farming systems. On average, significant differences between farming systems were visible after potato cultivation. The K concentrations of the Organic CC, control, $N_{average}$ and N_{high} systems were significantly lower compared to that of the other systems. The concentration of soil K required for optimal growth is much greater for potato than for many other crops. Thus, potato production needs excessive quantities of K, which in most soils is 170–210 kg K ha^{-1} (White et al., 2007). This high amount of K can only be provided with K fertilisers or with very large quantities of manure. Therefore, in organic farming systems where manure deficiency is a problem, the soils become successively poorer in K after potato cultivation. There are no consistent recommendations for critical levels of soil K for crop production as different studies have recommended different ranges. Thus, the average soil K concentrations in specific regions should be taken into consideration. Furthermore, the soil K is more mobile than soil P, for example, and unavoidable leaching losses for K are high (Vos, 1996) and must be taken into account.

Due to the lack of additional Ca and Mg fertilisers, the Mg and Ca concentrations mainly decreased after potato cultivation because potato assimilated these elements from the soil resources leading to their reduction in time (Table 9). A statistically significant decrease was only measured in Mg concentrations when potato was grown under the control system and under the system in which the highest amount of nitrogen fertiliser was used. There were no clear soil Ca differences between farming systems, on average, before or after potato cultivation. However, a small non-significant increase was

Table 9
Plant available phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) concentrations in soil before and after potato planting.

Farming system	P (mg kg^{-1})				K (mg kg^{-1})				Ca (mg kg^{-1})				Mg (mg kg^{-1})			
	Before potato															
	2009	2010	2011	Average	2009	2010	2011	Average	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC	112^{A1}	103^{A}	115^{A}	110^{AB}	177^{AB}	139^{A}	170^{A}	162^{A}	1045^{A}	1377^{A}	1133^{A}	1185^{A}	156^{A}	143^{A}	123^{A}	141^{A}
Organic CC + M	105^{A}	92^{A}	112^{A}	103^{AB}	200^{C}	167^{B}	170^{A}	179^{AB}	1071^{A}	1452^{A}	1197^{A}	1240^{A}	203^{A}	161^{A}	170^{A}	178^{B}
$N_0P_0K_0$	100^{A}	119^{A}	125^{A}	114^{AB}	164^{A}	146^{AB}	173^{A}	161^{A}	921^{A}	1156^{A}	1111^{A}	1063^{A}	168^{A}	128^{A}	136^{A}	144^{AB}
$N_{50}P_{25}K_{95}$	108^{A}	121^{A}	133^{A}	121^{B}	177^{AB}	171^{B}	215^{B}	188^{B}	1091^{A}	1310^{A}	1099^{A}	1167^{A}	195^{A}	147^{A}	142^{A}	161^{AB}
$N_{100}P_{25}K_{95}$	106^{A}	121^{A}	120^{A}	115^{AB}	175^{AB}	167^{B}	207^{AB}	183^{B}	907^{A}	1248^{A}	1066^{A}	1074^{A}	149^{A}	147^{A}	143^{A}	146^{AB}
$N_{150}P_{25}K_{95}$	95^{A}	97^{A}	109^{A}	100^{A}	189^{BC}	165^{AB}	177^{AB}	177^{AB}	956^{A}	1185^{A}	1025^{A}	1055^{A}	156^{A}	121^{A}	121^{A}	133^{A}
	Year after potato															
	2010	2011	2012	Average	2010	2011	2012	Average	2010	2011	2012	Average	2010	2011	2012	Average
Organic CC	104^{A}	118^{A}	91^{A*2}	104^{A}	141^{A}	137^{A}	135^{A*}	138^{A*}	1493^{A*}	1121^{A*}	1003^{B}	1206^{A}	146^{A}	119^{A}	121^{A*}	129^{AB}
Organic CC + M	109^{A}	119^{A}	123^{B}	117^{AB*}	155^{AB*}	166^{BC}	181^{B}	167^{B}	1425^{A*}	1233^{A*}	1090^{B}	1249^{A}	170^{A*}	179^{A*}	189^{B*}	179^{B}
$N_0P_0K_0$	133^{A}	130^{A*}	112^{AB*}	125^{B*}	152^{AB*}	155^{ABC}	129^{A*}	146^{A*}	1116^{A*}	1127^{A}	810^{A*}	1017^{A}	131^{A}	138^{A}	103^{A*}	124^{AB*}
$N_{50}P_{25}K_{95}$	128^{A}	133^{A*}	115^{AB*}	125^{B}	176^{B}	177^{C}	157^{AB*}	170^{B}	1445^{A*}	1106^{A*}	774^{A*}	1108^{A}	162^{A}	132^{A}	99^{A*}	131^{AB}
$N_{100}P_{25}K_{95}$	132^{A}	125^{A*}	111^{AB*}	123^{AB*}	171^{B}	171^{BC}	155^{AB*}	166^{B*}	1327^{A*}	1098^{A*}	732^{A*}	1052^{A}	161^{A}	156^{A}	100^{A*}	139^{AB}
$N_{150}P_{25}K_{95}$	107^{A}	110^{A}	93^{A*}	103^{A}	156^{AB*}	145^{AB*}	134^{A*}	145^{A*}	1234^{A*}	1022^{A*}	854^{A}	1037^{A}	123^{A*}	116^{A}	108^{A*}	116^{A*}

[1] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[2] Means followed by a * indicate significant difference ($P < 0.05$) between values before and after potato.

observed in soil Ca concentrations after potato production in the organic systems, which was most likely due to the use of catch crops. Catch crops used in organic systems helped to decrease Ca losses from the soil during the autumn–winter period and even promoted plant available Ca mineralisation from soil minerals. White and Broadley (2003, 2009) considered that most agricultural soils have adequate amounts of Mg and Ca in the soil solution to ensure that the plant gets enough of these nutrients. Similarly, Gunter and Palta (2008) considered amounts of Ca in soil to be sufficient. However, soil resources are not endless. Therefore, preventative measurements, such as catch cropping and additional fertilisation, must be used to maintain soil quality.

5. Conclusion

Farming systems under the same crop rotation affect tuber and soil quality parameters differently. The conventional systems in which nitrogen fertilisers were used gave significantly higher fresh tuber yields. In contrast to some studies that surveyed the years separately, our study indicated that as an average of three years, the yield differences between conventional and organic systems had non-significant effects on tuber K, Ca, dry matter and starch concentrations, thereby indicating that yield increases through different agronomic practices may have non-significant effects on some mineral elements in tubers. In our study, differences between organic and conventional systems under the same crop rotation were found only on tuber fresh yield as well as N, nitrate, Mg and P concentrations. Therefore, there were some differences among the systems, but the systems did not differ completely. Importantly, all quality parameters are somehow related to each other. Deficiency or abundance of some parameters may affect others. Therefore, when growing potatoes, their future use should be considered.

The potato crop requires many nutrients, so attention should be paid to soil quality because nutrients are removed from the field with tuber harvest. If insufficient nutrients are provided, plants will take them from the soil resources. Therefore, soil may become deficient in nutrients over time. In some cases, plants may overuse nutrients even if there are enough nutrients provided, which may also lead to soil exhaustion. In this study, some significant changes occurred after potato cultivation. The most soil exhausting systems under potato production were the control and N_{high} systems. The Organic CC + M and $N_{average}$ systems were statistically most effective to build up soil quality. The soil C_{org} and P concentrations mainly significantly or non-significantly increased after potato cultivation, and the soil K, Ca and Mg concentrations mainly decreased after potato cultivation. Soils in organic systems with no added fertilisers are especially at risk of nutrient deficiencies. Soils in conventional systems are also in danger even if mineral fertilisers are used. Many conventional systems do not use cropping systems, catch crops, leguminous plants or green manures, and the fertiliser amounts are too low to supply the needs of the plants and soil. Despite the fact that the investigated years were under the first rotation, changes in soil quality already occurred, and potato cultivation as a rotation link had an impact on soil quality under different farming systems. It can be concluded that potato is generally suitable for crop rotation as a rotation link if additional fertilisers are used, but there is still a high risk of soil exhaustion if other agronomic practices are poorly executed or insufficient.

Therefore, the key element for sustainable potato production is fertilisation together with an appropriate crop rotation. Because only the results from the first rotation of three years were investigated in this study, it would be valuable to further study how potato cultivation affects soil quality over a longer period and if the same trends remain visible after several rotations.

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Appendix A. Supplementary data

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II

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Cultivation technology influences the occurrence of potato early blight (*Alternaria solani*) in an organic farming system

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Abstract

Nowadays, organically produced products have become more popular than ever and interest in them is still growing fast. The early blight causal pathogen *Alternaria solani* has not been considered a great threat to potato in northern climate conditions in the past and has not been routinely sprayed against. During our study early blight was evaluated in 2010 and 2011 on the plants of a potato cultivar 'Reet' in an organic farming experiment. In our study, both growing seasons were very favourable for early blight development. Significant differences between the two cultivation technologies were found ($F_{1,12} = 4.84$, $p = 0.048$). In 2010, the area under disease progress curve (AUDPC) value was 303 on cover crop (CC) plots and 990 on CC + M (manure) plots that is three times higher, whereas in 2011, the AUDPC value was 967 on CC plots and 1195 on CC + M plots. Our results confirm that potato early blight has become a serious problem in North-East European organic potato fields and thus susceptible potato cultivars cannot be recommended for growing in an organic farming system. However, it is possible to influence the development severity of early blight by selecting the proper growing technology. Since, in the changing climate conditions and in susceptible cultivars, early blight is a potato disease that can cause early defoliation of plants and crop death, there is a need for resistant potato cultivars.

Key words: *Alternaria solani*, disease severity, organic growing system.

Introduction

Potato early blight, caused by the pathogens *Alternaria solani* (Ellis and G. Martin) L.R. Jones and Grout and *A. alternata* (Fr.) Keissl., is one of the most destructive fungal foliar diseases in many potato growing regions (Shtienberg et al., 1990; Leiminger, Hausladen, 2012). In susceptible cultivars, it leads to early defoliation and death of the crop (Pelletier, Fry, 1989). The disease occurs particularly in regions with high temperature and alternating periods of dry weather and high humidity and/or in irrigated potato soils that are light-textured, sandy, and low in organic matter (Gudmestad, Pasche, 2007). By contrast, potato late blight (*Phytophthora infestans*) is the most destructive potato disease in North-East European conditions due to its diverse populations (Runno-Paurson et al., 2010; 2011; 2012; 2014); it is quite difficult to control and needs numerous and consistent applications of fungicides for effective control as in other temperate regions (Cooke et al., 2011; Runno-Paurson et al., 2013).

However, occasionally *Alternaria solani* does cause a severe incidence of early blight in potatoes in the Nordic/Baltic region and application of fungicides is necessary to control it (Salonen et al., 2001). In recent years, early blight has occurred with increasing frequency in potato fields in northern regions, especially on fields with susceptible potato cultivars and damage has been more serious than before due to changed climate conditions (Kocmánková et al., 2010). Moreover, Jönsson et al. (2013) predict further increase in warmer summers, which could cause greater problems from this pathogen in northern regions. In Latvia, Treikale et al. (2008) have reported increased potato early blight damage in recent years on potatoes grown as a monoculture with a high level of nitrogen. Based on disease frequency monitoring, early blight has become more important as a pathogen in recent years in Germany and in Poland (Latorse et al., 2010). Epidemics caused by *Alternaria* species can cause significant economic damage to potato production if not sufficiently chemically controlled (Kapsa, Osowski, 2004; Leiminger, Hausladen, 2012). For organic potato producers the main challenge is disease management, which is limited by regulations that prohibit the use of synthetic pesticides (EU-regulation 2092/91). Thus, early blight represents a risk to crop production and results in significant yield losses (Rotem, 1994). In conventional cultivation in a warm and dry growing season, early blight susceptible cultivars need to be sprayed against the pathogen; otherwise haulms can be destroyed too early in the growing season (Kapsa, Osowski, 2004; Treikale et al., 2008). Growing more resistant cultivars of potato is considered the most efficient, cost-effective and environmentally-friendly control method for both conventional and organic growing systems. However, growing early blight resistant cultivars is not widespread (Dita Rodriguez et al., 2006). The locally bred potato cultivar 'Reet' was described by breeders Tsahkna and Tähtjärv (2008) as quite late, blight resistant and medium ripening with potential to form tubers early, and therefore is suitable for growing in an organic farming system. Also the cultivar 'Reet' has good quality characteristics like shallow eyes, regular shape and no darkening which are important for food market requirements and processing factories, all very important qualities for marketing (Tsahkna, Tähtjärv, 2008).

In the organic cultivation system, different alternative fertilizers and cultivation technologies including cattle manure and green manure are used to maintain and enhance soil fertility. Studies have shown that winter oilseed rape as a cover crop has the ability to suppress some soil borne diseases of potato (Larkin et al., 2010). Therefore, the main aim of this research was to test how different organic cultivation technologies influence early blight development in disease-favourable conditions. A further aim was to test the suitability of a locally bred quite late blight resistant cultivar recommended for growing in an organic farming system.

Materials and methods

Field experiment. Early blight (*Alternaria solani*) was evaluated in 2010 and 2011 on the plants of a potato cultivar 'Reet' in an organic farming experiment of the Department of Field Crops and Grassland Husbandry, Estonian University of Life Sciences located at Eerika (58°22′ N, 26°40′ E), near Tartu. The potato trial is part of a 5-year crop rotation experiment with red clover, winter wheat, peas, potato and barley following each other. The rotation experiment was started in 2008. Different field operations and their timing are shown in Table 1.

