Improving fertilisation and crop protection regimes for organic potato production systems in Crete

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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May 2015

Dedicated to my lovely parents,

Theodor and Athena

ABSTRACT

Yields in organic production systems in Crete are significantly (up to 50%) lower than those obtained in conventional farming. This is mainly thought to be due to less efficient crop protection (especially for late blight and invertebrate pests) and fertilisation methods. However, there is limited information on the effects of alternative blight management approaches (e.g. the use of more blight resistant varieties) and different organically acceptable fertiliser inputs available in Crete/Greece on potato yields in organic production.

The objectives of the study were therefore to **(a)** quantify the effect of different organic fertilisers available in Crete (chicken manure pellets, sheep manure and communal waste compost) on crop health, yield and quality parameters of two cultivars Spunta (the main potato cultivar grown and consumed in Greece) and Sarpo Mira (a more late blight and possibly pest resistant/tolerant cultivar), **(b)** identify interactions between organic fertiliser types, cultivar choice and biochar soil amendments with respect to crop health, yield and quality parameters in both spring and autumn potato crops **(c)** compare insect resistance in the potato cultivars Spunta and Sarpo Mira using *Tuta absoluta* (which is endemic in the Messara Valley of Crete where field trials were carried out) as the model pest species, and **(d)** compare sensory quality of the potato cultivars Spunta and Sarpo Mira using untrained taste panels composed of local consumers in Crete.

The study demonstrated that chicken pellets and sheep manure produced the highest yields and that Sarpo Mira has a greater disease and pest resistance than Spunta, the main variety currently used by organic farmers in Greece. Sarpo Mira also produced higher yields that Spunta, but this was only significant in spring season 2011 and autumn 2011 when compared with chicken pellets. The finding of greater resistance to *Tuta absoluta* indicated greater pest resistance, but the impact of switching from Spunta to Sarpo Mira on more important potato pests (e.g. Colorado beetle) should be investigated in future studies. This indicates that Sarpo Mira and a switch to chicken pellets or sheep manure may allow organic potato yields to be increased significantly, compared to currently used production methods. However, exploratory sensory evaluations indicated that consumers

show a greater acceptance/preference for Spunta compared to Sarpo Mira for a range of sensory quality parameters. This should be investigated/confirmed in future studies.

ACKNOWLEDGEMENTS

The biggest thank you is to my supervisor Prof. C. Leifert, for adopting and supporting this project, for his active personal support and encouragement, as well as for his assistance in all stages of this project. He was always there for me.

In addition, a great thank you is to my Greek supervisor Dr. N. Volakakis, because without his help this project would not have succeeded.

For the statistics, I would like to thank Dr. M. Eyre, who helped me with all the ANOVA analysis and with the entomological sorting, giving me useful information.

The assistance of all in the Nafferton Ecological Farming Group staff, was also important. I am also grateful to my colleague Gavin Hall for helping me in the field trials and especially to Dr. Julia Cooper for providing all her scientific support and knowledge and made my life easier with the soil analysis, which was of great importance.

I would also like to thank Ms L. Bell, Ms T. Jordon and Ms J. Gilroy who helped me with all the paperwork and were there at any time to help me and organise all the details for my research and Thesis.

Moreover, I am grateful to Dr. E. Kampourakis because he offered me his help and his lab for the Dry matter analysis.

Furtheromore, it’s vital to thank the people of Newcastle upon Tyne and Sivas Village for their smiles and support during my experiments.

Many thanks to all the Greek and foreign people that I met during all these years of my research, who helped in their way, my friends in Newcastle upon Tyne my best mate Leonidas Rempelos, and especially to my lifetime flat mate, Socrates Stergiades.

I am also thankful to my Grandmother Vasilia Varouha and all the family members and particularly Ntina Billi and her husband Stauros Kaukakis for offering their office and designing knowledge and being there for support.

My best friends Alexandra Vouidaski, Mano Papoutsaki, Giorgo Lyraraki, Polivio Damianaki, Mano Papoutsaki Giorgo Nikiforo, Giorgo Xilouri, Gianni and Niko

Antonomanolaki, were always there for support and help on good and bad days.

I would also like to thank the “Tiganitis self-organized athletic team” which was a shelter when I was in high stress and helped me through playing football to relax and continue my work and write up.

Last but definitely not least, I would like to note a great thank you to my lovely colleague Marina Rokadaki who encouraged me all the time to finish my final corrections and not to give up.

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1.1 History and commercial importance of the potato

Potato (*Solanum tuberosum*) originated from the Andes and was already cultivated 6000 - 7000 years ago by the Incas and the other South American civilisations of that time period (Hawkes and Francisco-Ortega, 1992). Domestication of wild *Solanum* spp. is believed to have started around Lake Titicata at an altitude of 3800m. Potato was first introduced to Europe in the 1570's by Spanish explorers and by the late 17th Century was already grown all over the world (Birch *et al.*, 2012).

The potato (*Solanum tuberosum*) is the world's most important non-cereal food crop and is closely related to the eggplant, pepper, and tomato (Rempelos, 2013). After rice, wheat and maize it is considered the fourth largest (in terms of calories) food crop and is consumed by more than a billion people every day. The worldwide production of potatoes is estimated at around 321 million tonnes and potatoes are cultivated in more than 125 countries (da Cunha *et al.*, 2011).The potato is considered as one of the major crops and is of great importance because it produces more protein and dry matter per hectare than any cereal crop (Buono *et al.*, 2009). It has a higher nutritional value compared to many cereals and many other tuber crops. It is also used for processing (e.g. starch and bioethanol manufacture etc.) (Orlowska *et al.*, 2012).

Between 1992 and 2010 Europe was the leading potato production region, globally producing 45% of the world's potato harvest, with Asia producing 37%, America 13%, Africa 5% and Oceania 0.5% of the total (FAOSTAT, 2012).

Potato tubers have a high nutritional value (Venketeshwer, 2012) and contain substantial amounts of minerals, vitamins (Table 1.1) and other phytochemicals like natural phenols and carotenoids (Furrer *et al.*, 2018). Also, with approximately 26 grams of carbohydrate in a medium tuber, the potato can be considered a high carbohydrate vegetable. All the above contribute to reports linking certain health benefits to potato consumption such as reduced plasma cholesterol and triglyceride concentrations, improved glucose tolerance and insulin sensitivity and protection against colon cancer. It is suggested that potato consumption provides significant amounts of fiber and can possibly reduce body fat storage (Higgins, 2004).

Table 1.1 Potato tuber Nutritional value

Potato, raw, with skin	
Nutritional value per 100 g (3.5 oz)	
Energy	
Carbohydrates	17.47 g
Starch	15.44 g
Dietary fibre	2.2 g
Fat	0.1 g
Protein	2 g
Vitamins	
Thiamine (B1)	(7%) 0.08 mg
Riboflavin (B2)	(3%) 0.03 mg
Niacin (B3)	(7%) 1.05 mg
Pantothenic acid (B5)	(6%) 0.296 mg
Vitamin B6	(23%) 0.295 mg
Folate (B9)	(4%) 16 μg
Vitamin C	(24%) 19.7 mg
Vitamin E	(0%) 0.01 mg
Vitamin K	(2%) 1.9 μg
Trace metals	
Calcium	(1%) 12 mg
Iron	(6%) 0.78 mg
Magnesium	(6%) 23 mg
Manganese	(7%) 0.153 mg
Phosphorus	(8%) 57 mg
Potassium	(9%) 421 mg
Sodium	(0%) 6 mg
Zinc	(3%) 0.29 mg
Other constituents	
Water	75g
Link to USDA Database entry	
Percentages are roughly approximated using US recommendations for adults. Source: USDA Nutrient Database	
• Units • μg = micrograms • mg = milligrams • IU = International units	

1.2 Potato taxonomy, physiology and morphology

The potato belongs to the family of Solanaceae (dicotyledon) and the main cultivated species is *Solanum tuberosum* L., which is a tetraploid species (48 chromosomes). However, some other species of potato are grown mainly in South America and the initial species imported into Europe was *Solanum antigena* which is also tetraploid (48chromosomes) (Olympios, 2015). The genus Solanum has over one thousand species. The species *Solanum tuberosum* is sub-divided into several sub-sections, of which the sub-section potatoes contains all tuber-bearing potatoes (Weese and Bohs, 2007). Within the sub-section potatoes only seven species are cultivated (Hijmans and Spooner, 2001) and one sub-section *Solanum tuberosum L.*, dominates production worldwide (Mackay, 1996).

The potato is cultivated as an annual crop with a growing season of between three and six months, depending on the climate and variety (Stephen, 2013).Potatoes are vegetative propagated by using tubers (rather than true seed).This clonal propagation is the main reason for (a) the preservation of variety characteristics and (b) the relatively low within variety/genotype variation. Potatoes can also produce true seeds, but these tend to have low germination and establishment rates. Thus, seeds are mainly used for reproduction as part of breeding programmes designed to develop new genotypes/varieties (Malagamba and Monares, 1988).

Late blight (*Phytophthora infestans*) is the most important disease of potato in most regions of Europe including the main potato growing areas in Greece such as the Kalamata- a region on the Peloponnese - or the Lasithi Plateau in Crete. Varieties recently shown to have high late blight resistance in organic farming field trials include Lady Balfour, Sarpo Mira and Cara (Speiser *et al*., 2006).

