Improving organic potato production systems in Greece; Understanding the influence of variety selection, organic fertilisation and irrigation on potato yield and disease severity

A thesis submitted in the Faculty of Science, Agriculture and Engineering, for the degree of

Doctor of Philosophy (Ph.D)

By

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November 2019

ABSTRACT

Messinia prefecture, is considered to be one of the most important potato production areas in Greece mainly due to its favourable pedo-climatic conditions and availability of irrigation water. The main challenges that organic potato growers are facing are specific diseases (especially late blight), pest (especially nematodes and Colorado beetle) and nutrient management (e.g. availability of suitable organic fertilizers). Furthermore, the main potato variety used in Greece is Spunta, since it is desired by Greek consumers for characteristics such as shape, color, texture and cooking properties. However, Spunta is a variety with low nutrient use efficiency and high susceptibility to light blight.

The main objectives of the project reported here was to (a) identify varieties that are more suitable for organic production under the pedo-climatic conditions in Southern Greece and (b) develop improved agronomic protocols (fertilization and irrgigation regimes) in pot and field experiments established in four growing seasons/years. The twelve varieties included in trials were chosen based on existing information on (a) foliar blight resistance and (b) performance in conventional production systems in the spring potato growing season in Greece

Results from the study suggest that the variety Sarpo mira may be a sutiable replacement for Spunta (especially for organic production systems) under the pedo climatic conditions in Southern Greece, since it (a) was highly late blight resistant, (b) appeared to be more tolerant to Colorado beetle and (c) produced the highest tuber yield (and mean tuber weights and size) in both field trial seasons, and especially for organic production. Results also showed that fertilisers with a high content of plant available NH_4^+-N (chicken manure and sheep manure plus agrobiosol) resulted in substantially higher yields than sheep manure and seaweed compost. In pot trials, yields obtained with chicken manure and sheep manure plus agrobiosol were also higher than those obtained with standard mineral NPK fertilisation regimes used in conventional farming practices. Results also suggest that the effect of fertilizer input types on potato health and yield parameters depends on both disease/pest pressure and variety.

This study demonstrated that increasing the water input level to approximately 1.5 times the usual amount of water applied to potato crops with standard sprinkler systems will slightly (by approximately 15%) increase tuber yields. Increasing water input levels also

resulted in significantly higher late blight severity and the ability to increase yields via improved irrigation protocols therefore depends on the availability of blight resistant varieties such as Sarpo mira. Sprinkler irrigation (which was compared to drip irrigation systems in field trials) was found to be the most efficient irrigation system due to **(a)** its relatively low cost (compared to drip irrigation), and **(b)** the ability to reduce foliar frost-damage and (c) the finding that it resulted in lower levels of potato beetle infestation in the field trials.

The study reported here showed for the first time that irrigation type has a major effect on Colorado beetle infestation with drip irrigation resulting in approximately 3 times higher infestation than sprinkler irrigation. However, the reasons for this difference are unknown, since the experiments were not designed to assess potential mechanisms.

The availability of late blight resistant varieties such as Sarpo mira may therefore allow the use of sprinkler irrigation (a) without substantial losses due to late blight while (b) delivering additional benefits from reduced Colorado beetle infestation/damage. However, additional experiments, in which different varieties are compared under conditions of no or low late blight disease pressure and/or Colorado beetle infestation levels, are required to determine to what extent foliar blight resistance, insect resistance/tolerance and agronomic factors (e.g. differences in soil physical, and nutrient and water supply resulting from contrasting irrigation methods and fertiliser types) have contributed to the yield difference between varieties. Also future studies should focus on investigating the effect of irrigation and fertiliser types on **(a)** soil nutrient (especially N, P and K) availability release characteristics, **(b)** root distribution and root system development and **(c)** soil penetration resistance within the soil profile throughout the growing season.

This Thesis is dedicated to my beloved parents Ilias and Vasiliki Giannakopoulos

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ACKNOWLEDGEMENTS

It is important for me, to thank those who encouraged, helped and support me during my PhD studies. Undoubtedly, without them, I would not be able to complete my doctoral degree. I feel blessed that I met each one of them and I would like to thank them from my heart.

First and foremost, to my academic supervisor Carlo Leifert for his guidance and support throughout my studies even in difficult times, he stood by me encouraging me to continue. During my studies he was always present giving me the feedback and the inspiration I needed. Special thanks to Nikos Volakakis, who shared with me his knowledge and advised me during my studies. He supported me not only in practical things but also psycollogically when I thought I couldn't manage all the pressure throughout my studies. The help and the support of Leonidas Rempelos was priceless. He helped and encouraged me throughout my studies, giving me advice, strength to continue and he was alaways there for me to help me during my studies. He has become one of my precious friends and I will always be gratefull.

At this point, I would like to thank Dr. Chris Seal. His support and kindness throughout my studies gave me another reason to work hard in order to complete this thesis. He was always by my side, giving me strength to continue, no matter what.

This thesis, which based on experiments, wouldn't have been accomplished without the support of Mr. Peter Vlachogeorgakopoulos. Apart from the field that he kindly conceded in order to set up my experiments, he gave me all his knowledge and advice on the agronomic practises that I should follow during the experiments. I feel that whatever I say about him can't describe his kindness and support to me.

I would like to thank the staff of Nafferton Ecological Farming Group (NEFG) for welcoming and helping me during my stay there. I felt as if I was a member of their "family".

Moreover, special thanks to all my friends who supported and encouraged me. One of the benefits of my doctoral degree was the "new" friends I met; Nikos Dafermos, NikosVoutzourakis.

Last but not least I would like to thank my beloved parents Ilias and Vasiliki Giannnakopoulos for their unconditional love and support. Without my parents' support the completion of my doctoral degree would be impossible. Iwould also like to thank them for believing in me throughout this journey of my doctoral studies, even when I had doubts of completing it.

Finally, I would like to thank my husband Petros and my son Michael for being next to me and giving me strength in difficult times. I would also like to apologise to them for being away, many times, in order to complete my studies.

CHAPTER 1: GENERAL INTRODUCTION

1.1 History of Potato

The potato plant (*Solanum Tuberosum L)*, comes from the Andes of South America (Perou, Colombia, Bolivia) and was introduced in Europe in 1537 by Spanish explorers (Birch et al., 2012). According to Bradshaw and Ramsay (2009) potato plant was cultivated by Incas almost 2000 years before America was discovered. Archaeological evidence suggests that potato tubers were an important component of human nutrition as long as 8000 years ago (Bradshaw &Ramsay, 2009; Hawkes, 1992)

1.2 Potato physiology and taxonomy

Potato species are member of *Solanaceae* (Dicotyledon) family and the main cultivated species *Solanum tuberosum L*, is a tetraploid species with 48 chromosomes. Its biological growth cycle typically lasts 3-6 months, depending on the variety type and the climatic conditions (Alexander, 2012).

Potatoes, are vegetatively propagated via tubers, and this results in variety characteristics being maintained (Passam et al., 2011c). Although potatoes can produce true seeds as well, these seeds have a low germination rate and they are usually only used in breeding programmes to develop new varieties/genotypes (Malagamba, 1988).

The potato plant has a “bushy” root distribution and a canopy growth pattern which is described at Figure 1.3.1. The stems above the surface are green, which at first are horizontal and then as the foliage develops further, they branch and increase in length reaching 40-160cm. At tuber maturation, the foliage senesces and is destroyed by farmers either mechanically or chemically (Passam et al., 2011c).

The underground roots/stems are developed horizontally and their length depends on the variety and the cultivation techniques. Tubers develop at the end of the stolon and usually, every stolon forms one tuber. However, in some cases a stolon may form more than one tuber (Jackson, 1999). Therefore, the number of tubers and total tuber production/yield, depends on the number of stolons. According to Lovell and Booth (1969), the number of stolons is affected by environmental and nutrient conditions, especially water and nutrient availability. Commercial potato cultivars tend to have short stolons, whereas, wild potato species have long stolons (Passam et al., 2011c).

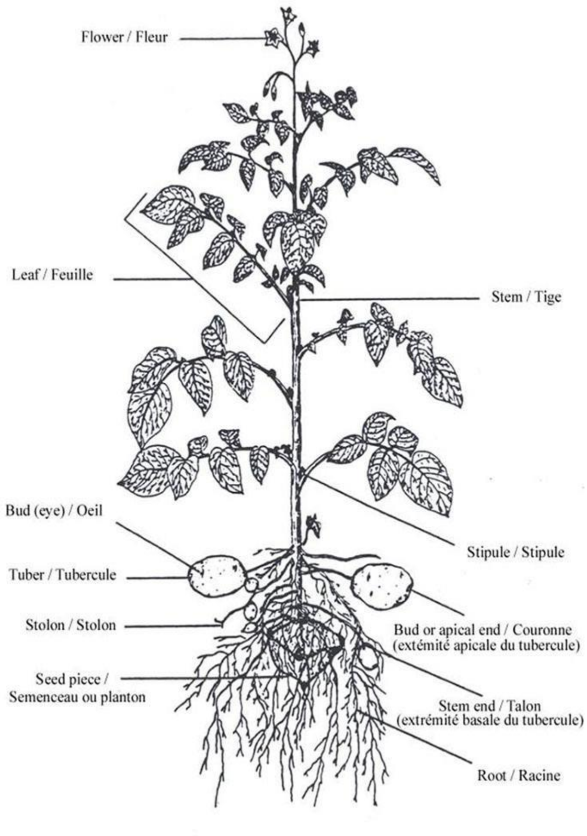


Figure 1.1 Potato plant morphology (redrawn from Canadian Food Inspection Agency 2013)

The potato has a relatively shallow root system which develops from meristematic tissues in the tuber and has a multitude of thin fibrous roots, which supply the plant with nutrients and water. In contrast, to stolons and tubers, potato roots cannot store nutrients (Cutter, 1992). In contrast, potato plants developed from true seed, the main tap root is formed, which then branches and develops into a "bushy" root system (Rowe, 1993).

The potato plant's foliage consists of compound leaves with 7-11 leaflets. Potato leaves are green with an eliptic shape and fluffy surface. They have stomata on both, the upper and lower leaf surface, but the majority of stomata are on the lower leaf surface. Environmental factors such as daylength and temperature were shown to affect the leaf characteristics (e.g. size and colour) (Almekinders and Struik, 1996). Potato leaves cannot be consumed by humans as they are toxic; which is a characteristic of most species in the *Solanaceae* family. The potato flowers are hermaprhodite , usually white, sub-yellow and purple coloured and they grow from the base of the last leaf of each stem (Hawkes, 1992).

New potato tubers, develop first on the lower stolons and tubers have been described as “swollen stolons” with two ends; the heel which is attached to the stolon and the epical or distal end. According to Hawkes (1992), tuber description can be separated into the following tissues (from outside to inside): skin/periderm, cortex, vascular system, storage parenchyma and the pith. The skin protects the tuber and provides the characteristic tuber colour. Varieties differ in colour which is due to differences in the levels of phytochemicals such as anthocyanins in the skin. Skin colour can be white, yellowish, purple, red and when tubers are exposed to light they become green (Jansen and Flamme, 2006).

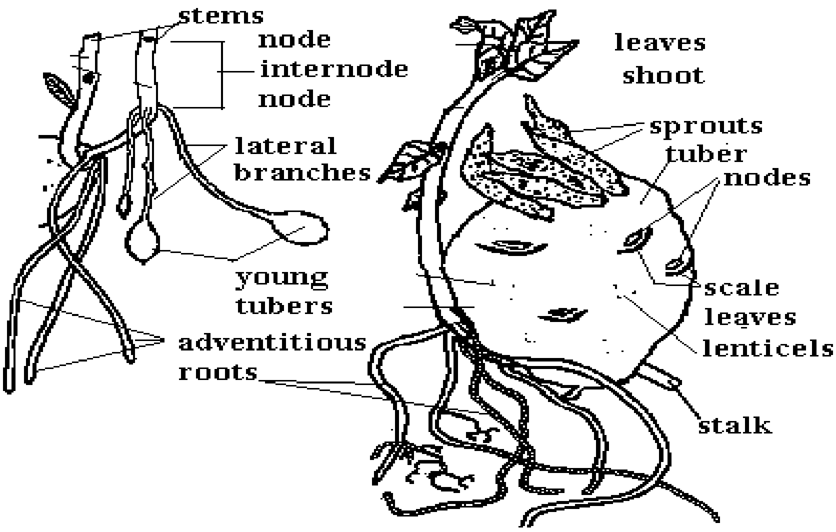


Figure 1.2 Tuber morphology (redrawn from School of Science, University of Queensland 2015)

Below the skin there is the cortex, a narrow storage tissue, which contains protein and starch . The vascular system, connects the tuber with the rest of the plant. The storage parenchyma is the actual storage tissue and represents most of the tuber volume inside the vascular system ring (Harris, 1992).

1.3 Commercial importance of potato and production

Potato is known to be one of the major food crops and produces higher levels of protein and dry matter per hectare compared to cereal crops (Paradiso et al., 2009). It is estimated that potatoes are consumed by a billion humans daily and in terms of human calorie intake, is the fourth largest food crop after rice, wheat and maize. Potatoes are cultivated in more than 125 countries and worldwide production is about 320 million tones per annum (FAO, 2017). Potato consumption and popularity in developing countries is high due to its nutritional value. In developed countries, however, there is an increase of the demand for potato as well as potato precessed products like French fries, crisps and frozen potato products (Rempelos, 2013). Potatoes have a high nutrition value compared to other tuber crops and contain approximately 2% protein, 20.8% carbohydrates and also high concentrations of vitamins C and D (Berti et al., 2010).

Globally potato crops are grown over a wide range of climatic zones, (Haverkort, 1990). Haverkort and Struik (2015) defined six main potato production systems worldwide: (1) Rainy summer crop production, (e.g., Northern Europe and the South African High Veld characterized by long growing seasons of around 180 days); (2) Dry land summer crop production when rainfall is sparse (e.g. in the North-West of the United States of America; (3) partly irrigated spring crop production (e.g. in Mediterranean climates such as in North Africa, South America and South Africa); (4) Irrigated autumn crop production (e.g. crops are planted in Mediterranean climates after the summer heat and harvested before winter frosts with a crop cycle of about 100 days); (5) irrigated winter crops in monsoon climate regions where rice is grown during the rainy summer; and (6) Equatorial highland crop production systems (e.g.production above 1800 m with two rainy seasons such as in East and Central Africa).

Figure 1.3 shows that since 2012 there has been a steady increase in world potato production which reached 382 million tonnes in 2014. In Greece, however, both the total area used for potato growing and total potato production has decreased in recent years. Specifically, according to ELSTAT, in 2016 the total area of potato cultivation was approximately 20,000 hectares and total potato production 492,000 tonnes, whereas, in 2009 the area was 46,000 hectares and total production 944,000 tonnes (fig1.4). According to the farmers, this reduction is mainly due to the high cost of the potato cultivation (fertilizers, fungicides, seed) and cheap imports resulting in low profitability of potato production in Greece (personal communication with Mr. Peter Vlachogeorgakopoulos). In the area of Mesinia, this reduction is even more visible, as in 2013 the total area used for potato growing and production was 2.236 ha with a production of 48 thousand tonnes, whereas in 2016 the total area was 480 ha, with a production of 14 thousand tonnes (ELSTAT, 2016).

Early potato production is of major importance in Greece, as in 2016, the total area of potato production, was recorded to reach about 20760 ha and almost half of them (10143 ha) are devoted to early potato production. In the area of Messinia, 320 ha out of 480 ha of potato production are devoted to early potato production (ELSTAT, 2016).

Organic potato production in Greece, is currently very limited and there are no official data. It is estimated that the total area of the organic potato production in Greece is around 40 hectares (personal communication with Mr. Spyroulis, ELSTAT).

In Greece, approximately 1 million tonnes are consumed annually with 90% being from domestic production and 10% from imports. Although, Greece could potentially be self sufficient in potato production the lower price of the imported potatoes has resulted in an increasing amount of potatoes being being imported. The main countries, from which Greece imports potatoes are Egypt, France, Cyprus, Holland and Germany (FAO,2017). According to ELSTAT (2017), currently between 130,000-160,000 tonnes of potato are imported to cover domestic needs. Some potatoes are also exported from Greece (estimated to be between 15,000-25,000 tonnes). For instance, in 2015, 36% of Greek exports were to Poland, 20% to Cyprus, 12% to Romania and Bulgaria and 5% Albania (ELSTAT, 2017).

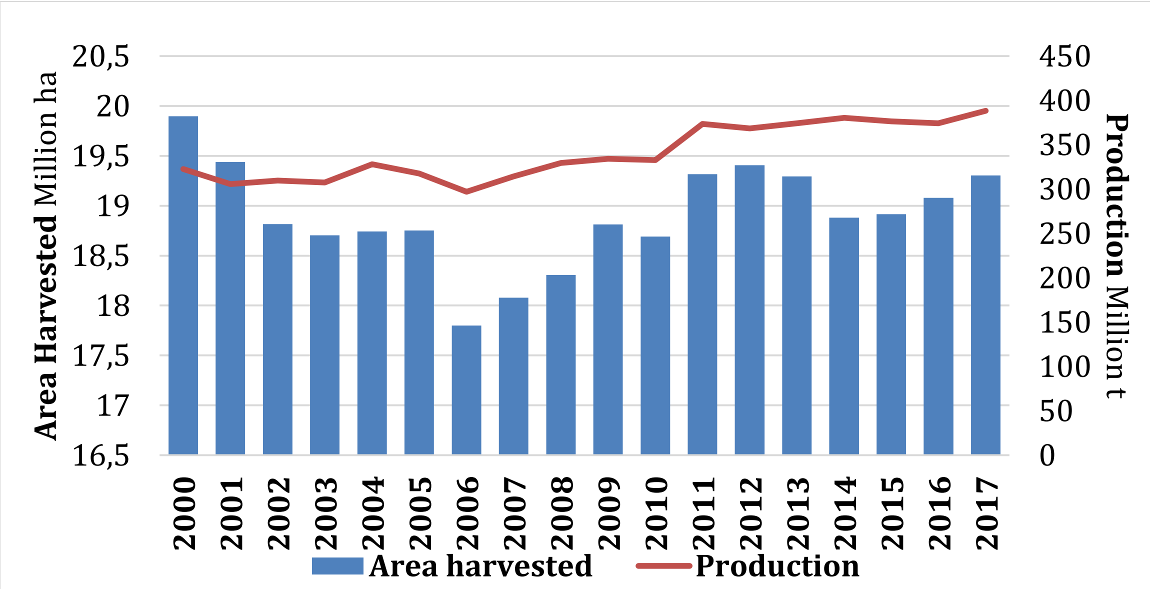


Fig. 1.3 World potato production from 2000 -2017 (FAO, 2019)

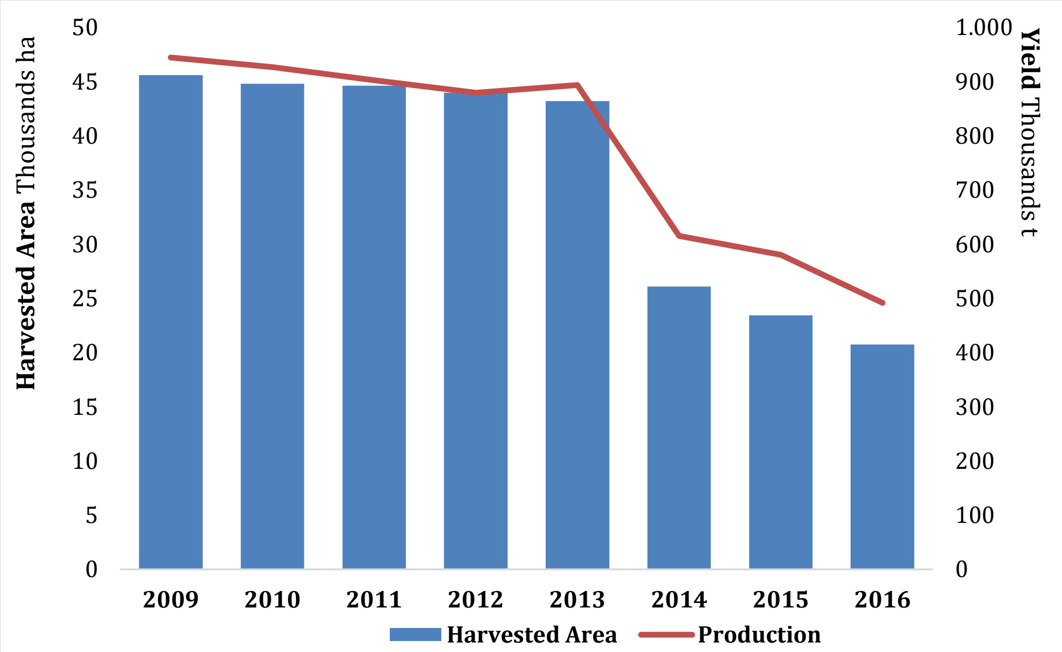


Fig. 1.4 Potato production in Greece from 2009 -2016 (FAO, 2019)

1.4 Crop establishment

Prior to planting a potato crop, stones should be removed from the soil, as their presence increases the time needed for harvest and increases tuber damage during the harvesting period (Witney and McRae, 1992).

Prior to planting of potatoes soils are usually deep ploughed (30-40 cm depth) and it is recommended for ploughing to be done to different depths each year in order to avoid the formation of an impermeable soil horizon. In Greece the period in which soil tillage is done is winter (August/September) for autumn (fall) crops and in autumn (December/January) for spring crops, unless there are special climatic conditions (excess rainfall, drought) which make difficult any soil treatment (Passam et al., 2011b).

After tillage, weed control (e.g.harrowing), is needed in order to generate a uniformly loose soil aggregate structure and to remove weeds. A loose/soft soil to a depth of 20-25 cm, is very important for potato crops, as it facilitates root development, allows water movement and ensures sufficient oxygen supply in the soil, factors which were all shown to improve tuber yield and quality (Passam et al., 2011b).

If planting is done by hand, ridges are made before planting, whereas in cases of mechanical planting, ridges are produced at the same time as planting. In conventional production systems, mechanical planting is widely used, whereas in organic production systems, semi-automatic planting is used in order to avoid tuber injuries and removal of shoots when chitted tubers are used for planting (Hospers-Brands et al., 2008).

In organic cultivation, chitted seed potato tubers are used for planting, to minimise potato blight by reducing the time to maturity, allowing harvesting period to take place before periods of high late blight pressure (Hospers-Brands et al., 2008). Planting timing also affects potato development and depends upon the variety used, the geographic location and pedo-climatic conditions. In Greece, planting can take place: a) between the end of November and January (spring cultivation), b) around March (summer cultivation) and c) July till August (autumn cultivation) (Passam et al., 2011b).

1.5 Potato Varieties

Although potato is one of the most important food crops worldwide, definition/interpretation of its genetic development and gene pool structure remains controversial. The first cultivated potato in South America was diploid and Peru has the highest number of wild potato species (Hijmans and Spooner, 2001, Spooner et al., 2007). Potato taxonomy is a complicated task, therefore it has been a subject of study for many years (Spooner et al.,2007). Potato belongs to the *Solanaceae* family. Cultivated potato and its wild relatives belong to the genus Solanum, the largest genus with 1500-2000 species. *Solanum* species, which are cultivated for tubers are grouped in the *Petota* section and this section is further divided in two sub-sections, *Potatoe* and *Estolonifera* (Hawkes, 1990). Many authors have presented different taxonomic classifications of cultivated and wild potatoes (Huamán and Spooner 2002, Ovchinnikova et al. 2011, Spooner and Hijmans 2001) For instance, 228 species are recognized by Hawkes (1990), 196 species by Spooner and Hijmans (2001), and approximately 110 species by Spooner (2009).

Potato tuber quality is one important characteristic of potato cultivars/varieties and specific market standard are used to define/describe cultivated varieties in terms of growth, resistance and tuber processing quality parameters. For organic potato production, where synthetic chemical pesticides are prohibited disease and pest resistance traits are particularly important, as well us high nutrient use efficiency (since mineral N-fertiliser inputs are prohibited and mineral P and K inputs restricted under organic farming standards) and adaption to local pedo- climatic conditions (Speiser et al., 2006, Ghorbani et al., 2008, Palmer et al., 2013).

Two of the most important criteria for potato variety choice by Greek producers are high productivity as well as the short growth cycle (around 100 days) (personal communication with Peter Vlachogeorgakopoulos). Both criteria are driven by economic reasons since potatoes in Greece are sold based on the weight but not the quality, as well as early potatoes achieving higher prices in the market. Consumer preferences also determine the Greek potato market demand and are mainly related to their appearance. Greek consumers prefer large, oval potatoes, with yellow or light yellow, but not white flesh colour with good chip-making and slow-oven roasting characteristics (such as Spunta). In contrast round potatoes and varieties with red skin are not currently very popular in Greece. Furthermore Greek consumers, are not used to buying specific potato varieties for different intended usages (e.g. boiling, slow roasting, frying) and prefer to buy a single variety that can be used for all types of popular potato dishes (Passam et al., 2011a). Producers in addition demand certain agronomic chracteristics especially resistance to pest and diseases, with the most important problem of potato growers in Greece being late blight/downy mildew caused by *Phytophthora infestans* (Giannopolitis, 2011) (details for agronomic performance and tuber quality trade see Appendix, pg 155-159). Producers therefore also demand varieties with resistance to foliage tuber blight and a range of other important diseases including viral, bacterial, fungal and nematode diseases) and pests such as Colorado beetle (personal communication with Peter Vlachogeorgakopoulos).

The most popular and widely grown potato variety is Spunta, followed by Bamba, Liseta, Agria, Jaerla or Hermes (for chips). Spunta is a traditional variety used in 40-45% of certified seed, while all other new and old varieties accound for 55-60% of certified seed. In recent years, there has been an increase in the use of new potato varieties in conventional farming systems (compared to traditional varieties such as Spunta), and this was mainly due to these varieties providing better agronomic characteristics and higher yields (Passam et al., 2011a). However, there is currently no information on the relative performance of different potato varieties in organic production systems in Greece.

Certified seed potatoes produced in Greece account for only 1.4% of the total seed potatoes used in the country (www.minagric.gr). On the domestic market, imported certified varieties are constantly gaining market share, which exhibit certain characteristics desired by the producers (high productivity, early appearance, durability). Altogether in spring and autumn potato production, about 114.000 hectares of potato are grown in Greece. The amount used for planting is on average of 500 kg of seed / ha (Passam et al., 2011b), with Greek producers using a total of 57.000 tonnes of potato seed per annum (ELSTAT, 2017). The annual total quantity of certified seed used for both crops is 18.800 tonnes, ie 33% of the total (ELSTAT, 2017). The remaining seed (67%) is from crops harvested by the farmers which often has not been certified.

1.6 Fertilization

In conventional production systems, the N, P and K input levels that are usually used are between 200 and 250 kg ha^{-1} $year^{-1}$ and in organic farming systems potato crops are often located early in the rotation; as the 1st or 2nd crop after a fertility building crop (e.g. a legume or legume grass mixture). EU/national environmental legislation, also defines the organic maximum levels that can be used (Palmer et al., 2013). For instance, in the UK organic fertilizer inputs (e.g. manure, green waste composts) equivalent to a total of 250kg N ha^{-1} $year^{-1}$ are usually used (Munoz et al., 2005a).

Potato is a crop with very high demand for both mineral macro (N, P, K, Ca, S) and micro (Cl, Fe, Mn, Cu, Mo, Ni) nutrients (Harris, 1992, White et al., 2008). According to Munoz et al (2005), potato plants require approximately, 2.5 -5.9 kg/ha of N and 3.5-10 kg/ha K per tonne of tuber yield. Although P requirements are lower than those for N and K, in conventional production systems phosphorus (P) is often applied in similar amounts to N-fertiliser, since a large proportion is lost due to run-off (Bélanger et al., 2002, Dean, 1994).

These high input NPK levels are due to (a) the high nutrient demand of potato crops, but also (b) potato plants having a relatively low low nutrient use efficiency compared to other arable crops (e.g. cereals and oil seed rape), because they have a really shallow root system (Palmer et al., 2013). This and, the fact that potato plants are usually grown in light sandy soils increases the risk of nutrient losses and potato crops are known to result in relatively high negative environmental impacts including nitrate leaching, phosphorus run-off and leaching, and greenhouse gas emissions associated with N-manufacture, use and losses (Belanger et al., 2003).

Nitrogen (N) is the most important and often yield limiting nutrient in both organic and conventional production, especially in sandy soils (Mortvedt et al., 2001, Errebhi et al., 1998, Zebarth and Rosen, 2007). N is essential for the growth of the plant (foliage), canopy as well as root system and tuber development. Low levels of nitrogen at tuber initiation reduces the number of stolons and potato tubers and low N-supply at later stages of development reduces foliage and tuber growth and size and results in earlier senescence (Harris, 1992).

The timing of fertilizer application, is an important factor affecting yield and the relative levels of negative environmental impacts from N-fertilisers. N fertilizer applications should be timed so that N- availability coincides with periods of high N-demand by the crop (e.g. tuber initiation in order to optimise final tuber yields (Finckh et al., 2006). More specifically, the biological cycle of potato plants can be divided into seven different growth stages; with each stage requiring different amounts of N being available to the crop (Hack, 2001). Figure 1.5 shows the different growth stages of potato plant.

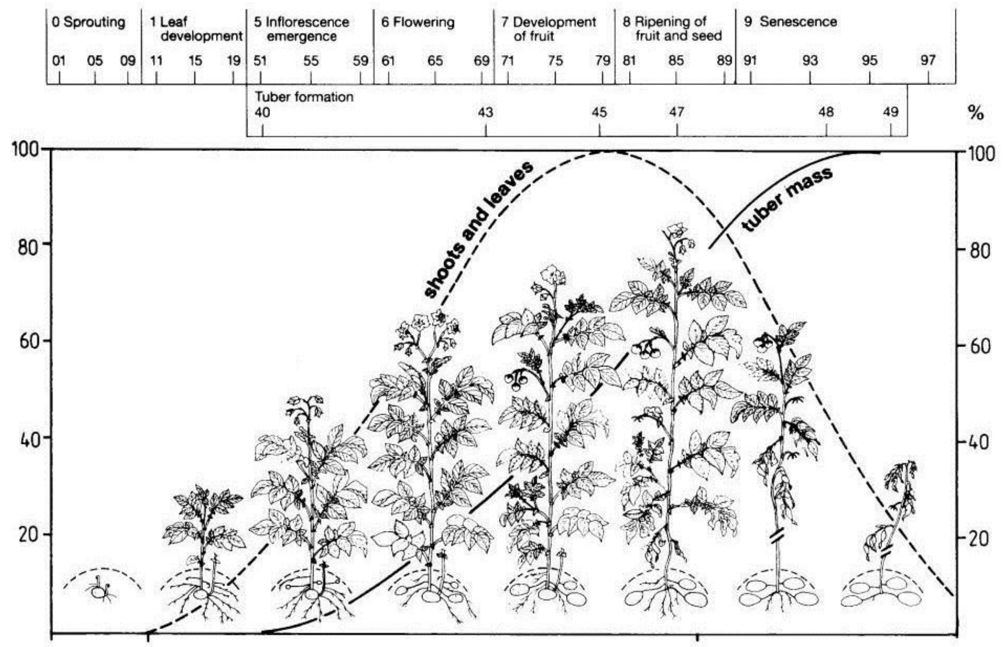


Fig. 1.5 Potato phenological growth stages (Hack, 2001)

The first growth stage, is the sprouting stage (GS 01-09), which lasts about 30 days after the planting date. At this growth stage, all the nutrients that are necessary to be taken by the plant, are derived from the tuber seed, so N-availability can be relatively low since uptake from the soil at this stage is relatively low. The subsequent growth stages (GS 10-19) are the vegetative growth period, which takes place from 30 to 55 days after planting. At this growth stage, roots start to supply nutrients to the plant, which are used for the development of the foliage (shoots) and photosynthesis takes place in the leaves and therefore, N-demand increases significantly and drives growth. At the end of this growth stage, about 20% of the crops total N-demand has been taken up, and if high amounts of N fertiliser is applied at this time, high levels of leaching are likely to occur (Westermann and Kleinkop, 1985).

Vegetative growth is followed by the tuber initiation period (GS 40) and GS 51-59, when canopy development and flowering takes place respectively. At this stage, both N-demand and vegetative growth further increase. Apart from N-availability tuber initiation, is affected by a range of other pedo-climatic factors including soil moisture, disease severity, temperature, and radiation. Experiments have shown, that N fertilization at this stage, increases canopy (shoot) formation and growth as well as number of tubers per plant (Belanger et al., 2001).

During the subsequent tuber bulking period (GS 42-47) and a further foliage development period (GS 61-89), the vegetative growth of the plant as well as N-uptake are reduced and then stop completely, in the case of early maturing varieties, as nutrients are re-located from the leaves into the tubers. Finally, the tuber maturity growth stage (GS 91-97), is the stage when canopy starts to die and more nutrients being solubilized in the roots and leaves are re-located into the tubers. At this stage N uptake and demand is minimal (Zebarth and Rosen, 2007, Westermann and Kleinkop, 1985, Westermann, 2006). Experiments have shown that the optimum N- input levels varies between varieties and the type of mineral N-fertilizer used (urea, NH_4' NO_3) (Zebarth et al., 2004b, Zebarth et al., 2004a, Zebarth and Rosen, 2007).

Tuber quality is found to be affected by N fertilization as well. More specifically, it has been reported that tuber specific gravity decreases with increasing N- fertiliser use (Dahlenburg et al., 1990). Also, field experiments have shown that nitrate fertilisation may also affect other tuber quality parameters including tuber bruising (Thornton and Timm, 1990), crisp colour (Dahlenburg et al., 1990, Feibert et al., 1998) and tuber shape (Roberts et al., 1982). Excessively high nitrate fertilization, was shown to result in a reduction of tuber dry matter and starch content as well as a delay of tuber maturation and senescence of the foliage. Also, high N-inputs were shown to increase the susceptibility to fungal pathogens, including *Phytopthora infestans,* (Nowicki et al., 2012, Palmer et al., 2013).

Love et al. (2005), reported that when nitrate was applied weekly (30 kg/ha) for 3 weeks, starting immediately after tuber initiation, there was a significant higher percentage of blight affected tubers compared to those with the nitrate fertiliser applied at planting or in smaller amounts within a period of 6 weeks. The relative effect of N-fertilisation on tuber blight is affected/confounded by soil moisture; the largest number of blight affected tubers was found when soil moisture was kept between 80-90% of field capacity compared to soil that was allowed to dry further between irrigation inputs (Ojala et al., 1990, Stark and Porter, 2005).

According to Finckh et al. (2006), in order to achieve a potential yield of 35 t/ha, potato plants nedd to take about 110-130 kg ha^{-1} N, in the period between the main foliage growth till the beginning of tuber bulking. However, it has been recorded that in high nitrate input conventional systems 40-50 kg N are required per 10 t of tuber yield (Harris, 1992) . A large proportion of mineral N-fertiliser applied to conventional potato crops is lost mainly due to nitrate-leaching and run off. According to Munoz et al. (2005b), the NUE of potato plants is only around 37%, whereas the rest (67%) is lost into the environment, contribution to euthrophication. Nitrogen losses from organic fertilisers (e.g. manure, compost) are thought to be lower, because plant available NH_4^+ is (a) released more slowly from the organic matter via mineralisation in the soil and (b) may be held at cation exchange sites in the soil and thus prevented from being lost via nitrification and nitrate leaching (Berry et al., 2006).

1.6.1 Fertilisation in conventional potato production systems in Greece

In Greece, the standard applied amount of N is up to 200kg N ha year^{-1} (Mouzakis, 2011). The amount of nitrogen applied is associated with the photosynthetic capacity in leaves and the dry matter/starch content (a quality parameter) in the tuber (Harris, 1992).

As in other potato production areas (e.g. the UK; (Palmer et al., 2013), P and K mineral fertilizer inputs are often applied at similar levels to N-inputs. In the Messinia county of the Pelleponnes, early spring potato production is one of the most important potato production systems. Planting usually takes place in the middle of December (15th December) and harvest starts in mid-April. The total acreage that is cultivated with early potato crops in the Messinia region is estimated to be approximately 500 ha. Approximately 150 ha of potato crops are located around Kalamata, the area in which the pot and field experiments reported here were carried out. The remaining 350 ha are in other areas of the Messinia county. Most potato production is conventional in the Messina region and average tuber yields are round 35 t ha^{-1} (Giannopolitis, 2016). Spunta is the main variety used and it is common for farmers to use chitted/pre-sprouted tubers, to allow early harvest. However, chitting does result in crop losses in seasons with late frost after planting, especially if soils are wet (Mr Petros Vlachogeorgakopoulos, personal communication).

The standard fertilization regimes used by conventional farmers the Messinia region is bassed on a split application of mineral compound NPK-fertiliser (15-15-15) fertiliser with half of the total amount (=120 kg each of N, P and K), which results in the fertiliser being applied to the soil before planting, and the same amount again before ridging takes place. In addition, and four more applications of approximately 100 kg per ha of Nitrogen fertilisers are applied after ridging via the irrigation water (Kostantakopoulos, 2017).

1.6.2 Fertilisation in organic potato production systems

There is currently no published information on the fertilisation of organic potato crops in the Messinia region, since ,according to the Greek Ministry of Agriculture,, there were no certified organic potato producers in this region of Greece, at the time the experiments were carried out (personal communication with Mr. Pettas Nikos, Greek Ministry of Agriculture). In organic production systems, the use of all mineral N, water-soluble P and KCl fertilizers is prohibited, and fertilisation relies primarily on animal manures, composted organic waste and other organic fertilizers, as well as the use of legume fertility building crops (Mader et al., 2002). Ground phosphorus rock, potassium sulphate, lime and gypsum, and most mineral micro-nutrient fertilizers (e.g. Fe, Cu, Zn) are permitted, as long as deficiency is demonstrated via soil or plant analyses (Soil Assosiation, 2016).

In addition, other waste products (bloodmeal, bone meal, hoofs, hides, straw) can be used in organic cultivation provided they are appropriately processed (e.g. via composting, heat treatments, anaerobic digestion) (Dittmar et al., 2009). However, othe use of organic fertilizers based on human sewage are not currently allowed in organic farming systems. Different animal manures and other organic fertilizers used by organic farmers differ substantially in moisture content, total N, P and K levels, C:N ratios and the speed at which they are mineralised and nutrients become available after application to soils (Munoz et al., 2005a). The fertiliser value and nutrient availability from different organic fertilisers therefore depends on a range of factors that affect their mineralisation after application to soils including soil moisture. In many areas in Europe, chicken manure pellets are the preferred manure type used for organic potato production systems, as they have a high content of available N, P and K and are thought to result in higher yields than other manures (e.g. cattle and sheep manure when applied at the same N-input levels (Tétard-Jones et al., 2013). However, there is currently very limited information on the effects of different manures, composts and other organic fertiliser types in organic farming systems in Greece and other southern Mediterranean countries.

Similar to mineral N-fertilisers, organic fertilisers such as chicken manure pellets with relatively high concentration of water soluble NH_4^+-N and NO_3^--N are more prone to losses via nitrate leaching, and they may therefore not be the best option for organic potato production in the sandy soils of the Messinia region. However, since potato crops in the

Messinia region are irrigated it may be possible to optimise mineralisation pattern from manures via the management of soil moisture levels. However, there is currently no information on the effect of different irrigation regimes (irrigation systems and water input levels) on fertiliser use efficiency.

1.7 Irrigation

Potato plants are extremely sensitive to water stress due to their shallow root systems and therefore require irrigation for maximum yield, even in temperate maritime climates with high and regular rainfall such as the UK or the Netherlands. Even short periods of water stress/insufficient soil moisture levels were shown to result in reduction of yield, tuber number and tuber quality (Yuan et al., 2003, Epstein and Grant, 1973, Foti et al., 1995). However, yield reductions may occur when frequent irrigation with relatively cold water is applied as the soil temperature may be below the optimum value for tuber formation (15- 18^0 C) (FAO, 2017).

Where potato crops are grown in sandy soils, frequent irrigation with small amounts of water is recommeneded, whereas for clay soils less frequent irrigation with higher amounts of water is used (Passam et al., 2011b). The level of irrigation needs to be adjusted to climatic conditions (especially temperature or radiation) and plant density. At higher temperatures and radiation and planting densities higher irrigation levels are required due to higher levels of evapotranspiration. During the initial stages of potato growth (planting until canopy development), potato plants don't require high amounts of water. However, irrigation levels need to be higher in autumn crops (where early stages of crop development fall into relatively hot periods in late summer/early spring) than spring crops (where early developmental stage are in winter). Higher levels of irrigation are required during tuber formation and expansion, while soil water holding capacity should be about 80% (Passam et al., 2011b). It is recommended that irrigation stops 20-25 days before harvest and that soil water holding capacity during tuber maturation should not be greater than 60-65% (Plissey, 1993). Several different irrigation types/methods are used in potato production including furrow, drip/tape, sprinkler and boom irrigation systems. Boom irrigation systems, are used widely in large scale potato production systems in Northern Europe, while sprinkler, drip/tape and traditional furrow irrigation systems are more commonly used in Southern Europe (Steele, 2013). Furrow irrigation is more commonly used in developing countries (e.g. Egypt) in the Southern Mediterrranean. Some soil borne potato diseases such as *Verticillium* wilt are more frequently observed with furrow irrigation, since it may result in long periods of too high water levels in soil (Rowe et al.,1993).