Table 1. Different field operations and their timing

Field operation	Experimental year 2010	Experimental year 2011
Cultivar	'Reet'	'Reet'
Planting date	6 May	12 May
Planting rate	3 t ha^{-1} 57 000 tubers ha^{-1}	3 t ha^{-1} 57 000 tubers ha^{-1}
Harvest date	30 August	24 August
Fertilization	winter cover crop + composted cattle manure – 20 April 40 t ha^{-1} composted cattle manure	winter cover crop + composted cattle manure – 27 April 40 t ha^{-1} composted cattle manure

Year 2010 was the third year for conversion to organic with 2011 the first fully organic year. Winter oilseed rape was used as a winter cover crop before the potato. The experiment was carried out in two different organic growing systems (treatments). In both, a winter cover crop (CC) for green manure (winter oilseed rape) was used; it was planted in both years in September and ploughed down in April the following year. No cattle manure was added to treatment CC, whereas composted cattle manure (M) was added to the second treatment CC + M (Table 1). There were four replicates of each treatment. The size of each test plot was 60 m^2. The distance between seed tubers was 27 cm and the distance between rows was 70 cm. In both years only certified seed potatoes were used. Seed tubers with a diameter of 35−55 mm were used. No fungicides, herbicides or insecticides were applied. The soil was *Stagnic Luvisol* (*LVj*) by WRB 2006 classification (FAO, 2006), the texture of which is sandy loam with a humus layer of 20–30 cm. No irrigation was used.

Weather conditions. In 2010, spring/summer temperature records (Eerika Weather Station) were similar to the long-term (20-year) average, except in July which was hotter by 4.2°C (Table 2). Rainfall in 2010, was similar to the long-term average in June and August, but, in July, was lower with only 36 mm (20-year average is 69.3 mm). In 2011, May, August and September temperature records were similar to the long-term average, but June was hotter by 1.9°C and July by 2.4°C (Table 2). Rainfall was much lower than the long-term average in June, July and August but in the first ten-day period of September more than the long-term average. In July, the warm (with temperatures over 30°C for more than 10 days) and humid conditions were conducive to early blight infection in the third ten-day period of July.

Early blight assessment. Disease assessments were made from 23 July to 27 August in 2010 (6 observations), and from 29 July to 2 September in 2011 (6 observations). Foliar disease was evaluated in natural infection conditions as a percentage of total foliage once each week, until harvesting. In each of the replications, 25 plants per plot were assessed. Early blight infection was assessed according to the 0−100% scale (Granovsky, Peterson, 1954). The area under the disease progress curve (AUDPC) was calculated from the date of first occurrence of early blight until the last observation of the disease in the trial according to Shaner and Finney (1977) by using the following formula: $\Sigma_i < n\ [(Ri +1 + Ri)/2)]\ (t_{i+1} - t_i)$, where R_i is the disease severity (percentage leaf surface blighted) at the *i*ths observation, t_i – the time in days since the previous rating at the *i*ths observation, and *n* – the total number of observations. The early blight tuber assessment was made three months after harvest. From each replication, 100 tubers were randomly selected to characterize the total yield. A few days before the assessment the tubers were washed in order to see the lesions better.

Data analysis. Statistical analyses were performed with the programme *Statistica 11* (StatSoft Inc., Tulsa, USA). The differences in the severity percentage of early blight between treatments were tested with one-way *ANOVA*. Kruskal-Wallis *ANOVA* was used to determine the effects of year and cultivation technology on the early blight tuber infection as the data were not normally distributed. The dependence of AUDPC value and marketable yield of tubers on year and cultivation technology was analysed with type III *ANOVA*. Both factors such as "year" and "cultivation technology" were treated as fixed categorical variables. Tukey HSD post-hoc tests (α = 0.05) were applied to find specific differences between years and cultivation technologies. Interactions between variables were also tested for.

Table 2. Average monthly temperatures and rainfall at Eerika during the vegetation periods of 2010 and 2011 together with long-term averages (according to Eerika Weather Station, Estonia)

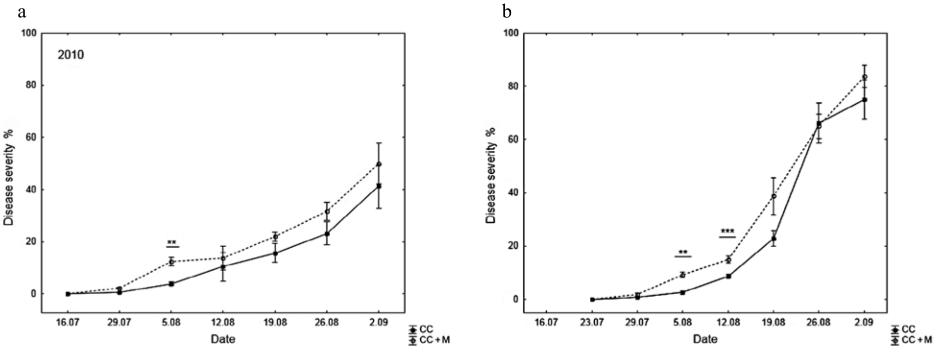
Month	Ten-day period	Temperature °C			Rainfall mm		
		Average of 2010	Average of 2011	Average of 1969–2011	Sum of 2010	Sum of 2011	Average sum of 1969–2011
May	I	7.3	8.0	9.7	39.2	0.2	12.9
	II	16.7	11.8	11.4	44.6	46.6	20.9
	III	12.4	13.0	12.8	13.6	11.6	22.8
June	I	13.3	19.7	14.9	41.4	0.0	20.9
	II	13.6	15.9	15.1	17.8	24.8	26.9
	III	15.9	16.2	16,2	38.8	10.4	28.0
July	I	19.9	20.0	17.3	11.6	9.2	19.3
	II	22.9	18.6	17.4	3.0	30.4	24.8
	III	22.4	21.0	17,8	23.8	8.6	26.5
August	I	20.9	16.1	17.6	18.2	16.2	33.3
	II	19.1	15.6	16.2	74.6	17.0	28.5
	III	13.7	15.8	14.6	55.6	21.4	28.0
September	I	10.4	13.0	12.7	32.6	32.2	20.3
	II	12.1	12.2	10.6	46.4	28.4	18.3
May–September	I–III	15.8	14.8	14.6	461.2	257.0	331.5

Results

Development of foliar early blight. In both years, early blight was the primary foliar disease on the trial plots. Infection by potato late blight was not recorded in either year. Both growing seasons were very favourable for early blight development and evaluation, with weather conditions even more favourable in 2011 than in 2010. In 2010, the first early blight symptoms were recorded on 23 July, with both treatments infected (Fig. 1 a). The disease-conducive conditions allowed rapid establishment and progression of the disease from the time the first symptoms had been recorded. Winter cover crop (CC) plots had significantly slower progression at the beginning of disease development than the CC + M (manure) plots (29 July, $p = 0.003$; 5 August, $p = 0.66$) (Fig. 1 a) and the disease developed more slowly on the CC plots than on the CC + M plots ($F_{5,18} = 54.70$, $p < 0.0001$, Tukey HSD test $p < 0.05$). By the end of growing season, 50% of foliage was destroyed by early blight on the CC + M plots and 40% on the CC plots. In 2011, the first early blight symptoms were found on 29 July with both CC and CC + M plots infected (Fig. 1 b). Disease developed moderately until 12 August and thereafter increased abruptly (Fig. 1 b). At the beginning of the observation period, early blight developed significantly more rapidly on the CC + M than on the CC plots. On 26 August, both treatments were similarly infected, but later again the CC treatment developed more slowly than the CC + M (Fig. 1 b). On the CC + M plots more than 80% of the foliage was destroyed by 2 September (Fig. 1 b). Disease severity in the CC + M plots increased from less than 2% at the start to more than 83% within five weeks.

The early blight tuber infection. Infection of tubers by early blight was found in both years. In both 2010 and 2011, it was higher on the CC + M plots than on the CC plots, although not statistically so (H(1, N = 16) = 0.631, $p = 0.427$) (Table 3). Data also showed differences between years; tuber infection was higher in 2011 than in 2010, but not statistically significant (H(1, N = 16) = 2.527, $p = 0.112$).

Resistance evaluation using area under the disease progress curve (AUDPC). Both growing years were very favourable for early blight foliar resistance



* – $p < 0.05$, ** – $p < 0.01$ (*ANOVA*)

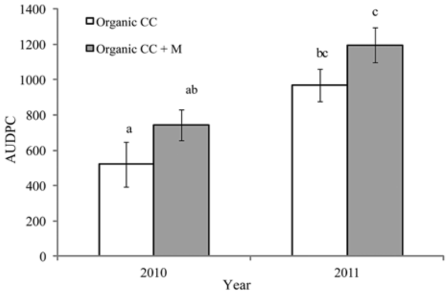
Figure 1. Development of potato early blight on organic plots with previous cover crops (CC) or with cover crops and added cattle manure (CC + M) in 2010 (a) and 2011 (b)

Table 3. Results of the early blight tuber infection (%)

Treatments	Year	
	2010	2011
Organic CC	0.25 a	1 a
Organic CC + M	0.5 a	1.75 a

Note. a – statistically significant differences between treatments not found; CC – winter cover crop, CC + M – winter cover crop + composted cattle manure.

evaluations; still early blight pressure was different in 2010 and 2011. Significant differences were found in AUDPC values between the two years ($F_{1,12}$ = 19.29, $p < 0.001$) (Fig. 2). In both years, AUDPC values were very high; the mean AUDPC in 2010 was 632 and, in 2011, even higher – 1081 (Fig. 2). Significant differences between the two cultivation technologies were found ($F_{1,12}$ = 4.84, p = 0.048). In 2010, the AUDPC value was 303 on CC plots and 990 on CC + M plots, that is three times higher (Fig. 2), whereas in 2011, the AUDPC value was 967 on CC plots 1195 on CC + M plots (Fig. 1). There was no interaction between cultivation technology and year ($F_{1,12}$ = 0.0008, p = 0.978).



Notes. The boxes indicate the mean value and whiskers the standard error of the mean. Different letters above the boxes indicate statistically significant differences among treatments (*ANOVA*, Tukey HSD test). Potatoes were grown on plots following a cover crop (CC) of winter oilseed rape and with (CC + M) or without added cattle manure.

Figure 2. Mean area under the disease progress curve (AUDPC) values of foliar early blight in organic potato field trials in 2010–2011

Early blight effect on potato tuber yield. There were significant differences in marketable tuber yield between years ($F_{1,12}$ = 16.33, p = 0.0016) and treatments ($F_{1,12}$ = 8.39, p = 0.013) (Fig. 3). In 2010, marketable tuber yield was approximately 9 t ha^{-1} lower than in 2011 (Fig. 3), although there were no differences in marketable yield between treatments. In 2011, marketable tuber yield was 8 t ha^{-1} higher on CC + M plots than on CC plots.

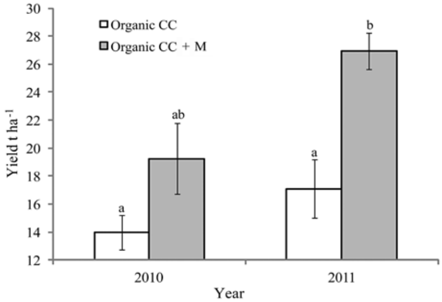


Figure 3. Marketable potato tuber yields in 2010 and 2011 from organically farmed plots with a previous cover crop (CC), winter oilseed rape, some with and without added cattle manure (M)

Discussion

This study indicates that potato early blight is a great problem for potato growing in an organic farming system, and especially so in years with higher than average temperature. In both our study years, the severe early blight infection caused defoliation, especially in 2011 on the plots with added cattle manure CC + M, where more than 80% of foliage was killed. The direct cause of this was probably the extremely low rainfall in May, June and July in 2011 compared to the long-term average. Drought influences the normal functioning of potato plants; stressed plants are more susceptible to early blight. The early blight pathogens are typical examples of a necrotrophic organism, where a pathogen infects weaker and older plants (Rotem, 1994). The same trend of a recent increase in damage by potato early blight has been reported from other European countries, including some where potato early blight has been problematic for some time, for instance in south-eastern Sweden (Blixt, Andersson, 2010) and in Germany (Leiminger et al., 2010). In Poland, regional losses of up to 45% have been found, mostly associated with cultivars with recognized susceptibility to early blight (Kapsa, Osowski, 2004), and Kapsa and Osowski (2011) have reported a recent increase in the importance of the disease.

In our two year study, the CC + M plots gave higher potato yields than the CC plots despite having more of their foliage destroyed by early blight disease. These results seem quite contrary to the findings in the literature. Early canopy defoliation reduces assimilate accumulation in the tubers (Rotem, 1994) resulting in yield loss (Shtienberg et al., 1990). James et al. (1972) have stated that the tuber-filling process paralyzes when defoliation reaches over 75%. Researchers Campo Arana et al. (2007) have observed even more serious consequences of early blight damage, where, at 50% to 100% defoliation, yield loss was about 55%. Both our cultivation systems had significant differences in AUDPC value, with both levels quite high. Therefore, early blight defoliation apparently did not have as great an effect on marketable yield as fertilization with cattle manure. On the other hand, CC + M plots had a more nutritious soil due to the cattle manure, supplying nutrients earlier and enabling higher tuber yields.