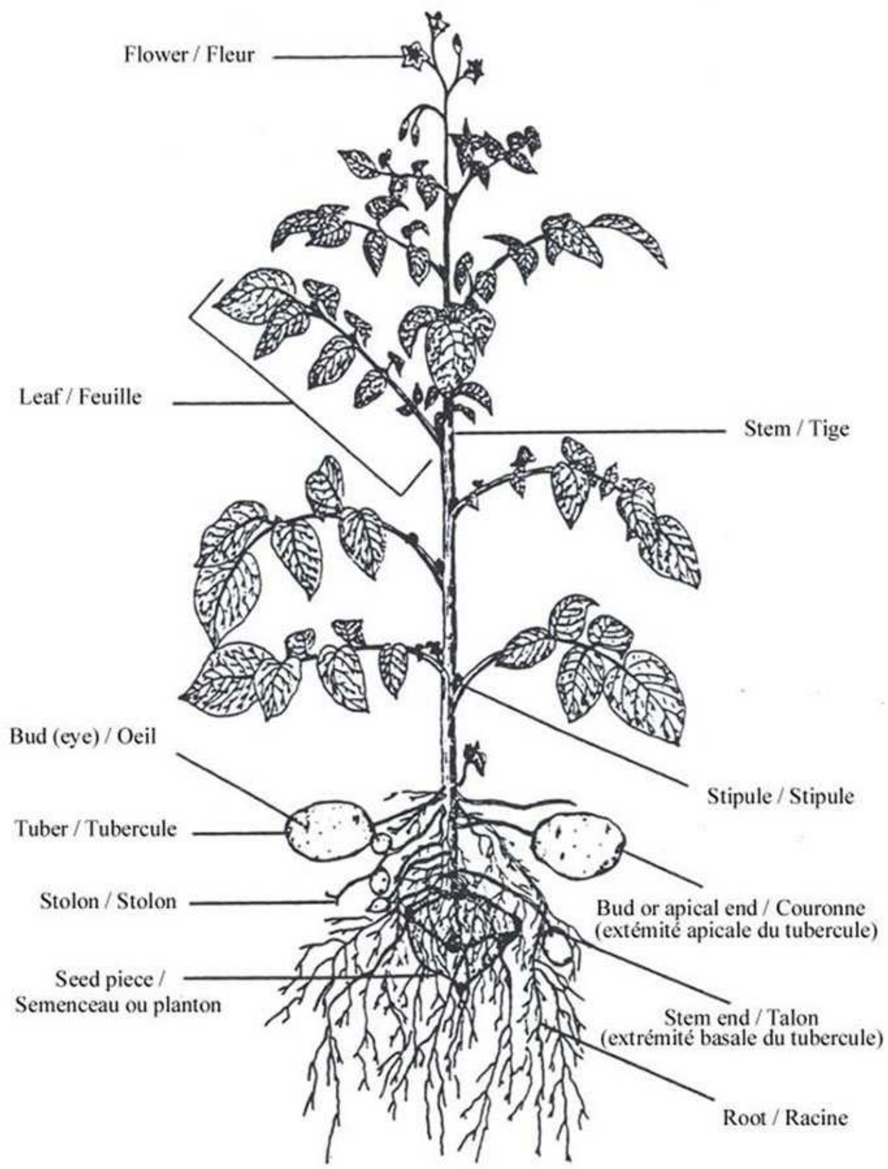


Figure 1.1 Potato plant morphology

(adopted from Canadian Food Inspection Agency, 2013)

The potato plant (Figure 1.1), has a bushy growth habit with stems above and below the ground. The over ground stems are green coloured, and initially standing while later they branch and bend in a length that reaches 40-160cm. When tubers are matured, the aboveground stems/foliage senesce and this observation is used as an indicator that tubers are ready to be harvested.

In commercial practice the foliage is often removed at the onset of senescence to get a uniform tuber skin finish/maturation and in an effort to minimise tuber blight.

The below ground stem or stolons grow into the soil horizontally and their length varies depending on the variety and the cultivation method used. Generally, the wild potato genotypes have longer stolons than those of the cultivated genotypes. The tuber is developed at the end of the stolon (Jackson, 1999). As a result, the number of tubers and potato yields are affected by the number of stolons formed, which in turn is dependent on several environmental conditions (e.g. nutrient and water availability) (Lovell, 1969). Every stolon usually forms one tuber, but it is possible that two or more tubers can be formed on the same stolon.

The roots grow from the base of the stem originating from meristematic tissues of the tuber (Cutter, 1992). The plant produces multiple thin fibrous roots that absorb water and nutrients. These, do not store nutrients unlike stolons and tubers. The root system that develops from true potato seed has only one main tap root which later branches and creates a bushy root system. Root systems developing from tubers have several main roots (Jellis, 1994).

The potato plant has leaves that consist of 7-11 leaflets. They have a deep green color and an elliptic shape with a fluffy surface. They have stomata not only on the underside (where a greater density of stomata is found), but also on the surface of the leaf (where stomata are less dense than the ones on the underside (McCauley and Evert, 1988). As with other solanaceous crops the leaves are poisonous to humans and cannot be consumed (Friedman *et al.*, 2003).

The flowers are set as inflorescences that have a long axle and grow from the base of the last leaf of each stem. Potatoes have hermaphrodite flowers and consist of a five piece crown, colored white, blue, sub yellow or purple (Winch, 2006). The pole is long, and is situated outside the cone of the anther. The ovary has two compartments and grows as a small sized oval shape fruit (1.3 – 2 cm long) which looks like a small tomato (berry) and contains the pollen.

Tubers are underground and represent modified stems, and the shape and the size of tubers varies depending on the variety and pedo-climatic conditions. The depth of the meristems of the tuber is a quality characteristic. As the depth is decreased, due to smaller losses during peeling, the smaller it is, the better it is for the processing quality of the potato. The tubers may be round, long shaped or egg shaped (Figure1.2) depending on the variety (Mauseth, 2012). The colour of the skin varies from white-yellow, red, purple to dark red. The flesh of the tubers can be white, yellow or shades of yellow and more recently potato varieties with purple flesh have been released. Under conditions of low light intensity and high relative humidity, tubers might be developed above ground, having a green to dark green colour (Pavlista, 2001).

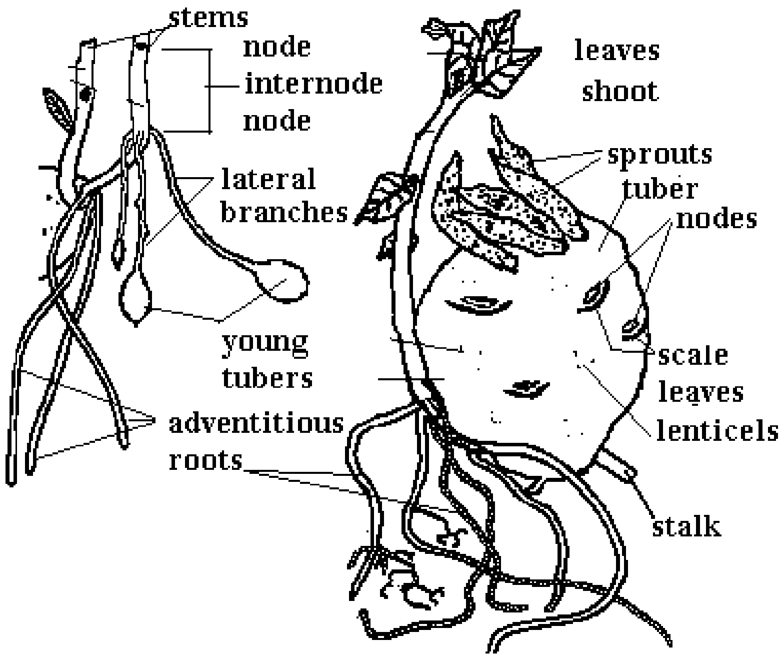


Figure 1.2 Tuber morphology

(adopted from School of Science, University of Queensland, 2015).

Tubers are formed at the end of stolons which are underground stems that grow horizontally near the surface. Tubers are swollen stolons, and have two ends (Hartmann and Kester, 1968). One end is called the heel and it is attached to the stolon and the opposite end is called either the epical or distal end.

From the outside to the inside, the potato tuber has the following tissues; skin/periderm, cortex, vascular system, storage parenchyma and the pith (Cutter, 1992).

Skin or periderm is the outer thin layer that protects the tuber (Cooper *et al.*, 1954). The skin colour varies between varieties, primarily due to its anthocyanins and may be white, white-cream, orange, yellow, purple, or red (Jansen and Flamme, 2006). The skin is usually smooth but, in some varieties, may be rough. When exposed to natural light, the skin of the tubers will turn to a greenish colour.

The cortex, is a narrow band of sapped storage tissue. It contains mainly protein and starch and is located immediately below the skin. The vascular system (phloem and xylem) connects the tuber with other parts of the plant. The storage parenchyma is the principal storage tissue and accounts for most of the tuber volume inside the vascular system ring. The pith is located in the central part of the of the tuber (Huaman, 1980).

1.3 Pedo-climatic conditions required for potato production

The potato plant is considered to be a cool region crop that can be grown in a wide variety of soils. However, if efficient water is supplied, it can also be cultivated at higher temperatures. The planting time period which depends on agronomic and pedo-climatic conditions and varies between regions; it may also be affected by market demand pattern (Chittenden Solid Waste District/CSWD, 2007). The plant needs about 12 hours daylight per day and an average rainfall of between 1500mm-5000mm during the growing season. In areas with relatively low rainfall, irrigation management is a main yield determining factor. Temperatures during the growing season should ideally be between 10 to 22°C and the average temperature should be around 15°C (Warsito and Van de Fiert, 2006).

The cultivation of the potato is possible in a wide range of soils, but the most suitable soils for commercial production are freely draining, light, sandy soils without stones, which have a depth of at least 60cm and are rich in organic matter (Olympios, 2015). However the highest yields are usually obtained in soils with a clay content of between 10-25% (Liopa, 2011). In shallow soils, re-adjustment of the fertilisation schedule (usually more frequent or split applications of fertilisers), is required in conventional production. Moreover, since the plant is very sensitive to high soil chloride concentrations, it is usually recommended that soils with good aeration and low salt concentration are more appropriate for potato cultivation (Soquimich, 2001).

Potatoes can be grown in a wide range of soil pH (4.5-7.5), but highest yields are usually obtained at a slightly acidic pH (5.5-6.5). It has been reported that in acidic soils, plants are more productive but have smaller tubers (Liopa, 2011), resulting in a similar total tuber fresh and dry weight yield than crops grown in soils with a neutral pH. This is undesirable for a part of consumers since northern Greek consumer/market currently prefers larger tubers as they lose less flesh during the peeling while smaller and rounder tubers are preferred in the southern part of the country (British Potato Council/BPC, 2006).

Apart from soil moisture and temperature, a range of other factors determine yield during the growing season including fertilisation/ soil nutrient availability and balance, and pest and disease pressure, crop protection regimes and biotic stress resistance of varieties (Samuel, 1944).

1.4 Potato Cultivation

1.4.1 Planting and chitting/pre-sprouting

Potatoes may be planted by hand or mechanically, by using either semi-automatic (where operators are required to deliver seed tubers into planting chambers) or fully automatic planting machines (Figure 1.3). In commercial practice, only mechanical planting systems are used and in conventional production fully automatic planting machines are nearly exclusively used in many areas of Europe. However, in commercial organic production semi-automatic planting systems are used more widely, especially on smaller holdings and/or where chitted seed with longer shoots are used for planting. Fully chitted seed potato tubers cannot be planted using automatic planting machines (Figure 1.4.1), without causing significant damage to shoots (Hospers-Brands *et al*., 2008).

Chitting/pre-sprouting of potato seed tubers is more widely used in organic farming due to the lack of efficient fungicide treatments for late blight (*Phytophthora infestans*). Thus, farmers use mainly chitting as a late blight avoidance practice, which reduces the time to maturity and thereby allows harvest before periods of high blight pressure (Hospers-Brands *et al.*,, 2008).