Furrow irrigation (Fig. 1.6), is a traditional irrigation method which does not require special equipment and has relatively low capital costs. Compared to sprinkler irrigation furrow irrigation is associated with lower levels of late blight in Southern Europe crops, since it results in limited leaf wetnes. However, it is associated with problems such as waterlogging and salinity (Jha et al., 2017).

Drip/tape irrigation systems (Fig. 1.7) require both high capital and significant labour inputs, but are the most water efficient irrigation systems. Sprinkler irrigation (Fig. 1.8) is the most widely used irrigation method for potato crops in Greece and is associated with lower labour and capital costs than drip irrigation systems However, sprinker irrigation generates longer periods of high humidity and leaf wetness resulting in higher foliar blight severity (Olanya et al., 2007). In contrast, sprinkler irrigation has been reported to result in lower levels of leptidopteran pest damage (Talekar et al., 1986). In addition, sprinkler irrigation allows mineral fertilisation to be applied efficiently with the irrigation water (Waddell et al., 1999) and is an efficient method to protect potato plants from frost damage, which frequently affects potato crops in Greece.

Fig. 1.6 Irrigation with furrows

Fig. 1.7 Drip irrigation system (www.shutterstock.com)

Fig. 1.8 Sprinkler irrigation system (www.shutterstock.com)

1.8 Crop protection

1.8.1 Late Blight (Phytophthora infestans)

Late blight (caused by the oomycete fungus *Phytopthora infestans*) is the most serious potato disease, in many potato growing regions. Late blight was first introduced into Europe in the mid-1840, when it led to complete potato crop failure and famine in many areas of Europe (e.g. the Irish potato famine) where potato had become a stable food crop. Approximately, one million people died and up to two million people emigrated because of the famine caused by this one fungal disease (Tamm et al., 2004).

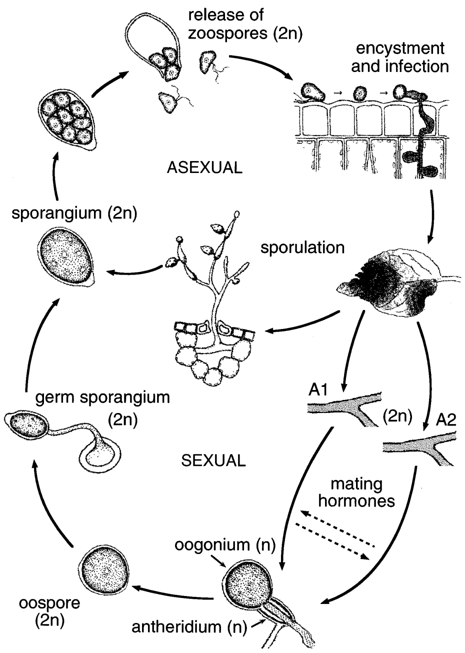


Fig.1.9 Disease (asexual) and sexual cycles of *P. infestans,* adapted from Agrios (1978).

P. Infestans is an oomycete fungus, with both an asexual and sexual life-cycle. Until 1984, only the A1 mating type was present in Europe, but in 1984 the A2 mating type was discovered in Switzerland and later in 1986 was present in Sweden (Hermansen et al., 2000). The sexual life-cycle only occurs in regions where both mating types (A1 and A2) are present and results in the production of sexual spores called oospores which can survive a long periods of time in soil even under extreme climatic conditions (Andersson et al., 1998). Sexual reproduction is thought to accellerate the development of resistance to fungicides and late blight resistance genes in potato varieties (Flier et al., 2007).

However, the spread of the disease and late blight infection epidemics are due to the asexual lifecyle/spores. When the climatic conditions are favourable for *P. infestans*, it can complete its asexual lifecycle in less than five days on potato or tomato foliage (Nowicki et al., 2012). When temperature is 10^0 C or above and humidity is over 75-80% for 2 days or more, *P.infestans* will spread rapidly through potato crops. Typical symptoms of late blight are dark blotches on leaves and plant stems. Under humid conditions, white/grey mould (which consists of the sporangiophores and the fungus's asexual spores called sporangia) becomes visible on the underside of potato leaves and the plant foliage may be destroyed very rapidly (within days).

Environmental and agronomic factors affecting late blight severity

The development of late blight, which is caused by *Phytopthora infestans*, depends to a large extend on climatic conditions and is favoured by wet (especially conditions with free water on leaves) and cool (12-20 °C) weather conditions. Cooler periods in autumn and spring, in nights with high relative humidity and periods of rainfall are ideal for the development and spread of late blight in the Southern Mediterranean region. When temperatures are above 25 ^{0}C there is a much slower development of epidemics and at temperatures over 30 $^{\circ}$C the spread of the disease stops completely. However, when environmental circumstances become more favourable again (high levels of relative wetness), the disease will start to develop again (Giannopolitis, 2011).

Agronomic practices (especially irrigation and fertilisation regimes) were also shown to affect *Phytopthora infestans* severity and epidemic development. For example, applications of high levels of mineral nitrogen to potato crops was shown to increase periods of leaf wetness, increase spore formation, spore germination and accelerate late blight epidemics (Hospers-Brands et al., 2008, Olanya et al., 2007, Ghorbani et al., 2004). Also, as described above, compared to furrow or drip irrigation, sprinkler irrigation increases the severity of late blight by increasing humidity and periods of leaf wetness within the crop (Rowe, 1993).

Control of late blight in conventional potato production systems

Controlling late blight with ordinary methods, is still considered to be a rather difficult task. In conventional production systems, late blight is primarily controlled via fungicide applications especially where consumer demand is for relatively blight susceptible varieties (e.g. Spunta in Greece). However, resistance within the *P. infestans* population against the most widely used oomycete fungicides (e.g. metalaxyl) is increasing in Europe and some of the fungicides used for late blight control may have to be withdrawn from the market in the near future due to environmental and/or concerns about potential negative human health impacts following a review of pesticide use in the EU as part of EU Regulation 1107/2009 (Cooke et al., 2011).

Currently both protective and systemic oomycete fungicides are applied at a very high frequency in many regions to minimise late blight. For example, in the Netherlands, the frequency of sprayings varies from seven to twenty times per season, depending on the weather conditions (if temperature, precipitation favors the appearance or the expansion of *Phtypthora infestans)* and crop growth. Fungicides currently used for late blight control in conventional potato crops include fluazinam, mancozeb, metalaxyl, cyazofamid, mandipropamid, cymoxanil and copper based fungicides (Cooke et al., 2011). The risk of crop failures due to metalaxyl resistance in *P. infestans* has resulted in farmers excluding metalaxyl-M from the spraying programme against blight in some regions of Europe (Hermansen et al., 2000).

Control of late blight in organic potato production systems

The only fungicides currently used (under derogation) in organic farming systems are copper (Cu) fungicides. However, Cu-fungicides are significantly less effective (Palmer, 2013) than the synthetic chemical pesticides available to conventional farmers and there is increasing pressure to omit the use of Cu fungicides completely.

Late blight control in organic farming systems therefore has to rely on an “integrated” crop protection approach based on preventative management, variety resistance and optimum use of Cu-fungicide. For example in the UK as part of the “Fight against Blight” project (Leifert &Wilcockson, 2005), the following management practices were recommended to limit late blight severity in organic potato production: (1) The use of blight-free seed tubers; (2) Removal/destruction volunteer plants and waste potatoes from fields as they can become important sources of late blight inoculum; (3) Monitoring (prediction systems) using weather predictions to optimise the efficacy of Cu-fungicide applications; total Cu-application levels are now restricted to 5 kg Cu per ha and (4) the use of resistance genotypes/varieties (Finckh et al., 2006). Furthermore, results from the EU FP5 Blight-MOP project (Leifert & Wilcockson, 2005) showed that the use of resistant varieties is the most promising approach for reducing yield losses due to late blight in organic farming systems. Specifically, the use of resistant main crop varieties substantially reduced foliar and tuber blight severity and provided high tuber yield levels even in regions with high blight pressure and without additional protection by Cu-fungicides (Ghorbani et al., 2008). Recent studies also showed that the use of chitting/pre-spouting combined with the use of blight resistant varieties can further reduce foliar blight and increase potato yield (Speiser et al., 2006, Hospers-Brands et al., 2008). The EU- Blight MOP project also identified genetic diversification as a potential strategy for late blight control. This may involve planting varieties with different levels of blight resistance as mixtures or in alternative rows or planting them in beds, alternating “fence crops” such as cereals to reduce the spread of the disease. (Ghorbani et al., 2008, Tamm et al., 2004, Speiser et al., 2006).

1.8.2 Other Fungal and bacterial diseases

Although late blight *(Phytopthora infestans)* is the most serious disease of potato and a range of other diseases may cause substantial crop losses in both cool temperate regions (e.g. skin spot and gangrene) and warmer climates (e.g. early blight, bacterial wilt or brown rot) (Wale et al., 2008). However, in the experiments reported here, only late blight occurred at significant levels and other potato diseases are therefore not introduced in detail here.

1.8.3 Colorado (potato) beetle (Leptinotarsa decemlineata)

The Colorado or potato beetle (*Leptinotarsa decemlineata*) is perhaps the most destructive insect pest of potatoes. The pest can also feed and survive on several plants from the *Solanaceae* family including tomato, eggplant, ground cherry, tobacco plants, but is most destructive in potato crops. Cases where Colorado beetles were reported to feed on non-*Solanaceae* plants are rare and non-solanaceous plants are not considered as hosts for this pest (Capinera, 2001).

As with late blight, the pest was introduced into Europe from America. Prior to 1859, the Colorado potato beetle was a rather uncommon pest species present in the arid eastern foothills of the Rocky Mountains, where it fed on buffalo bur (*Solanum rostratum* and *Solanum angustifolium).* Adaptation that led to the beetle becoming a serious pest on cultivated potato species is thought to have taken a period of 40 years. It is now endemic in about 8 million km^2 in North America (Casagrande, 1987).

The first population of Colorado potato beetle in Europe was identified in Germany in 1877. However, until 1922, quarantine measures and eradication campaigns succeeded in keeping the pest out of Europe. However, it then finally established in France and by the end of the 20th century, had become a serious pest all over Europe, Iran, Western Asia, and western China and is now endemic in about 16 million km^2 in North America, Europe and Asia and continues to spread into new regions (Weber, 2003).

Colorado beetle larvae cause the most severe damage with one beetle consuming about 40 cm^2 of potato leaves per day, while adult beetles consume only 9.65 cm^2 of foliage. Once the leaves have been consumed, the pest also feeds on stems and exposed tubers. Epidemics can develop very rapidly due to the beetles high fecundity, with one female laying 300-800 eggs (total fecundity) (Ferro et al., 1985). Under optimum environmental conditions the Colorado potato beetle, may produce up to 4 generations per year, but the number of generations differs depending on the location and the length of the potato growing season.

For instance, in northern and high altitude areas of Europe there may be only one generation, whereas in Southern European regions four generations may occur (Harris, 1992).

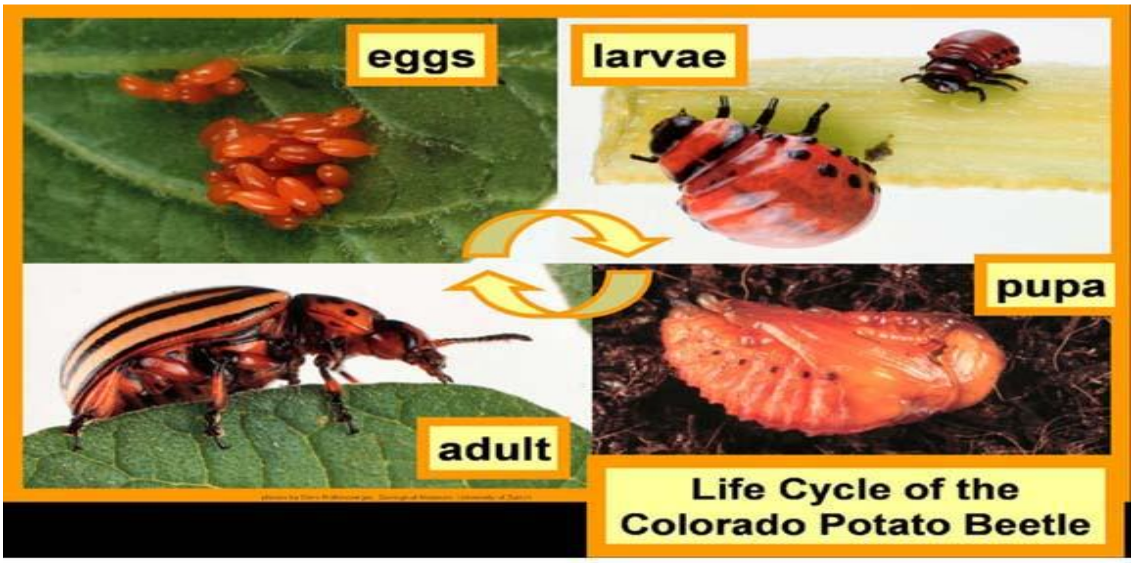
The pest overwinters as adult beetles in the soil, with the majority aggregating to woody areas near to the fields they inhabited during the summer. Eggs are usually laid in groups (usually around 20) on the underside leaves of potatoes, and are thereby protected from the direct sunlight. From the eggs, small reddish larvae emerge, which typically have two rows of black spots (Fig 1.10), start feeding within 24 hours. The time between oviposition and the mature beetle stage (see Fig 1.11) takes between 24-56 days (Weber and Ferro, 1993, Capinera, 2001).

The newly emerged adults need only a few days to develop their reproductive system and flight muscles (Alyokhin and Ferro, 1999) and as soon as their development is completed, the beetles mate and start laying eggs. Adult females deposit about 300 eggs within a period of 4 to 5 weeks. Eggs hatch after 4 to 10 days depending on environmental conditions especially temperature and humidity. Reproduction continues until the diapause starts,which is riggered by short daylength/photoperiod (Capinera, 2001).

Due to Colorado potato beetle's lifecycle , and (a) the overwintering in soil (where it cannot be controlled efficiently/cost effectively by pesticide applications), (b) its ability to migrate to host crops and (c) the high fecundity , make it extremely difficult to eradicate and/or manage the pest with insecticides and other (e.g. biological, cultural and physical) control methods (Voss and Ferro, 1990).

Fig. 1.10 Colorado beetle (larvae) (http://organicgrowersschool.org)

Fig. 1.11 Colorado potato beetles, *Leptinotarsa decemlineata* (Say), feeding on foliage. Photograph by David Cappaert, Michigan State University .(www.insectimages.org.)



Colorado potato beetle (Coleoptera: Chrysomelidae) has four life stages. The adults overwinter in the soil, and have 1 to 3 generations per year depending on food availability and climate. Female adults lay egg masses on potato and other nightshade family plants such as tomato and eggplant. Larvae and adults both feed above ground on the leaves. The insect undergoes complete metamorphosis from larva to adult; the intervening stage, the pupa, develops underground near the host plant.

Fig. 1.12 Life cycle of Colorado potato beetle (www.ars.usda.gov)

Control of Colorado potato beetle in conventional production systems

Potatoes were among the first transgenic crop plants (An et al., 1986). From 1995-2000 in the U.S, potatoes were sold which were genetically modified with *Bacillus thuringiensis* delta-endotoxin, which is toxic to Colorado potato beetle In the beginning, these crops were received well by farmers but after 5 years of use, its demand was discounted because of consumers concerns for genetically modified crops and growers concerns for their agronomic performance compared to non-genetically modified potatoes and competition from a new efficient insecticide imidacloprid (Grafius and Douches, 2008).

It was reported that certain soil amendments make potato plants more resistant to Colorado potato beetle (Alyokhin et al., 2005). More specifically, when manure was applied into the soil, in combination with reduced amounts of synthetic fertilizers, beetle populations were lower compared to plots which were fertilized only with synthetic fertilizers. Following field and laboratory experiments, confirmed that potato plants grown in manure fertilized soils, displayed less Colorado potato beetles compared to plants grown in synthetically fertilized soils. Female fecundity was lower in manure fertilized soils early in the season, although, later there was no difference between the treatments. In the laboratory, first instars consumed less foliage from the plants grown in the manure fertilized soils (Alyokhin and Atlihan, 2005).

In conventional production the main approach for Colorado beetle control is the application of pesticides. The use of pesticide started as early as in 1864 in France with the use of the insecticide Paris green (copper II- acetoarsenite) and continues to the present day. However, this and other arsenic based chemicals (arsenate and calcium arsenate) had to be withdrawn due to their tocicity. The organochlorine pesticides (e.g. DDT), were first tested for Colorado potato beetle control in 1939, and proved to be very effective. However, these also had to be withdrawn due to their toxicity and proven negative impacts on the environment, wildlife and human health (Casagrande, 1987).

In addition the Colorado potato beetle was shown to quickly develop resistance to a wide variety of pesticides and this was first recorded for the organochlorine pesticides with DDT failure to control the pest being reported in 1952 (Hofmaster et al., 1967). According to Jiang et al. (2010), Colorado potato bleetle has developed resistance to 52 synthetic chemical pesticides, and all major groups of insecticides, via a range of different resistance mechanisms. For example evidence for behavioral resistance (the beetle avoiding feeding on treated foliage) was reported in the 1990's (Jackson, 1999). Also resistance was linked to the Colorado potato beetle's capacity to feed on plants from the *Solanacea* family, which have high concentrations of toxic glycoalkaloids in their foliage, which makes them capable of detoxifying or tolerating high levels of toxic compounds in their environment (Ferro, 1993). However on conventional farms insecticides remain the foundation of Colorado beetle control. In many regions the pest is controlled (including North America and Greece) with the chloronicotinyl insecticide imidacloprid. Most potato growers, apply imidacloprid in furrows at planting or directly to seed tubers (Alyokhin, 2009). However, pesticides that

belong to the neonicotinoid insecticides are banned (only seed dressings, not foliar applications) within most countries in the EU, included Greece. According to the Agricultural Ministry of Greece there are other insecticides that are allowed for use against Colorado beetles (e.g chlorpyrifos, ambda-cyhalothrin)
(http://wwww.minagric.gr/syspest/syspest_ENEMY_crops.aspx)

Control of Colorado potato beetle in organic production systems

<u>Cultural and Physical control of Colorado beetle</u>

There are a number of methods available, that can control the Colorado beetle population such as :

(1) crop rotation, is thought to be one of the most effective ways to manage the Colorado potato beetle (Alyokhin, 2009). Research showed that in rotated fields, beetle egg population was 10% less than in non-rotated fields and when potatoes were cultivated following non-host crops (e.g. wheat, rye), adult population of Colorado beetle were reduced up to 95.8% (Wright, 1984).

(2) Flaming can also control the populaion of colorado potato beetle, by preventing their wintering. Best results are shown during the growth period between plant emergence and 8 inches height and overwintering adults can be reduced up to 90% and eggs by 30% (Kuepper, 2003).

(3**)** "Floating row rivers", can minimize the population of Colorado potato beetle. With this method, a thin fabric netting from a synthetic material, is placed over the potato plants, allowing only air and moisture (water) pass through this fabric and at the same time, prevents access to pests (Kuepper, 2003).

(4) The use of plastic-lined trenches, which function as a barrier to colorado potato beetle entering a potato field, can also control colorado potato beetle populations (Boiteau *et al.*,1994). This technique is based on the fact that beetles can walk on plastic mulch at an angle, provided that this plastic mulch is clean, otherwise (if the plastic mulch is covered with soil particles) their movements become impossible (Kuepper, 2003),

(5) The use of portable traps that are placed at the edges of the field, to prevent Colorado potato beetles entering the field after overwintering are also used (Hermansen et al., 2000).

(6) Mulching with wheat or rye straw can also lead to less colorado beetle population. This method, creates a microenvironment that favors the population of colorado beetle predators. Using mulch, could increase the time that is required by the beetles to find potato plants,

increase the number of beetles leaving the area by flight and increase egg and larvae predation (Brust, 1994). It is found that mulched plots had greater numbers of predators compared to non-mulched fields, resulting in less defoliation and increased tuber yield by a third (Kuepper, 2003).

(7) Another method to control Colorado beetle, is by removing them from the potato plants by using artificially created air. Then the removed beetles, are sucked inside the tractor-mounted machine, which actually operates as a vacuum cleaner. Boiteau et al. (1992) reported that vacuum collector removed 40% of small larvae, 27% of large larvae and 48% of adults from the foliage. Moreover, Lacasse et al. (1998) showed that it captured 24% of the first and second instars, 58% of the third instars and 61% of the fourth instars. Instead of capturing the beetles, another method is to allow beetles to fall on the rows between the potato plants and be burnt by propane burner.

Varietal Resistance

Potato is a plant which can tolerate defoliation without a negative impact on the yield. Defoliation up to 30-40% during early growth stages, 10-60% during middle growth stages and up to 100% late in the season, does not affect noticeably the yield (Hare, 1980, Cranshaw and Radcliffe, 1980). When Colorado beetle population density is high and results in defoliation levels above an acceptable threshold, it may lead to significant yield loss. For this reason, a variety which is (a) resistant to Colorado beetle, and has (b) desirable agronomic and sensory and processing characteristis (shape, colour, resistant to become black when fried etc) is a major objective especially for the organic farming sector.

Since the 19^{th} century, host plant resistance was an option in order to deal with Colorado potato beetle. Efforts were focused mainly on finding cultivars highly resistant to beetle feeding (Fisher et al., 2002). Efforts included incorporation of germplasm from other species of Solanum through cross-pollination, transgenic insertion of *Bacillus thurigiensis* genes and a combination of several methods (Cooper et al., 2004, Coombs et al., 2002). Due to the fact that potato breeding is rather complicated by tetraploidy in *S.tuberosum*, no commercial cultivars resistant to Colorado beetles are available in the market (Fisher et al., 2002, Grafius and Douches, 2008, Flanders et al., 1992). Finally, it is obvious that different approaches need to be integrated to achieve optimum control of the pest.

Natural enemies and biological control products for Colorado beetles

Another way to reduce Colorado potato beetle *(Leptinotarsa decemlineata)*, is by using its natural enemies. According to Ferro et al. (1985), even in the absence of insecticides, natural enemies can reach densities that reduce the population of Colorado beetle, below economically damaging levels. There are several anthropod species which attack the Colorado potato beetle, some of them are used as biological control agents and their performance has been reviewed by Hough-Goldstein et al. (1993).

Apart from the natural enemies of Colorado potato beetle which are mentioned above, there are many more **predators** which are occasionally fed with Colorado potato beetle. Some of them are : *Xysticus kochi*, a spider which was fed with Colorado potato beetle in the former Soviet union (Sorokin, 1976), the ground beetle *Pterostichus chalcites*, which was observed in Delaware (Heimpel and Hough-Goldstein, 1992) and the phalangid *Phalangium opillio*, which preys on the Colorado potato beetle eggs and larvae (Drummond et al., 1990).

A **bacterium species**, called *Chromobacterium subtsugae*, has been found to be toxic for the Colorado potato beetle , but its use as a biological control method in the field has to be determined (Martin et al., 2004). A fungus is known to limit Colorado potato beetle densities is *Beauveria bassiana* (Hyphomycetes). The commercial use of this fungus can be applied with a regular pesticide sprayer and is used in organic production systems, showing a beetle population reduction up to 75% (Cantwell et al., 1986), though this method is less efficient compared to conventional insecticides (Campbell et al., 1985).

Undoubtedly, using the natural enemies to control Colorado potato beetle is a valuable option but most of the time they cannot reduce Colorado potato beetle densities below the economically damaging levels. For this reason it is necessary to use them in combination with other control methods. Until now, none of the known biological enemies are capable to deal with the high reproductive rates of Colorado potato beetle. Increasing gradually the number of enemies in order to match the number of Colorado potato beetles, is not practical as the cost to raise and handle them is high (Weber et al., 1994).

Organic Pesticides

In organic production only a small number of botanical pesticides (based on plant extracts) are permitted. Rotenone is derived from root extracts of a South American plant from the *Fabaceae* family. Since it is relatively slow at killing the pests, it is often combined with pyrethrum a pesticide based on extracts from carnations to achieve a more rapid effect. The effect of both pesticides is relatively short, usually lasting two days or less and the timing of applications its therefore critical. Rotenone must be used with caution as it is quite toxic to fish and swine. Rotenone is a therefore a restricted material, which can only be used if a derogation from the organic certifying organisation is obtained. It should only be used only when other, less severe treatment and management approaches fail to provide exert adequate control (Kuepper, 2003).

Laboratory tests showed that there is a wide variety of secondary plant compounds that discourage feeding by Colorado potato beetle adults and larvae (Hsiao and Fraenkel, 1968, Drummond and Casagrande, 1985, Hough-Goldstein, 1990, Szczepanik et al., 2005). Field experiments indicated that seed extract containing azadiractin limited populations of Colorado potato beetle larvae and adults, application of a crude limonoid extract containing 78% limonin and 18% nomilin resulted in a 75% reduction in seasonal egg density and up to 41% reduction in seasonal adult incidence (Murray et al., 1995). Due to the fact that secondary compounds may both deter feeding and act as insecticides as well it is difficult to understand which of those effects was responsible for the decrease of beetle populations (Murray et al., 1995, Zehnder and Warthen, 1988).

Other control methods

Controlling the planting time may help to limit the second-generation larval populations. This may happen because summer-generation adults emerge later in the season on the late-planted crops, the short day photoperiod motivates reproductive diapause thus the second generation larval impact on the crop will be eliminated (Alyokhin, 2009). Early planting also reduces the second generation larvae because the crop has already been removed at the time of their emergence (Weber et al., 1994).

Planting trap crops, which would attract beetles away from the main crop can be effective for the beetles which overwinter, colonizing a field in the spring, as well as move them away from the potato crop, late in the season (Weber et al., 1994). Hunt and Whitfield (1996) used potato trap rows as a perimeter in order to protect tomatoes. Tomato production was 61-87% higher when trap crops were used, compared to control plots. Using mulch, could increase the time that is required by the beetles to find potato plants, increase the number of beetles leaving the area by flight and increase the egg and larvae predation (Weber et al., 1994).

Exposing Colorado beetles, particularly adults colonizing potato plants early, to high temperatures can be used as a control method. In trials, flaming resulted in 90% control of overwintering adult beetles (ATTRA, 2003). The remaining beetles usually suffer from the degeneration of leg muscles and antennae muscles, making it difficult for them to move or eat. The disadvantage of this method though, is that flame treatment of potato plants above 10 cm height, can also cause serious damage to the plant (Khelifi, 2007).

1.8.4 Other important potato pests

Apart from Colorado beetles, potato pests such as *Phthorimaea operculella* (Lepidoptera:Gelechiidae), *Myzus persicae, Aulachortum solani* and *Macrosiphum euphorbiae* (Homoptera: Aphididae) can also cause substantial yield losses in potatoes in Greece and other potato growing areas.

The potato tuber moth *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), also known as potato tuberworm or tobacco splitworm, is an oligophagous pest, an insect feeding on a restricted range of crops belonging to the family Solanaceae (mainly potatoes, tomatoes and tobacco). The insect can cause serious problems to winter planted spring/early summer harvested potato crops and in storage. Adult moths are about 1.5 cm long, and their front wings have black spots (Fig.2.4a) (Ksanthis et al., 2011).

Adults mate and lay eggs in foliage or tubers throughout the growing season, preferring foliage over tubers. When foliage has naturally or artificially sensced and/or tubers are accessible, they deposit eggs in or near the eye buds. The larvae mine leaves, stems, and petioles causing irregular galleries, and excavate tunnels through tubers. Foliar damage to the potato crop usually does not result in significant yield losses but infested tubers may have reduced marketability and losses in storage may be up to 100% especially in non-refrigerated systems (Rondon, 2010).

This lepidopteran pest appears when temperature increase in late May and June and is the main reason why late maturing crops are difficult to grow under Greek conditions. During dry periods in June and July the larvae can reach potato tubers in the soil and cause significant tuber damage and generate wounds for fungal tuber infection and this results in crops having to be harvested as soon as lepidopteran pest is detected in the area.

Fig 1.13 Adult of *Phthorimaea operculella* (http://idtools.org)

Pesticides can and are being used to control the pest in some regions, but often with limited effect, especially against the larvae in soil that cause most of the damage. However, it has been reported that the use of pesticides, the last weeks before harvesting, can substantially reduce tuber infestation by larvae (Ksanthis et al., 2011). Also, tuber applications of *Bacillus thuringiensis,* reduce tuber infection during storage (Rondon, 2010).

The peach potato aphid (*Myzus persicae Aulachortum solani* and *Macrosiphum euphorbiae* Homoptera: Aphididae), can also cause serious problems in potato crops in Greece. However, problems with aphid infestations and other pests of potato were not observed in the experiments reported here. These pests are therefore not described in detail here. The usual method to control aphids are leaf sprayings with pesticides as soon as they appear (Giannopolitis, 2011).

1.9 Tuber yield and quality in organic and conventional potato production

As with other broad acre arable crops (Smith et al., 2008), potato yields are substantially lower in organic compared to conventional production . For example, (de Ponti et al., 2012) reported that tuber yields in organic production systems are on average 80% of conventional yields in Europe with a high variation of the yield gap of organic agriculture (standard variation 21%), with potato scoring less than 80% (de Ponti et al., 2012). This large variable yield gap between organic and conventional potato production may be due to two main reasons. The level of late blight severity (the main potato disease) and certain potato diseases (e.g. potato beetle) being strongly affected by environmental conditions. This would be expected for the more efficient pesticide based crop protection methods available to conventional farmers resulting in a larger yield gap in seasons and/or regions with high disease/pest pressure (Finckh et al., 2006, Tamm et al., 2004, Speiser et al., 2006, Hospers-Brands et al., 2008).

The other main reason may be associated with the differences in fertilisation; where high precipitation levels may have contrasting effects on nitrogen availability in organic and conventional production systems. High rainfall may result in reduced availability of mineral N applied in conventional systems (due to N-losses from leaching and run-off), while it may increase mineralisation capacity and N-release from organic fertiliser inputs in organic systems rainfall organic fertiliser inputs. However, there is virtually no information on the interactions between pedo-climatic conditions and the types of fertiliser used, with respect to tuber yields in organic and conventional systems.

Variability may also be caused by interactions between the contrasting fertilisation and crop protection regimes. For example high mineral nitrogen fertilizer inputs applied to increase tuber yields also increase foliar blight severity (Lambert et al., 2005).

According to Palmer et al. (2013), who carried out long term studies into the effects and interactions between contrasting rotation, fertilisation and crop protection regimes used in organic and conventional farming, the yield gap between organic and conventional production systems is mainly mainly due to differences in (a) fertililisation regimes (resulting in a more sub-optimal N-availability in organic systems) and to a lesser extent (b) crop protection methods (resulting in higher late blight losses in years with high blight pressure). This conclusion was supported by a survey carried out by Tamm et al. (2004) which concluded that sub-optimal N supply was the main reason for lower yields, in organic compared to conventional croping systems. Improving fertilisation regimes in organic farming systems may therefore be the most promising approach to maximise yields and close the yield gap to conventional potato production.

1.10 Aims and objectives of the study

As it is described above, it is clear that agronomic management (fertility treatment and irrigation, crop rotation) and variety choise might affect important factors of potato production like yield, plant infestation with blight and colorado beetle. However at the study area of Messinia; a county with a major role in Greek potato production (a) Spunta variety is mainly used, due to its agronomic characteristics that have set it as the most famous potato variety in Greek market. (b) only conventional potato production systems are used as all the growers believe that by using mineral-NPK fertilizers can achieve the maximium yield and as a result maximum profit. Moreover, crop rotation is not used in a great scale, since there is no market demand for legume crops while (c) the standard irrigation method which is applied in the area is sprinkler irrigation, as it is cheaper compared to drip irrigation system. Therfore the aims and the specific objectives of this study were:

1. To evaluate the suitability of potato varieties for organic potato production in Southern Greece and potential interactions with fertilisation regimes, with specific objectives to ivestigate :

(i) the performance (late blight resistance and yield parameters) of potential alternative varieties (11 varieties) to “Spunta” (the main cultivar currently grown in Greece);

(ii) the variety performance in soils with different previous cropping history either (a) had not been used for potato production for 6 years (left fallow to develop a natural legume/grass/herb vegetation) and (b) soils which had been used for continuous potato production for more than 10 years. Soils with contrasting previous cropping history were used to identify potential effects of differences in soil fertility and potato specific pathogen/pest pressures on the performance of different varieties.

(iii) the interactions between growing season, previous cropping history and variety with respect foliar and tuber blight resistance, and yield parameters.

2. To evaluate the suitability of local available organic fertilizers (with contrasting nutrient content and availability) for organic potato production in Southern Greece and potential interactions with variety, with specific objectives to investigate the effect of:

(i) different organic fertilizer types/ products and regimes (compared to a standard mineral-NPK fertilizer treatment) on the performance (foliar blight resistance and yield parameters) of 4 selected potato varieties. Organic fertilizer types and input levels used reflected treatments typically used or recommended for organic production in other regions of Greece (e.g. the Lasiti area in Crete) and compared to mineral fertilizer treatments typically used by conventional farmers in the Kalamata region;

and

(ii) interactions between growing season, fertility type and variety on foliar and tuber blight resistance, and yield parameters.

3. To evaluate the suitability of sprinkler and drip irrigation systems for organic potato production in Southern Greece and potential interactions between fertilisation regime and variety, with specific objectives to investigate the effect of:

(i) irrigation type (sprinkler vs drip irrigation) on crop health and especially late blight severity and potato yield parameters;
(ii) irrigation level (standard vs 1.5 times higher than the standard) on crop health and especially late blight severity and potato yield parameters;
(iii) interactions between irrigation type, irrigation level, variety and selected fertilization regimes (those that resulted in optimum performance in pot trials)

CHAPTER 2: Effect of growing season (year), previous cropping history and variety on late blight severity, yield and chorophyll levels (SPAD) of 12 potato varieties (pot trials)

2.1 Introduction

Two repeat pot trials were established in 2009 and 2010 to investigate **(a)** the performance (late blight resistance and yield parameters) of potential alternative varieties to "Spunta" (the main cultivar currently grown in Greek conventional and organic production systems) in **(b)** soils with different cropping history (continuous potato vs fallow/natural grass/legume vegetation) in 2 growing seasons with different climatic conditions.

A pot trial approach was used to enable a large number of treatment combinations to be compared which would not have been possible using plot based field trials; This approach also allowed the confounding effect of soil borne disease severity (which is known to occur in fields at Kalamata (e.g. differential nematodedisease pressure) to be minimized.

The factorial design used in pot trial 1 enabled identification of potential interactions between **(a)** growing season, **(b)** previous cropping history and **(c)** variety with respect foliar and tuber blight resistance, and yield.

The **fertility treatment** used in these experiments was sheep manure (from a local semi-intensive sheep producer) plus agrobiosol (a commercial pelleted fertilizer made from alfalfa with a high water soluble N content (Table 2.2) (made in Italy) since combinations of sheep manure and agrobiosol (at the input levels applied in pot trials) are widely used in organic potato production systems in Crete (Nikos Volakakis, personnal communication).

The **12 varieties** included in pot trial 1 were chosen based on existing information on varieties **(a)** being suitable to climatic conditions during the spring potato growing season in Greece and **(b)** having high levels of foliar and tuber blight resistance/tolerance (and in case of Sarpo mira also virus and insect resistance), which are major yield determining crop protection challenges especially in organic production; the standard variety "Spunta" has relatively low blight resistance.

To compare performance in soils with different previous cropping history we used soils which either **(a)** had not been used for potato production for 6 years (left fallow to develop a natural legume/grass/herb vegetation) and **(b)** soils which had been used for continuous potato production for more than 10 years. This aimed at identifying potential effects of differences in **(a)** soil fertility (assumed to be higher in soils previously under natural legume/grass/herb vegetation) and/or **(b)** potato specific pathogen and pest pressure (assumed to be higher in soils continuously cropped with potato) on the performance of different varieties.

2.2 Materials and Methods

2.2.1 Area in which experiments were carried out

The experiments presented were carried out at the west end of Kalamata, in the Messinian prefecture in the Peloponnese, Greece (54:59:09 N; 1: 43:56 W). The main crop grown in this region is potato and especially early potato production due to the climatic conditions and the sandy soils in this area. The pot experiments were carried out in two cropping seasons (2009/2010 and 2010/2011). The field experiments were also repeated in 2 cropping seasons (2013 and 2014).

Figure 2.1 Survey area

2.2.2 Experimental design

<u>**Experiments** were carried out in 2009 and 2010:</u> In both years, two separate experiments were carried out. Soils were collected from 2 different fields which were either cropped continuously with potato or left under natural grass/legume vegetation for more than 5 years respectively. Data from the soils that were used in the experiments are shown in Table 2.1.Soils were mixed with different fertilisers (Table 2.3) and then filled into 21.2 litre pots

(30 cm diameter, 30 cm height) and then used to to cultivate/grow individual potato plants. In each pot it was planted one potato tuber. Pots were arranged in a field at a spacing distance (one near the other) which reflected the standard density of potato plants in commercial conventional production systems in the Kalamata region (30 cm distance between potato plants). The crop was irrigated and grown according to the standard protocol used by local growers in Kalamata region. Irrigation was applied by hand in order to be able to measure the exact amount of water applied.

Pot trial 1. Effect variety (and soil type)

The same factorial experimental design was used in both years (2009 and 2010) and involved **(a)** two soil types/cropping histories (continuous potato cultivation versus more than 5 years natural grass/legume vegetation) **(b)** twelve potato varieties as factors and a randomised block/split plot design, with soil type/cropping history main plots and variety subplots (Figure 2.2 for the arrangement of pots with different treatment combinations in the field).
The **12 varieties** (details for agronomic performance and tuber quality trade of the varieties chosen see Appendix pg. 155-159) included in pot trial 1 were chosen based on existing information on varieties **(a)** being suitable to climatic conditions during the spring potato growing season in Greece and **(b)** having high levels of foliar and tuber blight resistance/tolerance (and in case of Sarpo mira also virus and insect resistance), which are major yield determining crop protection challenges especially in organic production; the standard variety "Spunta" has relatively low blight resistance (AHDB, 2017).
In the area of Kalamata, conventional farmers commonly use mineral N fertilizers inputs of around 900 kg/ha of product, since leaching losses are high in the sandy soils used for potato production. For organic farming systems, the highest fertilization treatment used by farmers (e.g. in the Lasiti region of Crete) and recommended for sandy soils by organic advisors was a combination of sheep manure and agrobiosol which results in the application of 680 kg N/ha.
In pot trial 1 we therefore compared the (a) standard conventional mineral fertilisation regime based on a compound NPK (11:15:15) fertiliser (Yara Hellas). with (b) the highest organic fertilisation regime used/recommended for organic systems in Greece.
Table 2.2 shows the chemical composition of the organic fertilizers that were used in pot experiments and Table 2.3 the amounts of N added with mineral of organic fertilisers in the different fertilisation regimes compared in pot trials. Since 2-factor ANOVA identified no main effect of soil type or interaction between soil types and variety for any of the parameters

assessed in both years, soil type was removed as a factor from the ANOVA. This experiment primarily aimed at assessing late blight resistance and tuber yields in varieties considered as alternatives to Spunta in 2 soils with two previous cropping histories (legume vs potato as pre-crops).

Pot trial 2. Effect of variety and fertilisation treatment

A factorial experiment with **(a)** 7 fertilisation regimes (see description below) and **(b)** 4 potato varieties (Spunta, Lisetta, Remarka and Lady Balfour [in 2009] or Sarpo mira [in 2010]) was established using a randomised block, split plot design, with fertilisation main and variety sub-plots (see Figure 2.3 for the arrangement of pots with different treatment combinations in the field). The choice of the 4 varieties in 2009, was made based on their performance in other projects (EU-Blight MOP). In 2010, the variety Lady Balfour was replaced by Sarpo mira as performance, in the experiment in 2009 was really poor.

The 7 fertilisation regimes included in the second pot trials included (a) the two standard fertilisation regimes recommended/widely used for conventional and organic potato production in sandy soils that were also used in the first pot trials and (b) five additional fertilisation regimes based on three different fertiliser types (a) composted sheep and goat manure (from a local farm), (b) seaweed (*Posidonia oceanica*) compost (obtained from Compost Hellas, Kefalonia, Greece) and (c) Agrobiosol, an organic NPK (7:1:1.5) fertilizer made from alfalfa (Intrachem Hellas) (Table 2.3). The additional fertilisation regimes were designed to identify (a) the effect of replacing sheep manure with a seaweed compost and (b) to reduce the organic fertiliser input rate to half of the recommended N-input level for organic potato production (680 kg N/ha). Fertilisation treatment 4 (sheep manure at a rate equivalent to 340 kg N ha^{-1}) is also commonly used by organic farmers for potato crops in Greece (Nikos Volakakis, personal communication).

All organic fertilisers were analysed for total N content and fertiliser amendements to pots were the adjusted to two different total nitrogen input levels (13.6 and 27.2 g N pot^{-1}) which was equivalent to 340 or 680 kg N ha^{-1}, at the density of pots/plants used in the field experiment (Table 2.3). Specifically, the two composts (seaweed and sheep manure) were applied as % v/v whereas Agrobiosol was applied in gr per pot (Table 2.3). The compound mineral NPK fertiliser was applied at a rate of 35.7 g N pot^{-1} which was equivalent to the 893 kg N ha^{-1}. This experiment primarily aimed at identifying main effects and potential interactions between variety and fertilization regimes with contrasting N-availability pattern on late blight resistance and tuber yields.