The lower crop yields we obtained in 2010 are quite hard to explain, because disease pressure was lower and overall humidity conditions were more favourable in 2010 than in 2011. Still, after potato plants emerged in June in 2011, it was 3°C warmer than in 2010. Also, in July 2010, there were several days with an air temperature above 28°C. Temperature is a major factor regulating biomass accumulation and tuber development in potatoes. Cao and Tibbitts (1994) have indicated that tuber development of potatoes is optimized by high temperature during early growth and low temperature during later growth.

AUDPC values were lower on our CC plots than on CC + M plots, even though the former were less fertilized. There is less information available about early blight damage on potato and its relation to obtaining nutrients in an organic growing system. For comparison, in conventional potato growing increased rates of nitrogen fertilizer application reduce the apparent infection rate and the final amount of early blight disease (MacKenzie, 1981). Also, Christ and Haynes (2001) showed that application of more fertilizer and low rainfall in the early part of the season prevented an early blight epidemic. An initial result of our research indicated that manure inhibits the suppressive effect of winter oilseed rape. We could only hypothesize that the suppressive cover crop effect of winter oilseed rape appeared clearer on the treatment without cattle manure.

Genetic resistance of cultivars to pathogens is a major factor for consideration where there is severe pressure from the early blight pathogen (Kapsa, Osowski, 2011). Even the late blight resistant potato cultivar 'Reet' is recommended by breeders for economical cultivation (Tsahkna, Tähtjärv, 2008), although our experience has shown that, in a dry and hot growing season, conditions are favourable for a very severe early blight infection that destroys most of the foliage. The early blight damage evaluation showed that foliage was notably less destroyed by disease in CC plots than in the CC + M plots. As our results have indicated, it is possible to influence the development severity of early blight by selection of growing technology, although further work is necessary. As early blight is not the main foliar disease of potato in Estonia, the extraordinarily heavy early blight infection was not expected. A very severe outbreak of early blight occurred in the organic plots and destroyed most of the canopy. Therefore, from the experience of this two-year trial we can state, that besides the threat from potato late blight, potato early blight can also cause serious infection in Estonia and thus, early blight susceptible potato cultivars cannot be recommended for an organic farming system. From our results, we conclude that for environmentally-friendly farming early blight resistant potato cultivars should be grown in both organic and conventional growing systems. In an organic farming system, chemical control is not allowed and, in conventional systems, the disease requires the application of expensive fungicides.

In changed warmer climatic conditions, new pathogens will give rise to new problems in the future (Jönsson et al., 2013). Our results confirm that potato early blight has already become a more serious problem for North-East European organic potato growers. In the future, we need to investigate what is behind the more serious early blight infections: warmer summers (the global climate change), more susceptible cultivars or even changes in pathogen epidemiology?

Conclusions

1. Potato early blight is a grave problem for potato growing in an organic farming system, and especially in years with higher than average temperatures.

2. In both our study years, early blight infection was more severe in the plots with added cattle manure (CC + M) than in the cover crop (CC) plots.

3. The development severity of early blight can be influenced by selecting appropriate growing technology, but more research on this is needed.

4. In the changed climatic conditions, early blight can cause early defoliation of plants and crop death in susceptible cultivars, indicating the need for resistant potato cultivars.

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Auginimo technologijos įtaka bulvių sausligės (*Alternaria solani*) plitimui ekologinėje žemdirbystės sistemoje

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Santrauka

Pastaruoju metu ekologiški produktai tapo itin populiarūs, ir susidomėjimas jais vis didėja. Bulvių sausligės sukėlėjas *Alternaria solani* anksčiau nebuvo laikomas itin grėsmingu bulvėms šiaurinio klimato sąlygomis, todėl nuo šios ligos bulvės nebuvo reguliariai purškiamos. Tyrimo metu bulvių sausligė vertinta 2010 ir 2011 m., vykdant ekologinės žemdirbystės bandymą su veislės 'Reet' bulvėmis. Abiem tyrimų metais bulvių vegetacijos laikotarpis buvo labai palankus bulvių sausligės vystymuisi. Tarp dviejų auginimo technologijų nustatyti esminiai skirtumai ($F_{1,12}$ = 4,84, p = 0,048). 2010 m. ligos pažeistų lapų ploto indeksas (AUDPC) buvo 303 antsėlinių augalų laukeliuose ir 990 antsėlinių augalų bei mėšlo laukeliuose, t. y. tris kartus didesnis. 2011 m. AUDPC indeksas buvo 967 antsėlinių augalų laukeliuose ir 1195 antsėlinių augalų bei mėšlo laukeliuose. Tyrimo rezultatai patvirtina, kad sausligė tapo rimta problema Šiaurės Rytų Europoje ekologiškai auginamų bulvių laukuose, todėl ekologinės žemdirbystės sistemoje nerekomenduotina auginti sausligei jautrių veislių bulvių. Sausligės vystymosi intensyvumui gali turėti įtakos bulvių auginimo technologija. Kintančio klimato sąlygomis auginant sausligei jautrių veislių bulves, dėl šios ligos augalai anksti numeta lapus ir gali žūti, todėl yra poreikis kurti šiai ligai atsparių veislių bulves.

Reikšminiai žodžiai: *Alternaria solani*, ekologinė auginimo sistema, ligos intensyvumas.

III

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The potato tuber disease occurrence as affected by conventional and organic farming systems

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A B S T R A C T

A study was conducted which aimed to investigate the effect of farming systems (FS) (four conventional with increasing mineral N fertilizer amounts (0–150 kg of N ha^{-1}) vs. two organic with catch crops (CC) and cattle manure (CC+M)) under the same five crop rotation system on the occurrence of tuber diseases such as common scab (*Streptomyces* spp.), silver scurf (*Helminthosporium solani*), dry rot (*Fusarium* spp.), and soft rot (*Pectobacterium* spp.). As the average of the first rotation years 2009–2011, the FS had a significant effect on the occurrence of silver scurf, dry rot and common scab (surface cover <30 %). The organic systems had significantly more tubers (around 39 %) infected with common scab (surface cover 4–15 %) than in conventional systems (around 25 %). However, when the surface lesion severity increased (surface cover 16–30 %) then differences occurred only between organic systems (in system Organic CC 4.1 % and in system Organic CC+M 13.1 % of tubers infected). The Organic CC system had significantly fewer tubers infected with silver scurf compared to all conventional farming systems (10.5 % vs 17.8–23.4 %). During the first and after the second disease measurement there were less tubers infected with dry rot in Organic CC (0.8–0.9 %) and conventional N_{high} (0.5–1.4 %) systems compared to N_{low} (1.8–3.0 % of tubers infected) system. Soft rot infections were not influenced by farming systems. Thus we conclude that it is possible to influence the occurrence of some tuber diseases with FS.

Introduction

Potato (*Solanum tuberosum* L.) tuber diseases such as common scab (*Streptomyces* spp.), silver scurf (*Helminthosporium solani* (Durieu & Montagne)), dry rot (*Fusarium* spp.), and soft rot (*Pectobacterium* spp.) are a major problem in the potato industry. Common scab is a bacterial disease which affects the marketability of potato tubers (VanderZaag 2010). It causes corky-looking lesions on the tubers' surface (Lebecka et al. 2006), negatively impacting the appearance of the tubers; in severe cases, the entire surface of the tuber may be covered with scab. Silver scurf is a tuber fungal disease which causes metallic discoloration of the periderm (Secor and Gudmestad 1999). If the lesions are severe, the tubers lose water and will eventually shrink, resulting in serious loss of weight (Platt and Peters 2006). Tubers are infected already prior to the harvest, but the severity of the infection increases if the tubers are kept in storage for a prolonged period of time (Olivier et al. 1998). Dry rot (caused by *Fusarium* spp.) is a fungal potato tuber disease which enters tubers primarily through wounds caused during harvesting and transport, but infections may occur before the harvest as well as with silver scurf. The first dry rot symptoms are dark depressions on the surface of the tubers. In later stages the tubers become wrinkly, diseased tissue is brown and dry, and cavities may occur (Lui and Kushalappa, 2002). Once the tubers are already infected, the infection may spread further in storage. Soft rot (caused by *Pectobacterium* spp.) is the most severe potato disease, which can result in significant decreases in crop yields and economic losses (Czajkowski et al. 2009), as there are no efficient treatments to control the pathogen (Latour et al. 2008). Diseased tuber tissues are wet and cream to tan in color, with a soft, slightly granular consistency (Tweddell et al. 2003). The infection enters tubers through wounds caused during harvest or transport, but the bacteria can also enter tubers through natural openings (Lyon 1989). Tubers are contaminated with the bacteria prior to the harvest, but larger disease outbreaks can occur in storage as infected tuber fluids spread very easily, thus infecting nearby tubers as well.

How a particular crop is managed greatly influences disease levels as well as overall crop production (Larkin and Halloran 2014). Disease development in plants is greatly affected by plant nutrition, because nutrition affects both plant physiology and disease resistance (Dordas 2008). Plants have the highest resistance to disease when their nutritional status is at an optimal level, because nutritional status may influence the development of disease, but when it deviates from this optimum, susceptibility to disease increases (Huber et al. 2012). If there is a nutritional deficiency, then plants are weakened and thus more prone to various diseases (Czajkowski et al. 2011; Mulder and Turkensteen 2005), but over-supplying needed nutrients leads to more vigorous plant growth and therefore may reversely enhance disease susceptibility (Davies et al. 1993).

Long crop rotation is an effective tool to suppress diseases between potato crops (Peters et al. 2004). Monocropping and short rotations allow diseases and pests to develop and increase to economically damaging proportions (Firman and Allen 2007). *Brassica* crops in particular, in a rotation or as catch crops (CC), are known to have a positive effect on the reduction of soil-borne diseases (Cohen et al. 2005; Larkin and Griffin 2007), particularly fungal diseases (Sarwar et al. 1998), therefore these crops are very important in organic systems in which the use of synthetic agrochemicals for disease control is prohibited.

While there have been previous studies about the effect of crop rotation (Carter and Sanderson, 2001; Peters et al. 2003) or CC (Larkin et al. 2010; Lazarovits 2010) on tuber diseases, information about the effect of crop rotations with different plant nutrition regimes on the occurrence of these diseases is still insufficient. The tuber soil-borne diseases are the biggest unresolved problem (VanderZaag, 2010) because the current control methods of diseases are not always practical or effective and there is lack of information about the relationship between crop management and soil-borne diseases (Larkin et al. 2010). Thus, options for integrated sustainable disease-control (Larkin 2008) are needed. Previous research has focused mainly on the effects of specific crop rotations or practices, but not on integrated cropping systems that combine many aspects to increase productivity (Larkin et al. 2011). Previous research has also tended to focus on specific management systems, e.g. conventional or organic, but the two are rarely investigated together (Bernard et al. 2014; Palmer et al. 2013). Thus, this study was conducted with the aim to compare conventional and organic farming systems under the same five-crop rotation in order to identify systems that would ensure high quality tubers with low incidence of disease. This paper is part of the larger overall study in which the effects of farming systems is investigated on the other rotation crops as well as on soil health and weed populations (Alaru et al. 2014; Runno-Paurson et al. 2014; Tein et al. 2014; Kauer et al. 2015; Madsen et al. 2015; Runno-Paurson et al. 2015).

Materials and methods

Experiment description and management

In 2008, an experiment in crop rotation with four conventional and two organic farming systems was established at the Estonian University of Life Sciences, on the experimental fields in Eerika (58°22'N, 26°40'E), located near Tartu, Estonia. A more detailed description of this experiment is presented in Tein et al. (2014). There were four replications in each farming system (each plot 60 m^2). The plots were 6 meters wide by 10 meters long, with eight rows in each plot. There was an 18-meter-long buffer area of mixed grasses between the organic and the conventional plots. The organic plots were also buffered with a 10-meter-long protective area of potatoes, to avoid the spread of manure. Conventional systems and replications were placed next to each other without any separation. The soil on the experimental field is *Stagnic Luvisol* by World Reference Base classification (FAO 2006), with a sandy loam texture.

The potato was a part of the rotation link where five different crops: red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.), potato, and barley (*Hordeum vulgare* L.) undersown with red clover – followed one another in that sequence every year. The previous crops before the experiment started were cereals (barley (before experiment) and wheat (before barley)). Altogether there were 120 plots in one field: five crops, six farming systems, four replications. In both organic farming systems (Organic CC), the previous catch crop (CC) before the potato was winter oilseed rape (*Brassica napus* L. ssp. *oleifera biennis*) which was sown after the harvest of the previous main crop, the pea. The following CC after the potato harvest was winter rye (*Secale cereale* L.). After winter wheat, ryegrass (*Lolium perenne* L.) was sown as the CC. Altogether there were three CC used in the organic systems. All the catch crops were incorporated into the soil one (winter rye and ryegrass) or two (winter oilseed rape) weeks before the sowing/planting of the main crops. The CC were used to provide winter coverage as well as to avoid nutrient leaching. The second organic farming system also received composted cattle manure (Organic CC+M) with the amount of 40 t ha^{-1}, which contained an average of N_{tot} 9.7 g kg^{-1}, P_{tot} 4.6 g kg^{-1}, K_{tot} 8.6 g kg^{-1}, C_{tot} 138 g kg^{-1} and 44.8 % dry matter (DM). In 2009, the manure was added in autumn and then ploughed into the soil. Beginning in 2010, the manure was added in spring and incorporated into the soil by ploughing it in together with the previous year's CC. The years prior to 2011 were second/third year conversion to organic; beginning in 2011, the organic systems were fully converted to organic. For the sake of easier data monitoring, the term "organic" is used for all years investigated. Weeds in the organic systems were controlled by harrowing and, during later stages of potato growth, manually; no other means of plant protection were used. The four conventional farming systems differed in terms of mineral nitrogen fertilizer use. In the control system (control), no mineral nitrogen fertilizer was used. The remaining three systems differed from one another in levels of added mineral nitrogen: $N_{50}P_{25}K_{95}$ (N_{low}), $N_{100}P_{25}K_{95}$ ($N_{average}$), and $N_{150}P_{25}K_{95}$ (N_{high}). All mineral-fertilized systems received NPK fertilizers at the rate of 20:25:95 kg ha^{-1} during planting. During potato growth, one or two subsequent nitrogen supplements, as ammonium nitrate, were added: N_{low} – 30 kg ha^{-1}; $N_{average}$ – 60+20 kg ha^{-1}; and N_{high} – 90+40 kg ha^{-1}, respectively. In the conventional systems, synthetic pesticides were also used during potato growth as follows: herbicides one to two, insecticides two to three, and fungicides three to four times. The number of applications depended on necessity as evaluated during potato growth.