In Greece both automatic and semi-automatic planting systems are widely used, but chitting is not widely practiced (Liopa, 2011).

Automatic potato planter

Semi-automatic potato planting

Chitted/pre-sprouted seed potato tubers

Planting of chitted seed

Figure 1.3 Automatic and semi-automatic seed potato planting systems

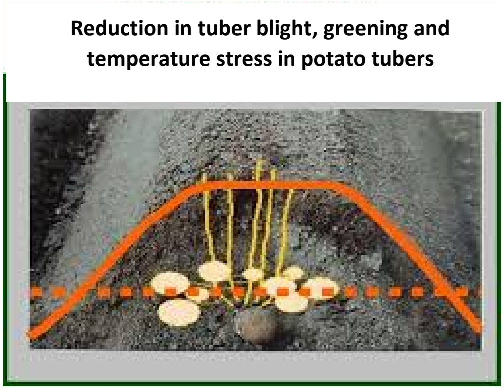
1.4.2 Ridging, re-ridging for weed control and mechanical flailing

Potatoes can be grown either in a bed system (usually with 3 rows per bed), or in a ridge system (Figure 1.4), but in organic production ridge systems are preferred since re-ridging during the growth period allows efficient mechanical weed control. In contrast, although the row mechanical weed control is possible in bed systems, it is less efficient than the use of re-ridging and the use of herbicides for weed control. Many fungal and bacterial tuber diseases and pests infect tubers via direct contact. Ridging is also carried out to achieve a good soil cover around the tuber which is known to reduce the frequency of infection/infestation by certain pests and diseases, including *Phytophthora infestans*, the most devastating disease of potato (Santos, 2006; Olle *et al.*, 2014).Tuber infection by *Phytophthora infestans* occurs mainly via zoospores formed on leaves and stems, which are washed onto the soil. The longer the distance between the soil surface and the tuber, the lower the chance of infections from zoo-spores (Santos, 2006).

Re-ridging of potatoes can be carried out before canopy closure in potato crops. It provides an efficient mechanical weed control method which helps with early weeds especially during the early growth period. Once the potato foliage canopy covers the soil completely, the crops are highly competitive against weeds and no further weed control is usually required (Klein *et al.*, 2007).

The foliage of the potato is usually removed 2-3 weeks before harvest in order to facilitate uniform tuber skin maturation. It can also be removed when foliar blight has destroyed a significant proportion of the foliage in order to reduce the risk of tuber blight (Santos, 2006).

Ridge building



Optimum position of potato within the ridges

Re-ridging of potato rows

Re-ridging of potato rows

Potato on ridge at flowering

Topping/mechanical flailing of potato crops on ridges

Figure 1.4 Building of ridges, potatoes on ridges at flowering, re-ridging and flailing of potatoes

1.4.3 Fertilisation

Potato crops rely on very high levels of N, P and K inputs for optimum yields, due to their relatively shallow root system and low nutrient use efficiency (Palmer *et al.*, 2013). Furthermore, the fact that potato crops are primarily grown in light sandy soils, results in a greater risk of nutrient losses. Besides, the growing of potato crops is associated with relatively high negative environmental impacts and particularly with regards to nitrate leaching, phosphorus run-off, leaching and Greenhouse gas emissions which are all related with N-losses (Lin *et al.*, 2001). In conventional farming, N, P and K input levels are often between 200 and 250 kg/ha/year. However, it is currently not possible to increase organic fertiliser inputs above 250 kg/ha, due to the environmental legislation which restricts organic fertiliser inputs in any year to a maximum input equivalent of 250 kg N (Van Grinsven *et al.* 2012; DEFRA, 2013). Therefore, in our experiments all the organic fertilisers used, were applied at rates equivalent to 250 kg N/ha. Additionally, in organic farming systems, potato crops are often placed early in the rotation; as the 1st or 2nd crop after a fertility building crop (e.g. a legume or legume grass mixture). They also use to receive organic fertiliser inputs up to the maximum levels permitted under EU/national environmental legislation (Palmer *et al.*, 2013). For example, in the UK when organic fertilisers are used (i.e. manure, green waste composts), are usually applied to a total of 250kg N /ha/ year. However, due to the lower availability of N and of other nutrients in organic fertilisers, yields in organically fertilised crops tend to be lower. Recently, it has been reported that more than half of the yield differential between organic and conventional crops, is due to "less efficient" fertilisation regimes in organic cropping systems. It has also been suggested that less efficient crop protection -especially of late bligh- explains the remaining of the yield differential between organic and conventional potato production systems (Palmer *et al.*, 2013).

Nitrogen (N) is the most important limiting factor among all nutrients in terms of potato yields in both organic and conventional production. N, is important for the growth of the plant, from the foliage to the underground stems (tubers). Low levels of nitrogen at tuber initiation, reduces the number of stolons and potato tubers. On the other hand, low N-supply at later stages of development, reduces foliage and tuber growth and causes earlier senescence (Harris, 1992).

In Greece, farmers apply up to 200kg N/ ha/ year (20kg N/ strema/ year) (Mouzakis, 2011). The amount of nitrogen applied, affects the photosynthetic capacity in leaves and the dry matter/starch content which are considered to be quality parameters of potato tubers (Harris, 1992). Optimum N-input levels are known to differ between varieties and also depend on the type of mineral N-fertiliser used (urea, NH_4^+, NO_3^-) (Schippers, 1968).

However, excessively high N-fertilization can reduce dry matter and starch content in tubers. Excessive N-fertilisation may also delay tuber maturation and senescence of the foliage and may increase the sensitivity of potato plants to fungal pathogens, including late blight caused by *Phytophthora infestans* (Nowicki *et al.*, 2012; Palmer *et al.,* 2013). Nitrogen and especially high levels of mineral N-fertiliser inputs, are known to (a) increase concentration of proteins, nitrate and nitrite in tubers and (b) to change gene-expression, protein and metabolomic profiles in potato tubers (van Dijk *et al.*, 2012; Lehesranta *et al*., 2007; Shepherd *et al.*, 2014).

Phosphorus and Potassium are also often yield limiting factors for potato crops, especially in conventional production (Palmer *et al.* 2013), where P and K mineral fertiliser inputs are often applied at similar levels to N-inputs (Palmer *et al.*, 2013). In contrast, in organic production (especially mixed farming) systems, P and K inputs via application of manure are often sufficient and not primary yield limiting factors, although the P and K-status (based on standard soil analysis) on organic farms is often low (Palmer *et al.*, 2013).

In organic potato production systems water-soluble, mineral N and P (such as superphosphate) fertilisers and potassium chloride (KCl) are not permitted as fertilisers in organic farming systems. However, ground phosphorus rock, potassium sulphate, lime and gypsum and most mineral micro-nutrient fertilisers (e.g. Fe, Cu, Zn) are permitted, if deficiency is demonstrated via soil or plant analyses (VanTine *et al.*, 2003).

However, organic standards and certification systems discourage the use of all mineral fertilisers and instead promote (a) the use of legume crops to increase nitrogen concentrations/availability in soils and (b) the recycling of mineral nutrients via the use of animal manures and of other organic fertilisers (Granstedt, 2000).

Other fertilisers permitted in organic farming include agricultural, food processing and urban waste products (e.g. domestic and communal waste, straw, crop and animal processing waste, blood meal, bone meal, hides, hoofs, and horns) as long as they are appropriately processed (i.e. by composting, anaerobic digestion and pyrolysis) (Dittmar *et al.*, 2000). However, human sewage based organic fertilisers are not currently permitted under organic farming standards. Apart from recycling/supplying mineral nutrients, organic fertilisers also (a) add organic matter/carbon to the soils (although the quantity and type of organic matter/carbon may differ greatly between organic fertiliser types) and (b) were reported to improve soil physical structural stability soil structure, aeration and water relations (Joosten, 2002).

Organic fertilisers (manures from different livestock species, communal waste compost, blood and bone meal) have contrasting (a) fertiliser value (N:P:K ratio's and availability pattern), (b) impacts on soil structure, biological activity and inherent fertility and (c) overall effects on potato yields and quality parameters (Tisdall and Oades, 1982; Goyal *et al.*, 1999, Waddell *et al.*, 1999; Carter *et al.*, 2004). In many regions of Europe, chicken manure pellets are the fertiliser chosen for commercial organic production, since they contain high levels of readily available N, P and K, and are easy to transport over longer distances. Thus, they allow organic production in areas dominated by stockless arable and horticultural production and usually result in higher yields of potatoes compared to other manure-based fertilisers when applied at the same N-input level (Leifert, 2013). It is therefore often essential for organic farmers to evaluate different available organic fertilisers and optimize organic fertiliser input regimes, depending on local/regional availability and cost, market tpressures and rotational sequences.

Biochar is a residue from pyrolysis based on processing of wood and other organic wastes (Harris, 1999). "Biochar" has similar properties to charcoal, is used as a soil amendment and the biochar carbon has been described as very resistant to microbial processes and is thought to persist in soil for thousands of years (Verheijen *et al.*, 2010). Such stable soil carbon amendments may therefore also mitigate climate change (Woolf *et al.*, 2010).

Depending on the feedstock and pyrolysis process type, biochar is usually characterised by a high stable carbon, reasonably high P and K (although there is limited information about these elements), but low in N content. There have been claims of agronomic benefits (i.e. disease suppression) of biochar amendments (Elad *et al*., 2011).

Biochar has been also reported to increase crop yields through (a) improvement of soil structure, (b) increase soil fertility of low pH/acid soils and (c) improve K supply to plants that require high potash levels for optimum yield (Lehmann *et al.*, 2003).

Biochar was also linked to (a) improved water quality, (b) reduced fertiliser input and irrigation needs (c) reduced nutrient leaching (Institute for Governance & Sustainable Development/IGSD, 2008), (d) increased systemic resistance responses to foliar diseases in plants (Elad *et al.*, 2010) and (e) reduced disease severity by soil borne pathogens (Meller - Harel, *et al.*, 2012; Jaiswal *et al.*, 2014).