Block 1						
V4	V1	V8	V10	V7	V11	Soil 2
V3	V9	V5	V2	V12	V6	
V11	V2	V5	V6	V3	V12	Soil 1
V1	V4	V9	V7	V8	V10	

Block 2						
V6	V2	V1	V5	V12	V9	Soil 1
V3	V8	V4	V7	V11	V10	
V5	V1	V2	V12	V4	V6	Soil 2
V7	V9	V8	V10	V3	V11	

Block 3						
V6	V5	V2	V12	V7	V4	Soil 1
V10	V8	V3	V11	V1	V9	
V11	V3	V9	V12	V1	V4	Soil 2
V7	V2	V10	V5	V8	V6	

Block 4						
V2	V7	V3	V12	V11	V6	Soil 1
V1	V10	V5	V9	V4	V8	
V6	V8	V9	V10	V4	V3	Soil 2
V7	V2	V5	V1	V12	V11	

Block 5						
V1	V6	V7	V3	V10	V8	Soil 1
V12	V2	V4	V11	V9	V5	
V12	V2	V7	V8	V3	V10	Soil 2
V1	V11	V4	V9	V5	V6	

Block 6						
V2	V6	V4	V12	V10	V1	Soil 2
V7	V8	V3	V11	V9	V5	
V6	V10	V8	V7	V10	V5	Soil 1
V2	V11	V12	V3	V4	V9	

Block 7						
V8	V4	V7	V6	V9	V12	Soil 2
V5	V1	V3	V2	V11	V10	
V1	V6	V4	V10	V3	V7	Soil 1
V12	V8	V5	V11	V2	V9	

Block 8						
V6	V1	V4	V12	V7	V2	Soil 2
V8	V9	V3	V11	V10	V5	
V4	V2	V6	V12	V9	V8	Soil 1
V1	V7	V10	V5	V11	V3	

Figure 2.2. Design of experiment 1 in seasons 2009 and 2010. V1: Spunta; V2: Lisetta; V3: Remarka; V4: Lady Balfour; V5: Sarpo mira; V6: Bellini; V7: Sante; V8: Cara; V9: Vales Emerald; V10: Arnova; V11: Vales sovereign; V12: Claret. Soil 1: continuous potato; Soil 2: Fallow

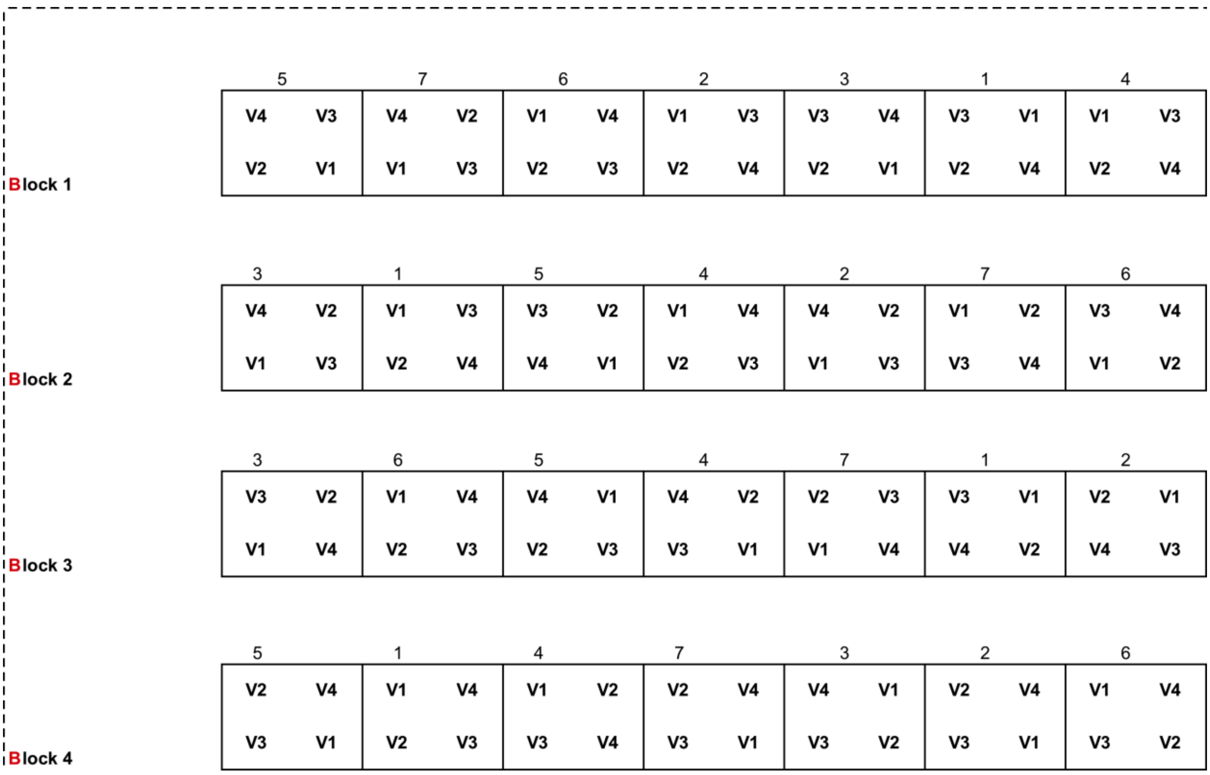


Figure 2.3 Design of experiment 2 in seasons 2009 and 2010. V1: Spunta; V2: Lisetta; V3: Remarka; V4: Lady Balfour at 2009 and Sarpo Mira at 2010. ft 1: S 40%; ft 2: S 50%+ M 50%; ft 3: M 40%; ft 4: A (181,3 g) ft 5: S+A; ft 6: M+A; ft 7: MF

Table 2.1 Soil chemical analysis

Soil type	pH	E.C (µS/cm)	Organic matter (%)	N (ppm)	K (me/100)	Na (me/100)	P (ppm)
Fallow	6.39	130	0.42	18.8	0.221	0.139	9
Cont.Pot.	6.16	113	0.66	21	0.272	0.087	19

Table 2.2 Chemical composition of the 3 organic fertilizers included in pot trials

Organic fertilizer type	Total organic N (%)	Total available N (%)	Total P (%)	Total K (%)	pH	E.C (mS)	Organic matter (%)	Organic C (%)
Seaweed compost	1	0.1	0.8	0.7	7.2	1.03	30	65
Sheep manure	2.5	0.377	0.9	1	7.5	10.1		70
Agrobiosol	7.5	<0.5	1	3	7			90

Table 2.3 Fertlity treatment inputs

Fertility treatments	Compost % (v/v)	Agrobiosol (gr)	Soil % (v/v)	N (g/pot)	N (kg/ha)
1 Seaweed compost (S)	60		40	13.6	340
2 S+M	50 (25+25)		50	13.6	340
3 Manure (M)	40		60	13.6	340
4 Agrobiosol (A)		181.3	100	13.6	340
5 S+A	60	181.3	40	27.2	680
6 M+A	40	181.3	60	27.2	680
7 MF Control				35.7	893*

* Mineral fertility treatment used as control based on the fertility rate that it is used by the farmers in the area.

2.2.3 Assessments

Growth stage

The growth stage of plants in each plot was assessed weekly in each experiment, according to the method described by Hack (2001; Figure 1.5).

Leaf chlorophyll (SPAD)

Leaf chlorophyll was recorded weekly in every pot or plot using a chlorophyll meter (SPAD-502, Konica Minolta Sensing Inc.-Japan). SPAD-502 was developed by Minolta Corporation to determine the chlorophyll status of plants. It measures a leaf area of 6 mm^2 in „SPAD units‟ with accuracy varied ±1.0 unit (Markwell et al., 1995, Richardson et al., 2002). The SPAD-502 utilizes two light-emitting diodes, one at 650nm and one at 940nm, and a photodiode detector to measure in sequence transmission through leaves of red and infrared light (Markwell et al., 1995).

The average SPAD values of the third, fourth and fifth leaves from the growing tip of all plants were recorded as described by (Gianquinto et al., 2006). Leaves included in assessments had recently emerged, but were fully developed and mature. During measurement, the SPAD sensor was placed at random on leaflet mesophyll tissue of each leaf, with veins or leaf disorders avoided (Pinkard et al., 2006). The mean SPAD values per plot from all the weekly assessments was then calculated, recorded and used for statistical analyses.

Late Blight

Potato late blight disease severity (% infected leaf area) was assessed weekly, according to a scoring regime published by Cornell University (http://ppathw3.cals.cornell.edu/fry/protocolos.htm). On leaves with less than 10% of leaf area infected (in visual assessments) the following scoring systems was used: 0.5%= 1-2 spots = 0.5%, 1-3 spots = 2%, 3-6 spots 5%, 6-9 spots = 10% (see Figure 2.6 for the graphic used to "calibrate" disease assessments below 10% ; and for leaves with more than 10% leaf area covered visual estimates of the proportion of leaf area were made.

Data of the percentage infected leaf area were used to calculate the area under the disease progress curve (AUDPC) per plant. The AUDPC, which is the disease intensity (y) integrated between two times (t), was calculated according to the following previously published formula (Shaner and Finney, 1977):

$$\textbf{AUDPC} = \sum_i^{(n-1)} [(y_i+y_{i+1})/2] \quad (t_{i+1} - t_i)$$

Where n= the number of assessments

The units of AUDPC were then standardised by dividing the AUDPC value by the total time duration (tn-t1) of the epidemic, in order to allow comparisons between epidemics of different durations. Assessments of disease severity started when the first disease symptoms were detected. After disease severity in individual pots/plots had reached more than 60% of foliage, the foliage was cut and removed in order to minimize spore transmission to the tubers and other pots/plots.

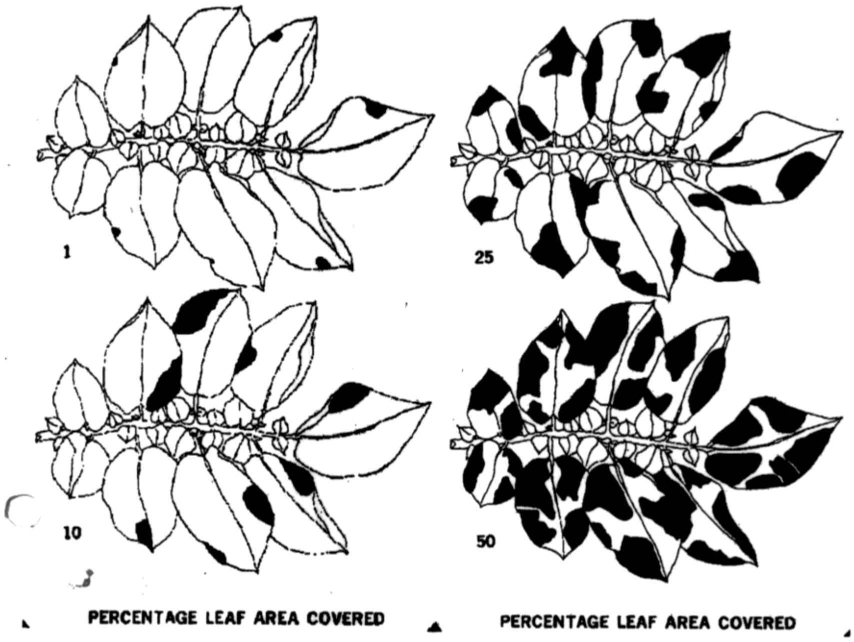


Figure 2.4 Late blight scoring system used (http://ppathw3.cals.cornell.edu/fry/protocolos.htm)

Yield and tuber blight assessment

The method described by Palmer et al. (2013) was used to assess total tuber yield and the total weight and number in different tuber size categories. Total yields were assessed by counting the number of tubers and weighing the total amount of tubers in each pot. Mean tuber weight was assessed by dividing the total tuber weight with the number of tubers in each pot separately.

In addition, the diameter of all tubers per pot was measured separately,and the mean tuber diameter was assessed. Damaged tubers and tubers which were infected by blight or other pathogens were weighed, measured and recorded separately. Data on the mean tuber weight per pot were calculated by dividing the total tuber weight recorded in a specific pot/plant by the number of tubers recorded in the same pot; the mean tuber weights calculated for each pot/plant were then used as replicates in the statistical analyses and to calculated the average mean tuber weights per pot/plant and SEs that are reported in Tables 2.4, 2.5, 2.7, 2.9, 2.11, 3.1, 3.3, 3.4 and 3.6.

Statistical analysis

Non lineral mixed-effects models (Pinheiro and Bates, 2000) were used to analyse the data in a series of analyses to produce ANOVA *p*-values for main effects and all interactions using the nlme (non-linear mixed effects) package in R software (Pinheiro and Bates, 2000). For pot experiment 1 three-factor analysis (ANOVA) with harvest year, previous cropping history and variety as fixed effects were carried out. Data from individual years were used in a model with previous cropping history and variety as fixed effects. For pot experiment 2, a three-factor analysis (ANOVA) with harvest year, fertiliser type and variety as fixed effects was carried out. Data from individual years were used in a model (2 factor ANOVA) with fertiliser type and variety as fixed effect. The hierarchical nature of the split-split plot designs was reflected in the random error structures that were specified as block/ year, fertiliser type.Where analysis at a given level of a factor was carried out, that factor was removed from the random error term. The normality of the residuals of all models was tested using QQ-plots. Differences between the crop management strategies (interaction between factors) were tested using Tukey contrasts in the general linear hypothesis testing (glht) function of the multcomp package in R. A linear mixed effects model was used for the Tukey contrasts, containing a treatment main effect, with four levels, with the random error term specified as described above.

2.3 Results: Effect of growing season (year), previous cropping history and variety on late blight severity, yield and chorophyll levels (SPAD)

The climatic conditions at the survey area, during 2009 and 2010 are shown in Figure 2.5a-d. The main difference in air temperature between years was in March, with mean monthly temperatures substantially higher in 2009 (18.1°C) than in 2010 (12.8°C) (Fig. 2.5a). In contrast, temperatures were similar in both years later in the growing season. (Fig. 2.5a). Precipitation levels in 2009 were substantially higher in March and April (two and three times those recorded in 2010 respectively) but lower than in 2010 in May and June (Fig.2.5b).

Solar radiation was slightly higher in 2009 than 2010 (Fig.2.5c) and as expected higher during May and June (Fig. 2.5c). Relative humidity levels were similar in both years and higher in March and April than May and June in both years (Fig. 2.5d).

Three factor ANOVA identified significant main effects of year and variety, but not pre-crop/soil type on late blight severity and all yield parameters (Table 2.4). Tuber numbers per plant and foliar blight severity were higher in 2009, while total tuber weight, mean tuber weight per plant and mean tuber diameter were higher in 2010 (Table 2.4).

The variety Sarpo mira produce significantly higher **(a)** total tuber weights compared to all other 11 varieties (Table 2.4). Sarpo mira also produced higher tuber number per plant, mean tuber weight and mean tuber diameter than most other varieties (Table 2.4). Overall, the variety Vale Sovereign showed the lowest yield performance of the 12 varieties, although differences with some other varieties were not significant (Table 2.4).

Sarpo mira had significantly lower foliar blight severity compared to all 11 other varieties (Tables 2.4). Also, the variety Sante had significantly higher blight severity than all other 11 varieties, although the difference was not significant for Vales Esmerald and Claret (Table 2.4). Other varieties with relatively low blight severity included Cara and Remarka (Table 2.4).

Symptoms of other foliar diseases and insect infestation remained at very low levels throughout the growing season and below the level at which quantification of severity was possible. Also, no symptoms of nematode infestation could be detected on roots, when plant roots were assessed at harvest.

There were significant interactions between year and variety for **(a)** late blight severity and **(b)** two (tuber number per plant and total tuber weight) of the four yield parameters assessed (Table 2.4). These were further analysed and interaction means/SE and results of Tukey's Honestly Significant Difference tests comparing means are shown in Table 2.5. We also carried out separate 2-factor ANOVAs for other yield parameters assessed in the 2009 and 2010 trials to investigate whether there are trends towards other main effects or interactions if data for the two years are analysed separately (Tables 2.5, 2.7 and 2.9).

When the interactions between season and variety were investigated for late blight severity, tuber number per plant and total tuber weight, similar overall trends were found for all three parameters (Table 2.5). Late late blight disease severity (AUDPC) was approximately 4 times higher in 2009 than 2010 (Table 3.1). In 2009 (the season with high blight severity), relative differences in tuber number per plant, total tuber weight and late blight severity between varieties were greater than in 2010 (the season with the low late blight disease pressure) (Table 2.5). Also the relative effect of season on late blight severity and yield parameters differed between varieties. For example, Sarpo mira (the variety with the lowest late blight severity in both seasons) produced higher tuber numbers in 2009 and a similar total tuber weights in both seasons, while all other varieties had significantly lower tuber yields in 2009 (the season with substantially higher late blight pressure). Also, in 2009, Sarpo mira (the variety with the highest tuber yield) produced more than 10 times higher total tuber weights than Lady Balfour (the variety with the lowest tuber yield in 2009), while in

2010 Sarpo mira (which again produced the highest yield) only had 2 times higher tuber weights than Vales Sovereign (the variety with the lowest yield in 2010) (Table 2.5).

There were significant main effects of variety for all performance parameters, but no significant main effects of previous cropping and no interactions when data for the 2 seasons were analysed separately by 2-factor ANOVA (Tables 2.7 and 2.9). However, in 2009, but not 2010, two-factor ANOVA detected a trend (*P*=0.078) towards a significant higher tuber numbers per plant in soil which had been fallow for 6 years (and was therefore assumed to have higher inherent soil fertility) compared to soils used for continuous potato production (Table 2.7).

Chlorophyll concentrations (estimated based on SPAD meter readings) were used to monitor and compare N-supply from soils for different potato varieties.
Significant main effects of year and soil type on leaf chlorophyll concentration were detected on all but one (the first) assessment dates. Plants assessed in 2009 and those grown in soils collected from fields used for continuous potato showed significantly higher chlorophyll levels (Table 2.6)

There was also a significant main effect of variety on all assessment dates. Varieties fell into three main groups with respect to chlorophyll concentrations. Group 1, which included Remarka and Claret, had high chlorophyll levels throughout the monitoring period (weeks 5 to 11 after planting). Group 2, which only included Sarpo mira, initially had lower chlorophyll levels than the group 1 varieties, but similarly high level later in the monitoring period. Group 3, which included Spunta and all other varieties, had lower chlorophyll levels than the varieties in group 1 on most assessment days. There were interactions between (a) year and the previous cropping history of soils and (b) year and variety. Differences in chlorophyll levels between varieties or the two soil types and were significant in specific years only (individual data not shown).

Table 2.4 Effect of previous cropping history and variety on tuber weight and size and late blight severity (AUDPC)(pot trials 1 and 2, years 2009 and 2010)

Factor	**Tuber number per plant**	**Total tuber weight per plant** (g)	**Average mean tuber weight per plant**[1] (g)	**mean tuber diameter** (mm)	**Late blight severity** (AUDPC)
Year (Y)					
2009	8 ±0.4	163 ±14	16.4 ±1	32 ±1	1161 ±31
2010	7 ±0.3	358 ±14	44.8 ±2	50 ±2	122 ±8
Previous cropping history (PC)					
cont. potato	8.1 ±0.3	264 ±16	29.5 ±1.7	41 ±2	636 ±44
Fallow	7.4 ±0.3	258 ±16	31.7 ±2.0	41 ±2	647 ±44
Variety					
1. Spunta	5.7 ±0.6 **e**	265 ±33 **bc**	41.7 ±6 **a**	50 ±5 **abc**	678 ±97 **bc**
2. Lisetta	8.1 ±0.6 **cd**	241 ±26 **bc**	32.3 ±4 **bc**	53 ±3 **ab**	700 ±114 **bc**
3. Remarka	7.6 ±0.8 **cde**	252 ±41 **bc**	30.5 ±5 **c**	37 ±5 **de**	578 ±91 **cd**
4. L. Balfour	6.1 ±0.8 **de**	191 ±37 **c**	21.0 ±4 **def**	35 ±4 **ef**	632 ±105 **bc**
5. Sarpo Mira	11.0 ±1.0 **a**	553 ±47 **a**	47.6 ±4 **a**	60 ±9 **a**	200 ±44 **e**
6. Bellini	8.0 ±0.6 **cd**	256 ±31 **bc**	31.7 ±4 **bc**	42 ±3 **cde**	694 ±118 **bc**
7. Sante	8.0 ± 0.5 **cde**	223 ±30 **bc**	27.4 ±4 **cde**	39 ±3 **cde**	868 ±136 **a**
8. Cara	8.4 ±0.8 **bc**	289 ±42 **b**	28.6 ±4 **cde**	34 ±3 **ef**	504 ±78 **d**
9. Vales Esmer.	8.3 ±0.8 **c**	185 ±29 **cd**	19.5 ±3 **ef**	31 ±3 **ef**	753 ±120 **ab**
10. Arnova	7.4 ±0.7 **cde**	291 ±37 **b**	41.0 ±5 **ab**	46 ±3 **bcd**	660 ±102 **bc**
11. Vales Sov.	3.5 ±0.6 **f**	107 ±27 **d**	16.1 ±4 **f**	24 ±4 **f**	680 ±110 **bc**
12. Claret	10.4 ±0.8 **ab**	277 ±39 **b**	29.6 ±4 **cd**	40 ±3 **cde**	749 ±112 **ab**
ANOVA					
Main Effects					
Year (Y)	**0.0337**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Previous Cropping (PC)	0.1466	0.7553	0.3194	0.8674	0.7418
Variety (V)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions					
Y x CH	ns	ns	***0.0952***	ns	ns
Y x V	**0.0094**	**0.0078**	ns	ns	**<0.001**
CH x V	ns	ns	ns	ns	ns
Y x CH x V	ns	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated.

Table 2.5 Effect of previous cropping history and variety on tuber yield parameters and late blight severity (AUDPC) in 2 different seasons (pot trials 1 and 2, years 2009 and 2010)

	Tuber number per plant		**Total tuber weight (g) per plant**		**Average mean tuber weight per plant[1] (g)**	
Factor	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**
Previous Cropping						
Continuous potato	9.1 ±0.5	7.1 ±0.4	180 ±21	347 ±21	17 ±1	42 ±2
Fallow	7.6 ±0.5	7.1 ±0.4	146 ±20	369 ±20	16 ±2	48 ±3
Variety						
1. Spunta	5.3 ±0.8 **D** **a**	6.2 ±0.8 **BC** **a**	150 ±25 **B** **b**	380 ±46 **BC** **a**	24 ±4 **B** **b**	60 ±9 **A** **a**
2. Lisetta	9.6 ±0.7 **ABC** **a**	6.5 ±0.6 **B** **b**	154 ±15 **B** **b**	329 ±39 **BC** **a**	16 ±1 **BCDE** **b**	49 ±6 **AB** **a**
3. Remarka	8.9 ±1.2 **C** **a**	6.2 ±1.1 **BC** **a**	146 ±45 **B** **b**	358 ±59 **BC** **a**	15 ±4 **CDEF** **b**	46 ±8 **ABC** **a**
4. L. Balfour	4.4 ±1.0 **D** **b**	7.9 ±1.2 **AB** **a**	40 ±11 **C** **b**	342 ±51 **BC** **a**	6 ±1 **FG** **b**	36 ±5 **BCD** **a**
5. S.Mira	12.6 ±1.8 **A** **a**	9.4 ±0.7 **A** **b**	586 ±89 **A** **a**	520 ±34 **A** **a**	39 ±6 **A** **b**	56 ±3 **A** **a**
6. Bellini	8.8 ±1.0 **C** **a**	7.3 ±0.7 **AB** **a**	148 ±19 **B** **b**	363 ±46 **BC** **a**	17 ±3 **BCD** **b**	46 ±6 **ABC** **a**
7. Sante	8.4 ±1.0 **C** **a**	7.6 ±0.7 **AB** **a**	94 ±15 **BC** **b**	351 ±35 **BC** **a**	11 ±1**DEFG** **b**	44 ±4 **ABCD** **a**
8. Cara	9.3 ±1.1 **BC** **a**	7.6 ±1.2 **AB** **a**	187 ±41 **B** **b**	391 ±64 **ABC** **a**	19 ±3 **BCD** **b**	38 ±6 **BCD** **a**
9. Vales ES.	9.4 ±1.2 **BC** **a**	7.3 ±1.1 **AB** **a**	91 ± 7 **BC** **b**	279 ±45 **CD** **a**	8 ±1 **EFG** **b**	31 ±4 **CD** **a**
10. Arnova	8.3 ±1.1 **C** **a**	6.5 ±0.9 **B** **a**	164 ±24 **B** **b**	418 ±55 **AB** **a**	23 ±3 **BC** **b**	59 ±8 **A** **a**
11. V.Sov.	2.9 ±0.9 **D** **a**	4.1 ±0.9 **C** **a**	35 ±14 **C** **b**	178 ±46 **D** **a**	6 ±2 **G** **b**	26 ±6 **D** **a**
12. Claret	12.2 ±1.2 **AB** **a**	8.6 ±0.8 **AB** **b**	163 ±54 **B** **b**	390 ±40 **ABC** **a**	13 ±5 **DEFG** **b**	46 ±5 **ABC** **a**
ANOVA						
Main effects						
Previous cropping (PC)	***0.0777***	ns	ns	ns	ns	ns
Variety (V)	**<0.001**	**0.0076**	**<0.001**	**0.0014**	**<0.001**	**0.0006**
Interaction						
PC x V	ns	ns	ns	ns	ns	ns

Means labelled with the same letter upper case letter within the same column and the same low case letter within the same row for the same parameter are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated.

Table 2.5 cont. Effect of previous cropping history and variety on tuber yield parameters and late blight severity (AUDPC) in 2 different seasons (pot trials 1 and 2, years 2009 and 2010)

	Mean tuber diameter (mm)				**Late blight Severity (AUDPC)**			
Factor	**2009**		**2010**		**2009**		**2010**	
Previous cropping								
Continuous potato	33 ±1.6		49 ± 4		1155 ± 44		117 ±10	
Fallow	31 ±1.7		52 ± 2		1167 ± 42		127 ±12	
Variety								
1. Spunta	39 ±6 **AB**	**b**	61 ± 6 **AB**	**a**	1149 ± 75 **CD**	**a**	207 ±58 **A**	**b**
2. Lisetta	42 ±1 **A**	**b**	63 ± 5 **AB**	**a**	1293 ± 80 **BC**	**a**	106 ±13 **C**	**b**
3. Remarka	26 ±3 **CDE**	**b**	48 ± 8 **BCD**	**a**	1052 ± 66 **DE**	**a**	105 ±12 **CD**	**b**
4. L. Balfour	24 ±4 **DE**	**b**	45 ± 6 **BCD**	**a**	1174 ± 76 **BCD**	**a**	89 ±16 **CD**	**b**
5. S.Mira	43 ±6 **A**	**b**	76 ±17 **A**	**a**	362 ± 68 **F**	**a**	39 ± 7 **D**	**b**
6. Bellini	35 ±3 **ABC**	**a**	48 ± 5 **BCD**	**a**	1270 ±115 **BC**	**a**	118 ±12 **BC**	**b**
7. Sante	30 ±2 **BCD**	**b**	49 ± 5 **BCD**	**a**	1588 ± 84 **A**	**a**	149 ±22 **ABC**	**b**
8. Cara	31 ±3 **BCD**	**a**	38 ± 6 **CD**	**a**	903 ± 62 **E**	**a**	104 ±10 **CD**	**b**
9. Vales ES.	25 ±3 **DE**	**a**	37 ± 5 **CD**	**a**	1375 ± 84 **B**	**a**	131 ±24 **BC**	**b**
10. Arnova	39 ±3 **AB**	**a**	54 ± 6 **BC**	**a**	1196 ± 67 **BCD**	**a**	125 ±16 **BC**	**b**
11. V.Sov.	18 ±4 **E**	**a**	31 ± 7 **D**	**a**	1254 ± 78 **BCD**	**a**	106 ±16 **CD**	**b**
12. Claret	28 ±2 **CD**	**b**	53 ± 3 **BC**	**a**	1315 ± 85 **BC**	**a**	182 ±44 **AB**	**b**
ANOVA								
Main effects								
Previous cropping (PC)	ns		ns		ns		ns	
Variety (V)	**<0.001**		**0.0010**		**<0.001**		**0.0008**	
Interaction								
PC x V	ns		ns		ns		ns	

Means labelled with the same letter upper case letter within the same column and the same low case letter within the same row for the same parameter are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

Table 2.6 Effect of previous cropping history and variety on SPAD at different growth stages in 2 different seasons (pot trials 1 and 2 , years 2009 and 2010)

Year (Y)	**SPAD 1** (51 days after planting)	**SPAD 2** (59 days after planting)	**SPAD 3** (67 days after planting)	**SPAD 4** (75 days after planting)	**SPAD 5** (83 days after planting)
2009	51.8±0.59	49.9±0.42	48.8±0.36	46.3±0.3	42.2±0.32
2010	50.5±0.38	47.3±0.42	45.2±0.39	43.2±0.42	39.2±0.54
Previous cropping (PC)					
Continuous potato	51.4±0.53	49.5±0.43	48.1±0.36	46.2±0.33	42±0.49
Fallow	50.9±0.45	47.7±0.41	45.9±0.42	43.4±0.39	39.6±0.39
Variety (V)					
1. Spunta	53±1.43 **abcd**	50.3±1.09 **bcd**	48.9±0.8 **bc**	46.5±0.73 **ab**	44±1.23 **a**
2. Lisetta	47.2±0.77 **fg**	45.3±0.78 **e**	43.4±0.81 **f**	42.2±0.77 **d**	39.8±0.81 **de**
3. Remarka	54.9±0.75 **ab**	52.1±0.91 **abc**	49.7±0.71 **ab**	46.7±0.83 **ab**	42.6±0.74 **abc**
4. L. Balfour	46±1.32 **g**	44.3±1.12 **e**	43.4±0.88 **f**	41.4±0.81 **d**	38.2±0.85 **ef**
5. S.Mira	52.6±0.68 **bcd**	50±0.87 **bcd**	49.4±0.59 **abc**	47.8±0.66 **ab**	43.1±0.71 **ab**
6. Bellini	53.4±1 **abc**	50.6±0.71 **bcd**	47.5±0.85 **cd**	44.6±0.85 **c**	40.8±0.83 **bcde**
7. Sante	50.1±0.93 **de**	45.5±0.97 **e**	44.3±0.82 **ef**	41.7±0.92 **d**	36.7±1.31 **f**
8. Cara	50.2±1.16 **de**	48.9±0.57 **d**	47.5±0.65 **cd**	46±0.67 **bc**	41.2±0.8 **bcd**
9. Vales ES.	47.8±1.23 **efg**	44.2±1.18 **e**	43.4±1.31 **f**	41.5±1.24 **d**	36.6±2.06 **f**
10. Arnova	52±1.27 **bcd**	49.4±1.08 **cd**	46.3±1 **de**	44.3±0.88 **c**	41.3±0.86 **abcd**
11. V.Sov.	50.6±1.36 **cde**	49±0.77 **d**	48.8±0.87 **bc**	46±0.71 **bc**	40.5±1.18 **cde**
12. Claret	55.8±0.99 **a**	53.2±0.87 **a**	51.4±0.8 **a**	48.5±0.8 **a**	42.3±0.91 **abc**
ANOVA					
Main effects					
Year (Y)	0.0863	**0.0023**		**0.001**	**0.003**
Previous cropping (PC)	0.4393	**0.0075**	**0.001**	**<0.001**	**0,003**
Variety (V)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions					
Y x PC	**0.0224**	ns	**0.0122**	**0.001**	**0.0151**
Y x V	ns	ns	**0.0079**	**0.0148**	**0.0002**
PC x V	ns	ns	ns	ns	ns
Y x PC x V	ns	ns	ns	ns	ns

Means labelled with the same letter upper case letter within the same column and the same low case letter within the same row for the same parameter are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

Table 2.7 Effect of previous cropping history and variety on tuber weight and size and late blight severity (AUDPC)(pot trial 1, year 2009)

Factor	Tuber number per plant	Total tuber weight per plant (g)	Average mean tuber weight per plant[1] (g)	Mean tuber diameter (mm)	Late blight Severity AUDPC
Previous cropping (PC)					
cont. potato	9.1 ±0.5	180 ±21	17 ±1	33 ±1.6	1155 ± 44
Fallow	7.6 ±0.5	146 ±20	16 ±2	31 ±1.7	1167 ± 42
Variety (V)					
1. Spunta	5.3 ±0.8 **d**	150 ±25 **b**	24 ±4 **b**	39 ±6 **ab**	1149 ± 75 **cd**
2. Lisetta	9.6 ±0.7 **abc**	154 ±15 **b**	16 ±1 **bcde**	42 ±1 **a**	1293 ± 80 **bc**
3. Remarka	8.9 ±1.2 **c**	146 ±45 **b**	15 ±4 **cdef**	26 ±3 **cde**	1052 ± 66 **de**
4. L. Balfour	4.4 ±1.0 **d**	40 ±11 **c**	6 ±1 **fg**	24 ±4 **de**	1174 ± 76 **bcd**
5. S.Mira	12.6 ±1.8 **a**	586 ±89 **a**	39 ±6 **a**	43 ±6 **a**	362 ± 68 **f**
6. Bellini	8.8 ±1.0 **c**	148 ±19 **b**	17 ±3 **bcd**	35 ±3 **abc**	1270 ±115 **bc**
7. Sante	8.4 ±1.0 **c**	94 ±15 **bc**	11 ±1 **defg**	30 ±2 **bcd**	1588 ± 84 **a**
8. Cara	9.3 ±1.1 **bc**	187 ±41 **b**	19 ±3 **bcd**	31 ±3 **bcd**	903 ± 62 **e**
9. Vales ES.	9.4 ±1.2 **bc**	91 ±7 **bc**	8 ±1 **efg**	25 ±3 **de**	1375 ± 84 **b**
10. Arnova	8.3 ±1.1 **c**	164 ±24 **b**	23 ±3 **bc**	39 ±3 **ab**	1196 ± 67 **bcd**
11. V.Sov.	2.9 ±0.9 **d**	35 ±14 **c**	6 ±2 **g**	18 ±4 **e**	1254 ± 78 **bcd**
12. Claret	12.2 ±1.2 **ab**	163 ±54 **b**	13 ±5 **defg**	28 ±2 **cd**	1315 ± 85 **bc**
ANOVA					
Main effects					
Previous Cropping (PC)	***0.0777***	ns	ns	ns	ns
Variety (V)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interaction					
PC x V	ns	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated.

Table 2.8 Effect of previous cropping history and variety on SPAD at different growth stages (pot trial 1, year 2009)

Previous cropping (PC)	**SPAD 1** (51 days after planting)	**SPAD 2** (59 days after planting)	**SPAD 3** (67 days after planting)	**SPAD 4** (75 days after planting)	**SPAD 5** (83 days after planting)
cont. potato	51.2±0.91	50.2±0.61	49.3±0.51	46.7±0.45	42.3±0.48
Fallow	52.5±0.72	49.5±0.56	48.3±0.49	46±0.41	42±0.43
Variety (V)					
1. Spunta	52.9±2.85 **ab**	51.7±1.83 **ab**	49.3±1.12 **bcd**	47.3±0.89 **ab**	43.2±1.42
2. Lisetta	46.9±1.08 **d**	47±0.95 **cd**	46.2±0.95 **ef**	43.6±0.84 **cd**	41.3±0.92
3. Remarka	56±1.36 **a**	53.2±1.45 **ab**	51.3±1.1 **ab**	48.3±0.8 **a**	43.7±0.91
4. L. Balfour	47±2.81 **cd**	46±1.93 **d**	43.6±1.52 **f**	42.5±1.02 **d**	39.3±1.11
5. S.Mira	52.4±1.23 **abc**	50.6±1.3 **abc**	50.3±0.99 **abc**	48±0.73 **a**	42.4±1.01
6. Bellini	54.7±1.72 **ab**	52.3±1.05 **ab**	50.4±0.95 **abc**	47.3±0.92 **ab**	42±1.12
7. Sante	51.3±1.79 **abcd**	47.8±1.35 **cd**	46±1.16 **ef**	43.4±1.25 **cd**	40±1.84
8. Cara	52.2±1.73 **abc**	49.7±0.75 **bcd**	49.1±0.65 **bcd**	47.1±0.72 **ab**	42.1±0.74
9. Vales ES.	51.7±1.67 **abcd**	47.8±1.26 **cd**	47.3±1.24 **de**	45.2±1.2 **bc**	42.5±1.35
10. Arnova	51.7±2.02 **abcd**	49.9±1.6 **abc**	48.2±1.48 **cde**	45.3±0.99 **bc**	42.3±0.83
11. V.Sov.	49.1±3.14 **bcd**	49.6±0.98 **bcd**	50.9±0.72 **abc**	48.3±0.52 **a**	43.6±1.05
12. Claret	55.5±1.58 **a**	53.3±1.3 **a**	52.9±0.82 **a**	49.5±0.9 **a**	43.4±1.07
ANOVA					
Main effects					
Previous Cropping (PC)	ns	ns	ns	ns	ns
Variety (V)	**0.0244**	**0.0004**	**<0.001**	**<0.001**	*0.0953*
Interactions					
PC x V	ns	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

Table 2.9 Effect of previous cropping history and variety on tuber weight and size and late blight severity (AUDPC)(pot trial 2, year 2010)

Factor	**Tuber number per plant**	**Total tuber weight per plant (g)**	**Average mean tuber weight per plant[1] (g)**	**Mean tuber diameter (mm)**	**Late blight Severity AUDPC (% x days)**
Previous cropping (PC)					
cont. potato	7.1 ±0.4	347 ±21	42 ±2	49 ±4	117 ±10
Fallow	7.1 ±0.4	369 ±20	48 ±3	52 ±2	127 ±12
Variety (V)					
1. Spunta	6.2 ±0.8 **bc**	380 ±46 **bc**	60 ±9 **a**	61 ±6 **ab**	207 ±58 **a**
2. Lisetta	6.5 ±0.6 **b**	329 ±39 **bc**	49 ±6 **ab**	63 ±5 **ab**	106 ±13 **c**
3. Remarka	6.2 ±1.1 **bc**	358 ±59 **bc**	46 ±8 **abc**	48 ±8 **bcd**	105 ±12 **cd**
4. L. Balfour	7.9 ±1.2 **ab**	342 ±51 **bc**	36 ±5 **bcd**	45 ±6 **bcd**	89 ±16 **cd**
5. Sarpo Mira	9.4 ±0.7 **a**	520 ±34 **a**	56 ±3 **a**	76 ±17 **a**	39 ± 7 **d**
6. Bellini	7.3 ±0.7 **ab**	363 ±46 **bc**	46 ±6 **abc**	48 ±5 **bcd**	118 ±12 **bc**
7. Sante	7.6 ±0.7 **ab**	351 ±35 **bc**	44 ±4 **abcd**	49 ±5 **bcd**	149 ±22 **abc**
8. Cara	7.6 ±1.2 **ab**	391 ±64 **abc**	38 ±6 **bcd**	38 ±6 **cd**	104 ±10 **cd**
9. Vales Esmer.	7.3 ±1.1 **ab**	279 ±45 **cd**	31 ±4 **cd**	37 ±5 **cd**	131 ±24 **bc**
10. Arnova	6.5 ±0.9 **b**	418 ±55 **ab**	59 ±8 **a**	54 ±6 **bc**	125 ±16 **bc**
11. Vales Sov.	4.1 ±0.9 **c**	178 ±46 **d**	26 ±6 **d**	31 ±7 **d**	106 ±16 **cd**
12. Claret	8.6 ±0.8 **ab**	390 ±40 **abc**	46 ±5 **abc**	53 ±3 **bc**	182 ±44 **ab**
ANOVA					
Main effects					
Previous Cropping (PC)	0.8888	0.4495	0.1736	0.5780	0.5537
Variety (V)	**0.0076**	**0.0014**	**0.0006**	**0.0010**	**0.0008**
Interaction					
PC x V	0.4255	0.4942	0.2160	0.3999	0.8981

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated.