The potato was planted using certified whole seed tubers at the beginning of May at the rate 2.7–3.0 t ha^{-1} (52,910 tubers per hectare), and harvested in August-September. Before planting, seed tubers were pre-sprouted in a wooden box for 35–38 days in a humid, well-lit room kept at 12–15 °C. The diameter of the used seed tubers was 35–55 mm. The distance between seed tubers was 27 cm, and between rows, 70 cm. The early to medium maturing "Reet" cultivar of potato, a domestic Estonian cultivar also suitable for organic farming (Tsahkna and Tähtjärv 2008), was used for this study. The tuber harvesting procedure was similar in all the studied systems and years to ensure uniformity. The tubers were hand-picked after the rows were opened with two-row elevator-picker machine and then placed into large wooden containers that were then transported into storage room.

Before sowing the previous CC, winter oilseed rape, in organic systems, the soil was cultivated twice after pea. Winter oilseed rape was ploughed into the soil at the end of April. In conventional systems autumn ploughing was used in the end of October after the harvest of pea and potato. After the potato was harvested in organic systems, the field was cultivated twice and then the CC winter rye was sown. All other field operations with the potato followed normal cultivation practices.

Potato tuber analyses

During the years 2009–2011, different potato tuber diseases were monitored. After the potato was harvested, 100 tubers from each replication were randomly selected to characterize the marketable yield (tuber diameter over >35 mm), and were then placed into smaller wooden boxes (33×38×10 cm), with three layers of tubers in each box. The tubers were then stored in a dark room at a temperature of 4°C and with air humidity at 80–85 %. The first measurement of diseases was made three months and the second measurement seven months after harvest. During the first measurement, common scab, silver scurf, dry rot, and soft rot infections were visually determined. Common scab infections were divided into four categories based on disease severity : (0) <4 % of tuber surface infected, (1) 4–15 % of tuber surface infected, (2) 16–30 % of tuber surface infected, (3) 31–45 % of tuber surface infected, (4) >45 % of tuber surface infected (Estonian Plant Production Inspectorate 2001). The number of tubers from each category was then counted, and the disease occurrence in the marketable yield and infection severity rating (for common scab) were calculated based on the potatoes' surface infection category. The tubers which were grouped into category 0 were used only to calculate the infection severity rating. At the same time, tubers infected with silver scurf, dry rot, and soft rot were also recorded and the percentage of infected tubers was calculated. Tubers infected with soft rot were removed after first measurement to avoid further infestations from the already infected tubers to see new evolving disease lesions. For the second measurement, the same tubers were used as in the first measurement. During the second measurement, only dry and soft rot were assessed to see any further disease developments, because tuber rots are the main yield-decreasing storage diseases. To avoid the impact of human factor on the results, all disease assessments were made by the same person.

Weather conditions

Weather conditions during the potato growth period varied among the studied years (Table 1). Daily average temperatures were the highest in 2010, when the average temperature between May-September was 15.8 °C. It was 1.3 degrees warmer than the long-term average during the same time period. The potato growth period was warmer compared to the long-term average in 2011 as well in 2009, temperatures during the potato growth period were similar to the long-term average; the difference between the two was only 0.2 °C. Average temperatures in 2009 did not reach 20.0 °C. July was the warmest month across the years studied.

The potato growing season in 2010 can be described as extremely wet; precipitation exceeded the average of many years by almost 130 mm. In contrast to 2010, precipitation levels during the potato growing season in 2011 remained much lower, and the year as a whole could be described as extremely arid. In 2011, there were 75 mm less precipitation compared to the long-term average, and 204 mm less precipitation as compared to 2010. The amount of precipitation in year 2009 was relatively similar to the average of many years; there was only 10 mm less precipitation compared to long-term average. The precipitation rate during the potato growth period was very inconsistent across all years monitored.

Statistical data analysis

Data was analyzed with the statistical package *Statistica* version *11.0* (Statsoft Inc.), using factorial ANOVA (Analysis of Variance) to test the effects of different farming systems, year, and time of disease measurement on tuber diseases. The significant levels ($P < 0.05$; $P < 0.01$; $P < 0.001$) of probability were tested by ANOVA. The Least Significant Difference test for homogenous groups was used to test significant differences between farming systems, experimental year and time of measure. Unless otherwise indicated, all tests for significance were conducted at the $P < 0.05$ level.

Results

Tuber marketable yield

The three year average tuber marketable yields were significantly higher in conventional systems in which additional mineral N fertilizers were used (Table 2). In more details, the tuber marketable yields ranged between 19.2 (Organic CC) and 55.1 ($N_{150}P_{25}K_{95}$ (N_{high})) t ha^{-1} in 2009, between 14.0 (Organic CC) and 26.6 ($N_{150}P_{25}K_{95}$

(N_{high})) t ha^{-1} in 2010, and between 19.2 (Organic CC) and 43.2 ($N_{150}P_{25}K_{95}$ (N_{high})) t ha^{-1} in 2011 which can be found in Runno-Paurson et al. 2014 and 2015.

Common scab

The percentage of tubers under categories 1 and 2, and the overall common scab severity rating, were all significantly affected by the factors of year (Y), farming system (FS), and the interaction of year and farming system (Y*FS) (Table 3). The total percentage of tubers infected with common scab was influenced by the experimental year and the year's interaction with farming systems but not farming systems alone (Table 3). The tubers in category 3 were significantly influenced only by year ($P < 0.05$) and tubers under category 4 were not influenced by any of the aforementioned factors, because less than 0.5% of the tubers belonged to that category (Table 3).

Regardless of the total percentage of the tubers infected, the total common scab incidences had, on average, non-significant differences ($P > 0.05$) amongst farming systems (Table 4). However, the organic system in which the composted cattle manure was used had, on average, the highest rating of infection severity ($P < 0.05$) amongst the systems (Table 4). The total percentages of tubers infected with common scab in organic systems were significantly ($P < 0.05$) higher in 2010 and 2011 experimental years and in conventional systems in the last experimental year (Table 4). In 2010, tubers grown under organic systems had significantly more tubers infected with common scab than in conventional systems.

The average infection severity ratings were all between categories 0–1 (Table 4), which means that, on average, the infection severity ranged between 0–15 % of tuber surface infected with common scab. The use of manure together with CC caused significantly higher common scab infection severity ratings amongst the systems. In organic systems the infection severity ratings were higher ($P < 0.05$) in 2010 and 2011 compared to 2009. In conventional fertilized systems ($N_{low-high}$), the infection severity ratings were the highest ($P < 0.05$) in the last experimental year.

When the tubers were categorized based on the incidences then from all the tubers monitored, on average, 25–39 % belonged to category 1 and 4–13 % into category 2 (Table 5). Under category 1 in organic systems, there were, on average, significantly ($P < 0.05$) more tubers infected with common scab than in conventional systems. Under category 2, there were, on average, significantly more tubers infected with common scab in the organic system in which composted cattle manure was used, compared to the other organic system in which only CC were used. Under category 2, non-significant ($P > 0.05$) differences were found between organic and conventional systems. In organic systems, the last two experimental years had significantly more tubers belonging to category 1 and 2 compared to the first experimental year. In the conventional fertilized systems, there were significantly ($P < 0.05$) more tubers belonging to category 1 in 2011, but under category 2 only N_{high} system had the highest number of tubers infected with common scab in 2011. Other conventional fertilized systems had non-significant differences between years under category 2.

Silver scurf

Tubers infected with silver scurf were significantly influenced by the farming systems ($P < 0.01$) (Table 6). There was no influence ($P > 0.05$) of year and year interaction with farming systems on tubers infected with silver scurf. On average, 10.5–23.4 % of all tubers were infected with silver scurf (Table 7). In both organic systems, the percentage of tubers infected were, on average, lower ($P < 0.05$) compared to the conventional system in which the highest amount of mineral nitrogen fertilizers were used. The organic CC system had, on average, fewer ($P < 0.05$) tubers infected with silver scurf compared to conventional farming systems in which no fertilizers were used and in which average and high amount of mineral fertilizers were used.

Dry rot

Dry rot and soft rot infections were measured twice during the storage period. Tubers infected with dry rot were significantly influenced by year, farming systems, time of measurement, year interaction with the time of measurement, and farming systems interaction with the time of measurement (Table 8). During the first and the second disease measurement, there were fewer ($P < 0.05$) tubers, on average, infected with dry rot in organic CC and conventional N_{high} systems, compared to the N_{low} system (Table 9). Only three significant ($P < 0.05$) increases occurred in dry rot infections between two measurement times: in 2009 the percentage of tubers infected with dry rot increased after first measurement in conventional N_{low} (from 2.8 to 4.8 %) and N_{high} (from 0.8 to 2.5 %) systems; in 2010 the increase was significant only in N_{low} system (from 0 to 1.0 %).

Soft rot

Soft rot infections were significantly influenced by year, time of measurement, and year interaction with time of measurement ($P < 0.001$) (Table 10). On average, no significant differences ($P > 0.05$) were found between farming systems on tuber soft rot infections (Table 11). Soft rot infections occurred only in 2011 during the first disease measurement. In 2011 the soft rot infections were lower ($P < 0.05$) in conventional control, N_{low} and N_{high} systems compared to organic system in which manure was used. No new soft rot infections were found during the second disease measurement time.

Discussion

The total percentages of tubers infected with common scab were, on average, relatively low compared to other findings (Hiltunen et al. 2005), ranging between 33–55 %, since the cultivar used in our experiment is relatively scab-resistant (Tsahkna and Tähtjärv 2008). Under category 1, the incidences of common scab remained, on average, smaller in conventional systems compared to organic systems. It has been confirmed that ammonia-based fertilizers have a side effect of reducing common scab (Huber and Haneklaus 2007). Organic fertilizers such as green and animal manures have rarely been found to have a disease increasing effect, and they mainly serve to decrease the occurrence of soil-borne diseases (Conn and Lazarovits 1999; Larkin and Griffin 2007; Termorshuizen et al. 2006). This finding was not supported in this study, however, because, on the contrary to those findings, common scab occurrences under category 1 were the highest in organic systems in which organic fertilizers were used. Under category 2, the differences occurred only when comparing organic systems. The scab incidences were, on average, the highest in a system in which cattle manure was used, and in this case the use of CC in organic CC system resulted in the lowest occurrence of common scab. Previous studies (Bailey and Lazarovits 2003; Bernard et al. 2014) have also found that manure increases the incidences of common scab. One of the reasons for this proposed by Moore et al. (2011) is that manure used on the fields provides optimal conditions for common scab development by altering the soil's pH level. According to the study by Tein et al. (2014), which is based on the same exact experiment, it was found that the use of cattle manure had an increasing effect on soil pH and the use of ammonium nitrate in a $N_{average}$ system, as the source of extra nitrogen for potatoes, had a significant decreasing effect on soil pH. The same trend occurred also in other mineral fertilized systems. Therefore, when the soil's pH level decreased, then the incidences of common scab decreased (Mizuno et al 2003) (like in conventional systems that received mineral N fertilizers), but if the soil's pH increases, then incidences of common scab may also increase (Goto 1985) (as in organic system in which cattle manure was used). Thus, the use of manure may increase the incidences and severity of common scab, but the use of ammonium nitrate, as the additional source of N, may decrease the incidences and severity of common scab by altering the soil pH which was also supported by this study, because common scab favors soils with more alkaline pH (Lebecka et al. 2006). Larkin et al. (2010) have also evaluated the effects of rapeseed rotations and CC winter rye and ryegrass on soil-borne tuber diseases, and found that these crops reduced the occurrence of tuber diseases such as common scab, black scurf and Rhizoctonia canker (caused by *Rhizoctonia solani*). Despite that, the use of similar crops in this study (winter oilseed rape and ryegrass) as CC in rotation before potato did not have such disease decreasing effect on common scab infections. Nevertheless, it still indicates that CC are able to keep common scab under control at higher severities (Table 5).

Severe incidences of common scab occurred mainly in 2010 and 2011. The 2010 growing season was extremely wet, but, in contrast, the 2011 growing season was quite arid (Table 1). Furthermore, in 2011, a few weeks before the harvest, relative air humidity rose to near 90 % (according to Eerika weather station; data not presented), and temperatures were very high at the same time. It is known that high air humidity and high soil moisture are favorable conditions for the spread of bacterial diseases, but some common scab species favor low levels of soil moisture (Fiers et al. 2012). Growing conditions affect the plants as well, which in unfavorable growing conditions may suffer under stress and therefore become more susceptible for diseases.