According to other studies, when biochar was applied to soil, increased crop productivity of between 38 - 45 % was reported. It was also indicated, that nitrate leaching may be reduced by up to 60 %. These studies also suggested that biochar soil amendment may increase water and fertiliser's efficiency and that this may be due to that biochar improves cation exchange and water holding capacity of soils (Pietikäinen *et al.*, 2000, Lehmann *et al.*, 2003).
More recently, it was shown that when using biochar in soils with low inherent fertility, productivity of crops can be improved by up to 140% (Lehmann *et al.*, 2003; Johannes and Marco, 2006). There are now reports of biochar soil amendments resulting in enhanced performance for a wide range of crops including sweet peppers , maize, wheat and tomato (Asai *et al.*, 2009; Graber and Elad, 2010, Major *et al.*, 2010; Vaccari *et al.*, 2011; Joseph *et al.*, 2013). Research carried out in Japan and the United States has shown that application of biochar to the soil, can affect soil microbial activity and diversity and to stimulate the activity of certain groups of soil microorganisms (Pietikäinen *et al.*, 2000; Yamato *et al.*, 2006). More recent studies have suggested that one mechanism for the improved activity may be explained by biochar influence in the pore size distribution in soils, which in turn provides habitats that protect micro-organisms from their natural predators (Saito and Marumoto, 2002; Warnock *et al.*, 2007).
Other soil parameters, have been assumed to be responsible for changes in soil microbial activity including changes in aggregate structure, associated changes in soil water infiltration and availability and last but not least increased access to inorganic nutrients (Coleman, 1986; Thies and Grossman, 2006).
Biochar soil amendments have been reported to result in the suppression of a range of diseases including foliar diseases (anthracnose, and powdery mildew in strawberry plant) (Meller - Harel *et al.*, 2012) and soil borne diseases such as Fusarium root rot of asparagus (Matsubara *et al.*, 2002; Elmer and Pignatello, 2011) and vascular diseases, Phytophthora canker of oaks and maples (Zwart and Kim, 2012). It has also been suggested that disease suppressions may be linked to a range of mechanisms including (a) induced resistance, (b) absorption of toxins (which weakens plant defenses) from the soil and (c) increased activity and competition by antagonistic/beneficial soil microorganisms (Jaiswal *et al.*, 2014).

However, there is currently limited scientific data to substantiate these claims and it has been suggested that more research is required to confirm the real benefits and potential problems associated with the use of biochar (Yin, 2009).

Manure from different animal species is the main organic fertiliser used in Greece. As far as Crete is concerned, manure from housed conventional sheep and goat herds, rabbits and poultry (and in some areas also pig) production systems are the main forms of manure available to organic farmers (Volakakis, 2013).

More recently communal waste composts have also become available in Crete and could potentially be used by organic farmers. However, there is limited experience among farmers in using communal waste compost and some of the farmers are concerned about nutrient (especially N) supply/availability from such composts.

1.4.4 Irrigation

Commercial potato crops are often irrigated, even in temperate maritime regions of Europe with high rainfall such as the British Isles (BPC, 2013). This is mainly because (a) potatoes are relatively water-use-inefficient crops due to their shallow root systems, (b) commercial crops are grown mainly on light soils where mechanical soil cultivation and harvest is easier and (c) even short periods of insufficient water supply may significantly affect crop yields (Marino *et al.*, 2014). A range of irrigation systems are used in potato production with boom irrigation systems dominating in Northern Europe, while sprinkler or drip irrigation systems are more widely used in Southern Europe (Onder *et al.*, 2005; BPC, 2013). Figure 1.5 shows several irrigation systems used in potato production.

Switching to drip irrigation was shown to be one of the most effective management practices for the control of late blight in Southern European potato crops (especially winter planted/summer harvested) (Stone, 2014). However, in many Southern European regions sprinkler irrigation is still the dominant form of irrigation, due to the higher labour cost associated with drip irrigation systems (Lamont *et al.*, 2012).

Drip or tape irrigation systems cannot be moved during the growing season, while sprinklers together with their pipes can be moved to new fields relatively easy, thus reducing the capital costs. Drip irrigation systems require constant maintenance, since many of the components are prone to break and often need replacement. Irrigation tape can only be used in one season. The maintenance of sprinkler systems is less demanding and expensive and the component parts tend to have a much longer life (Brouwer *et al.*, 1990; Burt *et al.*, 2000).

In Greece, sprinkler irrigation has remained the main irrigation system used in potato production, including organic production systems (Volakakis, 2013; Giannakopoulou, 2013).

(a) Boom irrigation systems

(b) Sprinkler irrigation systems

(c) Drip irrigation systems

Figure 1.5 (a) Boom, (b) sprinkler and (c) drip irrigation systems used in commercial potato production.

However, based on results of the EU FP5 Blight-MOP project (Leifert and Wicockson, 2005) a range of extension services now advise organic farmers to switch to drip irrigations systems. Their advices rely on the belief that drip irrigations systems are the most effective management practices for the control of late blight in Southern European potato crops and especially for winter planted/summer harvested crops (Stone, 2014).

1.4.5 Harvest

Specialised, large scale potato production in Northern Europe relies almost exclusively on fully automatic potato harvesters which remove tubers from the ground and immediately transfer them into a trailer for transport to the storage or to a pack house facility (Figure 1.6a). However, small scale producers and many organic farms that produce a wide range of crops for their direct marketing systems (i.e. box-schemes or farm shops) often use more traditional mechanical tuber lifting machines which require potatoes to be collected by hand (Figure 1.6b).

a. Modern potato harvester

b. Single row potato lifter

Figure 1.6 Potato harvesting equipment

1.5 Major potato diseases of potato plant

1.5.1 Potato Late blight

Late blight which is caused by the pathogen *Phytophthora infestans* is considered as one of the most important diseases in potato production worldwide. In organic farming, this pathogen is still an unresolved problem and can cause significant losses in crop yield and quality (Speiser *et al.*, 2006; Flier *et al.*, 2007).

The origin of *P. infestans* is likely to be Andes region of South America, which is also the origin of the potato plant, or the highlands of central Mexico (Grünwald and Flier, 2005).

Sporangia produced on plants are the main infective agents transferring the disease from plant to plant. Sporangia, either release zoospores that subsequently infect the plant (at temperatures < 18°C) or germinate directly via a germ tube that penetrates into leaf tissue (at temperatures >21°C) (Schumann and D'Arcy, 2000). Sporangia can germinate within a few hours after landing on potato foliage when temperatures are optimum and sufficient moisture (i.e. dew, rainfall, sprinkler irrigation, fog) is available on leaves (Mizubuti and Fry, 1998). Under optimum conditions (free water on leaves and temperatures between 18 and 22 °C) (Schumann and D'Arcy, 2000) the life cycle of the pathogen on potato leaves can be completed within three to seven days (Stein and Kirk, 2002). At humidity levels of above 75% and temperatures of above 10ºC, sporangia are developed on sporangiophores that emerge through the stomata on the underside of potato leaves and spread the disease through the crop. Spores can also be distributed by wind while rain splash can wash spores onto the soil and then cause tuber infections (Nowicki *et al.*, 2012).

After the first plants in a field become infected, the whole crop can be destroyed within 7-10 day under optimum climatic conditions (see Figure 1.7a). Late blight can cause great economic damage by destroying the foliage and thereby lowering yields, promoting tuber infection, and increasing the cost of cultivation (i.e. cost associated with fungicide applications and chitting) (Nowicki *et al.*, 2012).

Late blight on potato leaves and stems can be identified by the characteristic black/brown lesions that form and by mycelium with sporangiophores/sporangia that becomes visible on the underside of leaves during periods of high humidity and free water on leaves (see Figure 1.7b).

Initially these lesions appear as water-soaked areas (Figure 1.7c) and often have chlorotic borders, but soon expand rapidly and become necrotic.

On potato tubers infection often starts in the eyes and cracks in the skin of tubers and then spreads into the tuber tissue where it later results in brown to reddish coloration. Eventually results to a soft rot of the whole tuber that in turn results in a very strong, characteristic odour that is different to the odour associated with *Erwinia* soft rots (Schumann and D'Arcy, 2000).

Foliar fungicide sprays are widely used to control late blight; whose control primarily relies in organic farming blight on Cu-fungicides and/or clay preparations. In conventional farming both synthetic chemical and Cu-fungicides are widely used (Speiser *et al*, 2006; Bangemann *et al.*, 2014). In addition, cultural practices (i.e. greater spacing between rows, chitting and early planting, spatial separation of early, second early and late crops of potato) and the use of resistant cultivars is also widely used or recommended for organic farming practice (Speiser *et al.*, 2006; Hospers-Brands *et al.,* 2008; Tsedaley, 2014). Some late varieties (e.g. Lady Balfour, Eve Balfour and Sarpo Mira) were shown to have levels of foliar blight tolerance/resistance that allows them to produce high yields in organic systems even in regions with high blight pressure (i.e. in the UK) and without Cu-fungicide applications (Speiser *et al*., 2006).

a. Totally damaged field

b. Brown legions of the disease

c. Expand damage with necrotic areas

Figure 1.7 Effects of late blight on potato crops

1.5.2 Bacterial wilt

Bacterial wilt is caused by a soil-borne bacterium named *Ralstonia solanacearum.* Bacterial wilt has a very wide range of hosts and in potato plant is one of the most destructive diseases known also as brown rot (Muthoni *et al.*, 2012). It is generally favoured by high temperatures (25°C - 37°C), but causes very few problems in temperatures below 15°C. The most common symptoms are yellowing and wilting of the plant, and later on, wilting and die back of shoots/foliage (Figure 1.8a). In tubers, several brownish-grey areas are seemed to appear on the outside, especially near the point of attachment of the stolon. On the inside of tubers areas of white to brown pus or browning of the vascular tissue is often observed (Figure 1.8b) (Delleman *et al.*, 2005). There are no chemical or biological treatments for bacterial wilt and long rotations is the main approach for reducing disease pressure.

a. Damage on potato plant

b. damage on potato tuber

Figure 1.8 Bacterial wilt-symptoms

1.5.3 Black scurf and stem canker (Rhizoctonia solani)

Rhizoctonia solani is one of the most widely found disease of potato with usually for harmful symptoms in organic production systems. This may be due to the greater risk of organically produced seed tubers being contaminated with *R. solani* or the non-use of fungicide soil trenches in organic systems (Tsror, 2010). *R. solani* is the most studied species of genus *Rhizoctonia* (Kühn, 1858) and is a soil or seed-borne Basidiomycete pathogen that can be found world-wide. It can cause serious diseases in a wide range of different plant families and species (including the Solanaceae, Fabaceae, Asteraceae and Poaceae) (Lehtonen *et al.*, 2009). It attacks young shoots, roots, stolons (Lehtonen *et al.*, 2009), and tubers of potato and may cause yield losses of up to 30% in commercial crops (Tsror, 2010). Leaf blights, leaf spots, damping-off, rots on roots, shoots and fruits and canker lesions on sprouts and stolons are the most usual symptoms caused by this disease (Figure 1.9) (Wharton *et al.*, 2007). Apart from cultural methods such as regular organic matter inputs the use of long rotations, *Brassica* break/intercrops, suppressive composts and soil amendments with biological control agents may reduce soil inoculum and the disease severity of *R. solani* (Williams and Shafiq, 2016).