Table 2.10 Effect of previous cropping history and variety on SPAD at different growth stages (pot trial 2,year 2010)

Previous cropping (PC)	**SPAD 1** (51 days after planting)	**SPAD 2** (59 days after planting)	**SPAD 3** (67 days after planting)	**SPAD 4** (75 days after planting)	**SPAD 5** (83 days after planting)
cont. potato	51.6±0.54	48.7±0.61	47±0.47	45.7±0.5	41.5±0.91
Fallow	49.4±0.5	45.8±0.55	43.5±0.57	40.7±0.55	37.2±0.55
Variety (V)					
1. Spunta	53.2±0.58 **b**	48.8±1.12 **bc**	48.5±1.16 **ab**	45.8±1.15 **abc**	45.2±2.18 **a**
2. Lisetta	47.5±1.13 **cd**	43.6±1.12 **d**	40.7±0.91 **fg**	40.8±1.24 **ef**	37.8±1.25 **cde**
3. Remarka	54.1±0.8 **ab**	51.2±1.12 **ab**	48.1±0.75 **abc**	45.2±1.35 **abc**	41.7±1.11 **abc**
4. L. Balfour	45.1±0.84 **de**	42.6±1.04 **de**	43.1±0.94 **ef**	40.2±1.21 **f**	37.1±1.27 **de**
5. Sarpo Mira	52.7±0.73 **b**	49.5±1.18 **bc**	48.6±0.59 **ab**	47.6±1.12 **a**	43.7±1.01 **ab**
6. Bellini	52.1±0.96 **b**	48.8±0.72 **bc**	44.4±0.94 **de**	41.8±1.06 **def**	39.6±1.17 **bcd**
7. Sante	49±0.38 **c**	43.2±1.16 **d**	42.8±1.06 **ef**	39.9±1.22 **f**	34.3±1.53 **ef**
8. Cara	48±1.32 **c**	48±0.84 **c**	45.6±0.98 **cde**	44.8±1.11 **bc**	40.2±1.48 **bcd**
9. Vales Esmer.	43.4±0.87 **e**	39.8±1.37 **e**	38.6±1.74 **g**	36.9±1.62 **g**	30.7±3.09 **f**
10. Arnova	52.2±1.59 **b**	48.9±1.48 **bc**	44.5±1.21 **de**	43.1±1.46 **cde**	40.1±1.62 **bcd**
11. Vales Sov.	51.7±0.44 **b**	48.6±1.17 **bc**	46.9±1.39 **bcd**	43.9±1.03 **cd**	37.9±1.73 **cde**
12. Claret	56.2±1.21 **a**	53.1±1.18 **a**	49.9±1.31 **a**	47.2±1.36 **cd**	40.7±1.56 **abcd**
ANOVA					
Main effects					
Previous Cropping (PC)	**0.0199**	**0.0028**	**0.0006**	**0.0002**	**0.0016**
Variety (V)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions					
PC x V	ns	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

Table 2.11 Effect of previous cropping history and variety on number of tubers per ha and total tuber weight in tones per ha (pot trials 1 and 2 , years 2009 and 2010)

Factor	**Tuber number per ha**	**Tuber yield t ha^{-1}**	**Average mean tuber weight per plant**[1] (g)	**Mean tuber diameter** (mm)	**Late blight severity** (AUDPC)
Year (Y)					
2009	417512 ±14853	8.2 ±0.69	16.4 ±1	32 ±1	1161 ±31
2010	367747 ±9035	18.6 ±0.5	44.8 ±2	50 ±2	122 ±8
Previous cropping (PC)					
cont. potato	411706 ±13197	13.5 ±0.7	29.5 ±1,7	41 ±2	636 ±44
Fallow	374447 ±11681	13.2 ±0.8	31.7 ±2,0	41 ±2	647 ±44
Variety (V)					
1. Spunta	301231 ±19466**ef**	14.0 ±1.4**bc**	41.7 ±6 **a**	50 ±5 **abc**	678 ±97 **bc**
2. Lisetta	369889 ±22330**cde**	11.1 ±1.1**cde**	32.3 ±4 **bc**	53 ±3 **ab**	700 ±114 **bc**
3. Remarka	396704 ±31375**bcd**	13.3 ±1.9**bc**	30.5 ±5 **c**	37 ±5 **de**	578 ±91 **cd**
4. L. Balfour	348441 ±33914**def**	10.9 ±1.9**cde**	21.0 ±4 **def**	35 ±4 **ef**	632 ±105 **bc**
5. Sarpo Mira	539458 ±36891**a**	27.1 ±1.7**a**	47.6 ±4 **a**	60 ±9 **a**	200 ±44 **e**
6. Bellini	384670 ±24089**cd**	12.5 ±1.3**bcd**	31.7 ±4 **bc**	42 ±3 **cde**	694 ±118 **bc**
7. Sante	368455 ± 20109**cde**	10.2 ±1.3**de**	27.4 ±4 **cde**	39 ±3 **cde**	868 ±136 **a**
8. Cara	444440 ±24539**g**	15.2 ±1.8**b**	28.6 ±4 **cde**	34 ±3 **ef**	504 ±78 **d**
9. Vales Esmer.	439502 ±26345**bc**	9.8 ±1.3**de**	19.5 ±3 **ef**	31 ±3 **ef**	753 ±120 **ab**
10. Arnova	349626 ±29736**de**	13.8 ±1.6**bc**	41.0 ±5 **ab**	46 ±3 **bcd**	660 ±102 **bc**
11. Vales Sov.	259647 ±24570**f**	8.0 ±1.6**e**	16.1 ±4 **f**	24 ±4 **f**	680 ±110 **bc**
12. Claret	461107 ±34319**b**	12.3 ±1.7**cd**	29.6 ±4 **cd**	40 ±3 **cde**	749 ±112 **ab**
ANOVA					
Main Effects					
Year (Y)	**0.130**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Previous Cropping (PC)	0.0309	ns	0.3194	0.8674	0.7418
Variety (V)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions					
Y x PC	ns	ns	***0.0952***	ns	ns
Y x V	**<0.001**	**<0.001**	ns	ns	**<0.001**
PC x V	ns	ns	ns	ns	ns
Y x PC x V	ns	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); **[1]**, see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated.

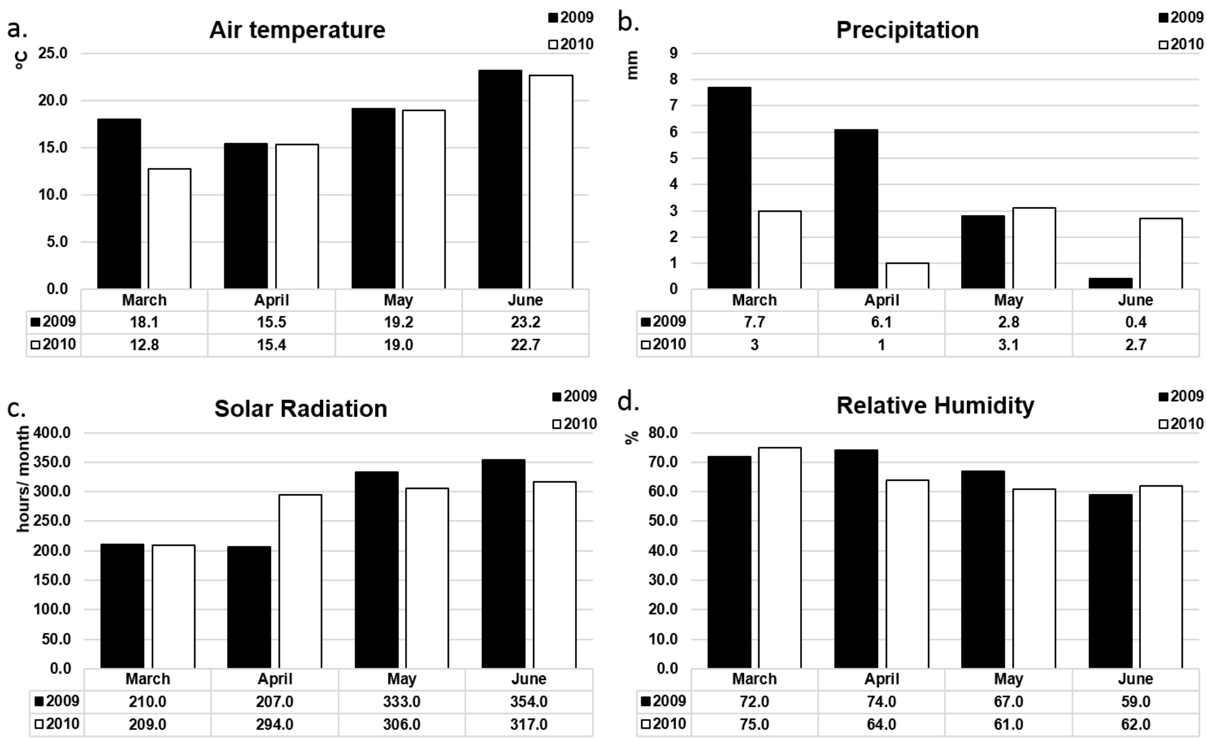


Figure 2.5(a-d) Air temperature, precipitation*, solar radiation (total sun hours per month) and relative humidity for 2009 and 2010 harvest years

*precipitation is presented as total mm per month.

2.4 DISCUSSION: Effect of growing season (year), previous cropping history and variety on late blight severity, yield and chorophyll levels (SPAD)

Virtually no differences in performance (disease severity and yield parameters) could be detected in plants grown in **(a)** soils used previously for continuous potato cultivation (which were assumed to have higher pest and disease inoculum levels) and **(b)** soils from fallow fields in which potato had not been grown for 6 years. This could indicate that **(a)** there was no difference in inherent soil fertility between the two soils, and/or **(b)** that the fertilisation treatments used compensated fully for any differences in inherent soil fertility.

However, there were significant differences in yield and foliar blight between the 12 varieties included in pot trials 1 and 2. In organic production foliar blight control is one of the main challenges, since the Cu-fungicides which are permitted for use (under derogation only) in organic farming are less efficient than the synthetic chemical fungicides available to conventional farmers (Palmer et al. 2013). This applies, in particular, to the potato growing areas in the Peleponnese region of Greece were high level of rainfall and long periods of wet or humid conditions (which favour late blight development (Olanya et al., 2007) are common in both the winter/spring and autumn growing period.

Disease management in organic farming therefore has to rely more on the use resistant/tolerant varieties (Speiser et al., 2006) or cultural methods such as optimising planting configurations and dates, and pre-sprouting (Karalus and Rauber, 1977; Hospers-Brands et al. 2008).

In Greece there is a particular demand of large tubers, since potatoes are primarily consumed fried (French fries, chips) or oven baked (BPC, 2006). The finding that Sarpo mira produced the highests mean tuber weights, but also had the lowests foliar blight severity and largest mean tuber size in both seasons, suggests that it is a suitable replacement for Spunta, under the agronomic and climatic conditions on the Peloponnese, and especially for organic production.

This conclusion is supported by previous studies which demonstrated that Sarpo mira has a very high level of foliar blight resistance/tolerance in a different regions of Europe with contrasting genetic population structures of P*hytopthora infestans* (Speiser et al., 2006, Flier et al., 2007, Palmer et al., 2013). Previous reports also suggested that Sarpo mira has a high yield potential and nutrient use efficiency especially from organic fertiliser inputs (Palmer et al., 2013, Swain et al., 2014). The finding that Sarpo mira produced similar total tuber weights in two seasons with very contrasting late blight severity and the greater relative differences in yields compared to other varieties in the season with the high blight pressure indicate that the higher yield in Sarpo mira was primarily due to its high levels of late blight resistance/tolerance, but superior nutrient use efficiency may also have contributed to the higher tuber yields. It is interesting to note that the varieties Remarka (which had previously shown the highests high late blight resistance and yield in trials in Switzerland; (Speiser et al., 2006) and Lady Balfour (which showed high late blight resistance and yields in UK variety trials (Speiser et al., 2006), also showed high late blight resistance in the pot trials reported here, but failed to produce high tuber yields. Additional experiments, in which varieties are compared under conditions of no or low foliar blight pressure would, therefore be required to determine to what extent foliar blight resistance or other traits have contributed to the yield difference between varieties.

The high chlorophyll levels in soils previously cropped with potato may have been due to residual N-levels from the high mineral fertiliser inputs (around 250 kg N ha^{-1}) used in potato in the Kalamata area (personal contact with Peter Vlachogeorgakopoulos). In contrast, the fallow soils used had no fertiliser inputs and were used to produce forages, but not for grazing animals, thus would be expected to have a fairly low N-status.

CHAPTER 3: Effect of growing season (year), fertilization and variety on late blight severity and yield of potato

3.1 Introduction

Two pot trials with very similar designs (differing only in the choice of one variety) were established in 2009 and 2010 to investigate **(a)** the effect of different organic fertilizer types/products and regimes (and standard mineral-NPK fertilizer treatment) on the performance of **(b)** 4 selected potato varieties under Southern Greek conditions. The factorial design used enabled the identification of potential interactions between **(a)** growing season (climate), **(b)** fertilization and **(c)** variety with respect to foliar blight resistance and yield parameters.

The **fertilizer types** included in the trial were **(a) sheep manure (**from a local semi-intensive sheep producer, sheep manure is the most widely used organic fertilizer in Southern Greece), **(b) seaweed compost** (from a commercial seaweed harvesting and processing company in Kefalonia, Greece), **(c) agrobiosol** (a commercial pelleted fertilizer made alfalfa with a high water soluble N content, made in Italy) which is widely used as a rapid N-release fertilizer in organic horticultural production in Greece and **(d)** combinations of sheep manure, seaweed compost and/or agrobiosol.

The **4 varieties** included in pot trials 3 and 4 were chosen based on existing information on varieties **(a)** being suitable to climatic conditions during the spring potato growing season in Greece and **(b)** high levels of foliar and tuber blight resistance/tolerance, which are a major yield determining factor in organic production; the standard variety "Spunta" has relatively low blight resistance. In the second experimental year/season (2010) the variety Eve Balfour (which performed very poorly in 2009) was replaced by Sarpo mira, resulting in slightly different experimental designs in the 2 growing seaons/years (2009/2010). In the 3-factor ANOVA (which included season as a factor) results for Eve Balfour and Sarpo mira were therefore not included (Table 3.1 below).

The **soil** used in pot trials had not been used for potato production for 6 years (left fallow to develop a natural legume/grass/herb vegetation); soils were collected from the same fields also used to collect one of the soils included in the variety evaluation focused pot trial 1 described in section 2.1 above.

3.2 Results: ANOVA - Effect of year/season, fertilistion regime and variety

Three-way ANOVA detected significant main effects of variety for all parameters and significant main effects of season/year for all parameters except tuber number per plant (Table 3.1). Also significant main effects of fertilization treatment were detected for **(a)** tuber number per plant and **(b)** total tuber weight and (Table 3.1).

Similar to the variety trial reported in chapter 1, total tuber weight, mean tuber number and mean tuber diameters were all higher in 2010 compared to 2009, while foliar late blight severity was more than 3 times higher in 2009 (Table 3.1).

The highest tuber number per plant was found when sheep manure plus agrobiosol or sheep manure only were used as fertilizers (Table 3.1). Seaweed treatments resulted in the lowest tuber number per plant (Table 3.1).

The highest total tuber weight, was recorded when manure plus agrobiosol was used as fertiliser, and the lowest when seaweed only was used. The second lowest tuber weight was recorded for the mineral NPK fertilizer treatment (Table 3.1).

Lisetta, gave the highest tuber number per plant, but numbers were not significantly different from those of Remarka, whereas, Spunta had the lowest tuber number per plant (Table 3.1). Remarka had the highest total tuber weight, and mean tuber weight, while Spunta produced tubers with the largest mean tuber diameter (Table 3.1). The variety Lisetta had significantly higher foliar blight severity compared to the other two varieties, which had similar late blight levels (Table 3.1).

There were interactions between **(a)** year and fertility treatment for the tuber number per plant and mean tuber weight and **(b)** fertility treatment and variety for the tuber number per plant and late blight severity (Table 3.1).

When the interactions between fertility management and variety were investigated further (Table 3.1.1) the relative performance of varieties differed between fertilization treatments.

For total tuber numbers, Lisetta was found to have significantly higher numbers than Spunta and Remarka when seaweed plus manure was used as fertiliser, while Remarka had higher number of tubers compared to Spunta when Agrobiosol alone was used. When seaweed plus agrobiosol was used both Lizetta and Remarka had higher tuber numbers than Spunta and with mineral NPK fertilizer Lisetta had higher tuber numbers than Remarka (Table 3.1.1).

For tuber blight, Lisetta had significantly higher AUDPC values compared to one or both of the other varieties when manure, manure plus agrobiosol and mineral NPK was used as fertilizers, while Spunta had significantly higher foliar blight severity than Remarka when seaweed plus agrobiosol was used (Table 3.1.1).

To **(a)** investigate the interactions with year/season in more detail and **(b)** allow data for two additional varieties (Lady Balfour and Sarpo mira), that were only compared in 2009 and 2010 respectively, to be included in analyses, separate 2 factor ANOVAs were carried out for the 2009 and 2010 data (section 4.2 and 4.3 below).

Chlorophyll concentrations (estimated based on SPAD meter readings) were used to monitor and compare N-supply in different varieties grown in soils treated with different fertiliser types. When year was included in the ANOVA only 3 varieties could be included in the analyses. Significant main effects of year were only detected on one assessment date and overall chlorophyll levels did not differ much between the 2 seasons (Table 3.2). For some assessment dates there were interactions between (a) year and fertility and (b) year and variety with differences between fertiliser treatments and/or varieties found to be significant in specific years only (individual results not shown). Significant main effects of fertiliser type and variety were detected on all assessment dates (Table 3.2).

Use of Agrobiosol alone or Agrobiosol plus sheep manure produced the highest chlorophyll levels on all assessment dates, although differences to some other fertiliser types were not significant on certain assessment dates (Table 3.2). Plants fertilised with seaweed compost had the lowest chlorophyll levels on all assessment dates. On the first three assessment dates, seaweed compost plus manure and mineral NPK fertiliser also resulted in lower chlorophyll levels than most other fertiliser types (Table 3.2). Spunta had higher chlorophyll levels than the other 2 varieties on all assessment dates, but differences between Spunta and the other varieties were only significant on certain assessment dates (Table 3.2).

There was an interaction between fertiliser type and variety on the first assessment date only (Table 3.2). Significant differences between varieties were only detected when seaweed compost, seaweed compost plus manure, seaweed compost plus agrobiosol and mineral NPK fertiliser was used (Table 3.2.1). With these fertilisers Remarka showed lower chlorophyll levels than Spunta and Lisetta (Table 3.2.1).

Table 3.1 Effect of growing season (year), fertiliser type and variety on tuber weight and size and late blight severity (pot trials 3 and 4, years 2009 and 2010)

Factor		**Tuber Number per plant**	**Total tuber weight per plant (g)**	**Average mean tuber weight per plant[1] (g)**	**Mean Tuber Diameter (mm)**	**Late blight Severity AUDPC (% x days)**
Year (Y)						
1. 2009		6.5 ±0.4	187.9 ±14.	29.3 ±1.9	45.7 ±1.8	810.2 (61.2)
2. 2010		6.4 ±0.2	314.6 ±15.1	51.4 ±2.6	59.0 ±1.3	245.7 (50.2)
Fertiliser type (FT)	N-input (g plant^{-1})					
1. S	13.6	3.9 ±0.4 **d**	162.8 ±20.1 **d**	42.4 ±5.6	52.4 ±3.8	433.4 ±101.8
2. S+M	13.6	5.6 ±0.5 **c**	230.1 ±23.7 **bcd**	38.8 ±4.3	51.2 ±3.9	291.0 ± 72.5
3. M	13.6	8.1 ±0.4 **ab**	284.8 ±19.2 **b**	36.6 ±2.9	50.5 ±2.5	669.0 ±136.8
4. A	13.6	6.8 ±0.5 **bc**	260.3 ±37.6 **bc**	37.2 ±4.0	54.6 ±2.2	457.5 ± 89.7
5. S+A	27.2	5.7 ±0.6 **c**	243.6 ±27.7 **bc**	45.6 ±6.6	54.1 ±4.0	750.0 ±140.7
6. M+A	27.2	8.6 ±0.4 **a**	378.8 ±38.8 **a**	46.0 ±5.3	55.8 ±3.0	492.0 ±105.8
7. MF	35.7	6.0 ±0.6 **c**	198.3 ±19.0 **cd**	35.8 ±4.0	48.4 ±3.3	602.8 ±154.3
Variety (V)						
1. Spunta		5.7 ±0.4 **b**	240.8 ±18.7 **b**	43.1 ±3.1 **a**	57.6 ±2.1 **a**	499.4 ±74.3 **b**
2. Lisetta		7.3 ±0.3 **a**	228.6 ±15.0 **b**	32.0 ±2.1 **b**	50.5 ±1.8 **b**	735.2 ±89.5 **a**
3. Remarka		6.3 ±0.4 **b**	284.3 ±24.1 **a**	45.9 ±3.8 **a**	49.0 ±2.3 **b**	349.3 ±60.4 **b**
ANOVA						
Main effects						
Y		ns	**0.0084**	**0.0062**	**0.0097**	**0.0084**
Fertiliser Type (FT)		**<0.001**	**0.001**	ns	ns	ns
Variety (V)		**0.0003**	**0.0208**	**0.0004**	**0.0051**	**<0.001**
Interactions						
Y x FT		**0.0387**	*0.0763*	**0.0236**	ns	ns
Y x V		ns	ns	ns	0.1012	*0.0684*
FT x V		**0.0085**[2]	ns	ns	ns	**0.008**[2]
Y x FT x V		*0.0593*	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, p < 0.05); [1], see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated; [2] see **Table 3.1.1** for interaction means ± SE.
S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser.

Table 3.1.1 Interaction between fertiliser type and variety on the number of tubers and late blight severity (AUDPC) (pot trials 3 and 4, years 2009 and 2010)

Parameter assessed	**Factor 1 Fertiliser type (FT)**	**Factor 2 Variety (V)**		
		1. Spunta	**2. Lisetta**	**3. Remarka**
Number of tubers	1. S	3.1 ±0.7 **D b**	5.4 ±0.8 **B a**	3.2 ±0.6 **D ab**
	2. S+M	4.6 ±1.0 **C b**	7.7 ±0.4 **A a**	5.0 ±0.8 **CD b**
	3. M	7.7 ±0.5 **A ba**	8.7 ±0.9 **A a**	7.9 ±0.6 **Ab a**
	4. A	6.0 ±0.7 **B b**	6.9 ±0.7 **AB ab**	7.5 ±1.3 **Ab a**
	5. S+A	3.5 ±0.8 **D b**	6.9 ±0.5 **AB a**	6.9 ±1.1 **B a**
	6. M+A	8.7 ±0.6 **A a**	7.9 ±0.7 **A a**	9.2 ±0.9 **A a**
	7. F	6.0 ±0.8 **B ab**	7.5 ±1.0 **AB a**	4.4 ±0.9 **D b**
Late blight severity (AUDPC)	1. S	262 ±156 **B a**	677 ±194 **B a**	361 ±163 **A ba**
	2. S+M	285 ±136 **B a**	491 ±141 **B a**	98 ± 50 **B a**
	3. M	516 ±123 **B b**	1174 ±315 **A a**	317 ±112 **AB b**
	4. A	385 ±135 **B a**	529 ±137 **B a**	459 ±203 **A a**
	5. S+A	1014 ±260 **A a**	558 ±192 **B b**	678 ±273 **A ab**
	6. M+A	391 ±161 **B ab**	774 ±242 **AB a**	312 ± 92 **AB b**
	7. F	644 ±274 **Ab ab**	943 ±340 **AB a**	222 ± 79 **B b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test *p*< 0.05).
S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser

Table 3.2 Effect of fertiliser type and variety on SPAD at different growth stages (pot trials 3 and 4, years 2009 and 2010)

		SPAD (51 days after planting)	**SPAD** (59 days after planting)	**SPAD** (67 days after planting)	**SPAD** (75 days after planting)
Year (Y)					
2009		40.7±2.15	47.4±1.11	46.5±0.86	42.3±1.44
2010		46.7±0.69	45.8±0.68	42.2±0.74	39.2±0.94
Fertiliser type (FT)	N-input (g $plant^{-1}$)				
1. S	13.6	36.2±3.53 **c**	37.4±2.54 **d**	39.3±2.32 **d**	35±2.47 **d**
2. S+M	13.6	39.4±3.42 **bc**	46.4±1.05 **c**	42.9±1.53 **cd**	42.7±1.56 **abc**
3. M	13.6	45.2±2.24 **ab**	46.5±0.81 **c**	44.1±0.92 **bc**	38±2.69 **cd**
4. A	13.6	50.1±2.44 **a**	51.9±0.84 **a**	48.7±1.3 **a**	46.9±1.52 **a**
5. S+A	27.2	43±3.5 **abc**	46.8±2.24 **bc**	46±1.27 **abc**	40.4±3.21 **bcd**
6. M+A	27.2	50.3±1.16 **a**	50.9±0.95 **ab**	47.4±1.22 **ab**	45.2±1.31 **ab**
7. MF	35.7	41.4±3.59 **bc**	46.6±0.98 **c**	42.4±1.3 **cd**	37.8±2.36 **cd**
Variety (V)					
1. Spunta		48.6±1.17 **a**	48.6±0.79 **a**	46.2±0.83 **a**	44.4±1.37 **a**
2. Lisetta		45.4±0.81 **a**	44.8±0.77 **b**	41.6±0.89 **b**	37.3±1.78 **b**
3. Remarka		37±3 **b**	46.4±1.62 **ab**	45.5±1.21 **a**	40.9±1.37 **ab**
ANOVA					
Main effects					
Year (Y)		*0,0503*	ns	**0.0196**	ns
Fertiliser Type (FT)		**0.0018**	**<0.001**	**0.001**	**0,003**
Variety (V)		**<0.001**	**0.0193**	**0.0005**	**0.0037**
Interactions					
Y x FT		ns	ns	**0.0476**	ns
Y x V		**<0.001**	**0.0002**	**0.0492**	ns
FT x V		**0.040**[1]	ns	ns	ns
Y x FT x V		**0.0372**	ns	ns	ns

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$).

S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser

[1] see **Table 3.2.1** for interaction means ± SE.

Table 3.2.1 Interaction of fertility treatment and variety on SPAD at 51 days after planting (pot trials 3 and 4, years 2009 and 2010)

Factors		**Variety (V)**		
Fertiliser type (FT)	N-input (g $plant^{-1}$)	1. Spunta	2. Lisetta	3. Remarka
1. S	13.6	37.7±5.7 **Ba**	40.7±1.9 **Aa**	30.1±8.8 **Ca**
2. S+M	13.6	47±1.1 **ABa**	43.9±2.7 **Aa**	25.7±9.1 **Cb**
3. M	13.6	48.1±1.4 **ABa**	44.3±1.4 **Aa**	43.1±6.3 **ABa**
4. A	13.6	52.8±1.7 **Aa**	49±2.2 **Aa**	48.3±7.0 **Aa**
5. S+A	27.2	52.3±1.3 **Aa**	45.7±1.3 **Aa**	30.9±9.1 **BCb**
6. M+A	27.2	53.3±1.9 **Aa**	47±1.9 **Aa**	50.5±1.8 **Aa**
7. MF	35.7	48.9±2.0 **ABa**	47±2.4 **Aa**	29.3±8.7 **Cb**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$).
S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser

Table 3.3 Effect of growing season (year), fertiliser type and variety on number of tubers per ha and tuber yield in tones per ha (pot trials 3 and 4, years 2009 and 2010)

Factor		**Tuber Number per ha**	**Tuber Yield t ha^{-1}**	**Average mean tuber weight per plant[1] (g)**	**Mean Tuber Diameter (mm)**	**Late blight Severity AUDPC (% x days)**
Year (Y)						
1. 2009		305482 ±14641	8.9 ±0.62	29.3 ±1.9	45.7 ±1.8	810.2 (61.2)
2. 2010		287012 ±10674	14.2 ±0.66	51.4 ±2.6	59.0 ±1.3	245.7 (50.2)
Fertiliser type (FT)	N-input (g plant^{-1})					
1. S	13.6	189897 ±17589**c**	7.9 ±0.8**d**	42.4 ±5.6	52.4 ±3.8	433.4 ±101.8
2. S+M	13.6	280805 ±18583**b**	11.2 ±0.9**bc**	38.8 ±4.3	51.2 ±3.9	291.0 ± 72.5
3. M	13.6	361108 ±17808**a**	12.7 ±0.9**b**	36.6 ±2.9	50.5 ±2.5	669.0 ±136.8
4. A	13.6	301849 ±24074**b**	11.6±1.7**bc**	37.2 ±4.0	54.6 ±2.2	457.5 ± 89.7
5. S+A	27.2	266664 ±23544**b**	11.3 ±1.2**bc**	45.6 ±6.6	54.1 ±4.0	750.0 ±140.7
6. M+A	27.2	383330±19070**a**	16.8 ±1.7**a**	46.0 ±5.3	55.8 ±3.0	492.0 ±105.8
7. MF	35.7	276326 ±22864**b**	9.2 ±0.8**cd**	35.8 ±4.0	48.4 ±3.3	602.8 ±154.3
Variety (V)						
1. Spunta		261726 ±15835**b**	11.1 ±0.8**b**	43.1 ±3.1 **a**	57.6 ±2.1 **a**	499.4 ±74.3 **b**
2. Lisetta		329694 ±12243**a**	10.3 ±0.6**b**	32.0 ±2.1 **b**	50.5 ±1.8 **b**	735.2 ±89.5 **a**
3. Remarka		296014 ±17265**a**	13.4 ±1.0**a**	45.9 ±3.8 **a**	49.0 ±2.3 **b**	349.3 ±60.4 **b**
ANOVA						
Main effects						
Year (Y)		ns	**0.0088**	**0.0062**	**0.0097**	**0.0084**
Fertiliser Type (FT)		**<0.001**	**0.001**	ns	ns	ns
Variety (V)		**0.0003**	**0.0049**	**0.0004**	**0.0051**	**<.0001**
Interactions						
Y x FT		**0.0185**	*0.0363*	**0.0236**	ns	ns
Y x V		ns	ns	ns	0.1012	*0.0684*
FT x V		**0.0207**	ns	ns	ns	**0.008**[2]
Y x FT x V		ns	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated; [2], see **Table 3.4** for interaction means ± SE.

S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser;

Table 3.3.1 Interaction between fertiliser type and variety on the number of tubers per ha (pot trials 3 and 4 , years 2009 and 2010)

Parameter assessed	**Factor 1 Fertiliser type (FT)**	**Factor 2 Variety (V)**		
		1. Spunta	**2. Lisetta**	**3. Remarka**
Number of tubers	1. S	138887±29621 **D b**	273013 ±11592**CD a**	165078 ±18691**D b**
	2. S+M	234918 ±41956 **BC b**	344441 ±20140**ABCDa**	253966±15978**BCDab**
	3. M	344441 ±23382**A a**	388885 ±41785**AB a**	349997 ±25803**A a**
	4. A	266664 ±31427**ABCa**	305552 ±29621**BCD a**	333330 ±59391**AB a**
	5. S+A	177776 ±32166**CD b**	305502 ±24397**BCD a**	305552±47093**ABC a**
	6. M+A	333330 ±42552**AB b**	422218±55924**A a**	237034 ±53415**BCDb**
	7. F	199998 ±28688 **CD a**	244442 ±28688**D a**	211209 ±42066**CD a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$).
S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser

3.3 Results: ANOVA - Effect of (fertilization regime and variety (pot trial 3; spring potato season 2009)

Two-factor ANOVA detected significant main effects of variety for all yield parameters (except mean tuber diameter) and late blight severity (Table 3.4). In contrast, main effects of fertilization regimes were only detected for the **(a)** tuber number per plant **(b)** total tuber weight per plant and **(c)** foliar late blight severity (Table 3.4).

The variety Lisetta produced the highest while Lady Balfour produced the lowest tuber numbers. Lady Balfour also produced lower tuber weights and mean tuber weights than the other three varieties, but the difference in mean tuber weight was not significant for Lisetta (Table 3.4). The variety Lisetta had significantly higher foliar late blight severity than the other 3 varieties, which all had similar late blight levels (Table 3.4).

The highest tuber number per plant and total tuber weights were obtained when sheep manure alone or a combination of sheep manure and agrobiosol was used for fertilization. Total tuber numbers and weights obtained with the sheep manure plus agrobiosol treatment were slightly, but not significantly, higher than those obtained with the standard mineral NPK fertilizer treatment (control) (Table 3.4). When compared to the sheep manure plus agrobiosol treatment significantly lower tuber numbers and weights were recorded in all treatments involving seaweed compost (Table 3.4). The highest levels of foliar blight were recorded for the seaweed compost plus agrobiosol (Table 3.4), while the lowest late blight severity was found in plants fertilized with seaweed plus sheep manure.

In the 2009 trial there was also an interaction between fertilization and variety for late blight severity (Table 3.4). The lowest late blight severity was detected for Spunta when seaweed compost, for Lisetta and Remarka when seaweed compost plus manure, and for Lady Balfour when sheep manure was used as fertilizer (Table 3.4.1). The highest late blight severity was detected for Spunta and Remarka when seaweed compost plus agrobiosol and for Lisetta and Lady Balfour when sheep manure was used as fertilizer. However, for Lady Balfour, Tukey’s Honestly Significant Difference Test did not detect significant differences between fertilizer treatments (Table 3.4.1).

When only data from the 2009 trial were included in the ANOVA, chlorophyll levels of Spunta, Remarka and Lisetta could be compared to Lady Balfour (Table 3.5). Lady Balfour had the lowest chlorophyll levels of the four varieties on the two first assessment dates, while there were no significnat differences between varieties on the two later assessment dates (Table 3.5). Since Lady Balfour also has very low yields it was not included in the 2010 pot trials.

Table 3.4 Effect of fertilisation treatment and variety on tuber weight, size and late blight severity (AUDPC)(pot trial 3, year 2009)

Factor		**Tuber number per plant**	**Total tuber weight per plant (g)**	**Average mean tuber weight per plant[1] (g)**	**Mean tuber diameter (mm)**	**Late blight Severity AUDPC (% x days)**
Fertiliser type (FT)	N-input (g plant^{-1})					
1. S	13.6	2.9 ±0.7 **c**	79 ±18 **c**	24 ±5.0	47 ±6.0	715 ±144 **bc**
2. S+M	13.6	4.6 ±0.8 **bc**	135 ±22 **bc**	26 ±4.0	43 ±4.0	498 ± 97 **c**
3. M	13.6	7.9 ±0.8 **a**	248 ±22 **a**	34 ±4.0	44 ±6.0	845 ±145 **ab**
4. A	13.6	4.9 ±0.7 **bc**	177 ±58 **ab**	28 ±6.0	38 ±5.0	780 ± 71 **bc**
5. S+A	27.2	5.1 ±1.0 **bc**	112 ±22 **bc**	18 ±5.0	43 ±3.0	1100 ±158 **a**
6. M+A	27.2	9.1 ±0.8 **a**	228 ±30 **a**	25 ±4.0	37 ±4.0	752 ± 91 **bc**
7. MF	35.7	6.8 ±0.8 **ab**	168 ±22 **ab**	27 ±4.0	37 5.0	730 ±137 **bc**
Variety (V)						
1. Spunta		5.1 ±0.6 **bc**	163 ±18 **a**	31 ±3.0 **a**	36 ±4.0	740 ±93 **b**
2. Lisetta		8.2 ±0.5 **a**	182 ±12 **a**	23 ±2.0**ab**	42 ±3.0	1088 ±91 **a**
3. Remarka		6.8 ±0.7 **ab**	217 ±33 **a**	31 ±4.0 **a**	42 ±3.0	659 ±92 **b**
4. L. Balfour		4.5 ±0.8 **c**	94 ±19 **b**	17 ±3.0 **b**	44 ±3.0	676 ±51 **b**
ANOVA						
Main effects						
Fertiliser Type (FT)		**<0.001**	**0.002**	0.257	0.651	**0.015**
Variety (V)		**<0.001**	**<0.001**	**0.002**	0.298	**<0.001**
Interaction						
FT x V		ns	ns	ns	ns	**0.038**[2]

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$); **[1]**, see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated; **[2]** see **Table 3.4.1.** for interaction means ± SEs

S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser;

Table 3.4.1 Interaction between fertiliser type and variety on late blight severity (AUDPC)(pot trial 3, year 2009)

Factor 1		Factor 2 potato variety			
		Spunta	**Lisetta**	**Remarka**	**Lady Balfour**
Fertiliser type (FT)	N-input (g $plant^{-1}$)				
1. S	13.6	325 ±325 **C b**	1058 ±263 **B a**	599 ±284 **BC ab**	878 ±233 **A ab**
2. S+M	13.6	433 ±259 **BC ab**	853 ± 50 **B a**	103 ±103 **C b**	601 ± 87 **A ab**
3. M	13.6	554 ± 48 **BC b**	1720 ±249 **A a**	572 ±123 **BC b**	533 ± 38 **A b**
4. A	13.6	712 ±107 **BC a**	868 ± 91 **B a**	900 ±249 **AB a**	639 ± 55 **A a**
5. S+A	27.2	1488 ±351 **A a**	966 ±237 **B ab**	1236 ±364 **A ab**	710 ±268 **A b**
6. M+A	27.2	741 ±196 **BC a**	1035 ±254 **B a**	495 ±108 **BC a**	737 ± 60 **A a**
7. F	35.7	679 ±119 **BC b**	1269 ±428 **AB a**	410 ± 69 **BC b**	561 ±179 **A b**

Means labelled with the same letter upper case letter within the same column and the same low case letter within the same row are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser

Table 3.5 Effect of fertiliser type and variety on SPAD at different growth stages (pot trial 3, year 2009)

Factor		**SPAD**			
Fertiliser type (FT)	N-input (g $plant^{-1}$)	**SPAD 1** (51 day after planting)	**SPAD 2** (59 days after planting)	**SPAD 3** (67 days after planting)	**SPAD 4** (75 days after planting)
1. S	13.6	26±5.95	35±4.42 **c**	39.2±3.07 **c**	37.8±2.96
2. S+M	13.6	26.8±6.21	44.5±3.12 **b**	45.8±1.71 **b**	44.6±1.43
3. M	13.6	41±4.23	47.9±1.26 **ab**	44.3±1.5 **b**	38.8±3.94
4. A	13.6	38.9±5.94	53±0.9 a	52.1±0.71 a	49.1±1.64
5. S+A	27.2	30.5±6.2	45.8±3.4 **b**	47.1±1.68 **b**	40.2±4.12
6. M+A	27.2	41.8±4.32	49.1±1.33 **ab**	49±1.4 ab	47.6±1.33
7. F	35.7	35.3±6.27	49.2±0.8 **ab**	47.4±0.9 **ab**	42.8±2.96
Variety (V)					
1. Spunta		49±1.99 **a**	50.6±0.91**a**	48.9±0.84	46.4±2
2. Lisetta		48.1±1.02 **a**	47.6±0.87 **bc**	44.7±1.19	39±2.81
3. Remarka		25.1±4.88 **b**	44±3.01 **c**	46±2.08	41.6±2.49
4. L. Balfour		15.1±3.99 **c**	43.2±2.59 **c**	46.1±1.35	45.1±0.99
ANOVA					
Main effects					
Fertiliser Type (FT)		*0.0579*	**0.0019**	**0.0018**	*0.0623*
Variety (V)		**<0.001**	**0.0212**	ns	*0.0564*
Interactions					
FT x V		ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).[1]

3.4 Results: ANOVA - Effect of fertilization treatment and variety (pot trial 4; spring potato season 2010)

This pot trial was a repeat of the pot trial carried out in 2009 (section 3.2 above). However, due to the poor performance of the variety Lady Balfour in 2009, Lady Balfour was replaced with Sarpo mira (which had shown the highest yield and late blight resistance in the variety trials in 2009, chapter 3) in the 2010 pot trial.

Similar to 2009 (see section 3.2 above), two-factor ANOVA detected significant main effects of variety for all yield parameters and foliar blight severity and for fertilizer treatment only for **(a)** tuber number per plant **(b)** total tuber weight per plant and **(c)** mean tuber weight (Table 3.6).

The variety Sarpo Mira produced significantly higher numbers of tubers than the other 3 varieties and a significantly higher total tuber weight when compared to Spunta and Lisetta. However, Remarka showed the highest mean tuber weight and Lisetta the lowest. Spunta had the highest mean tuber diameter, but the difference was not significant when compared to Remarka and Sarpo mira (Table 3.6). The varieties Spunta and Lisetta were found to have significantly higher foliar blight severity than Remarka and Sarpo mira, which had similar blight levels (Table 3.6).

The highest tuber number per plant and total tuber weight were obtained when sheep manure plus agrobiosol was used for fertilization. However, the difference in tuber numbers per plant between the sheep manure plus agrobiosol treatment and the **(a)** manure only and **(b)** agrobiosol only treatments was not significant (Table 3.6). Seaweed compost plus agrobiosol resulted in the greatest mean tuber weight, but the difference to mean tuber weights obtained with sheep manure plus agrobiosol was not significant. Tuber numbers per plant, total tuber weights and mean tuber weights were lowest with the standard mineral NPK fertilization (control) (Table 3.6).

Different to the 2009 trial, in 2010 there was a significant interaction between fertilization and variety for the number of tubers per plant (Table 3.6). The highest numbers of tubers were produced by Spunta and Sarpo mira when sheep manure plus agrobiosol, by Lisetta when agrobiosol alone, and by Remarka when sheep manure alone was used as fertilizer, while the lowest tuber numbers were produced by all varieties with seaweed compost and mineral NPK as fertilizers (Table 3.6.1).

Remarka produced significantly lower numbers of tubers than the other 3 varieties when seaweed compost plus manure was used as fertilizer (Table 3.6.1). However, it produced higher numbers of tubers than the other 3 varieties, when agrobiosol alone was used as fertilizer, but the difference was only significant for Spunta (Table 3.6.1). Lisetta and Sarpo mira produced significantly higher numbers of tubers than Spunta when seaweed plus agrobiosol was used as fertilizer and Sarpo mira produced higher numbers of tubers than the other 3 varieties when sheep manure plus agrobiosol was used as fertilizer (Table 3.6.1).

When only data from the 2010 trial were included in the ANOVA, chlorophyll levels of Spunta, Remarka and Lisetta could be compared to Sarpo mira (Table 3.7). Sarpo mira had relatively high chlorophyll levels compared to the other 3 varieties on all 4 assessment dates and on the last assessment date chlorophyll levels were significantly higher than those in the 3 other varieties (Table 3.7).