The organic systems in which CC as green manures were used had significantly lower percentages of tubers infected with silver scurf compared to conventional control and $N_{average\text{-}high}$ systems (Table 7). The CC grown directly before the potato in organic systems was winter oilseed rape. Winter oilseed rape, as a *Brassica* crop, contains glucosinolates, whose hydrolyzation products, isothiocyanates (Sarwar et al. 1998), are highly biocidal to fungi and bacteria (Brown and Morra 1997). As seen in the results, winter oilseed rape had great influence on reducing silver scurf occurrence in organic systems compared to conventional systems in which CCs were not used. Results revealed that the use of average or high amounts of mineral nitrogen fertilizers contributed to incidences of silver scurf. If higher rates of N are used to fertilize plants, then plant growth in the vegetative stage is also much greater, and the proportion of young to mature tissue changes in favor of the young tissues, which are more vulnerable to disease infections (Dordas 2008). More intensive plant growth and the absence of previous CC winter oilseed rape in average to highly fertilized systems led to an increase of silver scurf lesions. The occurrence of silver scurf was recorded only during the first disease measurement, but because the second measurement was also recorded to monitor how the tuber rots are evolving, then the same tubers were used again during the second disease measurement as during the first one. It was noted that the severity of silver scurf had increased meanwhile as well. When during the first disease measurement approximately 5–45 % of the tuber's surface was infected, during the second measurement the severity had increased to more than 45% of the tuber's surface already covered with silver scurf (data not presented). Because silver scurf has gained resistance against some fungicides (Errampalli et al. 2001) and the use of synthetic agrochemicals is prohibited in organic agriculture, it is very important to use agronomical practices that keep incidences of silver scurf as low as possible. Thus, it is recommended to use *Brassica* crops in crop rotation or as CCs, because as revealed they have silver scurf reducing effect.

The use of winter oilseed rape as the previous CC in the organic CC system had a beneficial effect on keeping the dry rot pathogen under control, and dry rot lesions therefore remained, on average, under 1 % at both measuring times (Table 9). The conventional system in which the highest amount of nitrogen was used had the lowest occurrence of dry rot next to the organic CC system. Similarly to this study, it has been found that the presence of high levels of nitrogen decreases the severity of the infection of the *Fusarium* species (Dordas et al. 2008). Higher nitrogen rates delay the senescence of the plant as well as metabolic activities which increase the resistance to pathogens such as *Fusarium* species (Agrios 2005).

The time of measurement had a significant effect on dry rot infections only in 2009 and 2010. In 2009 after the second disease measurement, a significant increase was observed only in conventional fertilized systems (N_{low} and N_{high}). This is possibly because is conventional fertilized systems the skin is setting later and when the tubers were harvested the skin was not as set as in organic systems which led also to a more serious infections during storage. Once the infections have already occurred, then it is difficult to avoid new lesions (Lui and Kushalappa 2002). When comparing the three experimental years, in 2009 the dry rot lesions were significantly (N0, $N_{low\text{-}average}$) or non-significantly more severe compared to other two experimental years. In 2009, the growing season was most similar to the long-term average, therefore climatically most optimal for the plant growth in this region. However, at the same time it was the coldest of the studied years. It has been stated previously that some dry rot-causing species favor cooler growth conditions over warmer (Platt and Peters, 2006).

The results revealed that farming systems had, on average, non-significant influences on tuber soft rot lesions. Rather, it was the year which was the main factor influencing soft rot occurrence (Table 11). In 2011, a few weeks after the tubers were harvested, the first symptoms of soft rot appeared among them. Three months after the harvest and the disease was already posing a significant problem. As the tubers were stored similarly throughout the whole study, storage conditions could not have been a factor affecting the soft rot lesions. In spring of 2011, the seed tubers were renewed as before – however, this year, the seed tubers were possibly already contaminated with soft rot bacteria. There were no visible soft rot symptoms on the tubers, however, and so they were used for planting. Soft rot bacteria can survive in tubers in latent form, but if the infected tubers are planted in a field, the symptoms may develop if the conditions are favorable (Lebecka et al. 2006). As soft rot bacteria can survive in the soil for only a few months (Pérombelon and Kelman 1987), the main way the bacteria may have gotten into the soil was with infected seed tubers. No soft rot disease was detected in previous years in our experiment. The other major factor influencing the occurrence of soft rot in 2011 was the extreme weather (minimal precipitation, high temperatures and air humidity before harvest) during the potato growing season, which made the tubers more susceptible to soft rot. Tubers under the conventional systems were able to reach maturity and were much larger in size compared to organic systems (Tein and Eremeev 2011) (article based on the same experiment). However, the tubers in organic systems were not fully matured because the weather conditions caused the aboveground biomass to die earlier before the tubers were able to reach the maturity (Tein et al. 2014). According to a previous study (Marquez-Villavicencio et al. 2011), larger and more mature tubers are more susceptible to the soft rot pathogen, but immature tubers are easily infected by pathogens as well because the periderm is less able to resist injuries compared to that of matured tubers, and thus the pathogens have easier access to the flesh of the young tubers. Also, as previously mentioned, humidity is an important factor that influences the spread of bacterial diseases; if tubers' surfaces are wet for long enough then the further spread of bacteria is ensured (Pérombelon 2000) due to the anaerobic conditions present. All of the aforementioned factors the tubers to become infected and highly susceptible to soft rot infections in 2011. Especially tubers under organic systems had more soft rot infected tubers in 2011. This was probably because of the lack of pest management and earlier foliage loss due to extreme weather that made the plants suffer under stress (Tein et al. 2014) that resulted also with higher incidences of soft rot, because the plants were weakened. After the first measurement, the infected tubers were removed from storage in order to check for new self-evolving lesions; no new lesions were found after the seriously infested tubers were removed, indicating that it is possible to halt the development of the disease if the diseased tubers are removed early enough. When storage conditions are favorable, then the tubers are able to heal themselves.

In conclusion, this study demonstrated that different farming systems had an effect on tuber disease incidences, indicating that tuber diseases can be managed by farming systems. As revealed, the use of above average amounts (>100 kg N ha^{-1}) of mineral nitrogen fertilizers in conventional systems kept the common scab incidences low. Even more, in a system with the highest amount (150 kg N ha^{-1}) of mineral nitrogen fertilizers used the incidences of dry rot remained one of the lowest. However, if there are problems with silver scurf then oppositely the higher amounts of mineral nitrogen fertilizers should be avoided, because with the increasing mineral nitrogen amounts also the silver scurf incidences tended to increase. The use of CC, particularly winter oilseed rape directly before potato, in organic system had a great beneficial effect on reducing the occurrence of silver scurf. In Organic CC system the use of CC also helped to keep the severity of common scab disease under control and the dry rot incidences remained also the smallest next to a system in which the highest amount of mineral nitrogen fertilizers were used. Thus, if the higher amounts of mineral nitrogen fertilizers are used then CC, especially winter oilseed rape or other *Brassica* crops, should be used, because they have a biocidal effect on fungal pathogens like dry rot and silver scurf. The use of cattle manure in Organic CC+M system resulted with the highest severity and incidences of common scab, but the use of CC at the same time helped to balance the effect. Therefore, with the use of manure the Brassica crops should be used simultaneously. Thus, despite that the fact that the same crop rotation was used in conventional and organic systems the crop rotation management practices determined how the system is able to cope with potato tuber diseases. In the future, it would be highly valuable to conduct molecular analyses of tuber and soil samples to ascertain the specific pathogen species which are causing tuber diseases under different farming systems.

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Table 1 The average monthly temperatures (ºC) and precipitation (mm) during the potato growing period in Eerika experimental field

Month	Decade	Temperatures (ºC)				Precipitation (mm)			
		2009	2010	2011	1969–2011	2009	2010	2011	1969–2011
May	I[1]	10.9	7.3	8.0	9.7	3.2	39.2	0.2	12.9
	II	9.3	16.7	11.8	11.4	7.6	44.6	46.6	20.9
	III	14.1	12.4	13.0	12.8	2.6	13.6	11.6	22.8
June	I	11.7	13.3	19.7	14.9	86.6	41.4	0.0	20.9
	II	13.1	13.6	15.9	15.1	34.0	17.8	24.8	26.9
	III	16.7	15.9	16.2	16.2	16.8	38.8	10.4	28.0
July	I	15.6	19.9	20.0	17.3	10.4	11.6	9.2	19.3
	II	17.9	22.9	18.6	17.4	21.4	3.0	30.4	24.8
	III	17.2	22.4	21.0	17.8	22.8	23.8	8.6	26.5
August	I	16.3	20.9	16.1	17.6	4.6	18.2	16.2	33.3
	II	15.1	19.1	15.6	16.2	54.2	74.6	17.0	28.5
	III	14.8	13.7	15.8	14.6	30.4	55.6	21.4	28.0
September	I	15.7	10.4	13.0	12.7	16.0	32.6	32.2	20.3
	II	11.8	12.1	12.2	10.6	11.2	46.4	28.4	18.3
May-September	I–III	14.3	15.8	15.5	14.5	321.8	461.2	257.0	331.4

[1] Period of 10 days

Table 2 Three year average tuber marketable yields

Farming system	Marketable yield t ha^{-1}
	2009–2011
Organic CC[1]	17.5 ^{A3}
Organic CC+M[2]	23.4 ^{B}
$N_0P_0K_0$ (control)	23.6 ^{B}
$N_{50}P_{25}K_{95}$ (N_{low})	34.2 ^{C}
$N_{100}P_{25}K_{95}$ ($N_{average}$)	38.5 ^{CD}
$N_{150}P_{25}K_{95}$ (N_{high})	41.60 ^{D}

[1] CC – catch crops.

[2] CC+M – catch crops + composted cattle manure.

[3] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

Table 3 Analysis of variance on total common scab infections, on common scab different tuber coverage percentages, and on common scab severity rating

	Total common scab (%)	Common scab (1) 4–15 % (%)	Common scab (2) 16–30 % (%)	Common scab (3) 31–45 % (%)	Common scab (4) >45 % (%)	Common scab severity rating
Year (Y)	***	***	***	*	ns	***
Farming system (FS)	ns	***	*	ns	ns	*
Y x FS	*	***	*	ns	ns	*

ns: not statistically significant; *significant < 5 % level of probability; ***significant < 0.1 % level of probability.

Table 4 Total percentage of tubers infected with common scab and average infection severity rating based on surface infection category – 0 (0–4 % of tuber surface infected); 1 (4–15 % of tuber surface infected); 2 (16–30 % of tuber surface infected); 3 (31–45 % of tuber surface infected)

Farming system	Common scab (%)				Infection severity rating			
	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC[1]	10.5 ^{A3a4}	63.3 ^{Bb}	58.8 ^{Ab}	44.2 ^{A}	0.1 ^{Aa}	0.7 ^{Bb}	0.7 ^{Ab}	0.5 ^{A}
Organic CC+M[2]	15.3 ^{Aa}	77.8 ^{Bb}	71.8 ^{Ab}	54.9 ^{A}	0.2 ^{Aa}	1.0 ^{Cb}	1.0 ^{Bb}	0.7 ^{B}
$N_0P_0K_0$ (control)	9.3 ^{Aa}	34.0 ^{Aab}	60.3 ^{Ab}	34.5 ^{A}	0.1 ^{Aa}	0.4 ^{ABab}	0.9 ^{ABb}	0.5 ^{A}
$N_{50}P_{25}K_{95}$ (N_{low})	14.3 ^{Aa}	32.3 ^{Aa}	61.5 ^{Ab}	36.0 ^{A}	0.2 ^{Aa}	0.4 ^{ABa}	0.8 ^{ABb}	0.5 ^{A}
$N_{100}P_{25}K_{95}$ ($N_{average}$)	15.3 ^{Aa}	25.0 ^{Aa}	60.5 ^{Ab}	33.6 ^{A}	0.2 ^{Aa}	0.3 ^{Aa}	0.9 ^{ABb}	0.4 ^{A}
$N_{150}P_{25}K_{95}$ (N_{high})	8.0 ^{Aa}	30.8 ^{Aa}	66.5 ^{Ab}	35.1 ^{A}	0.1 ^{Aa}	0.4 ^{ABa}	1.0 ^{Bb}	0.5 ^{A}

[1] CC – catch crops.

[2] CC+M – catch crops + composted cattle manure.

[3] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[4] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.