Figure 1.9 Damage on potato tuber caused by *Rhizoctonia solani*

1.5.4 Potato Blackleg

Blackleg is the most important bacterial disease in many potato growing areas and causes a soft rot of tubers apart from the typical blackleg symptoms on potato shoots (Figure 1.10). It is caused by *Pectobacterium atrosepticum* (previously known as *Erwinia)* which was first described in Germany between 1878 and 1900 (Hellmers, 1959) and can cause severe economic damage both by reducing yields in the field and destroying potato during storage (De Boer and Ward, 1995). The pathogen prefers moist and cool conditions and it typically causing symptoms at temperatures below 25 C (Pérombelon, 2000). It attacks both young and mature plants causing initially yellowing discolorations on the young and black discoloration to the more mature leaves, and in turn leaf wilting on the foliage. On tubers' infection, symptoms tend to start at the stolons and then they spread throughout the tuber causing a soft rot (De Boer and Ward,1995). Blackleg is a seed-borne disease. The specific pathogen can survive in tuber lenticels and wounds during storage. Planting clean pathogen-free seed is one of the most commonly used method to control blackleg. Additional disease can be controlled by avoiding tuber contamination using different cultural methods such as early harvesting and dry storage (Perombelon, 1992).

Figure 1.10 Damage by potato Blackleg on potato tuber and plant

1.5.5 Early blight

Early blight is caused by the fungal pathogen *Alternaria solani* which produces distinctive "bullseye" patterned leaf spots. *A. solani* also affects other solanaceous crops such as the tomato. It can also cause stem lesions and fruit rot on tomato and tuber blight on potato. Additionally, in tomato, can also affect tomato seedlings lesions where it may completely girdle the stem (a disease known as "collar rot"), which often leads to reduced plant vigor or even the death of the plant (Kemmitt, 2002). Early blight was not observed in the experiments described in the current study and therefore it is not described in detail.

1.6 Major potato pests

1.6.1 Major potato pests (Colorado beetle, Cyst nematodes, Potato tuber moth, Leaf miners and Tuta absoluta)

Colorado beetle

Colorado potato beetle, *Leptinotarsa decemlineata* (Say), is a native pest of Mexico and of the south of United States and was first described by Thomas Say, in 1824. It's a leaf beetle and it is recorded as the greatest defoliator pest of potato plant. It can also cause significant damage in tomato and eggplant. If not controlled following infestation, the beetle can multiply rapidly destroying completely crops within weeks.

The Colorado beetle was introduced into Europe from America around 1850, with the first epidemic in potato recorded in 1922 in France. The insect is now found throughout Europe and continues to expand (Weber, 2003), but is still not endemic in the British Isles and some other northern European countries (Alyokhin *et al.*, 2002).

The adult beetles are pale yellow with black dots in the head-pronotum and five black stripes across each elytron and have an oval shape (10mm long, 7 mm wide). Eggs are about 1.5mm long with their color changing from light yellow to orange. Larvae are cruciform red- orange colored with black legs head and dots across each side (Alyokhin *et al.*, 2012). Damage to the potato foliage is from both the larvae and adult beetles. The adult beetle can consume more than 10 cm^2 of foliage per day and larvae as much as 40 cm^2 (Ferro *et al.*, 1985).

Both larvae and adult beetles feed mainly on the blades of the leaves and when these are consumed, they will also feed on stems. Older larvae and adult beetles feed on all the areas of the leaf with young larvae biting only small holes in it (Bandyk *et al.*, 2015).

The pest overwinters in the soil as an adult and becomes active in the spring when temperature rises. The diapause is terminated when temperature is higher than 10°C (De Kort, 1990).

The post- diapauses beetles usually accumulate to 50–250 degree-days (DD >10°C) before they appear on the soil surface (Ferro *et al.*, 1999). The life-cycle from egg to adult lasts approximately 14 - 56 days (Alyokhin *et al.*, 2002), with temperature being a main factor affecting the speed of development of the insect (Pulatov *et al.*, 2016).

When beetles rise from the soil they can be spread to the potato fields both by walking (as they can travel several hundred meters) (Ferro *et al.*, 1985) and flying (they can travel several kilometers) (Alyokhin *et al.*, 2002).

The most common method to control the beetle in the commercial potato farms is by using pesticides with many different active products which are in fact available globally (Alyokhin *et al.*, 2002). In inorganic farming systems, the beetle can be controlled/reduced by using relatively common cultural methods such as crop rotation, manipulation of planting time and the use of cover and trap crops (Hough-Goldstein *et al.*, 1993). Additionally, natural enemies such as pathogenic fungus *Beauveria bassiana* (Hyphomycetes) which have been found able to reduce the populations of beetles by up to 75% (Alyokhin *et al.*, 2002) and different predatory and parasitic arthropods, can be used to control the pest populations (Hough-Goldstein *et al.*, 1993). Physical removal via suction machines are also used by some organic farmers (Volakakis, 2013).

Cyst nematodes

Potato cyst nematodes (PCN), *Globodera pallid* and *Globodera rostochiensis,* are obligate parasites of solanaceous plants, which cause severe yield and economic losses in potatoes world-wide (Jones *et al.*, 2013). Cyst nematodes cause damage to the roots of potato and the symptoms they cause usually include early senescence, yellowing and deficient growth of the plant. Cyst can be spread by attaching to tubers, tools, and farm equipment. Females, contain the eggs that infest the plant and can remain for several years in the soil, until the presence of a suitable solanaceous host which triggers them to germinate and infect roots (CIP, 1996; Lambert, 2002). Nematicides are commonly used to control the pest in conventional farming. It is worth mentioning, that varieties resistant against one of the PCN pathotypes are available (Whitehead, 1986). Organic producers rely on long and diverse rotations as the main control measure and as a result, PCN is not considered a very important problem in organic production (CIP, 1996; Lopez-Lima *et al.*, 2013).

Potato tuber moth

Potato tuber moth (*Phthorimaea operculella* Zeller) is a lepidopteran pest of potato which attacks tubers not only in the field but also during postharvest storage (Veale *et al.*, 2012). Is an oligophagous pest that can be found throughout the Mediterranean region but also worldwide and can cause infestations that destruct the whole crop (Saour *et al.*, 2012). Generation times in the Mediterranean region are around 30 days (egg to larva to pupa and then to adult). Depending on climatic conditions, 5-7 generations are produced per year. The life-cycle of Potato tuber moth can continue in storage of tubers in potato fields. Females, lay eggs on foliage or on exposed tubers in soil cracks (Trivedi *et al.*, 1994). The hatched larvae attack leaves, petioles and stems and infest tubers especially from the onset of senescence when plants become more susceptible (Rondon, 2010).

P. operculella is commonly controlled by various synthetic pesticides (Symington, 2003). In postharvest conditions it is controlled by discarding tuber with any signs of infestation with *P. operculella*. As in organic farming, the methods used to control the pest in the field or in potato storage are preventive cultural methods such as the use of disease free tuber-seeds and early planting and harvest dates in order to avoid high pest pressure. This period usually starts in April and continues all summer. Hilling and irrigation in regular base are essential, in order to avoid soil cracks and therefore to prohibit the pest from reaching the tuber (Chandel *et al.*, 2005). The use of bioincecticides and insect enemies like parasitoids, predators and entomopathogens are also common techniques (Kepenekci *et al.*, 2013). *Bacillus thuringiensis* is the mostly known natural enemy. It is a gram $^{+}$ bacterium that causes diseases in many insects with several formulations of the insecticidal bacterium that are available in the market. Most of these show good results in post-harvest storage use (Chandel *et al.*, 2005).

Leaf miners Liriomyza huidobrensis

Potato may also be attacked by the vegetable leaf miner *Liriomyza huidobrensis* (Diptera: Agromyzidae) and the tomato leaf miner (*Tuta absoluta*) (Figure 1.11) which both have a wide host range. While *L.huidobrensis* can cause serious yield reduction in potato, *Tuta absoluta* was not reported to cause serious economic losses in the potato crop (Terzidis *et al.*, 2014).
L. huidobrensis causes damage, as larvae bore tunnels inside the leaf which dry up, finally leading to plant death (Spencer, 1973; Weintraub and Horowitz, 1995). The usual method of protection in commercial farming is to control the populations of adults with chemical sprays and yellow sticky traps (Liu *et al.*, 2009). In organic mass trapping and yellow sticky traps (Chavez and Raman, 1987), sprays with organic pesticides and the use of natural pest enemies are the most common cultural methods to control the populations of the potato leaf miner (Liu *et al.*, 2009).

Tuta absoluta

Tuta absoluta (Lepidoptera; common names: tomato leaf miner; tomato moth, tomato leaf miner moth, tomato fruit moth, South American tomato moth, tomato borer) is an oligophagous, neotropical moth from the family Gelechidae (Lepidoptera) (Figure 1.11), which attacks a range of solanaceous crops (Pereyra and Sanchez, 2006).

Figure 1.11 *Tuta absoluta*, adult

(Visser *et al.*, 2017)

Tomato is the main crop species attacked by *T. absoluta* (Galarza 1984; CIP, 1996), but potato, aubergine and a range of other solanaceous plant species are also attacked by tis species (Galarza, 1984; Terzidis *et al.*, 2014).

The pest is native to South America, but is not found at high altitudes which are longer than 1000m in the Andes region, since periods of low temperature are a limiting factor for its survival (Notz, 1992).

It has been suggested that this species have been introduced into Europe in 2006 and first reported in Eastern Spain from where it was rapidly spread throughout the Mediterranean region (Urbaneja *et al.* 2009; Karadjova *et al.*, 2013) where it has become one of the major pests in *solanaceous* crops and especially in tomato (Desneux *et al.*, 2010).

It was first reported in Greece and specifically in Crete in around 2009. During this period, commercial losses in greenhouse and open field tomato and to a lesser extent in aubergine crops were recorded (Roditakis *et al.*, 2010).

T. absoluta hasVAr a high reproductive potential and, if suitable host plants are available, larvae do not enter a diapause, and can produce up to 12 generations per year. Generation times are temperature dependent and range from 24 days at 27°C, 40 days at 20°C to 76 days at 14°C (Barrientos *et al.*, 1998).

The adult insects are approximately one cm long (Vargas, 1970) and are nocturnal. During the day the adults hide/shelter among the host plant leaves. The female can lay more than 260 eggs throughout its adult life. Eggs are laid on aerial plant tissues (leaves, stems and fruit) and either pupate within the leaf or in soil depending on the environmental conditions. During the winter, *T. absoluta* may be found in the form of eggs, pupae or adult insects in greenhouse crops which are thought to play a major role in maintaining high populations throughout the winter period (Tropea Garzia *et al.*, 2012).