Table 3.6 Effect of fertiliser type and variety on tuber weight and size and late blight severity (AUDPC)(pot trial 4, year 2010)

Factor		**Tuber number per plant**	**Total tuber weight per plant (g)**	**Average mean tuber weight per plant[1] (g)**	**Mean Tuber diameter (mm)**	**Late blight Severity AUDPC (% x days)**
Fertiliser type (FT)	N-input (g plant^{-1})					
1. S	13.6	4.4 ±0.4 **c**	208 ±20 **e**	51 ±7 **bc**	57 ±2	217 ±40
2. S+M	13.6	6.4 ±0.6 **b**	310 ±24 **bc**	48 ±5 **bc**	56 ±4	137 ±36
3. M	13.6	8.1 ±0.3 **a**	359 ±31 **bc**	45 ±4 **c**	56 ±2	313 ±133
4. A	13.6	7.9 ±0.6 **a**	295 ±24 **cd**	39 ±3 **c**	60 ±2	68 ±23
5. S+A	27.2	6.1 ±0.4 **b**	395 ±29 **b**	69 ±6 **a**	67 ±2	211 ±73
6. M+A	27.2	8.7 ±0.6 **a**	536 ±43 **a**	62 ±5 **ab**	64 ±3	172 ±106
7. MF	35.7	5.2 ±0.3 **bc**	221 ±21 **de**	44 ±4 **c**	54 ±3	317 ±192
Variety (V)						
1. Spunta		6.1 ±0.4 **b**	315 ±26 **b**	54 ±4 **ab**	63 ±2 **a**	294 ± 95 **a**
2. Lisetta		6.9 ±0.3 **b**	277 ±25 **b**	40 ±3 **b**	55 ±2 **b**	361 ±111 **a**
3. Remarka		6.1 ±0.5 **b**	351 ±27 **a**	60 ±5 **a**	59 ±3 **ab**	82 ± 20 **b**
4. S. Mira		7.5 ±0.4 **a**	384 ±34 **a**	51 ±3 **ab**	60 ±1 **ab**	82 ± 26 **b**
ANOVA						
Main effects						
Fertiliser Type (FT)		**<0.001**	**<0.001**	**0.0130**	ns	ns
Variety (V)		**0.0044**	**0.0008**	**0.0005**	**0.0409**	**0.0085**
Interaction						
FT x V		**0.0063[2]**	ns	ns	ns	ns

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, p < 0.05); **[1]**, see methods on *Yield and tuber blight assessment* on page 41 for a description of how average mean tuber weights per pot/plant were calculated. **[2]** see **Table 3.6.1** for interaction means ± SE.

S: Seaweed compost; S+M: Seaweed compost and sheep Manure; M: sheep Manure; A: Agrobiosol; S+A: Seaweed compost and Agrobiosol; M+A:sheep Manure and Agrobiosol; MF: Mineral Fertiliser;

Table 3.6.1 Interaction between fertiliser type and variety on the number of tubers (pot trial 4, year 2010)

Parameter assessed	**Factor 1 Fertiliser Type (FT)**	**Factor 2 Variety (V)**			
Number of tubers		**1. Spunta**	**2. Lisetta**	**3. Remarka**	**4. S. Mira**
	1. S	3.8 ±0.6**C a**	5.8 ±0.3**B a**	3.8 ±0.5**C a**	4.5 ±1.0**Ca**
	2. S+M	6.8 ±1.0**ABa**	7.3 ±0.8**Aba**	4.3 ±1.5**C b**	7.3 ±0.8**Ba**
	3. M	8.0 ±0.7**A a**	8.5 ±0.6**A a**	7.5 ±0.6**Aba**	8.3 ±0.5**Ba**
	4. A	6.8 ±1.0**ABb**	7.5 ±0.9**ABab**	9.5 ±2.0**A a**	7.8 ±0.5**Bab**
	5. S+A	4.3 ±0.5**C b**	6.8 ±0.6**Aba**	5.8 ±0.5**BCab**	7.5 ±0.6**Ba**
	6. M+A	8.8 ±0.6**A b**	7.3 ±1.2**ABb**	7.3 ±0.8**ABb**	11.5 ±1.2**Aa**
	7. F	4.5 ±0.6**BCa**	5.5 ±0.6**B a**	4.8 ±0.9**C a**	6.0 ±0.4**BCa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test p< 0.05)

Table 3.7 Effect of fertiliser type and variety on SPAD at different growth stages (51, 59, 67 and 75 days after planting, respectively) (pot trial 4, year 2010)

Factor		**SPAD**			
		SPAD (51 days after planting)	**SPAD** (59 days after planting)	**SPAD** (67 days after planting)	**SPAD** (75 days after planting)
Fertiliser type (FT)	N-input (g plant^{-1})				
1. S	13.6	42.9±1.47 **d**	39.9±1.26 **c**	41±1.75 **cd**	34.2±2.42 **d**
2. S+M	13.6	44.5±1.05 **cd**	45±1.23 **b**	39.7±1.53 **d**	37.7±1.45 **cd**
3. M	13.6	46.9±1.03 **bc**	44.6±0.92 **b**	43.8±0.9 **bc**	40±1.19 **bc**
4. A	13.6	52.1±1.46 **a**	50.7±0.92 **a**	46.6±1.64 **ab**	47±1.83 **a**
5. S+A	27.2	49.6±0.96 **ab**	47.4±1.04 **b**	45±1.06 **abc**	43.8±1.72 **ab**
6. M+A	27.2	51.7±1.56 **a**	51.9±1.15 **a**	48.4±1.72 **a**	45.7±1.84 **a**
7. MF	35.7	45.5±0.84 **cd**	44.8±1.19 **b**	38.4±0.94 **d**	35.5±1.71 **cd**
Variety (V)					
1. Spunta		48.2±1.22 **b**	46.5±1.19 **b**	43.2±1.23 **b**	41.8±1.73 **b**
2. Lisetta		42.6±1.03 **c**	41.9±1.03 **c**	37.9±0.89 **c**	35.1±1.87 **c**
3. Remarka		49.4±0.89 **ab**	48.8±0.9 **a**	44.9±1.24 **ab**	40.2±1.11 **b**
4. S. Mira		50.3±0.67 **a**	47.8±0.79 **ab**	46.4±0.94 **a**	44.6±1.39 **a**
ANOVA					
Main effects					
Fertiliser Type (FT)		**0,0001**	**<0.001**	**0,0001**	**0,0003**
Variety (V)		**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions					
FT x V		ns	ns	ns	*0.0946*

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

3.5 DISCUSSION: Effect of growing season (year), fertilization and variety on late blight severity and yield of potato

The pot experiments described in results section 2 focused on evaluating the suitability of local available organic fertizers (with contrasting nutrient content and availability) for organic potato production in Southern Greece and potential interactions between fertilisation regimes and variety. A standard mineral fertilizer treatment (widely used by conventional farmers in the Kalamata area) was also included as a control, to estimate to what extent yield differences between organic and conventional production may be due to differences in fertilisation regimes, since previous studies reported that tuber yields obtained with composted cattle manure (applied at similar total N-input levels) are up to 40% lower than those obtained with mineral fertiliser inputs (Palmer et al., 2013, Swain et al., 2014, Tétard-Jones et al., 2013).

Different to previous studies which compared effects of organic (based on animal and green manures and organic waste based composts) and conventional (based on mineral NPK inputs) fertilisation regimes on potato performance, yields in the pot trials reported here were similar or higher with sheep manure and/or sheep manure plus agrobiosol than mineral NPK fertilisers. This was surprizing since the standard mineral fertilisation regime was based on higher total N inputs (35.7 g per pot) than these two organic fertilisation regimes (27.2 or 13.6 g per pot).

This may be explained by the very light sandy soils (typical for the coastal potato growing areas in the Kalamata region) used for pot trials, since it is known that mineral-N fertilisers are rapidly lost from sandy soils through leaching during periods of high precipitation or when sprinkler irrigation is used (Stalham and Allen, 2001). Compared to other field crops (e.g. cereals), potato crops have a relatively low nutrient use inefficiency, due mainly to their shallow root system (Stark and Porter, 2005). As a result they need very high nutrient inputs for optimum growth and in Northern Europe inputs are often around 200 kg each of N, P and K, with a high proportion of inputs being lost due to leaching and run-off (Palmer et al., 2013, Swain et al., 2014). The use of organic fertilisers such as manure, compost and agrobiosol, is known to result in a more gradual nutrient release via mineralisation, thus reducing nutrient losses (Karam et al., 2014). However, nutrient losses from different types of organic fertilisers (e.g. manure slurry, chicken pellets, composted farm yard manure) may also vary substantially.

Regular organic matter inputs were shown to improve soil structure and improve water holding capacity and this may also partially explain the lack of yield differences between organic and mineral fertilisation (Berry et al., 2006). Apart from reduced nutrient losses and improved water relations, organic fertiliser inputs were also shown to increase soil biological activity and suppressiveness against fungal disease and nematodes (Giotis et al., 2009, Giotis et al., 2012) and this may also have contributed to the lack of a yield gap between certain organic (sheep manure and agrobiosol) and mineral NPK fertilisers. However, no visible symptoms of soil borne disease or nematode damage were detected in the pot trials reported here.

It is interesting to note that in the Kalamata area the benefits of organic fertiliser inputs into the very sandy soils is increasingly recognised by conventional farmers and many producers have started to use manure and/or recycled waste based composts to maintain soil fertility (Peter Vlachogeorgakopoulos and Dr Nikos Volakakis; personal communication).

The finding that seaweed compost resulted in lower yields than agrobiosol (a commercial organic fertiliser based on an alfalfa extract) and sheep manure when used at the same N-input level, confirms previous studies which showed that seaweed compost has a lower fertiliser value or inhibitory effects on plant growth (López-Mosquera and Pazos, 1997). However, it has also been reported that seaweed productss may help to alleviating abiotic stress (Khan et al., 2009).

The finding that fertilisation affected late blight disease severity in the 2009 season also confirms previous studies, which reported a significant main effect of fertilisation on late blight severity (Lambert et al., 2005, Palmer et al., 2013). However, the relative impact of contrasting fertilisation regimes on late blight severity differed between varieties in 2009, the season with the higher late blight disease pressure.

The result of the pot trials suggest that similar yield were obtained with sheep manure only and manure + agrobiosol fertiliser treatments, and that these treatments gave higher yields than the other organic and the mineral NPK-fertilisation regimes. If confirmed this suggests that sheep manure only is the best fertilisation treatment, since the incorporation of the relatively expensive agrobiosol is unlikely to increase yields to an extent that justifies the cost of using agrobiosol.

Trials in which fertility treatments are compared under conditions of no or low foliar blight pressure would, however, be required to determine to what extent foliar blight resistance and other factors (nutrient release pattern and losses from different fertilisers and nutrient availability and uptake by plants during the growing season) have contributed to the yield difference between fertility treatments.

The finding of high chlorophyll levels in Remarka and Claret and the relative increase in chlorophyll levels in Sarpo mira (compared to other varieties) later in the growing period, suggests that these varieties have either a genetic pre-disposition (compared to the other varieties) for higher leaf chlorophyll or a higher N-use efficiency. This would support previous reports of Sarpo mira having a relatively high N-use efficiency (Swain et al., 2014). It is also interesting to note that both Remarka (e.g. in Switzerland) and Sarpo mira are widely used in organic farming systems, where N often is the main yield limiting factor. This would further support the hypothesis that these varieties are more N-use efficient and this should be further investigated in future studies.

The finding that seaweed compost (and combinations of seaweed compost with agrobiosol or sheep manure) resulted in significantly lower chlorophyll content than the other fertiliser treatments may have been due to the high C:N-ratio in seaweed compost resulting in low N-availability in soil. This confirms previous studies (Theodoropoulou, 2009) which showed that the use of seaweed compost results in lower yields than animal manure when applied at the same total N-input levels. However, it may have also been, at least partially, due to high salt levels or other inhibitory compounds in seaweed compost as suggested by other studies (Khan et al., 2009, López-Mosquera and Pazos, 1997). Some varieties (e.g. Remarka) had substantially lower chlorophyll levels when seaweed compost was used as fertiliser, but similar chlorophyll levels to other varieties with other organic fertilisers. This could indicate differences in nitrogen scavenging/uptake capacity between varieties or differences in tolerance to salt or other inhibitory compounds present in seaweed compost. The finding that mineral fertiliser controls also resulted in lower chlorophyll levels than some of the organic fertilisers used (e.g. sheep manure plus agrobiosol and agrobiosol alone) was surprising since mineral NPK inputs were based on the standard fertiliser treatments used in conventional potato production (200-250kg N, 200kg P and 200 kg K ha^{-1}) and involved substantially higher levels of plant-available N inputs than the organic fertiliser treatments. The most likely explanation is that there were much larger N-losses (e.g. through nitrate leaching, nitrification and/or denitrification) from the water soluble mineral N than the organic fertiliser inputs in the very sandy soils used for potato production in the Kalamata area. This view is supported by reports of very large nitrate leaching losses and associated eutrophication problems in the potato growing areas in the Peloponnese region (Giannakopoulou, 2003).

CHAPTER 4: Effect of growing season, irrigation type, irrigation level, fertilisation treatment, and variety on tuber yield, tuber size distribution, late blight severity and Colorado beetle infestation *(years 2013 and 2014)*

4.1 Introduction

Field experiments were established to **(a)** confirm the suitability of Sarpo mira and a potential replacement for Spunta in semi-arid organic potato production regions of Europe and **(b)** compare the performance of the two varieties with different fertilisers commonly used in organic farming systems (chicken manure, sheep manure, sheep manure plus agrobiosol). Different to the pot trials, chicken manure was included as an additional fertilizer type, since **(a)** sea-weed compost was shown to be unsuitable as a fertilizer for potato in pot trials and **(b)** chicken pellets are a widely available organic fertilizer in Greece.

In pot trials (chapters 2 and 3) a standard sprinkler irrigation system typically used in commercial potato-production was used for all treatment combinations. In the two replicate field experiments in 2013 and 2014 (described in this chapter), irrigation type (sprinkler vs drip irrigation) was included as an additional factor in the experimental design to test whether **(a)** irrigation type affects crop health and especialy late blight severity and potato yield parameters, and **(b)** whether there are interactions between irrigation and variety (Spunta vs Sarpo mira) and selected fertilization regimes (those that resulted in optimum performance in pot trials).

The two principle irrigation systems used in potato production (sprinkler vs drip irrigation) in the Mediterranean region and irrigation level (=amount of water applied) were included as additional factors in experiments, since previous studies had shown that irrigation regimes can affect **(a)** late blight severity (Olanya et al., 2007), **(b)** mineral nutrient availability and mineralisation driven-nutrient supply (Campbell and Paul, 1978, Sharpley and Moyer, 2000, Shang et al., 2015, Liu et al., 2017)and **(c)** nutrient uptake by plants (Leogrande et al., 2014). The levels of infestation with Colorado beetle, the main insect pest observed in field experiments, was also recorded field trials.

The **climatic conditions** during the 2013 and 2014 growing season are shown in Figure 5.1a-d. There were no large differences of the air temperature during the growing season between 2013 and 2014 (Fig 4.2a). Air temperature was slightly higher in 2014 than in 2013 and May was hotter (in both years) compared to the other two months. Precipitation, was higher in March and April compared to May and June in both years (Fig.4.2b). However, in April precipitation was three times higher in 2014 than 2013. In contrast, precipitation was two times higher 2013 than 2014 (Fig.4.2b). Solar radiation was higher in 2014 than 2013 in March and May. In contrast, in April solar radiation was higher in 2013 than 2014 (Fig.4.2c). Also, as expected solar radiation was lower March and April than May in both years (Fig.4.2c). Relative humidity during the growing period was higher in 2014 than 2013 (Fig.4.2d) and in 2013, relative humidity was higher in March than in April and May (Fig.4.2d)

When data from the two field experiments in 2013 and 2014 were analysed together by 5 factor ANOVA significant main effects of year and a wide range of interactions between year and the other experimental factors (irrigation type, irrigation level and/or variety) were detected for many of the parameters assesses (Tables 4.4.1., 4.4..2, 4.4.3, 4.4.4,4.4.5 and 4.4.6). Separate 4 factor ANOVAs were therefore carried for the 2 repeat field experiments to analyse differences in main effects and interactions between the three agronomic factors and variety separately for the 2 years.

The effects of experimental factors on Colorado beetle infestation could only be assessed in 2013, because in 2014 late blight destroyed a large proportion of foliage (especially in Spunta) in May. As a result, the foliage of the more blight susceptible variety Spunta had to be mechanically removed in May (to avoid tuber infection) before populations of Colorado beetle were detected in the crop. Separate 4-factor ANOVAs for the Colorado beetle data was carried out for **(a)** both seasons for the variety Sarpo mira only and **(b)** both varieties for the 2013 season only.

However, main effects of irrigation type, irrigation level, fertility treatment and variety (Tables 4.4 and 4.5) and interactions between variety and agronomic factors (Tables 4.4.1 to 4.4.6 and Tables 4.5.1 to 4.5.4) detected by 5-factor ANOVA were further investigated and are described below.

4.2 Materials and Methods

4.2.1 Experimental design

Field experiments

Factorial field experiments were carried out in two successive growing seasons (2013 and 2014) using the same randomised block/split plot design in both years, with irrigation system (sprinkler vs drip) as main plots,

(a) irrigation/water input level (standard irrigation vs 1.5 times the standard water input level) sub-plots. In order to measure the level of the applied water that was used in the standard irrigation protocol by the farmers a hydrometer was used. The standard irrigation amount that was applied was $3m^3$; thus the higher water level was $4.5\ m^3$. Irrigation was applied according to the environmental conditions. In the beginning of the cultivation irrigation is usually applied two times per week until the plant starts the formation tuber (growth stage 51, fig. 1.5). Then irrigation is applied more regular (every one or two days) as potato plant needs more water (personal communication with Peter Vlachogeorgakopoulos). Finally, the last irrigation was applied three days before harvesting, as the soil is sandy (personal communication with Peter Vlachogeorgakopoulos).

(b) fertilisation regime (sheep manure, vs chicken manure vs sheep manure plus Agrobiosol; all fertiliser treatments were applied at an input level equivalent to 500 kg N ha^{-1}) as sub-sub-plots. Table 4.2 shows the chemical composition of the organic fertilizers that are used. Specifically, in each sub-sub-sub plot ($9m^2$) were applied :sheep manure:18kg, chicken manure: 11.25 kg and sheep manure plus agrobiosol: 9 kg and 3.21 kg respectively

(c) variety (Spunta vs Sarpo mira) sub-sub-sub plots (see Figure 3.1 for a description of the arrangement of main, sub-, sub-sub- and sub-sub-sup-plots in the field experiments.

In each year 2013 and 2014, field trials were adjacent to each other and were both used for continuous conventional potato production prior to use in experiments. Soil was analysed and its chemical composition is shown in Table 4.1

The dimension/size of variety sub-sub-sub plots was 3m x 3 m ($9\ m^{-2}$) and four rows of potato plants were planted in each sub-sub-sub plot, with spacing of 30 cm between potato plants within rows and 75 cm spacing between rows. Only potato plants in the two middle rows were assessed, to minimize confounding effects of neigbouring plots.

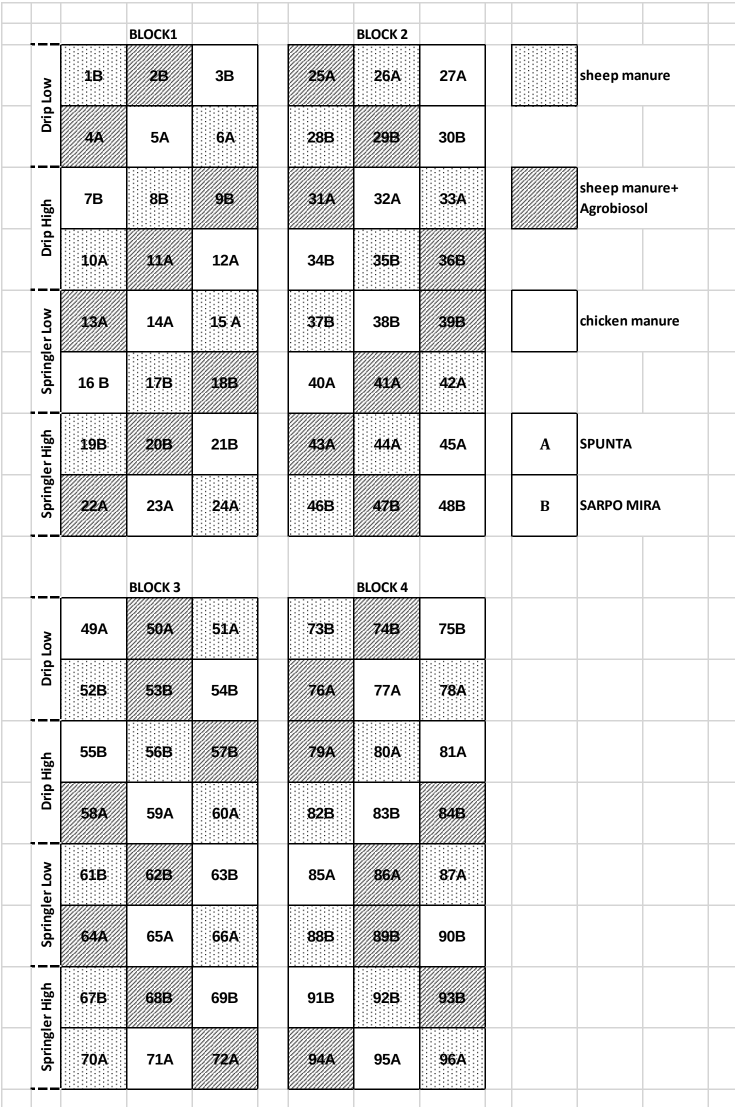


Figure 3.1 Design of field experiments carried our in 2013 and 2014

Table 4.1 Soil chemical analysis

Soil type	**pH**	**E.C** µS/cm	**Organic matter** %	**N** ppm	**K** me/100	**Na** me/100	**P** ppm
Fallow	6.39	130	0.42	18.8	0.221	0.139	9

Table 4.2: Chemical composition of the 3 organic fertilizers that were used in the field trials, years 2013 and 2014

Fertilizer type	**Total organic N %**	**Water soluble N %**	**Total P %**	**Total K %**	**pH**	**Organic matter %**
Chicken manure	4	0.4	4	3	7	70
Sheep manure	2.5	0.4	3	3.3	6.8	75
Agrobiosol	7	0.5	2	3	7	80

4.2.2 Assessments

The *growth stage* of plants in each plot was assessed weekly in each experiment, according to the method described by Hack (2001; see Figure 1.5).

Leaf chlorophyll (SPAD): was recorded weekly in every plot using a chlorophyll meter (SPAD-502, Konica Minolta Sensing Inc.-Japan) SPAD-502 was developed by Minolta Corporation to determine the chlorophyll status of plants. It measures a leaf area of 6 mm^2 in „SPAD units" with accuracy varied ±1.0 unit (Markwell et al., 1995, Richardson et al., 2002). The SPAD-502 utilizes two light-emitting diodes, one at 650nm and one at 940nm, and a photodiode detector to measure in sequence transmission through leaves of red and infrared light (Markwell et al., 1995).

The average SPAD values of the third, fourth and fifth leaves from the growing tip of 20 plants per plot (in the 2 middle rows of plots), were recorded as described by (Gianquinto et al., 2006). Leaves included in assessments had recently emerged, but were fully developed and mature. During measurement, the SPAD sensor was placed at random on leaflet mesophyll tissue of each leaf, with veins or leaf disorders avoided (Pinkard et al., 2006). The mean SPAD values per plot from all the weekly assessments was then calculated, recorded and used for statistical analyses.

Potato *late blight* disease severity (% infected leaf area) was assessed weekly, according to a scoring regime published by Cornell University (http://ppathw3.cals.cornell.edu/fry/protocolos.htm) (see Figure 2.4)

Colorado beetle damage in field trials, was estimated visually as the % leaf area destroyed using the the same scoring approach as for late blight.

Table 4.3 Rating Level for Disease and Insect Incidence

Rating Level	**Trace**	**Light**	**Moderate**	**Severe**
% of plants affected	<5%	5% to 10%	10%-50%	>50%
Number of beetles per plant	1	2 to 3	4 to 5	> 5
% leaf area affected	1%	1% to 5%	6% to 25%	> 25%

(http://www.inspection.gc.ca/plants/potatoes/guidance-documents/pi-005/chapter-5/eng)

Yield and tuber blight assessment: The method described by Palmer et al. (2013) was used to assess total tuber yield and the total weight and number in different tuber size categories. Total yields were assessed by counting the number of tubers and weighing the total amount of tubers in the 2 middle rows of field experimental plots (= 20 plants). In addition, the number of tubers in each sub-sub-sub plot was counted, the tuber size was assessed for every tuber individually, with a caliper and then tubers were then divided into 4 size categories (size1: <4.5 cm; size 2: 4.5-6.5 cm; size 3: 6.5-8.5 cm and size 4: >8.5 cm) and weighed. Damaged tubers and tubers which were infected by blight or other pathogens were weighed, measured and recorded separately. These data were then used to calculate the number and weight of undamaged/healthy tubers in each size category (Palmer et al., 2013).
Data on the mean tuber weight per plot were calculated by dividing the total tuber weight recorded in a specific experimental plot by the number of tubers recorded in the same plot; the mean tuber weights calculated for each plot were then used as replicates in the statistical analyses and to calculate the average mean tuber weights per plot and SEs that are reported in Tables 4.4, 4.4.4, 4.8, 4.8.4, 4.8.5 and 4.11.

Statistical analysis

A five factor analysis (ANOVA) with harvest year, irrigation type, irrigation level,fertility treatment and varriey as fixed effects was carried out. Data from individual years were used in a model (4 factor ANOVA) with irrigation type, irrigation level,fertility treatment and variety as fixed effects (Streck et al., 2007). The hierarchical nature of the split-split plot designs was reflected in the random error structures that were specified as block/ year, fertiliser type and variety or year, irrigation type, irrigation level, fertiliser type and variety . Where analysis at a given level of a factor was carried out, that factor was removed from the random error term. The normality of the residuals of all models was tested using QQ-plots. Differences between the crop management strategies (interaction between factors) were tested using Tukey contrasts in the general linear hypothesis testing (glht) function of the multcomp package in R. A linear mixed effects model was used for the Tukey contrasts, containing a treatment main effect, with four levels, with the random error term specified as described above.

The relationships between environmental, as well as agronomic factors, on yield parameters and disease severity were investigated using redundancy analysis (RDA). Redundancy analysis is a constrained ordination process that seeks combinations of explanatory variables (in this case environmental, agronomic and/or leaf resistance compound factors) that best explain variations in the dependent variables (e.g. disease severity). The environmental factors were the amount of precipitation, the daily relative humidity mean, air temperature, and radiation during the growth season. In all cases the RDAs were carried out using the CANOCO package (Ter Braak and Šmilauer, 2012). Automatic forward selection of the environmental and agronomic or phenolic factors within the RDAs was used and their significance in explaining additional variance calculated using Monte Carlo permutation tests.

Also, Pearson correlation analyses between late blight disease severity and (a) total tuber yield and (b) total tuber numbers were carried out for both varieties (Spunta and Sarpo mira). Correlation analyses were carried out using the 'cor.test' function in R.

4.3 Results: Effect of growing season (year), irrigation type and level, fertilisation treatment, and variety on yield parameters, foliar blight disease severity and Colorado beetle infestation

4.3.1 Crop yield parameters

ANOVA detected a range of significant **main effects** for all experimental factors.

Both **irrigation type** and **irrigation level** were shown to have significant main effects on **a)** tuber yield **b)** tuber size and **(c)** tuber size distribution. Specifically results showed that sprinkler irrigation resulted in 80% higher tuber yields compared to drip irrigation system (Table 4.4). In addition, higher irrigation level resulted in 17% higher tuber yields (Table 4.4).

The proportion of tubers size 2 (4.5-6.5 cm) was higher when drip irrigation system was applied and with the lower irrigation level (Table 4.5). However, higher proportion of large tubers (size size 4; >8.5 cm) was detected with sprinkler irrigation system and with higher irrigation levels (Table 4.5)

Significant main effects of **fertility treatment** were detected for **a)** the number of tubers, **b)** tuber yield, and **c)** tuber size distribution. Specifically: sheep manure plus agrobiosol resulted in the highest number of tubers and 17% higher tuber numbers than sheep manure alone (which gave the lowest tuber number) as fertiliser (Table 4.4). In addition, chicken manure or sheep manure plus agrobiosol resulted in 38% higher tuber yields than the sheep manure alone treatment (Table 4.4), and the proportion of size 1 (<4.5 cm) tubers was higher with sheep manure than the other fertility treatments (Table 4.5). The proportion of size 3 (6.5-8.5 cm) tubers, was highest with sheep manure plus agrobiosol and lowest with sheep manure (Table 4.5) and finally, the proportion of large size 4 (>8.5 cm) tubers, was highest with chicken manure and lowest with sheep manure (Table 4.5).

Significant main effects of **variety** were detected for all yield parameters except for mean tuber weight, with Sarpo mira, producing: 25% higher number of tubers (Table 4.4) and 17% higher tuber yield (Table 4.4). It also produced a higher proportion of smaller (size 1 and 2) tubers and lower proportions of larger (size 3 and 4) tubers (Table 4.5).

ANOVA also detected a range of significant **interactions** between experimental factors as explained in detail below. Interactions between **irrigation type and irrigation level** were detected for total tuber yield and the proportion of size 1 and size 4 tubers. When drip irrigation was used, similar yield were obtained with both irrigation levels, while the higher irrigation level resulted in significantly higher yields when sprinkler irrigation was used (Table 4.4.1). The proportion of size 1 (<4.5 cm) tubers was similar at both irrigation leves with drip irrigation, while the lower irrigation level resulted in a significantly higher proportion of size 1 tubers when sprinkler irrigation was used (Table 4.5.1). The proportion of large size 4 (>8.5 cm) tubers was similar at both irrigation levels with drip irrigation, while the higher irrigation level resulted in a higher proportion of size 4 tubers when sprinkler irrigation was used (Table 4.5.1),

Interactions between **irrigation type and fertility treatment** were detected for the total number of tubers and tuber yield. Drip irrigation resulting in similar yields with all 3 fertiliser types. In contrast, when sprinkler irrigation was used, sheep manure resulted in lower tuber numbers and yields than chicken manure and sheep manure plus agrobiosol (Table 4.4.2).

Interactions between **irrigation type and variety** were detected for the number of tubers only. The total numbers of tubers was lower in Spunta than Sarpo mira at the lower irrigation level, while there was no significant diiference in tuber numbers between varieties at the higher irrigation level (Table 4.4.3).

Interactions between **fertility treatment and variety** were detected for tuber yield, mean tuber weight (Table 4.4.4) and the proportion of size 1 and 3 tubers (Table 4.5.3). The total tuber yield was similar with all 3 fertiliser types for Spunta, while Sarpo mira produced significantly lower yields with sheep manure than chicken manure or sheep manure plus agrobiosol. Also, there was no significant difference in yield between varieties when sheep manure or chicken manure were used as fertilisers, but when sheep manure plus agrobiosol was used as fertiliser, Sarpo mira produced higher yields than Spunta (Table 4.4).

The mean tuber weight was similar with all fertilizer types for Sarpo mira, while Spunta producing a more than 2 times higher tuber weight with sheep manure than the other 2 fertiliser types. Also, the mean tuber weight of Spunta was 3 times higher than that of Sarpo mira when sheep manure was used as fertilizer, while there was no difference in tuber weight between varieties when chicken manure or sheep manure plus agrobiosol were used as fertilizer (Table 4.4.4).

The proportion of size 1 (<4.5 cm) and size 3 (6.5-8.5 cm) tubers was similar with all fertilizer types for Spunta, while Sarpo mira produced a significantly higher proportion of size 1 and a significantly lower proportion of size 3 tubers with sheep manure than the other two fertilizer types (Table 4.5.3).

Interaction between **irrigation type and variety** were detected for the proportion of size 1 and 3 tubers (Table 4.5.2). The proportion of size 1 tubers was similar with both irrigation types for Spunta, while Sarpo mira produced significantly higher proportion of more size 1 tubers and a significantly lower proportion of size 3 tubers with drip than sprinkler irrigation (Table 4.5.2).

A significant 3-way interactions between **irrigation level, fertility treatment** and **variety** was detected for mean tuber weight (Table 4.4.5). Spunta producing significantly higher mean tuber weights with sheep manure than the other two fertilizer types when the higher, irrigation level was used, while there was no difference between fertilizer types at the lower irrigation level. Also, Spunta produced significantly higher tuber weights than Sarpo mira only when sheep manure and the higher irrigation level were used (Table 4.4.5).

A significant 3-way interaction between **irrigation type, irrigation level** and **variety** was detected for the proportion of size 1 and size 3 tubers (Table 4.5.4). There was no effect of irrigation type and level on the proportion of size 1<4.5 cm) and size 3 for Spunta , while Sarpo mira produced a significantly higher proportion of of size 1 and less size 3 tubers with drip irrigation at the higher input level than the 3 other irrigation treatments (Table 4.5.4). Also, significant differences in the proportion of size 1 and 3 tubers between varieties were only detected when drip irrigation at the higher irrigation level was used (Table 4.5.4).

4.3.2 Crop health parameters (late blight severity and Colorado beetle infestation)

Colorado beetle infestation could only be assessed in Sarpo mira plots in both seasons (2013 and 2014), because high levels of late blight infestation in Spunta, resulted in foliage having to be destroyed before Colorado beetle infestation was observed in 2014.

There were a significant main effects of irrigation level and variety on late blight severity (AUDPC). The higher irrigation level resulted in a 10% higher late blight severity (Table 4.4) and use of the variety Spunta in more than 3 times higher late blight severity (Table 4.4).

There was a significant 2-way interaction between **fertilty treatment** and **variety.** Late blight severity, was highest for Spunta and lowest for Sarpo mira in sheep manure fertilized crops, but THSD test did not detect significant differences between fertilizer types for both varieties (Table 4.4.4)

There was a 3-way interaction between **irrigation type**, **fertilizer type** and **variety**, but further investigation of this 3-way interaction did not show any clear trends. However, the relative difference in blight severity between sheep manure and the other 2 fertilizer treatments was greater in sprinkler irrigated Sarpo mira crops than drip irrigated Sarpo mira and both drip and sprinkler irrigated Spunta crops (Table 4.4.6).

When data on Colorado beetle infestation in Sarpo mira from both field trial seasons were analysed, no significant effects of year, irrigation type and level and fertilizer type were detected (Table 4.6). However, trends towards significant main effects of year (P=0.065) and irrigation level (P=0.060) were detected by ANOVA, with infestation levels found to be more than 2 times higher in 2013 and with the lower irrigation level (Table 4.6).

ANOVA also detected significant 2-way interactions between **(a)** year and irrigation type and year and irrigation level (Table 4.6). See separate analyses for the two different growing seasons (2013 and 2014) in chapters 5.2 and 5.3 below for results on the effect of irrigation type and level on Colorado beetle infestation in the two years.

4.3.3 Leaf chlorophyll levels (SPAD)

Only the two early chlorophyll measurements could be carried out in plots in both seasons, since late blight had destroyed the foilage in all plots from some treatment combinations on later assessment dates in 2014. There was a significant main effect of fertility treatment and variety on the levels of chlorophyll. Chlorophyll levels were higher for the 2 early assessment dates in both years when chicken manure was used as fertility treatment (Tables 4.7) and Sarpo mira had higher chlorophyll levels than Spunta (Tables 4.7).

Also, there were significant 2-way interaction between (a) irrigation type and irrigation level (both assessment dates), (b) irrigation type and fertilizer type (both assessment dates), (c) irrigation level and fertililiser type (both assessment dates), (d) irrigation type and variety (both assessment dates), and (e) fertility treatment and variety (both assessment dates) (Table 4.7).

At the 1st assessment date, drip (but not sprinkler) irrigation resulted in lower chlorophyll levels at the higher but not the lower irrigation level (Table 4.7.1). In contrast at the 2nd assessment date, sprinkler (but not drop) irrigation resulted in lower chlorophyll levels at the lower, but not the higher irrigation level (Table 4.7.1).

At both the 1st and 2nd assessment dates, drip irrigation resulted in lower chlorophyll levels than sprinkler irrigation when sheep manure was used as fertilizer, and lower chlorophyll levels when chicken manure or sheep manure plus agrobiosol were used as fertilizer. However, the difference in chlorophyll levels between irrigation types was only significant for chicken manure fertilized plants on the second assessment date (Table 4.7.2).

At both the 1st and 2nd assessment dates, the lower irrigation level resulted in lower chlorophyll levels when sheep manure was used as fertilizer (significant only at the 1st assessment date) and higher chlorophyll levels when chicken manure was used, while no difference between irrigation levels was detected when sheep manure plus agrobiosol was used as fertilizer (Table 4.7.3).

At both the 1st and 2nd assessment date, with drip irrigation resulted in lower chlorophyll levels in Spunta than Sarpo mira leaves (Table 4.7.4), whereas spinkler irrigation resulted in similar chlorophyll levels in Spunta and Sarpo mira (Table 4.7.4).

At both the 1st and 2nd assessments chicken manure resulting in the highest chlorophyll levels for both varieties. However, Spunta had significantly lower chlorophyll levels with sheep manure than sheep manure with agrobiosol, while Sarpo mira had similar chlorophyll levels with sheep manure alone and sheep manure plus agrobiosol (Table 4.7.5).

There were 3-way interactions between (a) irrigation type, irrigation level and variety (1st assessment date only) and (b) irrigation level, fertility treatment and variety (1st assessment date only) (Table 4.7). At the 1st assessment date, Spunta had lower chlorophyll levels than Sarpo mira when drip irrigation was used at both irrigation levels, while there was no difference in chlorophyll levels between varieties when sprinkler irrigation was used. Also, for Spunta the higher irrigation level resulted in lower chlorophyll levels when drip irrigation, but higher chlorophyll levels when sprinkler irrigation was used, although differences between irrigation levels were not significant (Table 4.7.6). At the 1st assessment date, chicken manure resulted in higher chlorophyll levels than sheep manure and/or sheep manure plus agrobiosol at both irrigation levels with the variety Spunta. In contrast, with Sarpo mira chicken manure only resulted in significantly higher chlorophyll levels than the other two fertilizer types when the lower irrigation level was used (Table 4.7.7).

A significant 4-way interaction between irrigation type, irrigation level, fertility treatment and variety was detected on both assessment dates (Table 4.7). At the 1st assessment date sheep manure resulted in the highest chlorophyll levels with the high Sprinker irrigation input level, chicken manure with the low Sprinkler and drip irrigation input level, and sheep manure plus agrobiosol with the low drip irrigation input level in the variety Spunta. In contrast, for Sarpo mira, chicken manure resulted in the highest chlorophyll levels with the low drip and sprinkler irrigation level, while at the high irrigation input level there was no significant difference between fertilizer input types with both drip and sprinkler irrigation (Table 4.7.8). At the 2nd assessment date, sheep manure resulted in the highest chlorophyll levels with the high Sprinker irrigation input level, chicken manure with the low sprinkler and low and high drip irrigation input level in the variety Spunta. In contrast, for Sarpo mira, chicken manure resulted in the highest chlorophyll levels with the low drip and low sprinkler irrigation level, while at the high sprinkler irrigation input level there was no significant difference between fertilizer input types with both drip and sprinkler irrigation (Table 4.7.9).

4.3.4 Redundancy analysis; Associations between agronomic (irrigation type and level, fertilizer types) and climatic drivers (precipitation) and yield, crop health parameters

Redundancy Analyses (RDA) were carried out to investigate potential associations between climatic (air temperature, precipitation, solar radiation) and agronomic drivers and crop performance (yield parameters and disease severity) in field trials. Most variation (72.1%) was explained by axis1 and a further (0,1%) by axis 2. Precipitation (PRE: F=169, p=0.002), Variety (vr.SMI - vr.SPU: F=92.5, p=0.002), Irrigation (IR.SPRL: F=6.2, p=0.01), Fertility (ft.SM+A:F= 0.3, p=0.24), Irrigation (IR.DRIL: F=0.5 p=0.478) and Irrigation (IR.DRIH: F=0.1, p=0.732).

Only precipitation was identified as a significant environmental driver for performance, with late blight disease severity being positively and total tuber yield, large tuber size and SPAD readings negatively associated with high precipitation along axis 1 (Fig. 3.3). The use of the variety Sarpo mira and high levels of sprinkler irrigation were positively associated with yield and negatively with late blight severity along axis 1. Colorado beetle infestation was positively and late blight severity negatively associated with drip irrigation.

4.3.5 Correlation analysis

For Spunta Pearson's correlation analysis identified significant negative correlations between disease severity and (a) tuber yield ($p<0.01$; correlation coefficient= - 0.56) and (b) tuber number ($p<0.01$; correlation coefficient = -0.29) correlation between tuber number and disease severity. For the Sarpo mira Pearson's correlation analyses identified a weaker but significant negative correlations between disease severity and tuber yield ($p<0.01$) correlation coefficient = -0.28), but a positive correlation between disease severity and tuber number ($p<0.01$); correlation coefficient = 0.30).