Table 5 The percentage of tubers infected with common scab (4–15 %, 16–30 %, 31–45 %, and >45 % of tuber surface infected) from marketable yield

Farming system	(1) 4–15 % (%)				(2) 16–30 % (%)				(3) 31–45 % (%)				(4) >45 % (%)			
	2009	2010	2011	Average	2009	2010	2011	Average	2009	2010	2011	Average	2009	2010	2011	Average
Organic CC[1]	10.5 $^{\mathrm{A}}$[3]$^{\mathrm{a}}$[4]	55.8 $^{\mathrm{Bb}}$	51.8 $^{\mathrm{Bb}}$	39.3 $^{\mathrm{B}}$	0 $^{\mathrm{Aa}}$	6.8 $^{\mathrm{Ab}}$	5.5 $^{\mathrm{Ab}}$	4.1 $^{\mathrm{A}}$	0 $^{\mathrm{Aa}}$	0.8 $^{\mathrm{Aab}}$	1.3 $^{\mathrm{Ab}}$	0.7 $^{\mathrm{A}}$	0 $^{\mathrm{a}}$	0 $^{\mathrm{Aa}}$	0.3 $^{\mathrm{Aa}}$	0.1 $^{\mathrm{A}}$
Organic CC+M[2]	15.0 $^{\mathrm{Aa}}$	55.0 $^{\mathrm{Bb}}$	47.5 $^{\mathrm{ABb}}$	39.2 $^{\mathrm{B}}$	0.3 $^{\mathrm{Aa}}$	19.3 $^{\mathrm{Bb}}$	19.8 $^{\mathrm{Ab}}$	13.1 $^{\mathrm{B}}$	0 $^{\mathrm{Aa}}$	3.0 $^{\mathrm{Aa}}$	4.3 $^{\mathrm{Aa}}$	2.4 $^{\mathrm{A}}$	0 $^{\mathrm{a}}$	0.5 $^{\mathrm{Ba}}$	0.3 $^{\mathrm{Aa}}$	0.3 $^{\mathrm{A}}$
$N_0P_0K_0$ (control)	9.3 $^{\mathrm{Aa}}$	28.3 $^{\mathrm{Ab}}$	37.8 $^{\mathrm{Ab}}$	25.1 $^{\mathrm{A}}$	0 $^{\mathrm{Aa}}$	4.0 $^{\mathrm{Aab}}$	16.8 $^{\mathrm{Ab}}$	6.9 $^{\mathrm{AB}}$	0 $^{\mathrm{Aa}}$	1.5 $^{\mathrm{Aa}}$	5.3 $^{\mathrm{Aa}}$	2.3 $^{\mathrm{A}}$	0 $^{\mathrm{a}}$	0.3 $^{\mathrm{ABa}}$	0.5 $^{\mathrm{Aa}}$	0.3 $^{\mathrm{A}}$
$N_{50}P_{25}K_{95}$ (N_{low})	13.3 $^{\mathrm{Aa}}$	22.5 $^{\mathrm{Aa}}$	40.0 $^{\mathrm{Ab}}$	25.3 $^{\mathrm{A}}$	1.0 $^{\mathrm{Aa}}$	8.0 $^{\mathrm{Aa}}$	16.8 $^{\mathrm{Aa}}$	8.6 $^{\mathrm{AB}}$	0 $^{\mathrm{Aa}}$	1.8 $^{\mathrm{Aa}}$	4.5 $^{\mathrm{Aa}}$	2.1 $^{\mathrm{A}}$	0 $^{\mathrm{a}}$	0 $^{\mathrm{Aa}}$	0.3 $^{\mathrm{Aa}}$	0.1 $^{\mathrm{A}}$
$N_{100}P_{25}K_{95}$ ($N_{average}$)	13.8 $^{\mathrm{Aa}}$	21.3 $^{\mathrm{Aa}}$	40.0 $^{\mathrm{Ab}}$	25.0 $^{\mathrm{A}}$	1.5 $^{\mathrm{Aa}}$	3.0 $^{\mathrm{Aa}}$	16.3 $^{\mathrm{Aa}}$	6.9 $^{\mathrm{AB}}$	0 $^{\mathrm{Aa}}$	0.8 $^{\mathrm{Aa}}$	4.3 $^{\mathrm{Aa}}$	1.7 $^{\mathrm{A}}$	0 $^{\mathrm{a}}$	0 $^{\mathrm{Aa}}$	0 $^{\mathrm{Aa}}$	0 $^{\mathrm{A}}$
$N_{150}P_{25}K_{95}$ (N_{high})	7.3 $^{\mathrm{Aa}}$	26.5 $^{\mathrm{Ab}}$	41.8 $^{\mathrm{ABc}}$	25.2 $^{\mathrm{A}}$	0.5 $^{\mathrm{Aa}}$	3.8 $^{\mathrm{Aa}}$	20.3 $^{\mathrm{Ab}}$	8.2 $^{\mathrm{AB}}$	0.3 $^{\mathrm{Aa}}$	0.5 $^{\mathrm{Aa}}$	4.3 $^{\mathrm{Ab}}$	1.7 $^{\mathrm{A}}$	0 $^{\mathrm{a}}$	0 $^{\mathrm{Aa}}$	0.3 $^{\mathrm{Aa}}$	0.1 $^{\mathrm{A}}$

[1] CC – catch crops.

[2] CC+M – catch crops + composted cattle manure.

[3] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[4] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.

Table 6 Analysis of variance on silver scurf infections

	Silver scurf (%)
Year (Y)	ns
Farming system (FS)	**
Y x FS	ns

ns: not statistically significant; **significant < 1 % level of probability.

Table 7 The occurrence of tubers infected with silver scurf from marketable yield

Farming system	Silver scurf (%)		
	2009	2011	Average
Organic CC[1]	8.3^{A3a4}	12.8^{Aa}	10.5^{A}
Organic CC+M[2]	10.0^{ABa}	15.5^{ABa}	12.8^{AB}
$N_0P_0K_0$ (control)	17.5^{ABa}	21.8^{BCa}	19.6^{BC}
$N_{50}P_{25}K_{95}$ (N_{low})	11.0^{ABa}	24.5^{Ca}	17.8^{ABC}
$N_{100}P_{25}K_{95}$ (N_{average})	16.5^{ABa}	23.5^{BCa}	20.0^{BC}
$N_{150}P_{25}K_{95}$ (N_{high})	21.5^{Ba}	25.3^{Ca}	23.4^{C}

[1] CC – catch crops.

[2] CC+M – catch crops + composted cattle manure.

[3] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[4] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.

Table 8 Analysis of variance on tuber dry rot occurrence

	Dry rot (%)
Year (Y)	***
Farming system (FS)	***
Time of measure (TM)	**
Y x FS	ns
Y x TM	*
FS x TM	*
Y x FS x TM	ns

ns: not statistically significant; *significant < 5 % level of probability; **significant < 1 % level of probability; ***significant < 0.1 % level of probability.

Table 9 The occurrence of tubers infected with dry rot from marketable yield

Farming system	Dry rot (%)			
	Autumn			
	2009	2010	2011	Average
Organic CC[1]	1.3^{A3a4}	0.3^{Aa}	1.0^{Aa}	0.8^{A}
Organic CC+M[2]	2.8^{BCb}	0.5^{Ba}	1.5^{Aab}	1.6^{AB}
$N_0P_0K_0$ (control)	3.3^{Cb}	0^{Aa}	1.0^{Aa}	1.4^{AB}
$N_{50}P_{25}K_{95}$ (N_{low})	2.8^{BCb}	0^{Aa}	2.5^{Aab}	1.8^{B}
$N_{100}P_{25}K_{95}$ ($N_{average}$)	2.8^{BCc}	0^{Aa}	1.0^{Ab}	1.3^{AB}
$N_{150}P_{25}K_{95}$ (N_{high})	0.8^{Aa}	0^{Aa}	0.8^{Aa}	0.5^{A}
	Spring			
	2010	2011	2012	Average
Organic CC	1.5^{Aa}	0.3^{Aa}	1.0^{Aa}	0.9^{A}
Organic CC+M	3.0^{ABCb}	0.5^{Aa}	1.8^{Aab}	1.8^{AB}
$N_0P_0K_0$ (control)	4.3^{BCb}	0^{Aa}	2.5^{Ab}	2.3^{AB}
$N_{50}P_{25}K_{95}$ (N_{low})	$4.8^{\mathrm{Cb}*5}$	$1.0^{\mathrm{Aa}*}$	3.3^{Aab}	3.0^{B}
$N_{100}P_{25}K_{95}$ ($N_{average}$)	3.8^{BCb}	0.3^{Aa}	1.5^{Aa}	1.8^{AB}
$N_{150}P_{25}K_{95}$ (N_{high})	$2.5^{\mathrm{ABb}*}$	0^{Aa}	1.8^{Aab}	1.4^{A}

[1] CC – catch crops.

[2] CC+M – catch crops + composted cattle manure.

[3] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[4] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.

[5] Means followed by a * indicate significant difference ($P < 0.05$) between values during autumn and spring measuring times.

Table 10 Analysis of variance on tuber soft rot occurrence

	Soft rot (%)
Year (Y)	***
Farming system (FS)	ns
Time of measure (TM)	***
Y x FS	ns
Y x TM	***
FS x TM	ns
Y x FS x TM	ns

ns: not statistically significant; ***significant < 0.1 % level of probability.

Table 11 The occurrence of tubers infected with soft rot from marketable yield

Farming system	Soft rot (%)			
	Autumn			
	2009	2010	2011	Average
Organic CC[1]	0^{a4}	0^{a}	2.0^{AB3b}	0.7^{A}
Organic CC+M[2]	0^{a}	0^{a}	3.5^{Bb}	1.2^{A}
$N_0P_0K_0$ (control)	0^{a}	0^{a}	1.0^{Aa}	0.3^{A}
$N_{50}P_{25}K_{95}$ (N_{low})	0^{a}	0^{a}	0.8^{Aa}	0.3^{A}
$N_{100}P_{25}K_{95}$ ($N_{average}$)	0^{a}	0^{a}	1.3^{ABb}	0.4^{A}
$N_{150}P_{25}K_{95}$ (N_{high})	0^{a}	0^{a}	0.5^{Aa}	0.2^{A}

[1] CC – catch crops.

[2] CC+M – catch crops + composted cattle manure.

[3] Means followed by a different capital letters within each column indicate significant influence ($P < 0.05$) of farming systems.

[4] Means followed by a different small letters within each row indicate significant influence ($P < 0.05$) of year.

IV

Eremeev, V., Keres, I., **Tein, B.**, Lääniste, P., Selge, A., Luik, A., 2009.
EFFECT OF DIFFERENT PRODUCTION SYSTEMS
ON YIELD AND QUALITY OF POTATO
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Effect of different production systems on yield and quality of potato

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Abstract. In the experimental field of the Department of Field Crops and Grassland Husbandry the late maturing potato variety 'Ants' was grown in the following variants: conversion to organic, $N_0P_0K_0$, $N_{50}P_{25}K_{95}$, $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$. Pesticides were used in mineral fertilizer variants. In $N_0P_0K_0$ and mineral fertilizers variants insecticide Fastac 50 was used. The total yield of tubers as well as the proportion of marketable tubers increased significantly with the use of mineral fertilizers ($N_{50}P_{25}K_{95}$, $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$). Tubers from conversion to organic and $N_0P_0K_0$ variants had significantly higher starch content, compared to the variants where mineral fertilizers were used, but the overall yield of starch remained lower. Increasing the amount of nitrogen fertilizer is positively correlated with the nitrate content in the tubers. The number of tubers infected by potato brown rot and potato soft rot did not differ significantly, but there were fewer tubers infected with black scurf in conversion to the organic variant.

Key words: black scurf, brown rot, marketable yield, soft rot, *Solanum tuberosum,* starch content

INTRODUCTION

At present potato is one of the main food components in most European countries and therefore holds a strong position amongst the world's food crops. The wide acknowledgement of organic agriculture in the EU was initiated with the establishment of national subsidies and uniform requirements. Organic marketing holds a rather small share of the total food market but is growing fast. As with all organic production, higher prices can be asked for organically grown potatoes because of their healthfulness, rewarding the lower yields in organic farming (Luik et al, 2008).

Organically grown food is as attractive to scientists as it is to consumers (Hajšlová et al., 2005). The main focal point used in advertising organic food is its beneficial impact on human health (Heaton, 2001). The yield and quality of the tubers is related to the time and amount of nutrient application (Munoz et al, 2005). With lower fertilisation levels generally used in organic farming systems the yields and tubers remain smaller (Varis et al., 1996). It's necessary to know the factors influencing the nitrogen requirement for predicting the nutrient demand of crops to provide give the grower with reliable advice (Greenwood, 1982; van Keulen et al., 1989). Knowing the nitrogen demand is not only important from the economic viewpoint, but also from the environmental one, because an oversupply of nitrogen causes leaching of nitrates (Addiscott et al., 1991). Therefore knowledge about exact levels of nitrogen is a basis for ensuring maximum yields with good quality. There are significantly more nitrates in the tubers of conventionally grown potato compared to those from organic farming (Stopes et al., 1988; Rembialkowska, 1999; Guziur et al., 2000), thus it is considered a healthier product.

MATERIALS AND METHODS

Field trials with the late potato variety ‘Ants’ (bred in Jõgeva SAI) were carried out on the experimental fields of the Department of Field Crops and Grassland Husbandry, Estonian University of Life Sciences (EMU). There were five treatments – conversion to organic and $N_0P_0K_0$, $N_{50}P_{25}K_{95}$, $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$. Fields were fertilized with different fertilizers: Kemira Grow How Power N:P:K – 5:14:28, and **AN 34.4** N:P:K – **34:0:0.** The variants that had received $N_0P_0K_0$ and mineral fertilizers were sprayed with insecticide Fastac 50 (BASF Ag, Germany; the active ingredient alpha-cypermethrin 100 g l^{-1}). The experiments were laid out in four replications. The size of each test plot was 60 m^2. The distance between seed tubers was 25 cm and the distance between rows was 70 cm. Seed tubers with a diameter of 35–55 mm were used. The soil of the experimental field was *Stagnic Luvisol* by WRB (2002) classification (Deckers et al. 2002), the texture of which is sandy loam with a humus layer of 20–30 cm.

Table 1. Average monthly temperatures (ºC) and precipitation (mm) in Estonia during the vegetation period.

Month	Temperatures, °C		Precipitation, mm	
	2008*	Average of 1966–1998**	2008*	Average of 1966–1998**
May	10.6	11.6	27.4	55
June	14.5	15.1	110.6	66
July	16.1	16.7	53.8	72
August	15.8	15.6	117.8	79
September	9.8	10.4	45.6	66

* according to the Eerika weather station
** (Jaagus 1999)

Compared to the average temperatures of many years, 2008 was colder. May and June had less precipitation, but there was abundant rainfall in the first decade of August and September (Table 1).