T. absoluta has now become a major pest in Europe, Greece and Crete. It attacks potato crops, but appears to have no or more limited effects on the yields of potato crops (Terzidis *et al.*, 2014).This may be due to a greater resistance/tolerance of potato varieties (e.g. Spunta), and/or the routine use of pesticide sprays to control other pests, such as potato beetle and lepidopteran pests in conventional production.

However, potato crops may contribute to maintaining or increasing *T. absoluta* populations and thereby increase the severity of attacks and commercial losses in tomato crops grown in the same area (Kabourakis, 2013).

This may be due to potato crops which are grown between August and November/December (spring crops) and January/February (autumn crops). In particular, it is believed that these crops provide an alternative host or bridge on which the pest can survive between field tomato crops, which are typically grown between February and April depending the variety.

There is limited information on (a) the genetic resistance of different potato varieties and (b) the effect of standard pest control treatments used in potato production in Greece/Crete on the severity of *T. absoluta* and other pests attack/damage in potato.

1.7 Potato production in Greece and Crete

1.7.1 Environmental conditions and agricultural land use in Greece and Crete

Greece is located in the south eastern part of the Mediterranean and has a typical semi-arid Mediterranean climate, with warm/hot and dry summers to relatively cold winters, when most precipitation occurs (Hellenic National Meteorological Service/ HNMS, 2014). Average rainfall in Greece is between 850-900mm per year, but there is great variation between years, seasons and regions. For example, the annual rainfall in North-Western areas of the Greek mainland are between 800mm and 1200mm), while rainfall in the South-Eastern Islands (i.e. Aegean islands and Crete) is only 300-500mm (Tsagarakis *et al.*, 2001).

Off the total land area of Greece (approx. 13.1 million ha), 27% (3.6 million Ha) is used for agricultural production, but this includes a large proportion of semi-natural pasture/shrub land used for rough grazing only (approx. 400,000 ha). Of the 3.2 million ha or managed agricultural land, 28% is used for perennial tree crops (e.g. olives, citrus, almonds top fruit), 3% for vineyards, 7% for small scale horticulture, grasslands and other perennial crops (e.g. soft fruit, artichokes). Annual crops account for the rest of the production area (2 million ha), with cereals (including maize) accounting for 57% and industrial crops (e.g. cotton, tobacco) for 24% and potato for only 1% (20,078 ha) (BPC, 2006).

In Greece, potato is cultivated in two different growing seasons of the year (spring and autumn crops) in most regions of mainland and the island of Crete. Important areas for larger scale commercial potato production include the coastal plains (e.g. Messinian valley in south Peloponnese) and mountain plateaus (e.g. the Lassithi plain in Crete), which have very light sandy soils and access to water for irrigation. However, small scale potato production for local markets can be found throughout Greece. Longer term cold storage of potato crops is relatively uncommon and larger scale farmers tend to use a range of different planting dates to provide continuity of supply throughout the year (Patsalos, 2005).

Commercial potato production requires relatively large, and flat and/or only slightly sloping fields, since stronger sloping fields make the use of mechanised planting and harvesting operations and the use of irrigation more difficult and expensive. In fields with slopes of more than 5%, significant volumes of water and nutrients may be lost. In fields with slopes greater than 10%, the use of machinery for tillage, planting, crop protection and harvesting, becomes difficult, and very high water and nutrient losses and associated soil erosion and environmental pollution are often observed (Stoorvogel *et al.*, 1993).

The island of Crete is 245km long and ranges from 12 to 52km in width. Excluding the thirty-four offshore islets that girt the main island, Crete has a surface area of roughly 8,620 square kilometers (Morris, 2002). This makes Crete the fifth largest island in the Mediterranean Sea. Crete is located in the South-Eastern part of the Mediterranean region, has a semi-arid climate with virtually no rainfall between May and September and an average annual rainfall of 300mm-500mm. However, precipitation in the high mountain ranges (which have peaks of around 2500m) of the island can be much higher. On the higher ground, it is usually snowing during winter. The high mountain ranges, act as natural water reservoirs for the islands. Crete is the largest island of the country with a population of 600 000 inhabitants and until the late 1960's was self-sufficient for food production, with most of the food consumed on the island being produced there (Agrafioti and Diamadopoulos, 2012).

Crete has an average water consumption of 485 million m^3 per year, with approximately 85.2% being used for irrigation in agriculture. Domestic use accounts for 12.7% and industrial use for 2.1% of total water usage in Crete (Chartzoulakis *et al.*, 2001).The most important limiting factor for agricultural production in Crete is the regional and seasonal variation in water availability and demand (Angelakis, 2012).

Messara valley (where experiments reported in the current study were carried out), is located 50km South of Heraklion near the central South coast of the island. The valley is surrounded by three of the main mountain ranges of the island of Crete, the Asterousia mountain range (1231m) in the South, the Dikti Mountains in the North-East (2148m) and the Idi Mountain in the North-West (2456m). The valley is divided into two main basins (a) the West Messara and (b) the East Messara region, each named after the main rivers in the respective areas (Geropotamos and Anapodiaris) (Voudouris *et al.*, 2012).

The main crops cultivated in the area are olive trees, field vegetables (including potato) and greenhouse crops, grapevine and fruits (i.e. citrus, figs, pomegranate) and some cereals (mainly for livestock feed). The area (including its surrounding mountain ranges has an 750-1000mm average rainfall with dry hot summers and mild-moist winters (Kosmas, 2012).The area has significant water resources, mainly due to the surrounding mountain ranges acting as natural water reservoirs and supports a vibrant intensive farming industry, which consists of approximately 90% conventional and 10% organic production.

In Crete, potato cultivated areas are about 4000 to 6000 hectares mainly in the Lassithi plain while the main area is accounting for approximately 30% of potato production, which means approximately 2000 hectares (Hellenic National Statistics Service/HNSS, 2012).

1.7.2 Potato production in Greece

For the purposes of the current research, it was considered important to provide information regarding the potato production in Greece. Thus, a comparison between the yields of this study with the data of national and international statistics, will be enabled in the General Discussion.

According to Greek Ministry of Rural Development & Food (Minagric, 2018), 46,000 hectares from the total cultivated land (3,700,000 ha) is covered with potato cultivations, which equates to 1.2%. The average national production over the last decade is 943,000 tones.

In the map of Greece below (Figure 1.12), it is showed that in the prefecture “Heraklion” of Crete there is an area where more than 51% of the total cultivated areas is cultivated with potatoes. From this Figure, it is obvious that Heraklion it is one of the very few areas of Greece that has a high rate of cultivations of potato (Minagric, 2018). At this point, it is worth noting that the potatoes used in the experiments of this study, were grown in Heraklion.

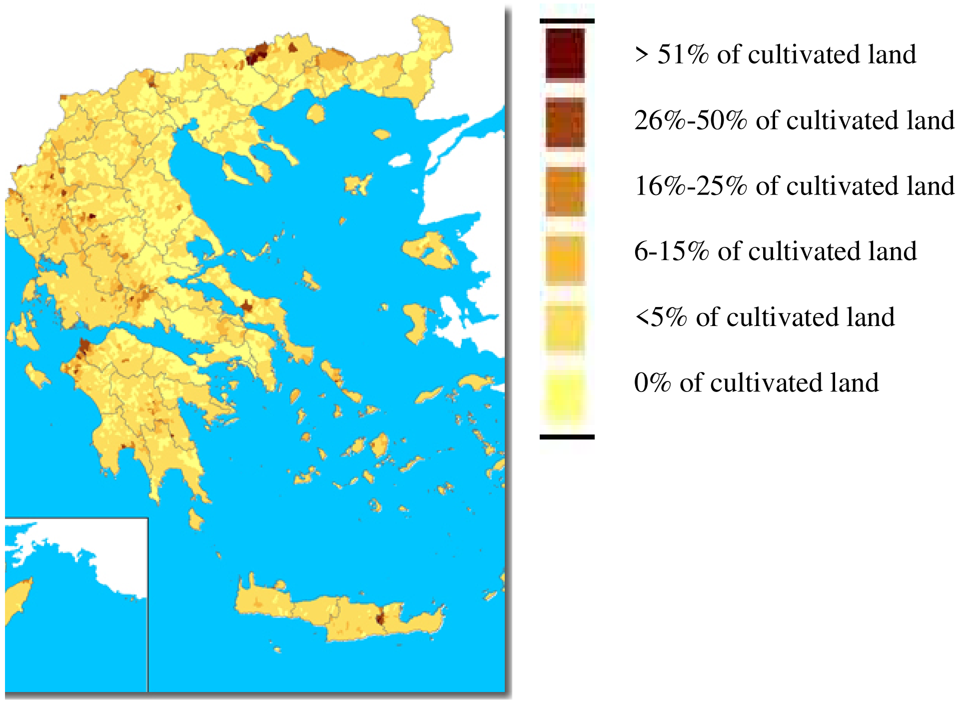


Figure 1.12 Percentage of potato cultivated area in Greece (Minagric, 2018)

Information regarding the potato cultivated area harvested in Greece, the yield and the production, from 2011 to 2015, are given in Table 1.3, according to which the average harvested area, the yield and the production of potato in Greece is approximately 34802 ha, 220695 hg/ha and 751437 tones respectively (FAOSTAT, 2018).

Table 1.2 Statistics for potato in Greece Area harvested, Yield and production (Minagric, 2018)

Year	**Area harvested (Ha)**	**Yield (t/ha)**	**Production (t)**
2011	44642	20.216	902492
2012	43979	19.917	875908
2013	43225	20.679	893833
2014	26100	23.580	615429
2015	24200	24.246	586750
2016	26670	23.780	634209

Table 1.3 Crop statistics (from 2000 onwards): Production of potatoes, including seed, 2015 (Adopted from: Eurostat, 2018).

	Harvested Production (1000 tonnes)	Share of EU-28 harvested production (%)	EU-28	Harvested Production (1000 tonnes)	Share of EU-28 harvested production (%)
EU-28	53160	100.0			
Belgium	3665	6.9	Bulgaria	165	0.3
Czech Republic	505	0.9	Denmark	1748	3.3
Germany	10370	19.5	Estonia	81	0.2
Ireland	360	0.7	Greece	556	1.0
Spain	2284	43	France	7114	13.4
Croatia	171	0.3	Italy	1355	2.3
Cyprus	96	0.2	Latvia	204	0.4
Lithuania	392	0.7	Luxemburg	13	0.0
Hungary	452	0.9	Malta	8	0.0
Netherland	6652	12.5	Austria	536	1.0
Poland	6152	11.6	Portugal	487	0.9
Romania	2625	4.9	Slovenia	91	0.2
Slovakia	145	0.3	Finland	532	1.0
Sweden	803	1.5	United Kingdom	5598	10.5
Norway	305	:	Switzerland	365	:
Montenegro	27	:	FYR of Macedonia	190	:
Albania	243	:	Serbia	639	:
Turkey	4763	:	Bosnia and Herzegovina	35	:
Kosovo*	71	:			
*This degination is without prejudice to position on status, and is in line with UNSCR 1244 and ICJ Opinion on the Kosovo Declaration of Independence					
(:) not available					

Moreover, statistical analyses from Eurostat (2018), show, that in international level, Greece shares only 1% of the total harvested production of the Member States of European Union (Table 1.2). However, it shall be noticed, that these data concerned the year 2015 and also included the production of seed potato.