Table 4.4 Effect of growing season (year), irrigation type and level, fertiliser type and variety on tuber yield parameters and foliar late blight severity (field trials, years 2013 and 2014)

Factor	**Number of tubers ha^{-1}**	**Tuber yield (t ha^{-1})**	**Average mean tuber weight per plot[1] (g)**	**Late blight (AUDPC)**
Year				
2013	166471 ±6941	10.9 ±0.7	107 ±20	168 ± 28
2014	170995 ±7049	*6.0* ±0.4	52 ±11	3183 ±185
Irrigation type				
Drip	146398 ±2085	6.0 ±0.4	74 ±18	1607 ±199
Sprinkler	190023 ±6916	10.8 ±0.7	85 ±14	1745 ±208
Irrigation level				
Low	161076 ±6699	7.8 ±0.6	59 ± 4	1594 ±201
High	176763 ±7220	9.1 ±0.7	100 ±22	1757 ±206
Fertiliser type				
Sheep M.	155626 ±6843 **b**	6.8 ±0.6 **b**	99 ±29	1666 ±237
Chicken M.	168817 ±8004 **ab**	9.3 ±0.8 **a**	77 ±16	1669 ±249
Sheep M.+AB.	182151 ±10303 **a**	9.3 ±0.9 **a**	62 ± 6	1692 ±263
Variety				
Spunta	146503 ±6507	7.8 ±0.6	91 ±19	2599 ±240
Sarpo Mira	191812 ±6689	9.1 ±0.7	68 ±11	752 ± 87
ANOVA-results				
Main effects				
Year (Y)	ns	**0.0080**	ns	**<0.001**
Irrigation type (IT)	**0.0036**	**0.0008**	ns	0.0833
Irrigation level (IL)	**0.05**	**0.0478**	0.0728	**0.0307**
Fertiliser type (FT)	**0.0143**	**0.0006**	ns	0.9111
Variety (V)	**<0.001**	**0.0301**	ns	**<0.001**
Interactions				
YxIT	ns	**0.0029**	ns	ns
YxIL	**0.0081**	**0.0414**	ns	ns
ITxIL	ns	**0.0133**[2]	ns	ns
YRxFT	**<0.001**	ns	**0.0496**	ns
ITxFT	**0.0163**[3]	**0.0071**[3]	ns	ns
ILxFT	ns	ns	ns	ns
YxV	**<0.001**	**0.0011**	ns	**<0.001**
ITxV	**0.0444**[4]	ns	ns	ns
ILxV	ns	ns	ns	ns
FTxV	ns	**0.0332**[5]	**0.0144**[5]	**<0.001**[5]
YxITxIL	**0.0136**	**0.0056**	ns	ns
YxILxFT	ns	ns	**0.0238**	ns
YxITxV	**0.001**	ns	ns	ns
YxILxV	ns	ns	**0.0262**	ns
YxFTxV	ns	ns	*0.0961*	**0.0004**
ITxFTxV	ns	ns		**0.0276**[7]
ILxFTxV	ns	ns	**0.0448**[6]	ns
YxITxILxV	ns	ns	ns	**0.0040**
YxITxILxFT	ns	**0.0420**	ns	**0.0399**

all other 3-way, 4-way and the 5-way interaction were not significant

M., manure; AB, Agrobiosol; Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$) . [1], see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated. [2] see **Table 4.4.1,** [3] see **Table 4.4.2,** [4] see **Table 4.4.3c,** [5] see **Table 4.4.4,** [6] see **Table 4.4.5** and [7] see **Table 4.4.6** for interaction means ± SE

Table 4.4.1 Interaction between irrigation type and irigation level on tuber yield (field trials, spring growing seasons 2013 and 2014)

Parameter assessed	Factor 1 Irrigation Type (IT)	Factor 2 Irrigation level (IL) 1. Low	2. High
Tuber yield	1. Drip	6.3 ±0.5**B a**	5.8 ±0.6**B a**
	2. Sprinklers	9.4 ±1.0**A b**	12.3 ±1.0**A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.4.2 Interaction between irrigation type and fertiliser type on the number of tubers and tuber yield (field trials, spring growing seasons 2013 and 2014)

Parameter assessed	Factor 1 Irrigation Type (IT)	Factor 2 Fertiliser type (FT) 1. Sheep M.	2. Chicken M.	3. Sheep M. + AB.
Number of tubers	1. Drip	155555 ±9146**Aa**	161528 ±10032**Aa**	166308 ±15243**Aa**
	2. Sprinkler	155699 ±1366**Ab**	176593 ±12637 **Aa**	197993 ±13515 **Aa**
Tuber yield	1. Drip	5.5 ±0.5**A a**	7.0 ±0.9**A a**	5.7 ±0.6**A a**
	2. Sprinkler	8.0 ±1.1**A b**	11.7 ±1.1**A a**	12.8 ±1.4**A a**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.4.3 Interaction between irrigation type and variety on the number of tubers (field trials, years 2013 and 2014)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Variety (V) 1. Spunta	2. Sarpo mira
Number of tubers	1. Drip	118534 ±6899	176162 ±8759
	2. Sprinkler	173889 ±9974	206157 ±9620

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.4.4 Interaction between fertiliser type and variety on the tuber yield and mean tuber weight (field trials, years 2013 and 2014)

Parameter assessed	Factor 1 Fertiliser type (FT)	Factor 2 Variety (V)	
		1. Spunta	2. Sarpo mira
Tuber yield (t ha^{-1})	1. Sheep M.	7.1±0.8 **A a**	6.4±0.8 **B a**
	2. Chicken M.	8.5±1.1 **A a**	10.1±1.0 **A a**
	3. Sheep M. + AB	7.9±1.0 **A b**	10.7±1.4 **A a**
Average mean tuber weight per plot[1] (g)	1. Sheep M	154.4 ±57.0 **A a**	43.6 ± 4.0 **A b**
	2. Chicken M.	62.1 ± 3.7 **B a**	91.7 ±31.3 **A a**
	3. Sheep M. + AB	56.5 ± 3.9 **B a**	67.8 ±11.6 **A a**
Late blight severity (AUDPC)	1. Sheep M	2400 ±396 **Aa**	932 ±192 **Ab**
	2. Chicken M.	2676 ±414 **Aa**	662 ±127 **Ab**
	3. Sheep M. + AB	2720 ±446 **Aa**	663 ±122 **Ab**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$); **[1]**, see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated.

Table 4.4.5 Interaction between irrigation level, fertiliser type and variety on mean tuber weight (field trial, years 2013 and 2014)

Parameter Assessed	Factor 1 Irrigation level (IL)	Factor 2 Fertiliser type (FT)	Factor 3 Variety (V)	
			1. Spunta	2. S. Mira
Average mean tuber weight (g) per plot[1]	1. Low	1. Sheep M.	54.6 ± 3.9**B a**	42.6 ± 3.0**A a**
		2. Chicken M.	63.0 ± 5.0**B a**	64.8 ± 5.2**A a**
		3. Sheep M. + AB	53.0 ± 5.7**B a**	75.6 ±21.9**A a**
	2. High	1. Sheep M.	254.1 ±110.0**A a**	44.6 ± 7.5**A b**
		2. Chicken M.	61.2 ± 5.6**B a**	118.6 ±62.7**A a**
		3. Sheep M. + AB	59.9 ± 5.3**B a**	60.1 ± 8.4**A a**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$); **[1]**, see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated.

Table 4.4.6 Interaction between irrigation type, fertiliser type and variety on late blight severity AUDPC (field trials, years 2013 and 2014)

Parameter Assessed	**Factor 1 Irrigation type (IT)**	**Factor 2 Fertiliser type (FT)**	**Factor 3 Variety (V)**	
			1. Spunta	**2. S. Mira**
Late blight severity (AUDPC)	1. Drip	1. Sheep M.	2394 ±568 **A a**	787 ±204 **A b**
		2. Chicken M.	2500 ±600 **A a**	655 ±178 **A b**
		3. Sheep M. + AB	2590 ±632 **A a**	714 ±190 **A b**
	2. Sprinkler	1. Sheep M.	2407 ±570 **A a**	1077 ±328 **A b**
		2. Chicken M.	2851 ±586 **A a**	670 ±187 **A b**
		3. Sheep M. + AB	2851 ±647 **A a**	613 ±158 **A b**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.5 Effect of growing season (year), irrigation type and level, fertiliser type and variety on tuber size distribution (field trials, years 2013 and 2014)

	% of tubers in different size categories			
	size 1	**size 2**	**size 3**	**size 4**
Factor	(<4.5 cm)	(4.5-6.5 cm)	(6.5-8.5 cm)	(>8.5 cm)
Year				
2013	16 ±1	29 ±1	32 ±1	23 ±2
2014	32 ±1	43 ±1	20 ±1	4 ±1
Irrigation type				
Drip	27 ±2	38 ±1	25 ±1	11 ±1
Sprinkler	23 ±1	34 ±1	27 ±1	16 ±2
Irrigation level				
Low	25 ±1	38 ±1	26 ±1	12 ±1
High	24 ±2	34 ±1	26 ±1	16 ±2
Fertility treatment				
Sheep M.	28 ±2 **a**	37 ±2	24 ±2 **b**	11 ±2 **b**
Chicken M.	23 ±2 **b**	35 ±2	26 ±1 **ab**	16 ±2 **a**
Sheep M.+AB.	23 ±2 **b**	36 ±2	28 ±2 **a**	13 ±2 **ab**
Variety				
Spunta	18 ±1	32 ±2	31 ±1	20 ±2
Sarpo Mira	32 ±2	41 ±1	21 ±1	7 ±1
ANOVA-results				
Main effects				
Year (Y)	**0.0015**	**0.0017**	**0.0053**	**0.0005**
Irrigation type (IT)	*0.0512*	**0.0305**	ns	**0.0036**
Irrigation level (IL)	ns	**0.0299**	ns	**0.0055**
Fertiliser type (FT)	**<0.001**	ns	**0.0468**	**0.0002**
Variety (V)	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions				
YxIT	**0.0403**	ns	ns	**0.0023**
YxIL	ns	ns	ns	**0.0167**
ITxIL	**0.0276**[1]	ns	ns	**0.0067**[1]
YxFT	ns	ns	ns	*0.0904*
ITxFT	ns	ns	ns	ns
ILxFT	ns	ns	ns	ns
YxV	**<0.001**	**<0.001**	**0.001**	**<0.001**
ITxV	**0.0266**[2]	ns	**0.0376**[2]	ns
ILxV	ns	ns	ns	ns
FTxV	**<0.001**[3]	ns	**<0.001**[3]	ns
YxITxIL	ns	**0.0154**	ns	**0.0098**
YxITxV	ns	ns	ns	**0.0436**
ITxILxV	**0.0484**[4]	ns	**0.0056**[4]	ns
YxITxILxV	ns	ns	*0.0697*	ns
all other 3-way, 4-way and the 5-way interaction were not significant				

M., manure; AB, agrobiosol

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).[1] see **Table 4.5.1**,[2] see **Table 4.5.2,**[3] see **Table 4.5.3,** and [4] see **Table 4.5.4,** for interaction means ± SE.

Table 4.5.1 Interaction between irrigation type and irrigation level on the % distribution of size 1 and size 4 tubers (field trials, spring growing seasons 2013 and 2014)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Irrigation level (IL)	
		1. Low	2.High
size 1 tubers (<4.5 cm)	1. Drip	24.9±1.9**Aa**	28.4±2.4**Aa**
	2. Sprinkler	24.2±1.9**Aa**	20.8±2.2**Ba**
size 4 tubers (>8.5 cm)	1. Drip	10.7±1.8**Aa**	10.6±1.9**Ba**
	2. Sprinkler	12.8±2**Ab**	19.9±2.8**Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test *p*< 0.05)

Table 4.5.2 Interaction between irrigation type and variety on the % distribution of size1 and size 3 tubers (field trials, spring growing seasons 2013 and 2014)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Variety (V)	
		1. Spunta	2. S.Mira
size 1 tubers (<4.5 cm)	1. Drip	18.4±1.1**Ab**	35.4±2.2**Aa**
	2. Sprinkler	16.6±1.3**Ab**	28.5±2.3**Ba**
size 3 tubers (6.5-8.5 cm)	1. Drip	30.4±1.2**Aa**	18.5±2.3**Bb**
	2. Sprinkler	30.9±1**Aa**	23.3±1.7**Ab**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test *p*< 0.05)

Table 4.5.3 Interaction between fertiliser type and variety on the % distribution of size 1 and size 3 tubers (field trials, years 2013 and 2014)

Parameter assessed	Factor 1 Fertiliser type (FT)	Factor 2 Variety (V)	
		1. Spunta	2. Sarpo mira
size 1 tubers (<4.5 cm)	1. Sheep M.	17.8 ±1.6 **Ab**	39.3 ±2.9 **Aa**
	2. Chicken M.	17.7 ±1.5 **Ab**	27.8 ±2.3 **Ba**
	3. Sheep M. + AB	17.0 ±1.5 **Ab**	28.1 ±2.6 **Ba**
size 3 tubers (6.5-8.5 cm)	1. Sheep M.	32.0 ±1.5 **Aa**	14.9 ±1.9 **Bb**
	2. Chicken M.	29.6 ±1.1 **Aa**	23.0 ±1.8 **Ab**
	3. Sheep M. + AB	30.3 ±1.4 **Aa**	25.1 ±3.2 **Ab**

M., manure; AB, agrobiosol

or each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test *p*< 0.05)

Table 4.5.4 Interaction among irrigation type, irrigation level and variety on the % distribution of size1 and size 3 tubers (field trials, years 2013 and 2014)

Parameter Assessed	**Factor1 Irrigation type (IT)**	**Factor2 Irrigation level (IL)**	**Factor 3 Variety (V)**	
			1. Spunta	2. S. Mira
size 1 tubers (<4.5 cm)	1. Drip	1. Low	18.4 ±1.7 **Ab**	31.1 ±2.8 **Ba**
		2. High	18.3 ±1.6 **Ab**	40.5 ±3.1 **Aa**
	2. Sprinkler	1. Low	18.0 ±1.9 **Ab**	30.5 ±2.7 **Ba**
		2. High	15.2 ±1.9 **Ab**	26.5 ±3.7 **Ba**
size 3 tubers (6.5-8.5 cm)	1. Drip	1. Low	29.6 ±1.8 **Aa**	22.1 ±3.8 **Ab**
		2. High	31.1 ±1.6 **Aa**	14.2 ±2.1 **Bb**
	2. Sprinkler	1. Low	31.6 ±1.4 **Aa**	21.3 ±2.1 **Ab**
		2. High	30.2 ±1.5 **Aa**	25.2 ±2.6 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.6 Effect of year, irrigation type and level and fertiliser type on Colorado potato beetle infestation in Sarpo mira (field trials, years 2013 and 2014)

Factor	% Colorado beetle infestation
Year	
2013	18.6 ±3.1
2014	6.7 ±1.4
Irrigation Type	
Drip	14.9 ±3.0
Sprinkler	10.4 ±2.0
Irrigation Level	
Low	17.0 ±3.1
High	8.3 ±1.6
Fertiliser Type	
Sheep M.	13.2 ±3.2
Chicken M.	12.7 ±3.3
Sheep M. + AB	12.1 ±2.9
ANOVA results	
Main effects	
Year (Y)	*0.0653*
Irrigation Type (IT)	ns
Irrigation Level (IL)	*0.0602*
Fertiliser Type (FT)	ns
Interactions	
Y x IT	**0.0268**
Y x IL	**0.0461**
IT x IL	ns
Y x FT	ns
IT x FT	ns
IL x FT	ns

all other 3-way, and the 4-way interaction were not significant
M., manure; AB, agrobiosol; Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).

Table 4.7 Effect of year, irrigation type and level and fertiliser type on SPAD (field trials, years 2013 and 2014)

Factor		
Year	**SPAD1** (53 days after planting)	**SPAD2** (61 days after planting)
2013	42.6±0.5	46.1±0.5
2014	42.9±0.4	44.4±0.4
Irrigation Type		
Drip	42.6±0.5	45.3±0.5
Sprinkler	42.9±0.4	45.1±0.3
Irrigation Level		
Low	43±0.5	45.6±0.5
High	42.5±0.4	44.8±0.4
Fertiliser Type		
1.Sheep M.	41±0.6 **b**	43.7±0.6 **b**
2.Chicken M.	45.1±0.5 **a**	47.4±0.5 **a**
3.Sheep M. + AB	42.1±0.4 **b**	44.5±0.4 **b**
Variety		
Spunta	41.9±0.5	44.2±0.5
Sarpo Mira	43.6±0.3	46.2±0.4
ANOVA		
Main effects		
Year (Y)	0.7553	0.0965
Irrigation Type (IT)	0.7183	0.7611
Irrigation Level (IL)	0.3718	0.0922
Fertiliser type (FT)	**<0.001**	**<0.001**
Variety (V)	**0.0004**	**<0.001**
Interactions		
IT x IL	**0.0109**[1]	**0.0069**[1]
IT x FT	**0.001**[2]	**0.0003**[2]
IL x FT	**0.001**[3]	**0.0007**[3]
IT x V	**<0.001**[4]	**<0.001**[4]
FTx V	**0.0011**[5]	**0.001**[5]
IT x IL x V	**0.0162**[6]	0.0525
IL x FT x V	**0.0443**[7]	0.0544
IT x IL x FT x V	**0.0307**[8]	**0.0471**[9]
Y xIT xIL xFT x V	0.8672	0.9897

all other 3-way, 4-way and the 5-way interaction were not significant
M., manure; AB, agrobiosol
Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).1 see Table 4.7.1,2 see Table 4.7.2, 3 see Table 4.7.3, 4 see Table 4.7.4, 5 see Table 4.7.5, 6 see Table 4.7.6, 7 see Table 4.7.7, 8 see Table 4.7.8 and 9 see Table 4.7.9 interaction means ± SE.

Table 4.7.1: Interaction between irrigation type and irrigation level on SPAD at the two first assessment dates (53 and 61 days after planting, respectively) (field trials, years 2013 and 2014)

	SPAD1 (53 days after planting)			**SPAD2** (61 days after planting)	
Irrigation	**Irrigation level**		**Irrigation**	**Irrigation level**	
Type	1.Low	2.High	**Type**	1.Low	2.High
1.Drip	43.5±0.7 **Aa**	41.7±0.7 **Bb**	1.Drip	46.5±0.8 **Aa**	44.2±0.7 **Ab**
2.Sprinkler	42.4±0.6 **Aa**	43.4±0.5 **Aa**	2.Sprinkler	44.8±0.5 **Ba**	45.4±0.5 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significant different (Tukey's honestly significant difference test *p*< 0.05)

Table 4.7.2 Interaction between irrigation type and fertiliser type on SPAD at the two first assessment dates (53 and 61 days after planting, respectively) (field trials, years 2013 and 2014)

	SPAD1 (53days after planting)			**SPAD2** (61 days after planting)		
Irrigation	**Fertiliser type**			**Fertiliser type**		
Type	1.Sheep M.	2.Chicken M.	3.Sheep M. +AB	1.Sheep M.	2.Chicken M.	3.Sheep M. +AB
1.Drip	39.4±0.9**Bc**	45.6±0.7**Aa**	42.9±0.6**Ab**	42.4±0.8**Bc**	48.4±0.9**Aa**	45.2±0.6**Ab**
2.Sprinkler	42.7±0.7**Ab**	44.6±0.6**Aa**	41.3±0.4**Ab**	44.9±0.7**Aab**	46.5±0.6**Ba**	43.9±0.4**Ab**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test *p*< 0.05)

Table 4.7.3 Interaction between irrigation level and fertiliser type on SPAD at the two first assessment dates (53 and 61 days after planting, respectively) (field trials, years 2013 and 2014)

	SPAD1 (53days after planting)			**SPAD2** (61 days after planting)		
Irrigation	**Fertiliser type**			**Fertiliser type**		
Level	1.Sheep M.	2.Chicken M.	3.Sheep M. +AB	1.Sheep M.	2.Chicken M.	3.Sheep M. +AB
1.Low	39.9±0.7 **Bc**	46.5±0.6 **Aa**	42.6±0.6 **Ab**	42.9±0.7 **Ac**	48.9±0.7 **Aa**	45±0.6 **Ab**
2.High	42.2±1 **Aab**	43.7±0.6 **Ba**	41.7±0.4 **Ab**	44.4±0.9 **Aab**	46±0.7 **Ba**	44±0.4 **Ab**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test *p*< 0.05)

Table 4.7.4: Interaction between irrigation type and variety on SPAD at the two first assessment dates (53 and 61 days after planting, respectively) (field trials, years 2013 and 2014)

	SPAD1 (53days after planting)			SPAD2 (61 days after planting)	
Irrigation	**Variety**		**Irrigation**	**Variety**	
Type	1.Spunta	2.S.Mira	**Type**	1.Spunta	2.S.Mira
1.Drip	40.8±0.8 **Bb**	44.5±0.5 **Aa**	1.Drip	43.3±0.8 **Bb**	47.4±0.6**Aa**
2.Sprinkler	43.1±0.6 **Aa**	42.7±0.4 **Ba**	2.Sprinkler	45.2±0.6 **Aa**	45±0.4 **Ba**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.7.5 Interaction between fertiliser type and variety on SPAD at the two first assessment dates (53 and 61 days after planting, respectively) (field trials, years 2013 and 2014)

	SPAD1 (53days after planting)			SPAD2 (61 days after planting)	
Fertiliser	**Variety**		**Fertiliser**	**Variety**	
Type	1.Spunta	2.S.Mira	**Type**	1.Spunta	2.S.Mira
1.Sheep M.	39.1±1 **Cb**	43±0.5 **Ba**	1.Sheep M.	41.5±0.9 **Cb**	45.9±0.5 **ABa**
2.Chicken M.	45.1±0.7 **Aa**	45±0.6 **Aa**	2.Chicken M.	47.4±0.8 **Aa**	47.5±0.7 **Aa**
3.Sheep M. + AB	41.6±0.5 **Ba**	42.7±0.5**Ba**	3.Sheep M. + AB	43.8±0.5 **Ba**	45.2±0.6 **Ba**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.7.6 Interaction of irrigation type, irrigation level and variety on SPAD at the 1st assessment date (53 days after planting) (field trials, years 2013 and 2014)

Parameter Assessed	**Factor1 Irrigation type**	**Factor2 Irrigation level**	**Factor 3 Variety** 1. Spunta	2. S. Mira
SPAD 1	1. Drip	1. Low	41.8±1.9 **Ab**	45.0±1.2 **Aa**
		2. High	39.0±1.6 **Ab**	43.7±0.9 **Aa**
	2. Sprinkler	1. Low	41.5±1.4 **Aa**	42.8±0.9 **Aa**
		2. High	44.5±1.0 **Aa**	42.7±0.6 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.7.7 Interaction of irrigation level, fertiliser type and variety on SPAD at the 1st assessment date (53 days after planting) (field trials, years 2013 and 2014)

Parameter assessed	**Factor 1 Irrigation level**	**Factor 2 Fertiliser type**	**Factor 3 Variety**	
			1. Spunta	2. S. Mira
SPAD 1	1. Low	1. Sheep M.	36.0±0.9 **Db**	42.2±1.1 **Ba**
		2. Chicken M.	46.4±1.7 **Aa**	47.2±0.9 **Aa**
		3. Sheep M. + AB	42.5±1.4 **BCa**	42.4±1.4 **Ba**
	2. High	1. Sheep M.	40.3±2.7 **Ca**	43.5±0.1 **ABa**
		2. Chicken M.	44.3±1.4 **ABa**	43.2±1.2 **B**
		3. Sheep M. + AB	40.7±0.6 **BCa**	42.9±0.7 **Ba**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.7.8 Interaction of irrigation type, irrigation level, fertiliser type and variety on SPAD at the 1st assessment date (53 days after planting) (field trials, years 2013 and 2014)

Parameter Assessed	Factor 1 Irrigation Type	Factor 2 Irrigation level	Factor 3 Fertiliser type	Factor 4 Variety	
				1. Spunta	2. S. Mira
SPAD 1	1. Drip	1. Low	1. Sheep M.	36.6±1.1 **FGb**	42.4±1.4 **CDa**
			2. Chicken M.	47.2±1.4 **Aa**	47.5±0.8 **Aa**
			3. Sheep M. + AB	42.7±1.3 **BCDa**	44.6±1.4 **BCa**
		2. High	1. Sheep M.	35.0±1.3 **Ga**	43.6±1.1 **BCb**
			2. Chicken M.	43.0±1.6 **BCa**	44.5±1.4 **BCa**
			3. Sheep M. + AB	40.0±0.4 **DEb**	44.2±0.9 **BCa**
	2.Sprinkler	1. Low	1. Sheep M.	38.2±0.8 **EFb**	42.3±0.9 **CDa**
			2. Chicken M.	45.3±1.5 **ABa**	45.8±0.9 **ABa**
			3. Sheep M. + AB	42.8±1.2 **BCDa**	40.1±0.3 **Da**
		2. High	1. Sheep M.	46.6±1.2 **Aa**	43.6±1.0 **BCb**
			2. Chicken M.	45.0±1.2 **ABa**	42.3±0.8 **CDa**
			3. Sheep M. + AB	40.7±0.4 **CDEa**	41.8±0.6 **CDa**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.7.9 Interaction of irrigation type, irrigation level, fertiliser type and variety on SPAD at the 2nd assessment date (61 days after planting) (field trials, years 2013 and 2014)

Parameter assessed	Factor 1 Irrigation Type	Factor 2 Irrigation level	Factor 3 Fertiliser type	Factor 4 Variety	
				1. Spunta	2. S. Mira
SPAD 2	1. Drip	1. Low	1. Sheep M.	39.3±0.5 **FGb**	46.7±1.1 **BCa**
			2. Chicken M.	50.3±1.7 **Ab**	50.4±1.5 **Aa**
			3. Sheep M. + AB	44.6±1.3 **CDa**	47.4±1.5 **Ba**
		2. High	1. Sheep M.	37.8±1.1 **Gb**	46.0±1.1 **BCa**
			2. Chicken M.	45.3±1.6 **BCDa**	47.5±1.7 **Ba**
			3. Sheep M. + AB	42.5±0.5 **Deb**	46.1±0.9 **BCa**
	2.Sprinkler	1. Low	1. Sheep M.	40.7±0.6 **EFa**	45.0±0.7 **BCDa**
			2. Chicken M.	45.5±1.4 **BCa**	47.4±0.9 **Ba**
			3. Sheep M. + AB	45.0±1.3 **CDa**	43.0±0.7 **Da**
		2. High	1. Sheep M.	48.1±1.4 **Aba**	45.9±0.9 **BCDa**
			2. Chicken M.	46.7±1.2 **BCa**	44.4±0.9 **CDa**
			3. Sheep M. + AB	43.2±0.7**DEa**	44.2±0.7 **CDa**

M., manure; AB, agrobiosol; For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

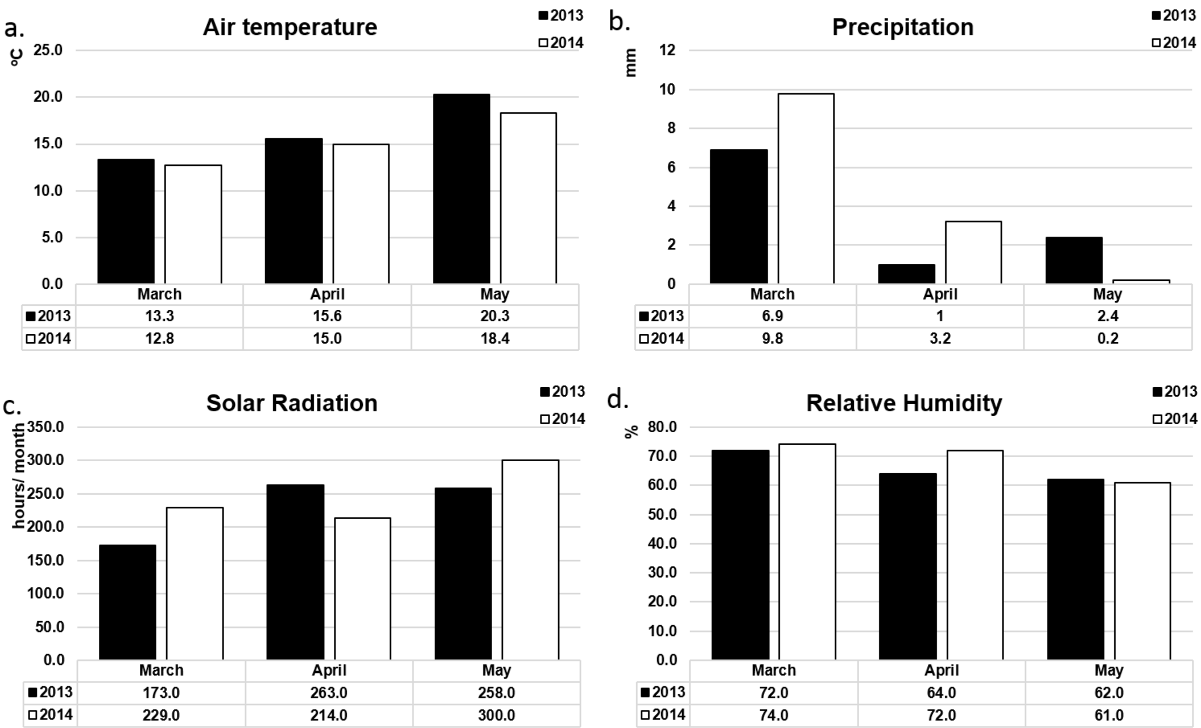


Figure 3.2(a-d) Air temperature, precipitation*, solar radiation, monthly accumulated (total sun hours/month) and relative humidity for 2013 and 2014 harvest years

*precipitation is presented as total mm per month

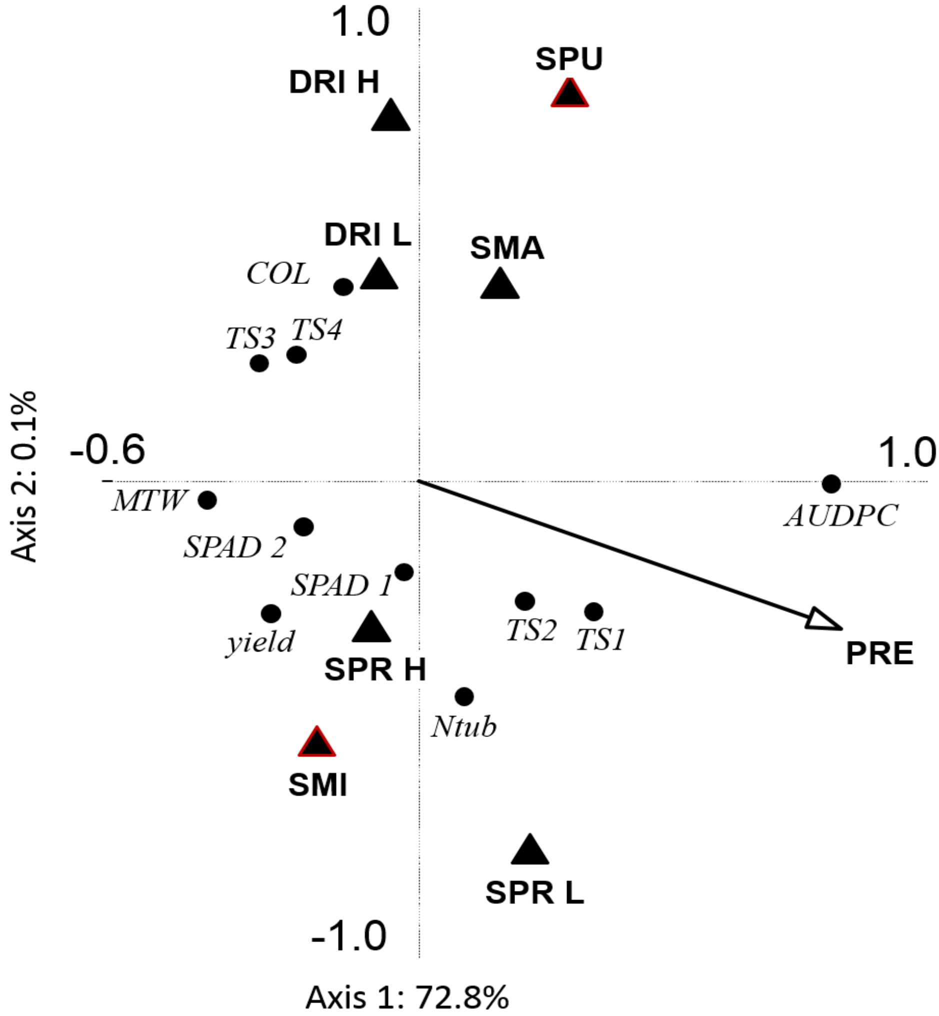


Figure 3.3 Bi-plot derived from redundancy analysis showing the relationship between weather conditions (2013 and 2014 growth season) agronomic management and variety drivers and (a) crop yield and (b) disease severity parameters.
PRE: Precipitation; SMA: fertility sheep manure ; SMI: Sarpo Mira; SPU: Spunta; SPR H: Sprinkler High rate; SPR L: Sprinkler Low rate; DRI H: High rate: Drip DRI L: Low rate Ntub: number of tubers; TS1:tuber size 1(<4.5 cm); TS2: tuber size 2 (4.5-6.5 cm); TS3: tuber size 3 (6.5-8.5 cm); TS4: tuber size 4 (>8.5 cm); MTW : meat tuber weight; COL: colorado beetle infestation; AUDPC: late blight severity

4.4 Results: ANOVA - Effect of irrigation type and level, fertilisation treatment, and variety on tuber yield and size, tuber size distribution, late blight severity (AUDPC) and Colorado beetle infestation (results from 2013 season only)

In 2013 late blight severity (based on AUDPC values) was approximately 20 times lower than in the 2014 season (Table 4.4). This allowed differences in both late blight severity and Colorado beetle infestation levels to be compared in the 2 contrasting varieties (Sarpo mira and Spunta).

4.4.1 Crop yield parameters (2013)

There was a significant main effect of **irrigation type** on the the total number of tubers and tuber yield (Table 4.8). Sprinkler irrigation resulted in 60% higher tuber numbers and more than 2 times higher tuber yield (Table 4.8).

There were significant main effects of **irrigation level** on total tuber yield (Table 4.8) and the proportion of large (size 4) tubers (Table 4.9). The higher irrigation level resulting in significantly higher yields (Table 4.8) and a higher proportion of tubers size 4 (>8.5 cm), (Table 4.9)

There were significant main effects of **fertiliser type** on the number of tubers, total tuber yield (Table 4.8) and the proportion of very small size 1 (<4.5 cm) and large size 4 (>8.5 cm) tubers (Table 4.9). Chicken manure resulted in significantly higher number of tubers and yields than the other two fertiliser types (Table 4.8). Sheep manure resulted in the highest proportion of size 1 tubers and chicken manure in the highest proportion of size 4 tubers (Table 4.9).

There were significant main effects of **variety** on the tuber size distribution (proportion of tubers in the tuber size categories) (Table 4.9). Sarpo mira produced a higher proportion of smaller size 1 and size 2 tubers, while Spunta produced a higher proportion of larger size 3 and 4 tubers (Table 4.9).

There were significant interactions between **irrigation type** and **irrigation level** for total tuber numbers and tuber yield (Table 4.8) and the proportion of size 2 and size 4 tubers (Table 4.9). Both total tuber numbers and yield were significantly higher with the higher irrigation level when sprinkler irrigation, but not when drip irrigation was used (Table 4.8.1). The higher irrigation levels resulted in a significantly lower proportion of size 2 and higher proportion of size 4 tubers when sprinkler irrigation was used, while there was no significnat difference between irrigation levels when drip irrigation was used (Table 4.9.1).

There was a significant interaction between **irrigation level** and **fertility treatment** for the mean tuber weight (Table 4.8). When the higher irrigation level was used, sheep manure resulted in more than 3 times higher mean tuber weights than chicken manure, and sheep manure plus agrobiosol, while there was no significant difference between fertiliser types when the low irrigation level was used (Table 4.8.2).

There was a significant interaction between **irrigation type** and **variety** for the number of tubers (Table 4.8) and the proportion of tubers size 3 (6.5-8.5 cm) (Table 4.9). Sprinkler irrigation resulted in significantly higher numbers of tubers in Spunta than Sarpo mira, while there was no significant difference in tuber numbers between varieties when drip irrigation was used (Table 4.8.3). Spunta produced the same number of tubers with both irrigation systems, while Sarpo mira produced higher numbers of size 3 tubers when sprinkler irrigation was used, but the differences between irrigation systems were not significant for both varieties (Table 4.9.2).

There was a significant interaction between **irrigation level** and **variety** for the number of tubers and mean tuber weight (Table 4.8). Spunta produced significantly higher tuber numbers and mean tuber weights than Sarpo mira at the high irrigation level, while there was no difference between varieties at the lower irrigation level (Table 4.8.4).

There was a significant interaction between **fertiliser type** and **variety** for mean tuber weight (Table 4.8) and on the proportion of small (size 1; <4.5 cm) and size 3 (6.5-8.5 cm) tubers (Table 4.9). Mean tuber weights were significantly higher with sheep manure than the other two fertiliser types for Spunta, while there was no significant difference in mean tuber weight between fertiliser types for Sarpo mira. Also, Spunta produced more than 5 times higher mean tuber weights than Sarpo mira when sheep manure was used as fertiliser; while there was no difference in mean tuber weight when chicken manure or sheep manure plus agrobiosol was used (Table 4.8.5). There was no difference in the proportion of size 1 and size 3 tubers between fertiliser types for the variety Spunta. In contrast, Sarpo mira produced significantly higher numbers of size 1 and lower numbers of size 3 tubers when sheep manure was used as fertiliser (Table 4.9.3).

There were significant 3-way interactions between **irrigation type**, **irrigation level** and **variety** for the proportion of small (size 1; <4.5 cm) and size 3 (6.5-8.5 cm) tubers. Spunta produced a significantly higher proportion of small (size 1) tubers with high levels of sprinkler irrigation than with low levels of drip irrigation, while there was no significant difference between the 4 irrigation regimes for Sarpo mira (Table 4.9.4). Sarpo mira produced a significantly higher proportion of size 3 tubers, with high level sprinkler irrigation than the high level drip irrigation, while there was no significant difference between the 4 irrigation regimes for Spunta (Table 4.9.4),

There was also a 3-way interactions between **irrigation level**, **fertiliser type** and **variety** for size 3 (6.5-8.5 cm) tubers. Spunta produced a higher proportion of size 3 tubers compared to Sarpo mira only when sheep manure was used in combination with the low irrigation level (Table 4.9.5).

4.4.2 Crop health parameters (late blight severity and Colorado beetle infestation)

There were significant main effects of **irrigation level** and **variety** on foliar late blight (Table 4.8).The higher irrigation level and use of the variety Spunta resulted in more than 2 and 10 times higher late blight severity than the lower irrigation treatment respectively (Table 4.8).

There were also significant main effects of **irrigation type** and **variety** on Colorado beetle infestation. Drip irrigation resulting in approximately 3 times, and the variety Spunta in approximately 30% higher Colorado infestation when compared to sprinkler irrigation and the variety Sarpo mira respectively (Table 4.8).

There were interactions for late blight severity, but not for Colorado beetle infestation (Table 4.8). For late blight 2-way interactions between **(a)** irrigation type and variety, and **(b)** irrigation level and variety and a 3-way interaction between irrigation type, irrigation level and variety were detected (Table 4.8). Blight severity was higher with sprinkler than drip irrigation in Spunta, while irrigation type had no significant effect in Sarpo mira (Table 4.8.3). Blight severity was significantly higher with the high than the low high irrigation level for Spunta, while irrigation level had no significant effect in Sarpo mira (Table 4.8.4). Also, late blight severity was significantly higher with Sprinkler irrigation at the higher irrigation level than the other 3 irrigation treatments when Spunta was used, while for Sarpo mira late blight severity was very low and there was no significant difference in late severity between all 4 combinations of irrigation type and irrigation level (Table 4.8.6).

4.4.3 Estimated chlorophyll levels via (SPAD)(2013)

There were significant main effects of fertility treatment and variety on chlorophyll levels (SPAD-readings; which were used as an estimate for N-supply/availability) on both assessment dates in 2013 (Table 4.10). Chicken manure resulted in higher chlorophyll levels in both dates than the other two fertility treatments (sheep manure and sheep manure plus agrobiosol) (Table 4.10). The variety Sarpo mira, showed higher chlorophyll levels on both assessment dates compared to Spunta (Table 4.10).

There were significant interactions between **irrigation type** and **irrigation level** on both assessment dates (Table 4.10). Drip irrigation resulted in higher chlorophyll levels at the lower irrigation level, while sprinkler irrigation resulted in higher chlorophyll levels at the higher irrigation level. However, there were no significant differences in chlorophyll levels between the 4 irrigation regimes (Table 4.10.1).

There were significant interactions between **irrigation type** and **fertiliser type** on both assessment dates (Table 4.10). Sprinkler irrigation resulted in significantly higher chlorophyll levels when sheep manure (both assessment dates) was used as fertiliser. In contrast, chicken manure and sheep manure plus agrobiolsol resulted in numerically higher chlorophyll levels with drip irrigation, but the difference between irrigation types was only significant for chicken manure at the 2nd assessment date (Table 4.10.2).