The tuber yield was determined by weighing directly after harvest. The starch content was determined by Parov’s weights (Viileberg, 1986). The starch yield was calculated according to starch content and tuber yield. The content of nitrates was analyzed in the plant biochemistry laboratory (EMU) by FiaStar 5000. Disease assessment of tubers was performed one month after the harvest by Rich (1983). For determination of the infection by black scurf, 100 tubers were taken from each treatment and the percentage of area damaged by black scurf was determined.

Experimental data were processed by Statistica 7.0 software (Anova, Fisher LSD test).

RESULTS AND DISCUSSION

The use of fertilizers on the potato field is based on the lack of nutrients in the soil for economically viable yields (Kuldkepp & Roostalu, 2002). Hence, the low yield of conversion to organically grown potato is the result of inadequate nutrient content in the soil.

Fertilization resulted in significantly higher tuber yield, compared to $N_0P_0K_0$ and conversion to organically grown potato (Table 2). Tubers more than 35 mm in diameter are considered as marketable yield. From Table 2 it can be concluded that marketable yields and their percentage of total yield is also higher in fertilized variants. In conversion to organic and $N_0P_0K_0$ variants the marketable and total yield is more than 50% lower than in $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$ variants (Table 2). The percentage of marketable yield of the total yield in conversion to organic and $N_0P_0K_0$ variants is 8% lower than in $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$.

Table 2. Tuber yield, marketable yield, percentage of marketable tubers, starch content and starch yield.

Variant	Yield, t ha^{-1}	Marketable tubers		Starch	
		yield, t ha^{-1}	%	content, %	yield, t ha^{-1}
Conversion to organic	20.1a	17.4a	86.3a	14.7a	3.0a
$N_0P_0K_0$	24.8a	21.7a	87.6a	14.5a	3.6ab
$N_{50}P_{25}K_{95}$	34.2b	31.7b	92.4b	12.7b	4.3bc
$N_{100}P_{25}K_{95}$	38.7b	36.6b	94.5b	12.8b	5.0c
$N_{150}P_{25}K_{95}$	38.0b	36.0b	94.7b	11.4c	4.3bc

Means followed by the different letter in the some column are significantly different ($P < 0.05$).

Starch is an important raw material for food and industrial applications. As a carbohydrate, starch stores energy in tubers and often influences their quality parameters (Jõudu, 2002). The starch content of tubers is affected by cultivar, maturity of tuber and climatic conditions during growth (Caldiz et al., 1996), and by cultivation methods, fertilization and storage conditions (Jõudu, 2002).

The results of our experiment showed that starch content was higher in conversion to organic and $N_0P_0K_0$ variants. The amount of nitrogen applied was negatively correlated with starch content (Table 2). Many researchers (Lampkin, 1990; Woese et al., 1995; Hajšlová et al., 2005) have found that the content of dry matter and starch are higher in organically grown potato than in the conventionally grown crop. In given conditions the starch content is determined by the total yield.

The tubers contain inorganic nitrogen compounds like ammonium, nitrates and, occasionally, nitrites in small amounts. The content of nitrates and the factors affecting its level are most often studied. Generally the content of nitrates is in the range of 40–250 mg kg^{-1} in raw material (Cieślik et al., 1990; Jõudu, 2002).

In our trials the highest content of nitrates was in $N_{100}P_{25}K_{95}$ (54.7 mg kg^{-1}) and $N_{150}P_{25}K_{95}$ (69.2 mg kg^{-1}) variants (Fig. 1). Generally the content of nitrates was higher in variants that received mineral nitrogen applications.

The tubers infected by potato brown rot (*Ralstonia solanacearum*) and potato soft rot (*Erwinia ssp.*) pathogens may start to decay in storage.

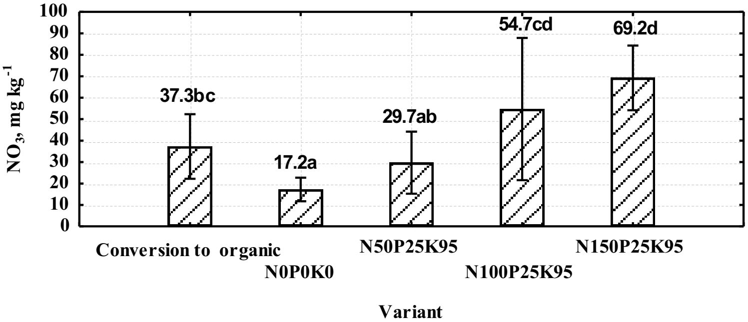

Fig. 1. The nitrate content in tubers, NO_3 mg kg^{-1}. Means followed by the different letter in the same row are significantly different ($P < 0.05$).

The infected tubers may also contaminate healthy tubers, which may result in enormous loss of yield and quality. Regarding the infection of tubers with potato brown and soft rot, no significant differences between variants were observed (Table 3).

Table 3. The percentage of number and weight of tubers infected with potato brown and soft rot.

Variant	The tubers infected with brown rot		The tubers infected with soft rot	
	number, %	weight, %	number, %	weight, %
Conversion to organic	3.4a	3.3a	2.0a	1.6a
$N_0P_0K_0$	1.8a	2.3a	1.2a	1.4a
$N_{50}P_{25}K_{95}$	3.4a	3.1a	1.0a	0.6a
$N_{100}P_{25}K_{95}$	2.5a	2.3a	2.2a	1.6a
$N_{150}P_{25}K_{95}$	2.0a	1.7a	2.1a	1.4a

Means followed by the different letter in the some column are significantly different ($P < 0.05$).

The damage caused by *Rhizoctonia solani* (the causal agent of black scurf) usually develops on the spot of mechanical injury on the tuber and is also affected by the handling of tubers. The injury is not necessarily visually detectable on the skin of the tubers. The probability of black scurf occurrence is higher during storage, when the tubers are experiencing stronger pressure and more injuries occur (Sawyer & Collin, 1960). The spread of black scurf is also favoured by abundant precipitation during growth and unsuitably high storage temperatures (Lõiveke, 2002).

It could be observed that all tubers in the experiment were infected by black scurf; its growth was especially favoured by abundant precipitation right before harvest (Table 1). Consequently, it can be concluded that various agrotechnical measures do not affect the spread of black scurf. Although all tubers were infected, the damaged area was only 2–12%. The area damaged by black scurf was smallest in conversion to organic and $N_{100}P_{25}K_{95}$ treatments and significantly larger in other treatments (Fig. 2).

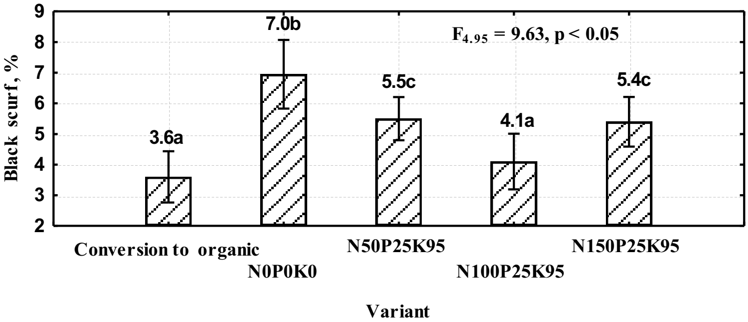

Fig. 2. The area of tuber peel infected by black scurf, %. Means followed by the different letter in the same row are significantly different (*P* < 0.05).

CONCLUSIONS

By using mineral fertilizers ($N_{50}P_{25}K_{95}$, $N_{100}P_{25}K_{95}$ and $N_{150}P_{25}K_{95}$), tuber yield, marketable yield as well as the percentage of marketable tubers increased significantly. The optimal amount of nitrogen for conventional farming is 100 kg ha^{-1}. The conversion to organic and $N_0P_0K_0$ variants had significantly higher starch content compared to variants where various levels of mineral fertilizers were used, but the starch yield remained lower. Increasing the amount of mineral fertilizers is positively correlated with nitrate content of the tubers. The number of tubers infected with potato brown or soft rot did not differ significantly between variants. Compared to other variants, the conversion to organic plot had the lowest percentage of tubers infected with black scurf. Therefore it could be concluded that while focusing on the quality and healthfulness of the product, potato should be grown via conversion to organic method. When higher yields are the main purpose, potato should receive adequate amounts of fertilizers.

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Research projects involved

Field of research	Conventional and organic farming systems, potato production, plant production
2015–2017	Fertility building management measures in organic cropping systems (Project 8-2/T15015PKTK)
2013–2016	From soil to crop: quality indicators of soil, plant production and crop in diferent farming systems (Project 8-2/T13001PKTM)
2011–2014	Reduced tillage and green manures for sustainable organic cropping systems, ERA-NET CORE Organic II (Project 8-2/T11104PKTK)
2010–2014	Finding alternative solutions to pre-sprouting, through longer thermal shock treatment and use of humic extract, explaining their effect on the formation of yield structure elements of potato (Project ETF8495)
2013–2013	The influence of the humic substances on the production of biogas from bioresidues (Project 8-2/T13076PKTM)

Teaching

Teaching subjects

Since 2015	Field crops production, lectures, seminars and practical sessions
Since 2014	Genetics, seminars and practical sessions
Since 2013	Field crops husbandry, seminars and practical sessions
Since 2009	General course in field crop husbandry; Quality and standards of horticultural and field products, substitute lecturer

Dissertations supervised

2015	Kaupo Kuusemaa, master thesis „The effect of cultivation methods on pea quality and economical efficiency“ (Estonian University of Life Sciences)
2014	Alo Põldmaa, master thesis „The effect of farming systems on potato yield quality and on economical efficiency“ (Estonian University of Life Sciences), co-supervisor researcher Viacheslav Eremeev

2012	Martin Okas, master thesis „Effect of organic and conventional production on the potato yield and economical efficiency“ (Estonian University of Life Sciences)
2011	Veljo Ilumäe, master thesis „The effect of organic and conventional production on the yield and quality of barley“ (Estonian University of Life Sciences), co-supervisor assistant Indrek Keres

Professional training

28 March – 22 Apr 2014	Course „Presentation Skills“, organized by the Estonian University of Life Sciences
29 Jan – 07 March 2014	Course „Different teaching skills and their use in teaching processes“, organized by the Estonian University of Life Sciences
05–08 Aug 2013	Course ”Ecological modelling”, organized by Estonian University of Life Sciences in co-operation with Leibniz Centre for Agricultural Landscape Research
14–15 Jan 2013	Course ”Supervising the students research projects“, organized by the Tartu University
01 Sept – 01 Dec 2011	Practical training in plant and soil sciences, in Univerity of Helsinki
08–11 Aug 2011	Course ”Spoken English”, organized by the Estonian University of Life Sciences
22–25 March 2011	Course ”Use of isotopic tracers in N dynamics studies in agricultural ecosystems”, organized by the Estonian University of Life Sciences
08–21 Aug 2010	Course ”Organic Food Production Chain”, organized by the Warsaw University of Life Sciences
22–27 Nov 2009	Kursus ”Global Organic Food Chains – Agroecology, Environment, and Livelihood”, organized by the University of Copenhagen

Administrative activities

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1992–2004	Tartu Forseliuse Gümnaasium

Teenistuskäik

Alates 2015	Eesti Maaülikool, Põllumajandus- ja keskkonnainstituut, taimekasvatuse ja rohumaaviljeluse osakond, lektor
2014–2015	Eesti Maaülikool, Põllumajandus- ja keskkonnainstituut, taimekasvatuse ja rohumaaviljeluse osakond, peaspetsialist
2012–2014	Eesti Maaülikool, Põllumajandus- ja keskkonnainstituut, taimekasvatuse ja rohumaaviljeluse osakond, spetsialist

Teadustegevus

Uurimissuund	Tava- ja maheviljeluse taimekasvatuslikud süsteemid, kartulikasvatus, taimekasvatus

2015–2017	Mullaviljakuse parandamise meetodid maheviljeluse süsteemides (Projekt 8-2/T15015PKTK)
2013–2016	Mullast saagini: mulla, taimekasvu ja saagi kvaliteedi hindamise indikaatorid erinevates viljelusviisides (Projekt 8-2/T13001PKTM)
2011–2014	Minimeeritud mullaharimine ja haljasväetised jätkusuutlikele mahetaimekasvatuse süsteemidele (Projekt 8-2/T11104PKTK)
2010–2014	Eelidandamisele alternatiivsete lahenduste leidmine läbi pikemaajalise termošoki ja humiinpreparaadi kasutamise, selgitades nende mõju kartuli saagistruktuuri elementide kujunemisele (Projekt ETF8495),
2013–2013	Humiinpreparaadi mõju hindamine humiinpreparaadi lisamisega biojäätmete biogaasi tootmises (Projekt 8-2/T13076PKTM)

Õppetöö

Õpetamine

Alates 2015	Taimekasvatuslikud õppeained, loengud, praktikumid ja seminarid
Alates 2014	Geneetika, seminarid ja praktikumid
Alates 2013	Taimekasvatus, seminarid ja praktikumid
Alates 2009	Taimekasvatuse üldkursus; Aia- ja põllusaaduste kvaliteet ja standardid, asendusõppejõud