1.7.3 Organic farming in Greece and Crete

Organic farming in Greece and Crete started prior to the introduction of EU regulations in 1993. The first organic production in Greece began in Aigialeia in 1982 when a small group of local farmers began producing organic Corinthian grapes for export to the Netherlands (Research Committee Support Team/RCST, 2005). This first organic farming union, the E.A.S. (Union of Agricultural Cooperatives) Aigialeias is still active today, with over 500 producers involved in the production of organic grapes, olives, and citrus fruits. The first organic olive production began in Mani (area of Peloponnese) in the mid-1990s. There is no official data regarding the size of the organic farming sector for the period from 1982 to 1992.

The introduction of a legally binding organic farming standard in Europe in 1991 (EU Regulation 2092/91) which accelerated conversion and certification to organic farming standards in Greece. In the early 1990's there were about 150 producers cultivating a total area of 2000 hectares (RCST, 2005). A second major expansion took place after the introduction of subsidies for organic farmers in 1996 with the adoption of the EU-Regulation 2078/92. In 1999, 0.5% of land and farming businesses were organically certified and organic agriculture has rapidly expanded since then, with annual growth rates of between 50% and 120%.

As in other regions of Europe organic farming historically was developed by forward looking farmers, consumers and organic farming Non-Government Organisations (NGOs). The support from organic sector bodies/support organisations based in Northern Europe and especially in Germany, Austria and Switzerland, was important. This support was actually a movement opposed to input-intensive, high-tech agriculture, (International Federation of Organic Agriculture Movements/IFOAM, 2014). Until recently, Organic farming received little structural/financial support from the Greek government and technical support from Universities/research institutes/agricultural advisory bodies.

Organic potato production in Greece has remained relatively limited compared to other vegetables and a significant proportion of organic potato is imported, mainly because of:

- the difficulty in growing the relatively late blight susceptible cultivar Spunta (for which there is the greatest market demand) under organic conditions,

- the specialized nature and structures in the conventional potato industry. This nature, is based on monoculture or short rotation-based production systems. For these systems, sequential (weekly or fortnightly) planting patterns are used to provide continuous supply, rather than cold storage systems. This makes it difficult for farmers to convert to organic production without increasing their land area and introducing new crops. Increasing land area is difficult in most potato production regions of Greece (since there is limited suitable land area available for sale or rent). In addition, most Greek farmers are relatively old with average age of 47.3 years (Kasimis and Zografakis, 2014), and are reluctant to take the risk of switching to organic production and/or to contemplate starting to grow new crops.

- the difficulty of controlling late blight in sprinkler irrigated production systems, which are the most commonly used irrigation systems on potatoes in Greece.

- concerns about the commercial viability of organic potato crops, based on existing knowledge about **(a)** yield reductions associated with switching from mineral to organic fertilisers (Palmer *et al.*, 2013) and **(b)** high cost and/or limited availability of organic fertilisers in Greece.

1.8. Potato varieties and their influence in consumer preferences

1.8.1 Potato varieties used in Greece and Crete

Currently there is only one main variety (Spunta) grown commercially in Greece while it is used for both late summer and winter planted crops (autumn and spring crops). However, in the past a greater diversity of varieties adapted to local pedo-climatic conditions and growing seasons was used (Cyprus Potato Marketing Board/ CPMB, 2013).

Spunta is one of the most widely cultivated varieties among the Mediterranean region (Ierna, 2009). It's a light yellow to white flesh variety which produces high yields with long and shallow shaped tubers. The plant is tall with an intermediate type foliage structure and has a very early maturing period (Haverkort and Anisimov, 2007).

Spunta has only moderate resistance to tuber and tuber blight (Table 1.2). However, in many areas of Greece, where potatoes are cultivated with sprinkler irrigation, it shows very little resistance to foliar blight (Giannakopoulou, 2013). It is also thought to be susceptible to potato beetle and tuber moth (Volakakis, 2013; Giannakopoulou, 2013), but there is, to our knowledge, no published information on insect resistance. In conventional potato production, crops are protected by regular fungicide sprays (up to 3 applications per week in periods of high blight pressure). Since conventional potato crops are grown in mono-culture or short rotations in Greece, chemical soil disinfection/insecticide treatments against potato cyst nematode and potato beetle are also routinely used in conventional systems (Patsalos, 2005).

Although it is widely used for organic production in Greece, Spunta is not thought to be an ideal variety for organic systems, due to its low resistance to late blight. On the other hand, Sarpo Mira produces large, red skinned and oval shaped tubers with deep positioned eyes and is a late maturing main-crop variety (see Table 1.2 for further characteristics of the variety). It can be grown in a great variety of soils, it rapidly produces a closed canopy and has a high capacity for suppressing weeds (White and Shaw, 2009). It is resistant/tolerant to bruising and to several pests (Stephen, 2013) and has exceptionally high late blight resistance (Kim *et al.*, 2011). It produces high yields (White, 2011) and the tubers are floury and rich in dry matter with a high potential of long storage periods.

Sarpo Mira is currently one of the most blight resistant varieties and its resistance is thought to be due to its range of resistance genes (R-genes) and due to the as yet poorly understood "tolerance" or "horizontal resistance". While horizontal resistance does not completely inhibit infection, it results in a slow foliar blight development (slow-blighting phenotype). In terms of disease epidemic development, the "tolerance" expresses itself by late blight symptoms spreading more slowly throughout the field in case of Sarpo Mira and other potato varieties (White and Shaw, 2010).

Table 1.4 Characteristics of the potato cultivars Sarpo Mira and Spunta			
		Sarpo Mira	**Spunta**
Quality			
Tuber shape	1-9; 1= round, 9=oval/long	7	7
Uniformity of shape	1-9, 1=variable, 9=uniform	5	6
Eye depth	1-9, 1=deep, 9=shallow	3	7
Skin color	Red, white, particolored	Red	White
Skin texture	1-9, 1=deep, 9 =shallow	4	5
Flesh color	1-9; 1=white, 9 = yellow	4	5
Dry matter	%	NI-	NI
Agronomy			
Foliage maturity	1-9, 9 =early	4	5
Tuber number	Number per plant	Variable	Variable
Resistance to damage	1-9, 9 =good	3	3
Resistance to bruising	1-9, 9 =good	6	4
Pest and disease resistance	1=low, 9=high		
Foliage Blight	1-9	9	7
Tuber Blight	1-9	9	6
Blackleg	1-9	7	NI
Common Scab	1-9	4	3
Powdery Scab	1-9	5	NI
Gangrene	1-9	4	5
PLRV	1-9	5	4
PVY	1-9	9	5
Spraing	1-9	NI	4
Insect resistance	1-9	NI	NI
Black Dot	1-9	NI	NI
Black Scurf	1-9	NI	NI
Skin Spot	1-9	NI	NI
Silver Scurf	1-9	NI	NI
Dry Rot	1-9	NI	BI
Dry Rot	1-9	NI	NI
PCN Ro1	Susceptible or resistant	Susceptible	Susceptible
PCN G. pallida	Susceptible or resistant	Susceptible	Susceptible
*Data derived from the UK NIAB, 2013			

Sarpo Mira was found to be one of the most blight resistant varieties in recent pot trials carried out in Kalamata (Messinian valley, south Peloponnese, mainland Greece) while its yield production under blight pressure was higher compared to Spunta. In terms of late blight resistance: Sarpo Mira seems to be more resistant compared to Spunta Cara, Lisetta and Sante. In terms of yield, Sarpo Mira has higher yield compared to Spunta, Cara, Lisetta and Sante (Giannakopoulou, 2013).

Sarpo Mira has also been described as being more resistant/tolerant to virus infection, and nematode and insect damage, but there is limited sound scientific information available to back up these claims (White and Shaw, 2010).

1.9 Insects and major pests on potato plant

Insects (Insecta) are a class in the Phylum Arthropoda. Insects have one pair of antennae and their body is divided/separated into three pieces (head, thorax and abdomen). They have three pairs of legs joined to the thorax, and compound eyes (Snodgrass, 1993). Their name comes from the Latin word insectum that is a calque of the Greek word "έντομον" (entomon, meaning "cut into pieces") (Liddell and Scott, 1990).

Insect Classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Clade:	Pancrustacea
Subphylum:	Hexapoda
Class:	**Insecta**
	Linnaeus,1758

Insects are known to be the most diverse group of animals globally (Chapman, 2009) and there are more than a million known/described species, which represent more than half of all known living organisms (Erwin, 1997). Figure 1 shows the proportion of different groups to the total number of species in the animal kingdom (Schminke, 2007).

Table 1.5 Insect Orders, common names and important morphological characteristics used for classification of insect orders (adopted from Wheeler *et. al.*, 2001)			
Order Name	**Common name**	**Adult mouthparts**	**Wings (no. and type)**
Protura	Proturans	Chewing	Lacking
Collembola	Springtails	Chewing	Lacking
Diplura	Diplurans	Chewing	Lacking
Microcoryphia	Jumping Bristletails	Chewing	Lacking
Thysanura	Bristletails, silverfish	Chewing	Lacking
Ephemeroptera	Mayflies	Vestigial	2 pair, may be reduced, membranous
Odonata	Dragonflies, damselflies	Chewing	2 pair, membranous
Orthoptera	Grasshoppers, crickets, katydids	Chewing	2 pair, or may be reduced; 1st pair: tegmina wings
Phasmatodea	Walking sticks	Chewing	variable, 0-2 pair; tegmina
Grylloblattodea	Rock crawlers	Chewing	Lacking
Mantophasmatodea		Chewing	Lacking
Dermaptera	Earwigs	Chewing	0-2 pair; front wings elytra
Plecoptera	Stoneflies	Chewing	2 pair, membranous
Embiidina	Web spinners	Chewing	0-2 pair; membranous
Zoraptera	Zorapterans	Chewing	0-2 pair
Isoptera	Termites	Chewing	0-2 pair
Mantodea	Mantids	Chewing	0-2 pair
Blattodea	Cockroaches	Chewing	0-2 pair;
Hemiptera* - now with 3 **suborders**; **Heteroptera** - bugs **Auchenorrhyncha** - cicadas, leafhoppers **Sternorrhyncha** - aphids, scales	"True Bugs"	Piercing, sucking	0-2 pair; hemelytra front wings
Thysanoptera	Thrips	Rasping, sucking	2 pair, fringed with hairs
Psocoptera	Book and bark lice	Chewing	0-2 pair

The class of insect (Hexapoda) is subdivided, in most classification systems, into approximately 30-32 orders. Some orders include animal and plant pests, important pollinators and/or natural enemies of pests.