There were significant interactions between **irrigation level** and **fertiliser type** on both assessment dates (Table 4.10). The higher irrigation level resulted in higher chlorophyll levels when sheep manure was used as fertiliser, but the difference was only significant on the first assessment date (Table 4.10.3). In contrast, the lower irrigation level resulted in higher chlorophyll levels when chicken manure or sheep manure plus agrobiosol were used as fertiliser, but the differences between irrigation levels was only significant for chicken manure on both assessment dates (Table 4.10.3).

There were significant interactions between **irrigation type** and **variety** on both assessment dates (Table 4.10). Sprinkler irrigation resulted in higher chlorophyll levels in the variety Spunta, but the difference was only significant on the 1st assessment date. In contrast, in the variety Sarpo mira, drip irrigation resulted in higher chlorophyll levels, but the difference was only significant on the 2nd assessment date (Table 4.10.4).

The were significant interactions between **fertility treatment** and **variety** on both assessment dates (Table 4.10). The variety Spunta had higher chlorophyll levels with chicken manure than sheep manure and sheep manure plus agrobiosol on both assessment dates. In contrast, the variety Sarpo mira had similar chlorophyll levels with all fertiliser types on the first assessment date, but significantly higher chlorophyll levels with chicken manure than sheep manure plus agrobiosol on the second assessment date (Table 4.10.5) .

Table 4.8 Effect of irrigation type and level, fertiliser type and variety on tuber yield parameters, foliar late blight severity and Colorado beetle infestation (field trial 1, year 2013)

Factor	**Number of tubers (ha)**	**Yield** (t ha^{-1})	**Average mean tuber weight per plot**[1] (g)	**Late blight severity** (AUDPC)	**Colorado beetle infestation** (%)
Irrigation type					
Drip	133127 ± 9299	6.6 ±0.6	86 ±29	121 ±29	35 ±4
Sprinkler	196343 ± 8093	15.1 ±1.0	128 ±27	215 ±48	12 ±2
Irrigation level					
Low	148463 ± 8697	9.7 ±1.0	76 ± 7	101 ±29	31 ±4
High	185707 ±10268	12.1 ±1.1	138 ±38	235 ±47	16 ±2
Fertiliser type					
Sheep M.	160358 ±10949**ab**	9.1 ±1.0**b**	162 ±57	145 ±42	24 ±4
Chicken M.	187852 ±10984**a**	12.4 ±1.1**a**	77 ± 5	216 ±61	24 ±5
Sheep M.+AB.	151407 ±13409 **b**	11.1 ±1.6**a**	82 ±11	143 ±41	23 ±5
Variety					
Spunta	168747 ±11021	11.3 ±0.9	139 ±38	313 ±47	29 ±4
Sarpo Mira	164040 ± 8335	10.5 ±1.2	75 ± 8	23 ± 9	19 ±3
ANOVA					
Main effects					
Irrigation Type (IT)	**0.0121**	**0.0071**	ns	ns	**0.0356**
Irrigation Level (IL)	**0.0128**	**0.0458**	ns	**0.0143**	*0.0508*
Fertiliser Type (FT)	**0.0142**	**0.0475**	ns	ns	ns
Variety (V)	ns	ns	*0.0812*	**<0.001**	**0.0029**
Interactions					
IT x IL	**0.0233**[2]	**0.0123**[2]	ns	ns	ns
IT x FT	ns	*0.0669*	ns	ns	ns
IL x FT	ns	ns	**0.0336**[3]	ns	ns
IT x V	**0.0006**[4]	ns	ns	**0.0039**[4]	*0.0516*
IL x V	ns	ns	**0.0447**[5]	**0.0039**[5]	ns
FT x V	ns	ns	**0.0224**[6]	*0.0899*	ns
IT x IL x FT	ns	ns	ns	ns	ns
IT x IL x V	ns	ns	ns	**0.0412**[7]	ns
IT x FT x V	ns	ns	ns	ns	ns
IL x FT x V	ns	ns	*0.0738*	ns	ns
IT x IL x FT x V	ns	ns	ns	ns	ns

M., manure; AB, agrobiosol

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$). [1], see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated, [2] see **Table 4.8.1**, [3] see **Table 4.8.2**, [4] see **Table 4.8.3**, [5] see **Table 4.8.4**, [6] see **Table 4.8.5** and [7] see **Table 4.8.6** for interaction means ± SE;

Table 4.8.1. Interaction between irrigation type and irrigation level on the number of tubers and tuber yield (field trial, year 2013)

Parameter Assessed	Factor 1 Irrigation type (IT)	Factor 2 Irrigation Level (IL)	
		1. Low	2. High
Number of Tubers	1. Drip	132077 ±14140 **Ba**	143333 ±12023 **Ba**
	2. Sprinkler	164167 ± 9543**Ab**	228519 ± 9305**Aa**
Tuber yield	1. Drip	7 ±1 **B a**	6 ±1 **B a**
	2. Sprinkler	12 ±2 **A b**	18 ±1 **A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.8.2 Interaction between irrigation level and fertiliser type on the mean tuber weight (field trial, year 2013)

Parameter Assessed	Factor 1 Irrigation level (IL)	Factor 2 Fertiliser Type (FT)		
		1. Sheep M.	2. Chicken M.	3. Sheep M. + AB.
Average mean tuber weight per plot[1]	1. Low	60 ± 5 **B a**	81 ±4 **A a**	87 ±26 **A a**
	2. High	264 ±154 **A a**	73 ±9 **A b**	77 ± 9 **A b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$). [1], see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated.

Table 4.8.3 Interaction between irrigation type and variety on the number of tubers and late blight severity (AUDPC) (field trial, year 2013)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Variety (V)	
		1. Spunta	2. Sarpo mira
Number of tubers	1. Drip	118647 ±12521 **Ba**	149778 ±13225 **Aa**
	2. Sprinkler	216759 ± 11279 **Aa**	175926 ± 10208**Ab**
Late blight severity (AUDPC)	1. Drip	209 ±118 **B a**	32 ±26 **A b**
	2. Sprinkler	417 ±149 **A a**	14 ± 8 **A b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.8.4 Interaction between irrigation level and variety on the number of tubers, mean tuber weight and late blight severity (AUDPC) (field trial, year 2013)

Parameter assessed	Factor 1 Irrigation level (IRL)	Factor 2 Variety (V)	
		1. Spunta	2. Sarpo mira
Average mean tuber weight per plot[1] (g)	1. Low	71 ± 6 **B a**	81 ±17 **A a**
	2. High	207 ±103 **A a**	69 ±13 **A b**
Late blight severity (AUDPC)	1. Low	189 ±119 **B a**	13 ± 9 **A b**
	2. High	436 ±147 **A a**	33 ±25 **A b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated.

Table 4.8.5 Interaction between fertiliser type and variety on the mean tuber weight (field trial, year 2013)

Parameter assessed	Factor 1 Fertiliser Type (FT)	Factor 2 Variety (V)	
		1. Spunta	**2. Sarpo mira**
Average mean tuber weight per plot[1] (g)	Sheep M.	267 ±150 **A a**	57 ± 9 **A b**
	Chicken M.	80 ± 6 **B a**	75 ± 7 **A a**
	Sheep M. + AB	71 ± 7 **B a**	93 ±29 **A a**

M., manure; AB, agrobiosol

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$); [1], see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated.

Table 4.8.6 Interaction of irrigation type, irrigation level and variety on late blight severity (AUDPC) (field trial, year 2013)

Parameter Assessed	Factor 1 Irrigation type (IRT)	Factor 2 Irrigation level (IRL)	Factor 3 Variety (V)	
			1.Spunta	2. S. Mira
Late blight severity (AUDPC)	1. Drip	1. Low	152 ± 74 **B a**	12 ± 5 **A b**
		2. High	265 ± 65 **B a**	53 ±36 **A b**
	2. Sprinkler	1. Low	226 ± 74 **B a**	14 ± 7 **A b**
		2. High	607 ±109 **A a**	13 ± 4 **A b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.9 Effect of irrigation type and level, fertiliser type and variety on tuber size distribution (field trial, year 2013)

	% of tubers in different size categories			
Factor	**size 1** (<4.5 cm)	**size 2** (4.5-6.5 cm)	**size 3** (6.5-8.5 cm)	**size 4** (>8.5 cm)
Irrigation type (IT)				
Drips	20 ±2	32 ±2	31 ±2	18 ±2
Sprinklers	13 ±1	26 ±2	33 ±1	28 ±2
Irrigation level (IL)				
Low	18 ±2	31 ±2	32 ±2	20 ±2
High	15 ±2	26 ±2	32 ±1	27 ±3
Fertiliser Type (FT)				
Sheep M.	19 ±2 **a**	314 ±3	30 ±2	20 ±3 **a**
Chicken M.	15 ±2 **b**	26 ±2	31 ±1	28 ±3 **b**
Sheep M. + AB	15 ±2 **b**	29 ±3	34 ±3	23 ±3 **a**
Variety (V)				
Spunta	12 ±1	20 ±1	34 ±1	34 ±2
Sarpo Mira	21 ±2	38 ±2	30 ±2	12 ±2
ANOVA results				
Main effects				
Irrigation Type (IRT)	*0.0605*	*0.0829*	ns	**0.0159**
Irrigation Level (IRL)	ns	*0.0953*	ns	**0.0158**
Fertiliser Type (FT)	**0.0257**	ns	ns	**0.0037**
Variety (V)	**<0.001**	**<0.001**	**0.001**	**<0.001**
Interactions				
IT x IL	ns	**0.0349**[1]	ns	**0.0138**[1]
IT x FT	ns	ns	ns	ns
IL x FT	ns	ns	ns	ns
IT x V	ns	ns	**0.0132**[2]	ns
IL x V	ns	ns	ns	ns
FT x V	**0.0034**[3]	ns	**0.0004**[3]	ns
3-Way interactions				
IT x IL x FT	ns	ns	ns	ns
IT x IL x V	**0.0030**[4]	ns	**0.0013**[4]	ns
IT x FT x V	ns	ns	ns	ns
IL x FT x V	*0.0815*	ns	**0.0093**[5]	ns
4-Way interactions				
IT x IL x FT x V	ns	ns	ns	ns

M., manure; AB, agrobiosol

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$). [1] see **Table 4.9.1,** [2] see **Table 4.9.2,** [3] see **Table 4.9.3,** [4] see **Table 4.9..4** and [5] see **Table 4.9.5** for interaction means ± SE

Table 4.9.1 Interaction between irrigation type and irrigation level on the % distribution of size 2 and size 4 tubers (field trial, year 2013)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Irrigation level (IL) 1. Low	 2. High
size 2 tubers	1. Drip	32 ±3 **A a**	32 ±2 **A a**
(4.5-6.5 cm)	2. Sprinkler	31 ±3 **A a**	21 ±3 **B b**
size 4 tubers	1. Drip	17 ±3 **A a**	18 ±3 **B a**
(>8.5 cm)	2. Sprinkler	22 ±3 **A b**	35 ±3 **A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.9.2 Interaction between irrigation type and variety on the % distribution of size 3 tubers (field trial, year 2013)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Variety (V) 1. Spunta	 2. Sarpo mira
size 3 tubers	1. Drip	34 ±2 **A a**	27 ±4 **A a**
(6.5-8.5 cm)	2. Sprinkler	34 ±1 **A a**	31 ±2 **A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.9.3 Interaction between fertiliser type and variety on the % distribution of size 1 and size 3 tubers (field trial, year 2013)

Parameter assessed	Factor 1 Fertiliser Type (FT)	Factor 2 Variety (V) 1. Spunta	 2. Sarpo mira
size 1 tubers	1. Sheep M.	11 ±1 **A b**	27 ±3 **A a**
(<4.5 cm)	2. Chicken M.	12 ±2 **A b**	18 ±2 **B a**
	3. Sheep M. + AB	12 ±2 **A a**	17 ±3 **B a**
size 3 tubers	1. Sheep M.	37 ±2 **A a**	23 ±2**Bb**
(6.5-8.5 cm)	2. Chicken M.	32 ±1 **A a**	30 ±2**Aa**
	3. Sheep M. + AB	33 ±2 **A a**	35 ±5**Aa**

M., manure; AB, agrobiosol

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.9.4 Interaction of irrigation type, irrigation level and variety on the % distribution of size 1 and size 3 tubers (field trial, year 2013)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Irrigation level (IL)	Factor 3 Variety (V)	
			1.Spunta	2. S. Mira
size 1 tubers	1. Drip	1. Low	17 ±3 **A a**	22 ±3 **B a**
(<4.5 cm)		2. High	13 ±2 **AB b**	31 ±4 **A a**
	2. Sprinkler	1. Low	10 ±1 **AB b**	21 ±3 **B a**
		2. High	7 ±1 **B a**	12 ±2 **C a**
size 3 tubers	1. Drip	1. Low	33 ±3 **A a**	31 ±7 **AB a**
(6.5-8.5 cm)		2. High	34 ±2 **A a**	22 ±3 **B b**
	2. Sprinkler	1. Low	36 ±1 **A a**	28 ±3 **AB a**
		2. High	33 ±1 **A a**	35 ±2 **A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.9.5 Interaction of irrigation level, fertiliser type and variety on the % distribution of size 3 tubers (field trial, year 2013)

Parameter assessed	Factor 1 Irrigation level (IL)	Factor 2 Fertiliser Type (FT)	Factor 3 Variety (V)	
			1. Spunta	2. S. Mira
size 3 tubers	1. Low	1. Sheep M.	39±3 **A a**	20±2 **B b**
(6.5-8.5 cm)		2. Chicken M.	31±2 **A a**	32±3 **A a**
		3. Sheep M. + AB	33±3 **A a**	36±9 **A a**
	2. High	1. Sheep M.	35±2 **A a**	27±4 **AB a**
		2. Chicken M.	33±2 **A a**	28±4 **AB a**
		3. Sheep M. + AB	33±3 **A a**	34±3 **A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.10 Effect of irrigation type and level, fertiliser type and variety on SPAD at different growth stages (53 and 61 days after planting, respectively) (field trial, year 2013)

Irrigation type (IT)	**SPAD 1**	**SPAD 2**
Drips	42.4±0.8	46.2±0.8
Sprinklers	42.9±0.5	46±0.5
Irrigation level (IL)		
Low	42.8±0.7	46.6±0.7
High	42.5±0.6	45.6±0.6
Fertiliser Type (FT)		
Sheep M.	40.5±0.9 **b**	44.1±0.9 **b**
Chicken M.	45.3±0.7 **a**	48.8±0.8 **a**
Sheep M. + AB	42.1±0.5 **b**	45.3±0.5 **b**
Variety (V)		
Spunta	41.7±0.8	45±0.8
Sarpo Mira	43.6±0.5	47.1±0.5
ANOVA results		
Main effects		
Irrigation Type (IRT)	0.7026	0.8761
Irrigation Level (IRL)	0.6612	0.1864
Fertiliser Type (FT)	**<0.001**	**<0.001**
Variety (V)	**0.004**	**0.0004**
Interactions		
IT x IL	**0.0371**[1]	**0.0293**[1]
IT x FT	**0.0088**[2]	**0.0096**[2]
IL x FT	**0.0054**[3]	**0.0285**[3]
IT x V	**0.0013**[4]	**0.0004**[4]
IL x V	0.5121	0.1532
FT x V	**0.0067**[5]	**0.0012**[5]
3-Way interactions		
IT x IL x FT	0.4192	0.318
IT x IL x V	0.0687	0.1312
IT x FT x V	0.1581	0.0841
IL x FT x V	0.1872	0.0679
4-Way interactions		
IT x IL x FT x V	0.0909	0.1873

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p< 0.05$)

Table 4.10.1 Interaction between irrigation type and irrigation level on SPAD at different growth stages (53 and 61 days after planting, respectively) (field trial, year 2013)

Irrigation type	SPAD1 Irrigation level		SPAD2 Irrigation level	
	1. Low	2. High	1. Low	2. High
1. Drip	43.4±1.2 **Aa**	41.4±1 **Aa**	47.6±1.2 **Aa**	44.7±1 **Ab**
2. Sprinkler	42.1±0.8 **Aa**	43.6±0.6 **Aa**	45.5±0.8 **Aa**	46.4±0.6 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.10.2 Interaction between irrigation type and fertiliser type on SPAD at different growth stages (53 and 61 days after planting, respectively) (field trial, year 2013)

Irrigation type	SPAD 1 Fertiliser type			SPAD 2 Fertiliser type		
	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB
1. Drip	38.6±1.4 **Bc**	45.9±1.1 **Aa**	42.7±0.9**Ab**	42.7±1.3 **Bc**	50.1±1.3 **Aa**	45.7±0.8 **Ab**
2. Sprinkler	42.3±1.1 **Aab**	44.7±0.9 **Aa**	41.6±0.6**Ab**	45.5±1.1 **Aa**	47.4±0.8 **Ba**	45±0.6 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.10.3 Interaction between irrigation level and fertiliser type on SPAD at different growth stages (53 and 61 days after planting, respectively) (field trial, year 2013)

Irrigation level	SPAD 1 Fertilliser type			SPAD 2 Fertiliser type		
	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB
1. Low	39.1±1.1**Bc**	46.8±0.9**Aa**	42.5±1 **Ab**	43.3±1.1**Ac**	50.3±1.2 **Aa**	46±0.9 **Ab**
2. High	41.9±1.5**Aa**	43.8±0.9 **Ba**	41.8±0.5**Aa**	44.9±1.4 **Aab**	47.2±0.9 **Ba**	44.7±0.5 **Ab**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.10.4 Interaction between irrigation type and variety on SPAD at different growth stages (53 and 61 days after planting, respectively) (field trial, year 2013)

Irrigation type	SPAD 1 Variety		SPAD 2 Variety	
	1. Spunta	2. S. Mira	1. Spunta	2. S. Mira
1. Drip	40.4±1.2 **Bb**	44.4±0.8 **Aa**	44.1±1.2 **Ab**	48.3±0.9 **Aa**
2. Sprinkler	43±0.9 **Aa**	42.7±0.6 **Aa**	46±0.9 **Aa**	45.9±0.4 **Bb**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.10.5 Interaction between fertiliser type and variety on SPAD at different growth stages (53 and 61 days after planting, respectively) (field trial, year 2013)

Fertiliser type	**SPAD 1**		**SPAD 2**	
	Variety		**Variety**	
	1. Spunta	2. S. Mira	1. Spunta	2. S. Mira
1. Sheep M.	38.1±1.5 **Cb**	42.8±0.7 **Aa**	41.5±1.4 **Cb**	46.7±0.6 **ABa**
2. Chicken M.	45.4±1.1 **Aa**	45.2±0.9 **Aa**	48.7±1.2 **Aa**	48.9±1.1 **Aa**
3. Sheep M. + AB	41.6±0.8 **Ba**	42.7±0.8**Aa**	44.9±0.8 **Ba**	45.8±0.7 **Ba**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

4.5 Results: ANOVA - Effect of irrigation type and level, fertilisation treatment, and variety on tuber yield, tuber size distribution, late blight severity (AUDPC) and Colorado beetle infestation (results from 2014 season only)

In 2014 late blight severity (based on AUDPC values) was approximately 20 times higher than in the 2013 season (Table 4.4). As a result, the foliage of the more blight susceptible variety Spunta had to be mechanically removed in May (to avoid tuber infection) before populations of Colorado beetle were detected in the crop. Colorado beetle infestation levels could therefore not be properly assessed in the 2014 season.

In contrast to the 2013 season (Table 4.8), no significant main effect of irrigation type or level could be detected for yield parameters or foliar blight severity in 2014 (Table 4.11). Also, in 2014, ANOVA detected significant main effects of both fertiliser type and variety for both the total tuber number and yield (Table 4.11), while in 2013 there significant main effects of fertiliser type on the total tuber number and total tuber yield (Table 4.8).

There were also differences in the effects of experimental factors on tuber size distribution between the two growing seasons (Tables 4.9 and 4.12). In 2013 variety had a significnat effect on all tuber size categories, while fertiliser type only had a significnat effect on the proportion of size 1 and 4 tubers, and irrigation type and level only affected the proportion of size 4 tubers (Table 4.9). In contrast, in 2014 significant main effects of both fertiliser type and variety were detected for three size categories of potato (1, 3 and 4) but there was no significant effect of irrigation type or level (Table 4.12).

4.5.1 Crop yield parameters (2014)

There were significant main effects of fertility treatment and variety on the mean number of tubers and total tuber yield (Table 4.11) and tuber size distribution (the proportion of tubers in different tuber size categories except for size 2 (4.5-6.5 cm) tubers (Table 4.12).

Sheep manure plus agribiosol resulted in significantly higher total tuber number and yield, than the two other fertiliser types (Table 4.11) and a lower proportion of very small size 1 tubers (<4,5 cm) (Table 4.12). Also, both chicken manure and sheep manure plus agrobiosol resulted in higher number of tubers size 3 (6.5-8.5 cm) and 4 (>8.5 cm) than sheep manure alone (Table 4.12).

The variety Sapro mira produced significantly higher tuber numbers and yield (Table 4.11) and a higher proportion of very small size tubers (size 1), while the variety Spunta produced a significantly higher number of large size 3 and 4 tubers (Table 4.12).

There was a significant interaction beween **irrigation type** and **fertiliser type** for the proportion of size 3 tubers (Table 4.12). Sheep manure resulted in a higher proportion of size 3 tubers with drip irrigation, while chicken manure and sheep manure plus agrobiosol resulted in a higher proportion of size 3 tubers with sprinkler irrigation. However, the differences between irrigation systems were not significant for all fertiliser types (Table 4.12.1).

There were significant interactions between **irrigation type** and **variety** for total tuber yield and the proportion of size 4 tubers (Table 4.11 and 4.12). Sprinkler irrigation resulted in significantly higher total tuber yields in Sarpo mira but not Spunta (Table 4.11.1). Sprinkler irrigation resulted in a larger proportion of large (size 4) tubers in Sarpo mira, while Spunta produced the same propotion of large (size 4) tubers with the two irrigation systems (Table 4.12.2)

The were significant interactions between **fertiliser type** and **variety** for the number of tubers, total tuber yield and the proportion of size 1 and 3 tubers (Table 4.11 and 4.12). Sheep manure plus agrobiosol produced significantly higher tuber numbers than the other 2 fertiliser types in both varieties, but the relative differences between fertiliser types were greater for Sarpo mira than Spunta (Table 4.11.2). Sarpo mira produced significantly higher tuber yields with chicken manure and sheep manure plus agrobiosol than sheep manure, while there was no significant difference between fertiliser types for Spunta (Table 4.11.2). For the variety Sarpo mira, the use of sheep manure as fertiliser resulted in a higher proportion of size 1 and lower proportion of size 3 tubers than the other two fertiliser types. In contrast, fertiliser type did not affect the proportions of size 1 and 3 tubers (Table 4.12.3),

4.5.2 Crop health parameters (foliar late blight in both varieties; Colorado beetle infestation in Sarpo mira) (2014)

Only variety had a significant main efffect on foliar blight severity which was more than 3 times greater in Spunta than Sarpo mira (Table 4.11). There were no significant main effects on Colorado beetle infestation in Sarpo mira, but a trend (P=0.09) towards lower infestation with sprinkler compared to drip irrigation was detected in 2014 (Table 4.11).

There was a significant 2-way interaction between **fertiliser type** and **variety** (Table 4.11). Late blight severity was significantly lower in Sarpo mira and higher in Spunta crops fertilised with sheep manure, when compared to crops fertilised with chicken manure and sheep manure plus agrobiosol (Table 4.11.2).

There was also a significant 3-way interaction of **irrigation type**, **irrigation level** and **variety** for foliar late blight severity (Table 4.11). The higher irrigation level resulted in significantly higher late blight severity with sprinkler irrigated Sarpo mira crops only, while there was no significant effect of irrigation level in all other combinations of variety and irrigation type (Table 4.11.3).

4.5.3 Estimated chlorophyll levels (SPAD)(2014)

There were significant main effects of fertility treatment and variety on all four assessment dates in 2014 (Table 4.13). Chicken manure resulted in higher chlorophyll levels compared to the other two fertility treatments (Table 4.13) on all four assessment dates. Also, Sarpo mira had higher chlorophyll levels on all four assessment dates, compared to Spunta (Table 4.13).

There were significant interactions between **irrigation type** and **fertiliser type** on the first three assessment dates (Table 4.13). On all three assessment dates sprinkler irrigation resulted in significantly lower chlorophyll levels than drip irrigation when sheep manure was used as fertilizer, while there was no significant effect of irrigation type with the other two fertilizer types (Table 4.13.1).

There was a significant interaction between **irrigation level** and **fertilizer type** on the two assessment dates (Table 4.13). The high irrigation level resulted in significantly lower chlorophyll levels when chicken manure was used as fertiliser, while there was no significant effect of irrigation level with the other two fertilizer types on both assessment dates (Table 4.13.2).

There was a significant interaction between **irrigation type** and **variety** on all 4 assessment dates (Table 4.13). Spinkler irrigation resulted in higher chlorophyll levels in Spunta (with the difference being significant on the first three assessment dates), but lower chlorophyll levels in Sarpo mira (with the difference being non-significant on all 4 assessment dates) (Table 4.13.3).

There were significant interactions between **fertilizer type** and **variety** on the 2nd, 3rd and 4th assessment date (Table 4.13). Chicken manure resulted in significantly higher chlorophyll levels than the other two fertilizer types in Spunta, while there was no significant effect of fertilizer type in Sarpo mira on all 3 later assessment dates (Table 4.13.4). On the 4th (but not the 2nd and 3rd) assessment date the chlorphyll levels in Spunta crops fertilized with sheep manure were significantly lower than those fertilized with sheep manure plus agrobiosol (Table 4.13.4).

Table 4.11 Effect of irrigation type and level, fertiliser type and variety on tuber yield parameters, foliar late blight severity and Colorado beetle infestation (field trial, year 2014)

Factor	**Number of tubers (ha)**	**Yield** (t ha^{-1})	**Average mean tuber weight per plot**[1] (g)	**Late blight severity** (AUDPC)	**Colorado beetle infestation** (%)*
Irrigation type					
Drip	158287 ±8236	5.5 ±0.4	61 ±21	3092 ±256	2.96 ±0.80
Sprinklers	183704 ±11233	6.6 ±0.5	42 ± 1	3274 ±269	10.50 ±2.57
Irrigation level					
Low	173425 ±9929	6.1 ±0.4	42 ± 1	3087 ±261	6.42 ±1.59
High	168565 ±10102	6.0 ±0.6	62 ±21	3279 ±265	7.04 ±2.43
Fertiliser type					
Sheep M.	151042 ±8404 **b**	4.4 ±0.2 **b**	36 ± 1	3187 ±278	4.44 ±1.46
Chicken M.	150972 ±10827 **b**	6.2 ±0.7 **a**	77 ±31	3122 ±335	7.88 ±3.27
Sheep M. + AB	210972 ±13845 **a**	7.5 ±0.7 **a**	42 ± 1	3241 ±354	7.88 ±2.47
Variety					
Spunta	124722 ±5551	4.4 ±0.2	43 ± 1	4885 ± 87	NA
Sarpo Mira	217269 ± 8886	7.7 ±0.6	61 ±21	1482 ± 87	NA
ANOVA results					
Main effects					
Irrigation Type (IT)	ns	ns	ns	ns	*0.0893*
Irrigation Level (IL)	ns	ns	ns	ns	ns
Fertiliser type (FT)	**<0.001**	**0.0010**	ns	ns	ns
Variety (V)	**<0.001**	**<0.001**	ns	**<0.001**	ns
Interactions					
IT x IL	ns	ns	ns	ns	ns
IT x FT	ns	ns	ns	ns	ns
IL x FT	ns	ns	ns	ns	ns
IT x VC	*0.0704*	**0.0342**[2]	ns	ns	ns
IL x VC	ns	ns	ns	ns	ns
FT x VC	**0.0159**[3]	**0.0006**[3]	ns	**0.001**[3]	ns
IT x IL x FT	ns	ns	ns	ns	ns
IT x IL x VC	ns	ns	ns	**0.0218**[4]	ns
IT x FT x VC	ns	ns	ns	*0.0624*	ns
IL x FT x VC	ns	ns	ns	ns	ns
IT x IL x FT x VC	ns	ns	ns	ns	ns

* Data is for Sarpo mira only and were cube root transformed;
NA, not assessed, since assessment of potato beetle infestation in Spunta plots was not possible
M., manure; AB, agrobiosol
Means labeled with the same letter within the same column are not significantly different (Tukey's honestly significant difference test, $p < 0.05$).
[1], see methods on *Yield and tuber blight assessment* on page 83 for a description of how average mean tuber weights per plot were calculated.
[2] see **Table 4.11.1**, [3] see **Table 4.11.2 and** [4] see **Table 4.11.3** for interaction means ± SE;

Table 4.11.1 Interaction between irrigation type and variety on tuber yield (field trial, year 2014)

Parameter assessed	Factor 1 Irrigation Type	Factor 2 Variety 1. Spunta	2. Sarpo mira
Tuber yield ($kg\ ha^{-1}$)	1.Drip	4.3±0.3 **A b**	6.6±0.8 **B a**
	2. Sprinkler	4.5±0.4 **A b**	8.7±0.8 **A a**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.11.2 Interaction between fertiliser type and variety on the number of tubers and tuber yield (field trial, year 2014)

Parameter assessed	Factor 1 Fertiliser type	Factor 2 Variety 1. Spunta	2. Sarpo mira
Number of tubers	1. Sheep M.	118194 ±6486**Bb**	183889 ±10295**Ba**
	2. Chicken M.	103472 ±7021 **Bb**	198472 ±11593 **Ba**
	3. Sheep M. + AB	152500 ±10673**Ab**	269444 ±14917**Aa**
Tuber yield ($kg\ ha^{-1}$)	1. Sheep M.	4.0 ±0.2 **A a**	4.7±0.3 **B a**
	2. Chicken M.	3.9 ±0.3 **A b**	8.5±1.1 **A a**
	3. Sheep M. + AB	5.4 ±0.4 **A b**	9.7±1.0 **A a**
Late blight severity (AUDPC)	1. Sheep M.	4551 ±160 **B a**	1823 ±212 **A b**
	2. Chicken M.	4932 ±133 **A a**	1311 ±101 **B b**
	3. Sheep M. + AB	5171 ±123 **A a**	1311 ± 72 **B b**

M., manure; AB, agrobiosol

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.11.3 Interaction of irrigation type, irrigation level and variety on late blight severity AUDPC (field trial,year 2014)

Parameter assessed	Factor 1 Irrigation type	Factor 2 Irrigation level	Factor 3 Variety 1.Spunta	2. S. Mira
Late blight severity (AUDPC)	1. Drip	1.Low	4600 ±183 **B a**	1483 ±139 **AB b**
		2.High	4961 ±14 **AB a**	1326 ± 80 **B b**
	2. Sprinkler	1. Low	4960 ±224 **AB a**	1305 ± 96 **B b**
		2.High	5018 ±128 **A a**	1814 ±284 **A b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test $p < 0.05$)

Table 4.12 Effect of irrigation type and level, fertiliser type and variety on tuber size (field trial,year 2014)

	% of tubers in different size categories			
Factor	**size 1** (<4.5 cm)	**size 2** (4.5-6.5 cm)	**size 3** (6.5-8.5 cm)	**size 4** (>8.5 cm)
Irrigation type				
Drips	32 ±2	44 ±1	19 ±1	5 ±1
Sprinklers	32 ±2	42 ±1	21 ±1	4 ±1
Irrigation level				
Low	31 ±2	44 ±1	21 ±1	4 ±1
High	34 ±2	42 ±1	20 ±2	5 ±1
Fertiliser type				
Sheep M.	38 ±3 **a**	42 ±2	17 ±2 **b**	3 ±1 **b**
Chicken M.	30 ±2 **b**	43 ±1	22 ±1 **a**	6 ±1 **a**
Sheep M. + AB	30 ±2 **b**	44 ±1	22 ±2 **a**	5 ±1 **a**
Variety				
Spunta	23 ±1	43 ±1	27 ±1	7 ±1
Sarpo Mira	42 ±2	43 ±1	13 ±1	2 ±1
ANOVA results				
Main effects				
Irrigation Type (IT)	ns	ns	ns	ns
Irrigation Level (IL)	ns	ns	ns	ns
Fertiliser Type (FT)	**0.0002**	ns	**0.0066**	**0.0403**
Variety (V)	**<0.001**	ns	**<0.001**	**<0.001**
Interactions				
IT x IL	ns	ns	ns	ns
IT x FT	ns	ns	**0.0417**[1]	ns
IL x FT	ns	ns	ns	ns
IT x V	ns	ns	ns	**0.0322**[2]
IL x V	ns	ns	ns	ns
FT x V	**0.0026**[3]	ns	**0.0101**[3]	ns
IT x IL x FT	ns	ns	*0.0928*	ns
IT x IL x V	ns	ns	ns	ns
IT x FT x V	ns	ns	ns	ns
IL x FT x V	ns	ns	ns	ns
IT x IL x FT x V	ns	ns	ns	ns

M., manure; AB, agrobiosol

Means labelled with the same letter within the same column are not significant different (Tukey's honestly significant difference test, $p < 0.05$).[1] see **Table 4.12.1,** [2] see **Table 4.12.2** and [3] see **Table 4.12.3** for interaction means ± SE.

Table 4.12.1 Interaction between irrigation type and fertiliser type on the % distribution of size 3 tubers (field trial, year 2014)

Parameter Assessed	Factor 1 Irrigation type (IT)	Factor2 Fertiliser type (FT)		
		1. Sheep M.	2. Chicken M.	3. Sheep M. + AB.
size 3 tubers (%)	1. Drips	19 ±3 **A a**	21 ±2 **A a**	19 ±2 **A a**
	2. Sprinkler	16 ±3 **A b**	24 ±2 **A a**	24 ±3 **A a**

M., manure; AB, agrobiosol
For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

Table 4.12.2 Interaction between irrigation type and variety on the % distribution of size 4 tubers (field trial, year 2014)

Parameter assessed	Factor 1 Irrigation type (IT)	Factor 2 Variety (V)	
		1. Spunta	2. Sarpo mira
size 4 tubers (%)	1. Drip	27 ±1 **A a**	11 ±1 **A b**
	2. Sprinkler	27 ±2 **A a**	15 ±2 **A b**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

Table 4.12.3 Interaction between fertiliser type and variety on the % distribution of size 1 and size 3 tubers (field trial, year 2014)

Parameter assessed	Factor 1 Fertiliser type (FT)	Factor 2 Variety (V)	
		1. Spunta	**2. S. mira**
size 1 tubers (%)	1. Sheep M.	25 ±2 **A b**	51 ±3 **A a**
	2. Chicken M.	23 ±1 **A b**	36 ±2 **B a**
	3. Sheep M. + AB	21 ±2 **A b**	39 ±2 **B a**
size 3 tubers (%)	1. Sheep M.	27 ±2**A a**	7 ±1 **B b**
	2. Chicken M.	27 ±1**A a**	17 ±2 **A b**
	3. Sheep M. + AB	28 ±2**A a**	16 ±2 **A b**

M., manure; AB, agrobiosol
For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

Table 4.13 Effect of irrigation type and level, fertiliser type and variety on SPAD at different growth stages (53,61,69, and 77 days after planting respectively) (field trial, year 2014)

Irrigation type (IT)	**SPAD 1**	**SPAD 2**	**SPAD 3**	**SPAD 4**
Drip	42.9±0.6	44.5±0.6	46±0.6	47.4±0.5
Sprinkler	42.9±0.5	44.2±0.4	45.8±0.4	47.3±0.4
Irrigation level (IL)				
Low	43.1±0.6	44.7±0.5	46.3±0.5	47.7±0.4
High	42.6±0.6	44±0.5	45.5±0.5	47.1±0.4
Fertiliser type (FT)				
Sheep M.	41.6±0.8 **b**	43.3±0.7 **b**	45.2±0.7 **b**	46.6±0.6 **b**
Chicken M.	44.9±0.6 **a**	46.1±0.7 **a**	47±0.5 **a**	48.5±0.3 **a**
Sheep M. + AB	42.1±0.5 **b**	43.7±0.6 **b**	45.5±0.5 **b**	47.1±0.5 **b**
Variety (V)				
Spunta	42.2±0.6	43.5±0.6	44.5±0.5	45.7±0.4
S. mira	43.6±0.5	45.3±0.5	47.2±0.4	49±0.3
ANOVA				
Main effects				
Irrigation Type (IT)	ns	ns	ns	ns
Irrigation Level (IL)	ns	ns	ns	ns
Fertiliser Type (FT)	**0.0003**	**0.001**	**0.0117**	**0.0024**
Variety (V)	**0.0298**	**0.004**	**<0.001**	**<0.001**
Interactions				
IT x IL	ns	ns	ns	ns
IT x FT	**0.0084**[1]	**0.0217**[1]	**0.0123**[1]	*0.0525*
IL x FT	**0.0222**[2]	**0.0216**[2]	ns	ns
IT x V	**0.002**[3]	**0.0006**[3]	**0.0007**[3]	**0.0082**[3]
IL x V	ns	ns	ns	ns
FT x V	ns	**0.0322**[4]	**0.0044**[4]	**0.0066**[4]
IT x IL x FT	ns	ns	ns	ns
IT x IL x V	ns	ns	ns	ns
IT x FT x V	ns	ns	ns	ns
IL x FT xV	ns	ns	ns	ns
IT x IL x FT x V	ns	ns	ns	ns

M., manure; AB, agrobiosol

Means labelled with the same letter within the same column are not significantly different (Tukey's honestly significantly difference test, $p < 0.05$).[1] see **Table 4.13.1,** [2] see **Table 4.13.2** , [3] see **Table 4.13.3** and [4] see **Table 4.13.4** for interaction means ± SE.

Table 4.13.1 Interaction between irrigation type and fertiliser type on SPAD at different growth stages (53,61 and 69 days after planting, respectively) (field trial,year 2014)

Irrigation type (IT)	SPAD 1			SPAD 2		
	Fertiliser type			Fertiliser type		
	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB
1. Drip	40.2±1.1 **Bb**	45.3±0.9 **Aa**	43.1±0.8 **Aa**	42.2±1.1 **Ab**	46.6±1 **Aa**	44.6±0.9 **Aa**
2. Sprinkler	43±1 **Aab**	44.5±0.8 **Aa**	41.1±0.6 **Ab**	44.4±0.8 **Aab**	45.6±0.8 **Aa**	42.8±0.6 **Ab**

	SPAD 3		
	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB
1. Drip	44.1±1.2 **Bb**	47.5±0.8 **Aa**	46.3±0.9 **Aa**
2. Sprinkler	46.2±0.6 **Aa**	46.6±0.6 **Aa**	44.6±0.6 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

Table 4.13.2 Interaction between irrigation level and fertiliser type on SPAD at different growth stages(53 and 61 days after planting, respectively) (field trial, year 2014)

Irrigation level (IL)	SPAD 1			SPAD 2		
	Fertiliser type			Fertiliser type		
	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB	1. Sheep M.	2. Chicken M.	3. Sheep M. + AB
1.Low	40.7±0.9 **Ab**	46.1±0.8 **Aa**	42.6±0.8 **Ab**	42.5±0.8 **Ab**	47.5±0.7 **Aa**	44±0.9 **Ab**
2.High	42.6±1.3 **Aa**	43.7±0.9 **Ba**	41.6±0.6 **Aa**	44±1.1 **Aa**	44.7±1 **Ba**	43.4±0.7 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

Table 4.13.3 Interaction between irrigation type and variety on SPAD at different growth stages (53,61,69 and 77 days after planting, respectively) (field trial, year 2014)

Irrigation type (IT)	SPAD 1			SPAD 2	
	Variety			Variety	
	1. Spunta	2. S. Mira		1. Spunta	2. S. mira
1. Drip	41.2±0.9 **Ab**	44.5±0.7 **Aa**	1. Drip	42.5±0.9 **Ab**	46.5±0.7 **Aa**
2. Sprinkler	43.2±0.8 **Aa**	42.6±0.6 **Aa**	2.Sprinkler	44.4±0.7**Aa**	44.1±0.6 **Aa**
	SPAD 3			**SPAD 4**	
	1. Spunta	2. S. Mira		1. Spunta	2. S. mira
1. Drip	43.7±0.9 **Ab**	48.3±0.5 **Aa**	1. Drip	45.2±0.6 **Ab**	49.7±0.3 **Aa**
2. Sprinkler	45.4±0.5 **Aa**	46.2±0.5 **Ba**	2.Sprinkler	46.3±0.5 **Ab**	48.4±0.4 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

Table 4.13.4 Interaction between fertiliser type and variety on SPAD at different growth stages(61, 69 and 77 days after planting, respectively) (field trial, year 2014)

ftvr	**SPAD 2**			**SPAD 3**	
Fertiliser type	**Variety**		**Fertiliser type**	**Variety**	
	1. Spunta	2. S. Mira		1. Spunta	2. S. mira
1. Sheep M.	41.4±1 **Bb**	45.1±0.7 **Aa**	1. Sheep M.	42.6±1 **Bb**	47.7±0.5 **Aa**
2. Chicken M.	46.2±1 **Aa**	46±0.9 **Aa**	2. Chicken M.	46.6±0.7 **Aa**	47.5±0.7 **Aa**
3. Sheep M. + AB	42.8±0.6 **Ba**	44.6±0.9 **Aa**	3. Sheep M. + AB	44.4±0.7 **Ba**	46.5±0.7 **Aa**

	SPAD 4	
	Variety	
	1. Spunta	2. S. Mira
1. Sheep M.	44±0.8 **Cb**	49.2±0.5 **Aa**
2. Chicken M.	47.5±0.4 **Ab**	49.5±0.4 **Aa**
3. Sheep M. + AB	45.7±0.6 **Bb**	48.4±0.6 **Aa**

For each parameter means labelled with the same capital letter within the same column and means labelled with the same lower case letter within the same row are not significantly different (Tukey's honestly significant difference test P < 0.05)

4.6 DISCUSSION

4.6.1 The impact of irrigation

Previous studies comparing irrigation systems for potato concluded that both sprinkler and drip irrigation systems are more water efficient that traditional furrow irrigation systems (Ierna and Mauromicale, 2012). Also drip irrigation systems (based on either non-reusable tape or re-usable black plastic pipes) were shown previously to substantially reduce late blight severity (Tamm et al., 2004). However, recent studies in Crete (Pakos, 2016) and Turkey (Yavuz et al., 2012) reported significantly lower yields with drip than sprinkler irrigation systems.