Juhendatud väitekirjad

2015	Kaupo Kuusemaa, magistritöö „Viljelusviisi mõju herne saagile ja kasvatamise tasuvusele“ (Eesti Maaülikool)
2014	Alo Põldmaa, magistritöö „Viljelusviisi mõju kartuli saagile ja kvaliteedile ning kasvatamise tasuvusele“ (Eesti Maaülikool), kaasjuhendaja Viacheslav Eremeev
2012	Martin Okas, magistritöö „Mahe- ja tavatootmise mõju kartuli saagile ja kasvatamise majanduslikule efektiivsusele“ (Eesti Maaülikool)
2011	Veljo Ilumäe, master thesis „Mahe- ja tavaviljeluse mõju odra saagile ning kvaliteedile“ (Eesti Maaülikool), kaasjuhendaja assistent Indrek Keres

Erialane täiendusõpe

28. märts –22. apr 2014	Kursus ”Esinemisoskused”, korraldaja Eesti Maaülikool
29. jaan – 07. märts 2014	Kursus ”Erinevad õppemeetodid ja nende rakendamine õpetamisprotsessis”, korraldaja Eesti Maaülikool
05.–08. aug 2013	Kursus ”Ecological modelling”, korraldaja Eesti Maaülikool koostöös Leibnizi Põllumajandusmaastike Uurimiskeskusega
14.–15. jaan 2013	Kursus ”Üliõpilaste uurimistööde juhendamine ja tagasisidestamine”, korraldaja Tartu Ülikool
01. sept – 01. dets 2011	Praktiline väljaõpe Helsingi Ülikoolis taimekasvatuse ja mulla valdkonnas
08.–11. aug 2011	Kursus ”Spoken English”, korraldaja Eesti Maaülikool
22.–25. märts 2011	Kursus ” Use of isotopic tracers in N dynamics studies in agricultural ecosystems”, korraldaja Eesti Maaülikool
08.–21. aug 2010	Kursus ”Organic Food Production Chain”, korraldaja Varssavi Maaülikool
22.–27. nov 2009	Kursus ”Global Organic Food Chains – Agroecology, Environment, and Livelihood”, korraldaja Kopenhaageni Ülikool

Teadusorganisatsiooniline ja –administratiivne tegevus

Alates 2013	Eesti Maaülikooli tudengite teaduse populariseerimise projekt „Elus teadus“
Alates 2012	Euroopa Agronoomia Selts
Alates 2011	Euroopa Kartulikasvatusuuringute Assotsiatsioon

Teaduspreemiad ja tunnustused

2014	Noorteadlase Mahestipendium

LIST OF PUBLICATIONS

1.1 Articles indexed by Thomson Reuters Web of Science

Tein, B., Kauer, K., Runno-Paurson, E., Eremeev, V., Luik, A., Selge, A., Loit., E., 2015. The potato tuber disease occurrence as affected by conventional and organic farming systems. American Journal of Potato Research (accepted for publication)

Kauer, K., **Tein, B**., Talgre, L., Eremeev, V., Sanchez de Cima, D., Loit, E., Luik, A., 2015. Soil carbon dynamics estimation and dependence on farming system in a temperate climate. Soil & Tillage Research, 154, 53–63.

Runno-Paurson, E., Loit, K., Hansen, M., **Tein, B**., Williams, I.H., Mänd, M., 2015. Early blight destroys potato foliage in the northern Baltic region. Acta Agriculturæ Scandinavica, Section B – Soil & Plant Science, 65, 422–432.

Alaru, M., Talgre, L., Eremeev, V., **Tein, B**., Luik, A., Nemvalts, A., Loit, E., 2014. Crop yields and supply of nitrogen compared in conventional and organic farming systems. Agricultural and Food Science, 23, 317–326.

Runno-Paurson, E., Hansen, M., **Tein, B**., Loit, K., Jõgi, K., Luik, A., Metspalu, L., Eremeev, V., Williams, I.H., Mänd, M., 2014. Cultivation technology influences the occurrence of potato early blight (*Alternaria solani*) in an organic farming system. Zemdirbyste-Agriculture, 101, 199–204.

Zou, L., Santanen, A., **Tein, B**., Stoddard, F.L., Mäkelä, P., 2014. Interference potential of buckwheat, fababean, oilseed hemp, vetch, white lupine and caraway to control couch grass weed. Allelopathy Journal, 33, 227–236.

Tein, B., Kauer, K., Eremeev, V., Luik, A., Selge, A., Loit, E., 2014. Farming systems affect potato (*Solanum tuberosum* L.) tuber and soil quality. Field Crops Research, 156, 1–11.

1.2 Peer-reviewed articles in ohter International research journals with ISSN and International editorial board

Margus, K., Eremeev, V., Lääniste, P., Mäeorg, E., **Tein, B**., Laes, R., Jõudu, J., 2014. Humiinainete mõju kartuli saagikusele ja mugula mõningatele kvaliteedi näitajatele. Agraarteadus: Journal of Agricultural Science, XXV, 82–88.

Eremeev, V., **Tein, B**., Lääniste, P., Mäeorg, E., Laes, R., Margus, K., Jõudu, J., 2014. Soojalöögi ja eelidandamise mõju kartuli saagikusele ning selle kvaliteedile. Agraarteadus: Journal of Agricultural Science, XXV, 64–69.

Tein, B., Eremeev, V., 2011. Eri viljelusviiside mõju kartuli saagistruktuuri elementide kujunemisele. Agraarteadus: Journal of Agricultural Science, XXII, 40–44.

Eremeev, V., Keres, I., **Tein, B**., Lääniste, P., Selge, A., Luik, A., 2009. Effect of different production systems on yield and quality of potato. Agronomy Research, 7, 245–250.

3.2 Papers in books or proceedings published by Estonian or ohter publishers not listed by Thomson Reuters Conference Proceedings Citation Index

Eremeev, V., Lääniste, P., **Tein, B**., Mäeorg, E., Kuht, J., 2015. Humiinpreparaadi kasutamise mõju kartulile. Agronoomia 2015, 56–61.

Eremeev, V., Lääniste, P., **Tein, B**., Mäeorg, E., Kuht, J., 2015. Seemnemugulate termilise töötlemise ja humiinainete kasutamise mõju kartuli saagikusele. Agronoomia 2015, 62–69.

3.4 Articles and presentations published in the conference proceedings not listed by Thomson Reuters Conference Proceedings Citation Index

Talgre, L., **Tein, B**., Eremeev, V., Matt, D., Reintam, E., Sanches de Cima, D., Luik, A., 2014 Green manures as winter cover crops enhance soil improvement and weed regulation in crop rotation. Reduced Tillage and Green Manures for Sustainable Organic Cropping Systems, pp. 23.

Matt, D. Eremeev, V., **Tein, B**., Roasto, M., Pehme, S., Luik, A., 2014. The metabolomic fingerprinting and microbiological quality of winter wheat (*Triticum aestivum* L.) in different organic growing systems. Proceedings of the 4th ISOFAR Scientific Conference 'Building Organic Bridges', at the Organic World Congress 2014, 227–229.

Talgre, L., **Tein, B**., Eremeev, V., Matt, D., Reintam, E., Sanches de Cima, D., Luik, A., 2013. In crop rotation green manures as winter cover crops enhance ecosystem services of farming. Proceedings of the NJF Seminar 461 Organic farming systems as a driver for change, 57–58.

Reintam, E., **Tein, B**., Talgre, L., Sanchez de Cima, D., Eremeev, V., Luik, A., 2013. Effect of green and cattle manure use on soil properties, weediness and crop production in Estonia. TILMAN-ORG Interim Meeting Book of Abstracts, pp. 11.

Tein, B., Kauer, K., Eremeev, V., Luik, A., Loit, E., 2013. Effect of inorganic and organic cropping systems on SOC dynamics. Proceedings of the International conference "Soil carbon sequestration for climate food security and ecosystem services", 267–269.

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Tein, B., Eremeev, V., Keres, I., Selge, A., Luik, A., *2010*. Effect of different plant production methods on yield and quality of winter wheat 'Portal' in 2009. Annual 16th International Scientific Conference Proceedings: Research for Rural Development 2010, 17–21.

3.5 Articles and presentations published in local conference proceedings

Talgre, L., Eremeev, V., Reintam, E., **Tein, B.**, Sanchez de Cima, D., Madsen, H., Alaru, M., Luik, A., 2015. Talvised vahekultuurid parandavad mulda ja kultuuride saagikust. Agronoomia 2015, 40–44.

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Kuht, J., Eremeev, V., Talgre, L., **Tein, B.**, Alaru, M., Luik, A., 2014. Herne saak ja kvaliteet maheviljeluses olenevalt orgaanilise väetamise viisist. Konverentsi "Eesti mahepõllumajandus täna ja tulevikus" toimetised 2014, 51–55.

Talgre, L., Eremeev, V., Alaru, M., **Tein, B.**, Alaru, M., Kuht, J., Luik, A., 2014. Teravilja saak ja saagi kvaliteet sõltuvalt viljelussüsteemist. Konverentsi "Eesti mahepõllumajandus täna ja tulevikus" toimetised 2014, 93–97.

Tein, B., Eremeev, V., Luik, A., Loit, E., 2014. Talvine vahekultuur mõjutab kartulimugulate hõbekärnaga nakatumist. Konverentsi "Eesti mahepõllumajandus täna ja tulevikus" toimetised 2014, 102–104.

Eremeev, V., **Tein, B.**, Luik, A., 2012. Kartul mahe- ja tavaviljeluse süsteemide võrdluskatses aastatel 2008-2012. Teaduselt mahepõllumajandusele, 25–27.

Kuht, J., Luik, A., Eremeev, V., Talgre, L., **Tein, B.**, 2012. Mulla umbrohuseemnete varu mahepõllul. Teaduselt mahepõllumajandusele, 56–58.

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Šarin, R., **Tein, B.**, Eremeev, V., 2012. Humiinpreparaadi mõju kartuli kaubanduslikule saagile ja ühe taime mugulate arvule. Agronoomia 2012, 61–66.

Tein, B., Eremeev, S., 2012. Kartuli mahapanekueelse ettevalmistusviisi mõju hilise kartuli 'Anti' tärklisesisaldusele ja toortumenemisele. Agronoomia 2012, 81–86.

Eremeev, V., **Tein, B.**, Šarin, R., Treimuth, M., 2011. Ruponicsi mõju kartuli mugulate arvule ja mugulate keskmisele massile 2010. Aastal. Agronoomia 2010/2011, 67–72.

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5.2 Published conference abstracts, not indexed by Thomson Reuters Web of Science

Tein, B., Kauer, K., Loit, E., Eremeev, V., 2014. The effect of tuber pre-planting thermal treatments and humic preparation "Ruponics" on potato tuber diseases. Abstracts of the 19th Triennial Conference of the European Association for Potato Research, pp. 83.

Eremeev, V., Lääniste, P., **Tein, B**., Lauk, R., Alaru, M., 2012. Effect of tuber pre-planting treatments and humic preparation on tuber yield and quality. Abstracts of the 12th Congress of the European Society for Agronomy, pp. 324.

Tein, B., Eremeev, V., Keres, I., 2010. Talinisu saagi ja saagi kvaliteedi sõltuvus eri viljelusviisidest. Noorteadlaste konverentsi teeside kogumik.

Tein, B., Eremeev, V., Valdmann, K., 2009. Mahe- ja tavatootmise mõju kartulisaagile ja kvaliteedile. Noorteadlaste konverentsi teeside kogumik, pp. 17.

VIIS VIIMAST KAITSMIST

BERT HOLM

CULTIVATION OF WILLOWS (SALIX SP.) USING RESIDUES OF THE WASTEWATER PURIFICATION PROCESS AND BIOGAS PRODUCTION AS FERTILISERS
PAJUDE (SALIX SP.) KASVATAMINE KASUTADES VÄETISTENA REOVEEPUHASTUSPROTSESSI- JA BIOGAASI TOOTMISE JÄÄKE
Vanemteadur **Katrin Heinsoo**
21. august 2015

MARTI TUTT

FACTORS AFFECTING BIOCHEMICAL COMPOSITION OF LIGNOCELLULOSIC BIOMASS AND ITS EFFECT ON SELECTION OF PRETREATMENT METHOD AND ON BIOETHANOL PRODUCTION POTENTIAL
LIGNOTSELLULOOSSE BIOMASSI BIOKEEMILIST KOOSTIST MÕJUTAVAD TEGURID NING BIOKEEMILISE KOOSTISE MÕJU EELTÖÖTLUSMEETODI VALIKULE JA BIOETANOOLI TOOTLIKKUSELE
Professor **Jüri Olt**, vanemteadur **Timo Kikas**
28. august 2015

MARET SAAR

ELECTRICAL CHARGE OF BASIDIOSPORES OF HYMENOMYCETES (FUNGI) AND ITS BIOLOGICAL SIGNIFICANCE
EOSLAVASEENTE KANDEOSTE ELEKTRILAENG JA SELLE BIOLOOGILINE TÄHENDUS
Professor **Tiiu Kull**
17. september 2015

GARRI TRALMAN

ROD-THROUGH-PLATE FIXATOR IN THE TREATMENT OF LONG BONE FACTURES OF SMALL ANIMALS
KOMBINEERITUD METALLOOSTEOSÜNTEES PIKKADE TORULUUDE MURDUDE RAVIKS VÄIKELOOMADEL
Professor **Vladimir Andrianov,** professor **Marina Aunapuu**
22. oktoober 2015

AARE AAN

ON USING MATHCAD SOFTWARE FOR MODELLING, VISUALIZATION AND SIMULATION IN MECHANICS
MATHCAD TARKVARAPÕHINE MODELLEERIMINE, VISUALISEERIMINE JA SIMULEERIMINE MEHAANIKAS
Professor **Mati Heinloo**
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