In this study, sprinkler irrigation resulted in substantially 80% higher tuber yields than drip irrigation. This may have been due to a) soil surface affecting shoot growth, as drip irrigation favors soil crusting, b) better water allocation into the soil via sprinkler irrigation system (Passam et al.,2011) . In the study reported here potatoes were irrigated on average 4-5 times per week and the drip irrigation pipes were placed on top of the ridge. Previous studies indicate that this low frequency and the placement of pipes on top of the ridge may also have affected potato growth and yields. For example, Wang et al. (2006) reported that increasing the drip irrigation frequency (e.g. from every 8 days to daily) at the same total water input level will affect soil water distribution, increase root length density in the top 60 cm of soil and enhanced potato tuber growth and water use efficiency (Wang et al., 2006). Also, Patel and Rajput (2007) showed that placing the irrigation tape at different depth in the soil affects potato yields. In this study it was also demonstrated that increasing the water input level to approximately 1.5 times the usual amount of water applied to potato crops with standard sprinkler systems will slightly (by approximately 15%) increase tuber yields.

However, when sprinkler irrigation was used, increasing water input levels also resulted in significantly higher late blight severity, but only in the season (2013) with relatively low late blight blight pressure, and when sprinkler irrigation systems and the more blight susceptible variety Spunta were used. Increasing water input levels to maximize yields may therefore be suitable for a more resistant variety like Sarpo mira, but will increase the risk of tuber infections and associated tuber losses in a more susceptible variety like Spunta. These results confirm findings of previous studies which reported that potato require high water input levels for high yields (Ojala et al., 1990) and that sprinkler irrigation will increase late blight severity (Tamm et al., 2004, Olanya et al., 2007). The finding that there was no effect of sprinkler irrigation on blight in the very wet growing season was probably due to high precipitation alone generating the environmental conditions necessary for maximum blight epidemic development.

The commercial benefit of increasing water input levels and using sprinkler systems may be even greater than suggested by the increase in total tuber yield, since both resulted in a higher number of very large tubers, for which there is the greatest market demand and premium prices (Karam et al., 2014).

Tape irrigation systems are now used commercially in some semi-arid regions, where potato are grown in very sandy soils (e.g. Israel). However, the use of tape/drip irrigation systems is very expensive and would need to be optimised considerably in Greece, especially with respect to watering frequency and placement depth of tapes within the soil. Specifically, in the study area of Messinia, the use of sprinkler irrigation seems to be necessary as it protects potato plants from frost, which is common in that area (personal communication with Peter Vlachogeorgakopoulos). A more suitable strategy to increase yields in organic production systems may therefore be to use blight resistant varieties in combination with sprinkler irrigation systems.

The results of the field experiments also indicate that **(a)** Sarpo mira (the more blight-resistant variety) is also less susceptible to potato beetle infestation and **(b)** that sprinkler irrigation results in lower potato beetle damage than drip irrigation. This would further support the conclusion that sprinkler irrigation combined with the use of more blight-resistant varieties my be the best approach towards improving yields and yield stability in organic production systems in Greece.

This is to our knowledge the first report of potato beetle resistance in the Sarpo potato varieties, although their blight and virus resistance is well documented (Speiser et al., 2006, Hospers-Brands et al., 2008, AHDB, 2017). Further research should investigate the mechanisms responsible for lower potato beetle infestation levels in *Sarpo mira* and when sprinkler irrigation was used. Such studies should also investigate whether Sarpo varieties are also less susceptible to attack by virus vectors (especially aphids), which could be one of the mechanisms for their greater virus resistance.

4.6.2 The impact of fertilizer type

Potato, especially main crop varieties, require large amounts of mineral nutrients to achieve their yield potential (Westermann, 2006). In conventional crop production in Western Europe up to 250 kg ha^{-1} N, 200 kg ha^{-1} P and 200 kg ha^{-1} K are commonly applied to main crop potato, resulting in tuber yields of up to 45 t ha^{-1} (Passam et al., 2011; (Palmer et al., 2013, Swain et al., 2014).

Yields in organic production are often substantially (30-50%) lower, and this was shown to be due to both less efficient fertilisation and crop protection methods (especially for late blight) being used in organic production (Finckh et al., 2006). Improving fertilisation strategies are therefore thought to be essential to improve yields in organic production systems.

A small number of previous studies investigated and compared the effect of different organic fertiliser input types and levels on the performance (tuber yield and quality and late blight disease severity) in potato (Lynch et al., 2008). Most of these studies were carried out in temperate climatic zones of Europe (e.g. Denmark, the Netherlands, Germany, France, Great Britain, Norway and Switzerland) and indicate that organic fertilisers with a high content of water-soluble, readily plant-available N-compounds (e.g. NH_4^+, NO_3^-) produced significantly higher yields when applied at the same total N-input level than composted manure (Tamm et al., 2004). Also, when compared to mineral N fertilizer (NH_4NO_3) at the same total N-input level (250 kg N ha^{-1} year^{-1}), composted manure was shown to produce substantially lower yields, but also lower late blight severity (Palmer et al., 2013). This suggests that at the maximum permitted levels of organic fertilizer used under current EU-legislation (250 kg N ha^{-1} year^{-1}) modern potato varieties cannot achieve their yield potential with commonly used organic fertilisers. It also suggests that organic fertilisers with a high level of content of water-soluble, readily plant-available N-compounds (NH_4^+, NO_3^-) will deliver significantly higher yields, and some authors suggested that this is due to the low nutrient use and especially uptake efficiency of potato plants which have a relatively shallow root system (Zebarth et al., 2004b).

There is limited information on the effects of **(a)** using resistant varieties (which could potentially increase yields via reducing losses associated with late blight) and **(b)** different organic fertilisers (e.g. products with contrasting N-release characteristics) on potato yields in semi-arid regions where irrigation is essential for plant growth and to allow efficient mineralisation of nutrients from organic fertiliser inputs (Ojala et al., 1990, Carter and Bosma, 1974, Waddell et al., 1999, Porter et al., 1999). However, a recent study, in Crete, also showed that chicken manure resulted in higher total weight of tubers compared to communal waste manure under semi-arid climatic conditions (Pakos, 2016).

Results from the study presented here confirmed the findings from northern Europe by showing that chicken manure and sheep manure plus agrobiosol (which has a high content of NH_4^+-N) resulted in approximately 38% higher tuber yield compared to sheep manure alone (Tamm et al., 2004, Tétard-Jones et al., 2013). Also, both chicken manure and sheep manure plus agrobiosol produced substantially more large tubers for which there is a higher demand in Greece, resulting in an even greater commercial benefit. Chicken manure in particular also contains larger levels of plant available P and K than cattle manure and the yield difference could therefore also been at least partially due to improved P and K supply, since potato plants are also known to have a large P and K demand (Balemi and Schenk, 2009).

Results from the current study also suggest that the effect of fertilizer input types on potato health and yield parameters depends on both disease/pest pressure and variety. Most importantly, in 2014, the year with high late blight disease pressure/severity, substantial foliar blight was recorded before and during tuber initiation, significant main effects of both fertilizer type and variety were detected and there was an interaction between fertilizer type and variety for the number of tubers and total tuber yield (but not mean tuber weight). The blight susceptible variety (Spunta) produced a lower tuber number and total tuber yield than the more blight resistant variety S. mira, indicating that both tuber initiation and growth in Spunta was substantially reduced by foliar late blight in 2014. The more late blight tolerant variety (S. mira) had the highest number of tubers and total tuber yield with sheep manure plus agrobiosol. Also, in 2014, sheep and chicken manure resulted lower tuber numbers than sheep manure plus agrobiosol in both varieties and sheep manure also produced the lowest total tuber yield for S. mira. This may indicate that the fertilizer input with a higher content of water soluble forms of N (sheep manure plus agrobiosol) resulted in more rapid early growth, thus facilitating both tuber initiation and tuber filling before severe late blight development.

In contrast, in 2013, the season with low late blight pressure, but high potato beetle infestation a main effect of fertilizer type was only detected for total tuber yield, but not tuber numbers. This may have been due to potato beetle infestation starting later in the season (after tuber initiation) resulting in only tuber development being affected by potato beetle infestation.

When both growing seasons were analysed together, there was a significant interaction between variety and fertilizer type for mean tuber weight. For Sarpo mira the lowest total tuber yield and mean tuber weights were recorded for crops fertilized with sheep manure (although the difference to other fertilizer treatments was not significant for mean tuber weight). In contrast, Spunta also produced the lowest total tuber yield, but significantly higher mean tuber weights when sheep manure was used as fertiliser. This was likely to be at least partially due to the lower numbers of tubers produced by Spunta fertilized with sheep manure.

As expected for a crop with high NPK requirement, in the studies reported here the higher fertiliser input rate resulted in higher yields. Also, when applied at the same total N input level (250 kg ha^{-1} per annum, the 2 fertiliser input types with the higher water soluble N (Table 2.2) (NH_4^+, NO_3^-) content resulted in higher tuber yields, tuber numbers and a higher proportion of large tubers, However, different to previous studies comparing mineral NPK with organic fertiliser inputs (Palmer et al., 2013) there was no significant effect of fertiliser type on late blight severity. This was likely due to the difference in the N-availability between mineral NPK and organic fertilisers in previous studies having been much greater than between the contrasting organic fertilisers used in the study reported here. It is important to point out that there was also no significant main effect of fertiliser type on potato beetle infestation, indicating that mineral nutrient supply has no substantial effect of insect resistance in potato.

4.6.3 Interactions between supplementary irrigation and fertilisation treatments

Previous studies have concluded that there are interactions between irrigation methods and fertiliser input types, and often also variety with respect to **(a)** nutrient availability, **(b)** late blight severity and **(c)** tuber yield (Porter et al., 1999, Opena and Porter, 1999, Waddell et al., 1999, Ojala et al., 1990), which need to be taken into consideration when designing optimised fertilisation and irrigation protocols for semi-arid, organic potato production systems.

However, there is currently very limited information on the effect of irrigation type and level (amount of water applied per ha) on mineralisation, mineral (especially N) availability and pest and disease severity (especially late blight) and the relative growth and yield potential of contrasting potato varieties. This is therefore, to our knowledge, the first study which showed that over two seasons of field trials sprinkler irrigation resulted in approximately 80% higher tuber yields, despite also resulting in higher blight severity.

In the year with low late blight pressure (2013) sprinkler irrigation resulted in higher tuber yields for both varieties (Sarpo mira and Spunta), but it remained unclear to what extent this was due to effects of irrigation type on nutrient availability and/or soil physical conditions (e.g. crusting). For example SPAD meter assessments indicated that Sarpo mira had slightly higher chlorophyll content with drip irrigation, while Spunta had higher chlorophyll content with sprinkler irrigation supply and relative penetration resistance (crusting) of soils was not assessed.

Due to this uncertainty, future studies should focus on investigating **(a)** soil nutrient (especially N, P and K) release characteristics and availability from different fertilisers, **(b)** root distribution and root system development and **(c)** soil penetration resistance with in the soil profile throughout the growing period to gain a more mechanistic understanding to the reasons for the lower yields in drip-irrigated potato of both varieties in the low blight pressure season 2013.

In the year with the higher bight pressure (2014) there was a significant interaction between variety and irrigation type for yield, with sprinkler irrigation resulting in higher tuber yields for the more blight resistant variety, while there was no effect of irrigation type for the blight susceptible variety Spunta. This suggests that in the blight susceptible variety Spunta, the yield increasing impact of improved soil conditions associated with sprinkler irrigation was compensated for by the higher late blight losses in Spunta in 2014.

4.6.4 The impact of disease and pest severity on the performance of potato varieties

The performance of potato crops was affected by both late blight and Colorado beetle infestation. Previous studies showed that Sarpo mira is one of the most foliar blight resistant varieties currently available in Europe (Speiser et al. 2006;). This is consistent with the results obtained in the study reported here which also showed substantially lower late blight severity in S. mira compared to Spunta. Also, Pearson correlation analyses showed a strong negative association between late blight severity and tuber yield for Spunta, while there was a weeker negative association for Sarpo mira.

In the year with the higher blight pressure tuber numbers were also lower in Spunta compared to Sarpo mira and this was probably due to substantial foliar blight having been present at the tuber initiation stage in Spunta, but not S. mira. This is supported by the results from the correlation analyses showed that late blight negatively correlated with the number of tubers per plant in Spunta, but not S. mira.

There have been, to our knowledge, no previous reports on differences in potato beetle infestation between potato varieties.

However, in this study it was found that in the season (2013) with low late blight, but high potato beetle infestation pressure, Sarpo mira had significantly (30%) lower level of Colorado beetle infestation than Spunta. The underlying mechanism could not be investigated in this study and it could have been due to both repellent effects in Sarpo mira or attraction of beetles towards neighboring Spunta plots. However this is consistent with results from a recent study in Crete which reported lower levels of Tomato leaf miner (*Tuta absoluta*) infestation in Sarpo mira compared to Spunta (Pakos, 2016). Sharpo mira is also known to have a higher level of resistance to a range of insect transmitted potato viruses, which would be consistent with these results and potentially indicate a horizontal, broad range resistance to insect damage. Given the commercial importance of Colorado beetle throughout the world, a major focus of future studies should be determining the physiological, biochemical and genetic mechanisms of insect resistance in Sarpo mira.

Previous studies linked both virus (e.g. potato virus Y or potyvirus Y [PVY]) and foliar blight resistance in Sarpo mira to specific R-genes and possibly horizontal tolerance genes for foliar blight. Until recently the molecular mechanisms for both late blight and PVY resistance were poorly understood. However, more recently late blight resistance in Sarpo mira were linked to at least 5 R-genes (R3a, R3b, R4, Pri-Smir1 and Pri-Smir2) (Stewart et al., 2003, Orlowska et al., 2012). Also resistance to PVV in S. mira was recently linked to the Ny-Smira gene which is associated with a hypersensitivity response in potato (Tomczynska et al., 2014). It would be important to investigate in future studies **(a)** to what extent these R-genes and associated physiological/biochemical characteristics are also involved in tolerance to insect pests and viruses and **(b)** whether any other (as yet unidentified vertical or horizontal resistance genes contribute to insect and virus resistance. Since late blight destroyed most of the foliage in Spunta prior to the start of the Colorado beetle epidemic in 2014, it was not possible to compare the relative insect tolerance in the second growing season.

CHAPTER 5: GENERAL DISCUSSION

The target of sustainable agriculture, is to maintain and ideally improve optimum crop yield and quality with the minimum environmental impact. This principle, should be of high importance in the survey area of Messinia, due to the environmental impact of the agronomic practises that are currently followed. Messinian plain area, suffers from the nitrate groundwater contamination as well as the eutrophication of river waters (Giannakopoulou, 2003). This is the result of the excessive use of mineral fertilization as well as the sandy soil type which makes the nitrates to move deeper in the soil, and to accumulate deeper in the groundwater. On the other hand, potato production is decreasing in the area mainly due to high production costs. The 30 % of the potato production cost is the seed which due to the lack of local seed potato production centres, is mainly imported from the Netherlands. However this cost might be compensated from a higher market price since the main advantage of the area is that it supplys the whole country with potatoes early in spring. Moreover, farmers, in order to maintain maximum yield, use large quantities of crop protection inputs (mainly for *Phytopthora infestans*) as well as fertility inputs and this is further increasing the cost. Spunta is the main variety used by farmers mainly because of the consumer demand. However it is not efficient due to its suceptibility to pests and diseases as well as its shallow root system which makes it unsuitable for cultivation in light sandy soils such as the ones in Kalamata region. Organic agriculture prohibits the use of chemosynthetic pesticides as well as mineral water soluble fertilisers and promotes the use of diverse rotations as well as resistant and resourse use efficient genotypes. However, in the survey area there are only conventional potato production systems, and it becomes clear that the negative environmental impacts could be minimized if cultivation methods that are currently used in organic farming will be introduced in the area. The main aim of this study, was therefore to improve our knowledge on the interactions between the potato varieties, alternative organic matter input based fertility treatments as well as irrigation systems on the yield and blight infestation of potato.

In the area of Kalamata (Messinia county), there is lack of information about the suitability and availability of organic fertilizers as well as their influence on potato yield parameters and foliar blight resistance. Therefore, in order to evaluate possible differences in yield and crop health of potato plants in pot experiment 2 we used a variety of locally available organic products such as chicken manure and sheep manure as well as imported products such as agrobiosol which is an alfalfa based product and seaweed compost and compinations between all the above products. Our results showed that higher yields were obrained with sheep manure or sheep manure plus agrobiosol than the mineral N-P-K, eventhough the total N input was higher in the standard mineral fertilization than in the organic fertilizers. This can explain further the need of using organic fertilizers in the study area, as the soil is sandy and nitrate leaching is common. Moreover, tha fact that the irrigation system that is used in the study area is sprinkler, as this method of irrigation protects potato plants from frosting, a common problem that the farmers have to face (personnal communication with Peter Vlachogeorgakopoulos), nitrate leaching is being reinforced (Stalham and Allen, 2001). Regular organic matter inputs were shown to improve soil structure, water holding capacity, biological activity (Berry et al., 2006), as well as they result in a gradual nutrient release via mineralisation can actually reduce nitrate losses (Karam et al., 2014). Low cost manure acquisition in the area of Kalamata, it is easy since there are many farmers who own animals (such as goats, cows). The result of the pot trials suggest that similar yield were obtained with sheep manure only and manure + agrobiosol fertiliser treatments, and that these treatments gave higher yields than the other organic and the mineral NPK-fertilisation regimes. If confirmed, this suggests that sheep manure only is the best fertilisation treatment, since the incorporation of the relatively expensive agrobiosol is unlikely to increase yields to an extent that justifies the cost of using agrobiosol. The high chlorophyll levels in soils previously cropped with potato may have been due to residual N-levels from the high mineral fertiliser inputs (around 250 kg N ha^{-1}) used in potato in the Kalamata area (personal contact with Peter Vlachogeorgakopoulos). In contrast, the fallow soils used had no fertiliser inputs and were used to produce forages, but not for grazing animals, thus would be expected to have a fairly low N-status.

In order to select the appropriate organic fertilizers for the specific area, we therefore, applied different organic fertilizers into pots with the most common varieties that are used in the area, in order to evaluate their efficiency and then the fertilizers with the best efficiency were applied into fields. The seaweed compost resulted in low yields in pot trials, we therefore, excluded it from the field trials. Results from the field trials are also consistent with the results from pot trials by showing that that optimum tuber yields are obtained by organic fertilizers with a high water-soluble N content such as chicken pellets and sheep manure plus agrobiosol, but future studies should investigate whether the use of the relatively expensive agrobiosol (an imported alfalfa based product developed for high value horticultural crops) is economically viable in potato production.

Apart from reduced nutrient losses and improved water relations, organic fertiliser inputs were also shown to increase soil suppressiveness against fungal disease and nematodes (Giotis et al., 2009, Giotis et al., 2012) as well as to reduce the severity of biotrophic foliar diseases. However, no visible symptoms of soil borne disease or nematode damage were detected in the pot trials reported here.

It is also interesting to note that in the Kalamata area the benefits of organic fertiliser inputs into the very sandy soils is increasingly recognised by conventional farmers and many producers have started to use manure and/or recycled waste based composts to maintain soil fertility (Peter Vlachogeorgakopoulos and Dr Nikos Volakakis; personal communication). Future studies in the area should therefore investigate and compare the relative amounts of nutrient losses (e.g. nitrate leaching, P-runoff) from conventional mineral NPK fertilized crops with that of organic fertiliser inputs, and if losses are much lower with organic fertilisers, maximum input levels may have to be revised to allow varieties to obtain their yield potential.

In Greece, there are no national statistics on potato yields in organic production (Dr Emilia Markelou, Dr Manolis Kabourakis and Dr Nikos Volakakis. personnal communication) , and it was therefore only possible to compare yields obtained in the field trials reported here with published national yield data for conventional production in Greece (ELSTAT,2017). Overall yields obtained our field trials in 2013 and 2014 followed the same trend as published data for conventional yields in Greece. Average yields in Greece were 32% lower in 2014 than 2013 and in our experiments, average yields were 40% lower in 2014 compared to 2013 (10.9 and 6 t ha^{-1} in 2013 and 2014 respectively).

However, average potato yields in other Mediterranean countries showed different trends in the two years . For example, in Malta yields in 2013 and 2014 were similar (12.600 and 12.560 t ha^{-1} in 2013 and 2014 respectively (www.potato.com, FAO) and in Israel yields were higher in 2014 than 2013 (591.000 and 627.000 t ha^{-1} in 2013 and 2014 respectively (www.potato.com). The difference between countries were likely due to differences in local climatic conditions, especially temperature and rainfall.

The finding that Sarpo mira which is a late maturing variety produced the highests mean tuber weights, but also had the lowest foliar blight severity and largest mean tuber size in both seasons, suggests that it is a suitable replacement for Spunta, under the agronomic and climatic conditions on the Peloponnese, and especially for organic production.

This conclusion is supported by previous studies which demonstrated that Sarpo mira has a very high level of foliar blight resistance/tolerance in a different regions of Europe with contrasting genetic population structures of P*hytopthora infestans* (Speiser et al., 2006, Flier et al., 2007, Palmer et al., 2013). Previous reports also suggested that Sarpo mira has a high yield potential and nutrient use efficiency especially from organic fertiliser inputs (Palmer et al., 2013, Swain et al., 2014). The finding that Sarpo mira produced similar total tuber weights in two seasons with very contrasting late blight severity and the greater relative differences in yields compared to other varieties in the season with the high blight pressure indicate that the higher yield in Sarpo mira was primarily due to its high levels of late blight resistance/tolerance. Superior nutrient use efficiency may also have contributed to the higher tuber yields since its well known that late maturing varieties are more efficienct compared to the early ones. It is interesting to note that the varieties Remarka (which had previously shown the highests high late blight resistance and yield in trials in Switzerland; (Speiser et al., 2006) and Lady Balfour (which showed high late blight resistance and yields in UK variety trials (Speiser et al., 2006), also showed high late blight resistance in the pot trials reported here, but failed to produce high tuber yields. Additional experiments, in which varieties are compared under conditions of no or low foliar blight pressure would, therefore be required to determine to what extent foliar blight resistance or other traits have contributed to the yield difference between varieties.

The choice of the potato cultivars, for the field trials, Spunta and Sarpo mira was made on the popularity of the first, in the Greek market and the resistance of the second to late blight *(Phytopthora infestans)*. Spunta, although its sensitivity against *Phytopthora infestans*, is the main variety growing in the area. Other potato varieties that are grown in Greece are Liseta, Kennebec, Marfona, Fabula, Jearla, Agria and Banba. Furthermore the varieties Hermes, Rosetta and VR 808 are growing (industry contracted) for the chrisps market and the variety Jearla for the frozen pre fryed potatoes market (Passam et al., 2011a).

Results from the field trials, showed a great difference of late blight infestation between years. In 2014, late blight infestation was approximately 20 times higher than in 2013. The lack of national disease levels (personal communication with Emilia Markellou) that could help us compare and validate them with our findings was therefore not possible.

This study suggests that Sarpo mira may be a suitable replacement variety for Spunta in organic potato production, due to its high level of resistance to Late Blight (and viruses). Results from the field trials also provide some evidence for Sarpo mira having higher levels of Colorado beetle tolerance, which is also thought to be a benefit in organic production, where synthetic chemical insecticides are prohibited. Sarpo mira matures later than Spunta and therefore needs to be planted as early (December, January) as possible while later planting dates might risk maturity being delayed until late June when the tuber infesting Lepidopteran pests become a major challenge in Greece. Furthermore Sarpo mira is producing red tubers which might not be popular to Greek consumers. Although this study, didn't examine the preference of the two main varietes, Spunta and Sarpo mira, for their sensory characteristics (e.g. taste, colour when fried etc) from the consumer, a recent study in Crete (Pakos, 2015) showed that there is relative little difference in consumer acceptance between these two varieties, but the consumer acceptance/ preference is slightly higher for Spunta than Sarpo mira. It also produces large tubers, which are preferred by Greek cusumers (BPC, 2006) if it can be grown to full maturity. So it is possible, that the variety Sarpo mira could also be competitive in the Greek market . However, further investigation is required on the sensory characteristics of different potato cultivars in order to evaluate possible varieties that could replace Spunta.

The relatively low yields obtained in trials with all fertilizer treatments and the higher yields with organic fertilisers with a relatively high water-soluble N-content also suggest that modern potato varieties have been bred from a very narrow genetic base under exposure to high fertilizer rates and cannot achieve their genetic yield potential with the maximum organic fertilizer input levels (equivalent to ≤250 kg N ha^{-1} $year^{-1}$) currently permitted under EU environmental legislation.

In general, the main objectives of potato breeding programs have been yield stability, biotic stress resistance, as well as focusing on tuber quality traits (such as dry matter, flavour, nutritional values, tuber defects, etc.) important for both table use and processing (Frusciante et al., 1999). Until recently water and nutrient use efficicncy traits were not part of breeding objectives despite the shallow and fibrous root system of the potato plant which makes it a poor nutrient and water scavenger (Munoz et al., 2005a).

Another important issue is the adaptability of new potato genotypes to the Greek climate as well as the availability of certified seed for each planting season. In Greece potatoes are grown in three seasons ie (1) winter (tubers planted in November-December); (2) spring (tubers planted in January-March); and (3) autumn (tubers planted in August-September). For example since there is no seed availability in the international market, for planting crops in the subsequent autumn season farmers use their own seed potatoes harvested in May and June; however this material is of bad quality not certified and consequently is influencing the crop performance. Furthermore, importing seed form

Northern Europe (for spring and summer seasons) is dramatically increasing the production cost. The re-opening of the local ‘’seed potato’’ production centres that closed down at the end of 80s would be a feasible solution that could reduce the potato production costs as well as provide farmers with certilfied seed of high quality that will increase the production.

Breeding targets for organic potato producers in Greece should therefore include abiotic (such as drought and nutrient) and biotic (pest and disease) stress resistance as well as tuber quality charatcteristics suitable for the local market. Future research should also continue the work that started in the late ‘80 s in order to select / breed ‘’Greek’’ potato genotypes. An outcome of this breeding effort was the firtst greek potato variety (Vaciliki) which was a cross between widely growin potato varieties and special varieties from Peru. Yields of this ‘’Greek’’ variety were higher compared to Spunta Jaerla and Marfona. Despite the fact this breeding effort was succesfull it never continued since it was lack f interest from the Greek government (Karafillidis, 1990).

Potato is often considered as a drought sensitive crop and its sustainable production is threatened due to frequent drought episodes. This study results indicates that, if blight resistant varieties such as Sarpo mira are available for use, sprinkler irrigation is currently the best irrigation system due to **(a)** its relatively low cost (compared to drip irrigation), and **(b)** the ability to reduce foliar frost-damage and potato beetle infestation through foliar applications of water.

This study also demonstrated that increasing water input levels to maximize yields may therefore be suitable for a more resistant variety like Sarpo mira, but will increase the risk of tuber infections and associated tuber losses in a more susceptible variety like Spunta. The commercial benefit of increasing water input levels and using sprinkler systems may be even greater than suggested by the increase in total tuber yield, since both resulted in a higher number of very large tubers, for which there is the greatest market demand and premium prices (Karam et al., 2014).

Other studies comparing the effect of various irrigation systems (such as sprinkler, drip, subsurface, furrow) irrigation on potato water use efficiency suggested that sites where water is limited, drip and subsurface irrigation are more efficient compared to sprinkler and furrow irrigation (Waddell et al., 1999, Smajstrla et al., 2000). However, when water is not limited, drip irrigation is suggested (Smajstrla et al., 2000) since sprinkler irrigation might increase leaching as well the non-uniform infiltration of water and decrease N availability in the root zone (Smajstrla et al., 2000).

Studies with different irrigation and fertilizer rates have shown that under typical potato production, excessive fertilization increases the risk of nitrate pollution in the groundwater more than does a moderate excess of irrigation, although it tended to increase the leaching process (Peralta and Stockle, 2002, Milburn et al., 1990). We could therefore hypothesise that increasing irrigation in organic systems will cause less leaching compared to the onventional ones. Further research on potato water management is therefore needed in order to minimize nitrate leaching without reducing yield and quality, especially when potato is grown in well-drained sandy soils such as the one in the study area of Greece where high nitrate concentration in groundwater have been previously reported (Giannakopoulou, 2003). The study reported here, also showed for the first time that irrigation type has a major effect on Colorado beetle infestation with drip irrigation resulting in approximately 3 times higher infestation than sprinkler irrigation. However, since the experiments were not designed to assess potential mechanisms, the reasons for this difference are unknown, and could investigated in future studies. Visual/physical comparison of Spunta and Sarpo mira leaves suggest that Spunta has softer and thinner leaves, and this may be linked to the difference in tolerance. The lower levels of infestation could have also been due to chemicals with toxic and or anti-feeding activity against Colorado beetle. Recent studies in Greece showed that feeding leaf extracts of plants like *Urginea maritima* (Liliaceaea "wild onion") and *Melia azedarach* (Sapindales, Meliaceae; Chinaberry) to potato beetle larvae significantly reduced the number of larvae when compared to potato extract controls (Andreou 2015). Ingestion of extracts killed more than 80% of Colorado beetle larvae within 96 hours and the remaining live larvae stopped feeding on potato leaves. The methodology used in these studies could easily be applied to comparing the effect of extract from different potato varieties and *U. maritima* or *M. azedarach* extracts could be used as "positive" controls. However, lower levels of infestation could also have been due to Colorado beetle preferring to feed on Spunta leaves. If this was the case, insect populations may develop faster in pure stands of Sarpo mira, in regions where alternative, "more palatable" are not nearby like in the plot based trials reported here.

The contrasting effect of irrigation type on late blight severity and Colorado beetle infestation does represent an "agronomic dilemma" especially for the late blight susceptible potato variety (Spunta), since sprinkler irrigation increases late blight while reducing Colorado beetle infestation. However, when a blight resistant variety is used, sprinkler irrigation should clearly be the method of choice, since Colorado beetle is main crop protection challenge in varieties such Sarpo mira.

Conclusions

In both experiments (pot/fields) of the current research it was found that the variety Sarpo mira showed higher resistance to Late blight than the cultivar Spuntain agreed with other studies (Speiser et al.,2006). For this reason, the variety Sarpo mira could replace Spunta, as it gave higher yields compared to Spunta under organic fertiliser treatments. This conclusion is also reinforced by the fact that the irrigation method that is used in the research area is sprinkler, as it is a method to avoid foliar frost (personnal communication with Peter Vlachogeorgakopoulos), thus a resistant variety to Late blight is required. This study also showed, for the first time, that sprinkler irrigation system resulted in lower infestation of Colorado beetles in potato plants compared to drip irrigation system. Moreover it was found that the variety Sarpo mira showed higher resistance to Colorado beetle than Spunta, but the reasons for this difference is unknown. For the reasons described, further investigation is required to examine the agronomic methods and the variety that affect Colorado beetle infestation in the study area as well as the case that if Sarpo mira is more resistant to Colorado beetle, it could be resistant to other pests as well.

The fact that there are no official national data on the occurrence of major diseases such as Late blight, creates a gap, in order to evaluate the environmental conditions that contribute to high severity of them on potato production systems. If these data are available, then it would be easier to predict growing seasons with high levels of disease occurrence, so farmers can then be informed how to face it.

Having in mind all the issues that are mentioned in this thesis, it is suggested that a replacement of Spunta variety with a more resistant variety to potato disease/enemies (Late blight, Colorado beetle) could be beneficial. Specifically, this thesis showed that the variety Sarpo mira could indeed replace Spunta as it is more resistant to Late blight and Colorado beetle and produced high yields in organic production systems.

This thesis also suggests that in the area of Kalamata, it is realistic to produce organic potatoes, without loses in yield from the use of organic fertilizers or from diseases/ pests, provided that varieties resistant those pathogens (such as Sarpo mira) are used. Farmers could benefit from this change, as their costs will be reduced (sprayings, insecticeds) and of course, they can profit more by selling organic products. In this way, the benefits for the environment would be great as less chemicals and fertilizers would be applied without reducing the profit for the farmers, which is their main concern. Further investigation is required in order to investigate more in which extend the replacement of Spunta by Sarpo mira can be positive under organic production systems.

Finally, it is necessary for the local farmers to be informed about the results of producing organic products and how they can apply organic production systems in the area without incresing their cost.

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Table S1 Plant and Tuber characteristics of the 12 selected varieties used in pot trial 1 and 2

	Spunta	Lisetta	Remarka	L. Balfour	Sarpo Mira	Bellini
PLANT CHARACTERISTICS						
Foliage cover	Good to dense	Moderate to good	Moderate to dense			Good to dense
Growth habit	Erect Spreading to semi erect	Spreading to semi erect	Semi erect to erect	Spreading	Erect	
Maturity	Early to intermediate	Very early to intermediate	Late Intermediate Early	Very late	Very late	Medium early
TUBER CHARACTERISTICS						
Primary tuber flesh colour	Light yellow Yellow	Cream Light yellow	Cream Light yellow Yellow	White	White	
Tuber eye colour	Yellow	Yellow	Yellow	Red	Yellow	
Tuber eye depth	Very shallow to shallow	Shallow	Very shallow to shallow	Medium	Shallow to medium	
Tuber shape	Long to oval	Long to oval	Oval to round	Oval	Long to oval	Long oval
Tuber skin colour	White to yellow	White to yellow	White to yellow	Part red	Red	Light yellow
Tuber skin texture	Smooth to intermediate	Smooth to intermediate	Very smooth to smooth	Intermediate	Smooth	
Dormancy period	Medium to long	Short Short to medium	Long to very long			
Early harvest yield potential	Very high	Very high	Very high			
Resistance to external damage	Moderate	Moderate to resistant	Moderate to very resistant	Resistant	Susceptible	Moderate resistant
Resistance to internal bruising	High to very high	High to very high	Very high	Low to medium	Medium to high	Moderate resistant
Secondary growth	Low to medium	High Low	Low			
Storage ability	Poor to moderate		Moderate to good			
Tuber shape uniformity	Medium to uniform	Medium to uniform	Uniform to very uniform			Very uniform
Tuber size	Large to very large	Large to very large	Large to very large			Large
Tubers per plant	Medium to many	Many to very many	Many			
Yield potential	Medium to very high	High to very high	Very high			Very high

Table S1 (cont.) Plant and Tuber characteristics of the 12 selected varieties used in pot trial 1 and 2

	Sante	Cara	Vales Esmer	Arnova	Vales Soverin	Claret
PLANT CHARACTERISTICS						
Foliage cover	Good to dense	Good to dense				Moderate
Growth habit	Spreading to semi erect	Erect to very erect	Semi erect		Erect	Spreading to semi erect
Maturity	Intermediate to late Early to Intermediate	Late to very late Intermediate to late	Very early		Late	Intermediate to late
TUBER CHARACTERISTICS						
Primary tuber flesh colour	Light yellow Yellow	Cream; Light yellow	Yellow	Oval	Cream	Light yellow
Tuber eye colour	Yellow	Red	Yellow	White to yellow	Red	Red
Tuber eye depth	Shallow to medium	Shallow to medium	Shallow		Shallow	Shallow
Tuber shape	Oval to round	Oval to round	Oval to round		Long to oval	Oval
Tuber skin colour	White to yellow	Part red	White to yellow		Part red	Red
Tuber skin texture	Smooth; Very smooth	Very smooth to smooth	Smooth		Smooth	Intermediate
Dormancy period	Medium to long	Medium to long				
Early harvest yield potential	Very high					
Resistance to external damage	Susceptible to moderate resistant	Moderate to resistant	Resistant		Susceptible to moderate	Moderate to resistant
Resistance to internal bruising	Low to medium High to very high		High		Medium to high	Medium to high
Secondary growth	Low to medium	Medium		Medium to high		
Storage ability						
Tuber shape uniformity	Medium to uniform	Medium to uniform		Uniform to very uniform		Medium to uniform
Tuber size	Large	Medium to very large		Large to very large		
Tubers per plant	Medium to many	Medium to many		Many		
Yield potential	Medium to high	High to very high				

Table S2 Pest, Disease and Virus resistance of the 12 selected varieties used in pot trial 1 and 2

	Spunta	**Lisetta**	**Remarka**	**L. Balfour**	**Sarpo Mira**	**Belini**
Disease						
Dry rot (Fusarium spp.)	Low to medium	Medium	High			High
Gangrene *(Phoma foveata)*	Very low to low			Low	Low to medium	
Late blight on foliage	Low to medium	Low	Low to medium	Low to medium	High to very high	Very low to low
Late blight on tubers	Medium to high	Medium to high	Low to Very high	High	Very high	Low to medium
Powdery scab *(Spongospora subterranea)*	Medium to high			High	Medium	
Wart (*Synchytrium endobioticum)*	Field immune	Susceptible	Field immune	Field immune	Susceptible	Resistant
Virus						
potato leaf roll virus	Low to High	Medium	Very low to Medium	Low	Medium	
potato virus A	Low High to very high	Medium to very high	High to very high			
potato virus X	Low to medium Medium to high	Medium to Very high	High to very high			
potato virus Y	High	High to very high	Medium to very high	Very high	Very high	
potato virus YN	Medium to very high	Very high				
tobacco rattle virus	High to very high	Medium to high	Very high			
Bacteria						
blackleg Erwinia spp.		Medium	High	High	High	
common scab *(Streptomyces scabies)*	Very low to medium	Low to medium	Low to High	Low to medium	Low to medium	Medium resistance
Pests (Nematodes)						
Globodera pallidarace 1	Low	Moderate to high	Low	Low to moderate	Very low to low	High
Globodera pallida race 2	Low	Low	Low	Moderate	Very low to low	
***Globodera rostochiensis* race 1**	Low	High to very high	High to very high	Low to moderate	Very low to low	
Abiotic stress						
Drought resistance	High to very high	Medium to high				
Frost resistance	Medium					

Table S2 (cont.) Pest, Disease and Virus resistance of the 12 selected varieties used in pot trial 1 and 2

	Sante	**Cara**	**Vales Esmer.**	**Arnova**	**Vales Sov.**	**Claret**
Disease						
Dry rot (Fusarium spp.)	Medium to high	Low to medium				
Gangrene *(Phoma foveata)*	Low	Very low to medium	Low		Medium	Low to medium
Late blight on foliage	Low to medium	Medium to high	Low	Low to medium	Low to medium	Low to medium
Late blight on tubers	Medium to High	Medium to Very high	Low to medium	Medium to high	Low	Medium to high
Powdery scab *(Spongospora subterranea)*	High	High to very high	High		Low	
Wart (*Synchytrium endobioticum)*	Field immune	Field immune	Susceptible		Field immune	Field immune
Virus						
potato leaf roll virus	Medium to high	Medium; High	Low to medium		Very low to low	Medium
potato virus A	High to very high	Low; Medium to high				
potato virus X	High to very high	Low to High		Medium to high		
potato virus Y	Very high	High to very high	Low to medium		Low to medium	Very high
potato virus YN	Very high					
tobacco rattle virus	Medium to high	Low to medium				
Bacteria						
blackleg Erwinia spp.	Low to medium		High		High to very high	Medium to high
common scab *(Streptomyces scabies)*	Low to high	Medium to high	Low to medium		Medium	Medium
Pests (Nematodes)						
Globodera pallidarace 1	Low to moderate	Low	Very low to low			Low
Globodera pallida race 2	Low to moderate	Low	Very low to low		Very low to low	Low
	High to very high					
***Globodera rostochiensis* race 1**	High	Very low to high	Very low to low		Very high	Low
Abiotic stress						
Drought resistance	Medium to high	High				
Frost resistance	Medium	Low				

Table S3 Tuber utilisation characteristics of the 12 selected varieties used in pot trial 1 and 2

	Spunta	Lisetta	Remarka	Lady Balfour	Sarpo Mira	Cara	Vales Esmer.	Arnova	Vales Soverin	Claret
After cooking blackening	Trace to little	None to trace	None to trace	None	None	None to trace	None to trace	None	Trace	Trace
	None to trace									
Cooking type	multi-purpose	multi-purpose	multi-purpose type			multi-purpose type		multi-purpose type		multi-purpose type
Crisp suitability	Poor; Good	Moderate to good; Poor				Poor				
Dry matter content	Very low to low	Low	Medium to high			Low to medium				Low to medium
	Low to high	Medium								
Frying suitability	Moderate to good	Poor to very good	Good			Poor				
Frying colour		Pale to medium	Medium			Dark				Medium
Starch content	Low to medium	Very low to medium				Low				
Taste		Moderate to good				Good				