However, orders are not of major importance in terms of agricultural production. It has been described that 5-6 orders dominate (Schminke, 2007) with respect to their importance for crop production systems. However, there is some controversy among taxonomists on the number of orders and the names (Moore, 2013).

Table 1.6 Proportion of species in the animal kingdom in different insect orders and other taxonomic groups of animals
(adopted from Wheeler *et. al.*, 2001)

Order Name	**Common name**	**Adult mouthparts**	**Wings (no. and type)**
Phthiraptera* - several suborders **Amblycera** **Ischnocera** **Anoplura**	Lice	Chewing, piercing	Lacking
Coleoptera	Beetles	Chewing	2 pair; front wings ***elytra***
Neuroptera	Lacewings, owlflies, mantispids, antlions	Chewing	2 pair, membranous
Hymenoptera	Bees, ants, wasps	Chewing	0-2 pair, membranous
Trichoptera	Caddis flies	Chewing	2 pair, hairy or with scales
Lepidoptera	Moths, butterflies	Siphoning, vestigial	0-2 pair; usually covered with scales
Siphonaptera	Fleas	Piercing sucking	Lacking
Mecoptera	Scorpionflies	Chewing	0-2 pair
Strepsiptera	Twisted-winged parasites	-	0-2(1) pair
Diptera	Flies	Piercing, sucking, lapping	0-1 pair

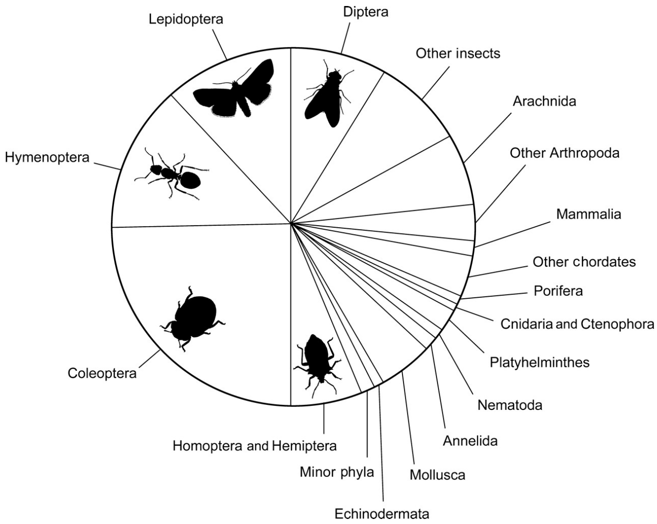


Figure 1.13 Proportion of species in the animal kingdom in different insect orders and other taxonomic groups of animals

1.9.3 Importance of insects as pollinators, crop pests and natural enemies of pests

From an economical point of view, the class Insecta includes the most important groups of invertebrate pests attacking crops. It is worth noting that most pollinators and known as natural enemies of invertebrate pests.

Insecticides and biological control products (e.g. pheromone traps, Bt. and natural enemies) are widely used to protect crops against insect damage (Resh and Cardé, 2009).

Insect pests are often monitored (e.g. using pest specific pheromone traps) to determine the best timing of pest control treatments. However, since pest population development may also be affected by naturally occurring enemies (e.g. predators/parasitoids) of pests monitoring of other groups of insects (which include known natural enemies of pests) is also often carried out in field experiments.

The most common insect orders found in Greece are: Coleoptera, Hymenoptera, Lepidoptera, Diptera, Hemiptera and Orthoptera. Among these orders, Coleoptera and Hymenoptera are known to include important natural enemies of insect pests. For example, Coleoptera include (a) ladybirds such as *Coccinella septempunctata* which is active against aphids, (b) *Cryptolae musmontrouzieri* which is active against mealybugs, and (c) which is *Chilocorus bipustulatus* active against scale insects (Flint, 1999). Hymenoptera include (a) Gravenhorst such as *Venturia canescens* which is active against different species of Lepidoptera pests which attack grain and corn mills (Harvey *et al*., 2001) *Opius concolor* also belongs to Hymenoptera and is active against olive fruit fly *bactrocera olea* (Loni, 2003) and *Metaphycus helvolus* is active against large scale insects such as *Saissetia oleae* which attacks olives (Argyriou and DeBach, 1968). These Hymenoptera are known to include important natural enemies of crop pests. Finally for the lepidopteran insect *Tuta absoluta* an active predator is *Nesidiocoris tenuis* (Urbaneja *et al.*, 2009). The most common method for monitoring the insect population density and diversity in the various orders is through mass trapping (Sheldon and Trumble, 1990).

1.10 Effect of cultivar on the sensory quality of potato – untrained taste panel analysis

The most common variety produced and consumed in Greece is 'Spunta' which has a market share higher than 60%. Other varieties used in Greece include Remarka (medium late crop), Kennebec (early main crop like Spunta) and Agria (second early crop) (Gaiapedia, 2013).

Sarpo Mira, a highly blight and also virus resistant cultivar that was originally bred in Hungary, is not currently available in the Greek market. This variety has high late blight resistance (late blight being the most important reason for yield losses in Greece) and has become very popular with organic producers in other European countries, including the UK. Thus, it was included in the field trials reported here (see section 1.3 to 1.5).

Results from field experiments suggest that Sarpo Mira has a higher yield and potentially also higher yield stability in organic production systems in Greece. The reason of this speculation relies mainly due to the high late blight resistance of this variety. Therefore, Sarpo Mira might be a suitable alternative for Spunta (the main potato cultivar currently grown and consumed in Greece) in organic production systems (see section 1.3 to 1.5).

However, little is known about the relative sensory quality of Spunta and Sarpo Mira, although Sarpo Mira is known to have a relatively high dry matter/starch content, which was confirmed in the field trials reported here (see section 1.3 to 1.5). It is therefore important to carry out comparative sensory evaluations of Spunta and Sarpo Mira to determine whether Sarpo Mira provides the processing and sensory characteristics demanded by the Greek consumer.

In Greece, average consumption of potato is relatively high (average 88 kg/year/person), with most potato being consumed as chips and to a lesser extent oven baked. Calorie intake for potato is similar to that of meat consumption in Greece (Alexandratos, 2006). However, total and the type of potato dishes consumed differs significantly between Southern and Northern Greece (Passam *et al.*, 2014).

Visual appearance is an important characteristic in the Greek potato market. For example, consumers in Northern Greece prefer large potatoes with yellow flesh (e.g. Spunta). Consumers in Southern Greece prefer smaller, round varieties with a cream coloured flesh and smaller, rounder varieties (Passam *et al.*, 2014). However, Spunta is, also the most widely used potato cultivar in the South, due to its suitability for chip making. Potatoes with a white flesh have been tested, but have not become popular to the Greek consumer.

The major part of potato consumption in Greece is reported as chips/French fries. The ability to produce chips with a high sensory values and minimum darkening during frying are therefore very important characteristics for Greek consumers (Passam *et al*, 2014).

The food processing industries require different potato characteristics/cultivars depending on the type of product (e.g. chips, potato granules, potato flours and potato flakes, pre- cooked convenient foods/ready, or snack foods like potato chips, crisps and salads) (European Commission, 2010).

Chapter 2. Materials and Methods

2.1 Field experiment location

The field experiments were carried out in the West Messara plain, an area near Moires in Southern Crete, Greece (Figure 2.1). Experiments were established in three different cropping seasons (spring 2011, autumn 2011 and spring 2012).

Figure 2.1 Map of Southern Crete, where experiments were carried out

The field used for the experiments was just outside Sivas village on the road to Listaros and was $4025m^2$ in size. The area used for planting potato crops had a size of $1728m^2$. An aerial photograph of the field, is given below (Figure 2.2).

Figure 2.2 Aerial photograph of the field used for potato experiments

2.2 Experimental design

A randomised factorial (split-split-plot) block design with 4 replicates/blocks was used. Potato plots were arranged in rows (1.5m width) separated by 6m wide strips. For each of the 3 successive potato experiments was used a new part of land which had width 1.5m/row.

The factors included in the experiments were: (a) fertiliser input type (sheep manure, chicken manure, communal waste compost) (=3 main plots), (b) biochar soil amendment (with and without) (=2 sub-plots) and (c) potato variety (Spunta, Sarpo Mira) (=2 sub-sub-plots).

Each sub-sub plot was 6 x 1.5m in size and consisted of 40 plants in 6m long double rows with 75cm space between rows and 30cm space between plants within rows (Figure. 2.3).

Spunta seed tubers used in spring trials were certified seed. They were produced in the Netherlands that conformed to the NL HZPC-norm, supplied by Troullinos livestock and agriculture supplies (Moires, Heraklion, Crete, 70400). Sarpo Mira seeds were certified and produced in the UK by Skea Organics Limited (East Mains Farm Auchterhouse Dundee DD3 0QN) and was supplied by Nafferton Ecological Farming Group (NEFG, Nafferton Farm, Stocksfield Newcastle upon Tyne). In autumn trials, as seeds were used the small tubers that were harvested in the 2011 spring trials.

Organic fertilisers were applied at a rate equivalent to 200kg N/ha immediately prior to ploughing and rotation of soil. The lastly mentioned procedures were carried out 2 weeks prior to planting of crops. Sheep manure was supplied by Vouzourakis Nikos Farm (Karines, Rethymo, Crete, Greece). The poultry manure pellets were supplied by Ladakis Poultry Farm (Misirgia, Rethymno, Crete, Greece). The communal waste compost (green compost made by plant residues) was offered by the Composting Research Unit, managed by Professor Thakis Manios, which is placed at the Technical Educational Institute/TEI of Crete (Heraklion, Crete, Greece). Table 2.1 shows the mean results of the fertiliser analysis carried out by Professor Manios in the Solid Waste & Wastewater Management analytical laboratory in TEI of Crete.

Biochar came from a standard charcoal production process (produced by grinding the screenings from charcoal production from pinewood) and was supplied by Papadogiannis Charcoal and Firewood Company (Agia, Rethymno, Crete, Greece). Biochar was added in a concentration of 8 t/ha, immediately prior to ploughing.

Potatoes were hand-planted into standard ridges which were prepared by using a tractor pulled mechanical automatic ridger.

All plots were irrigated using a drip irrigation system to minimize late blight infection pressure. No crop protection measures were taken, other than the traps placed in the crops in order to monitor the insect populations, in all experiments carried out.

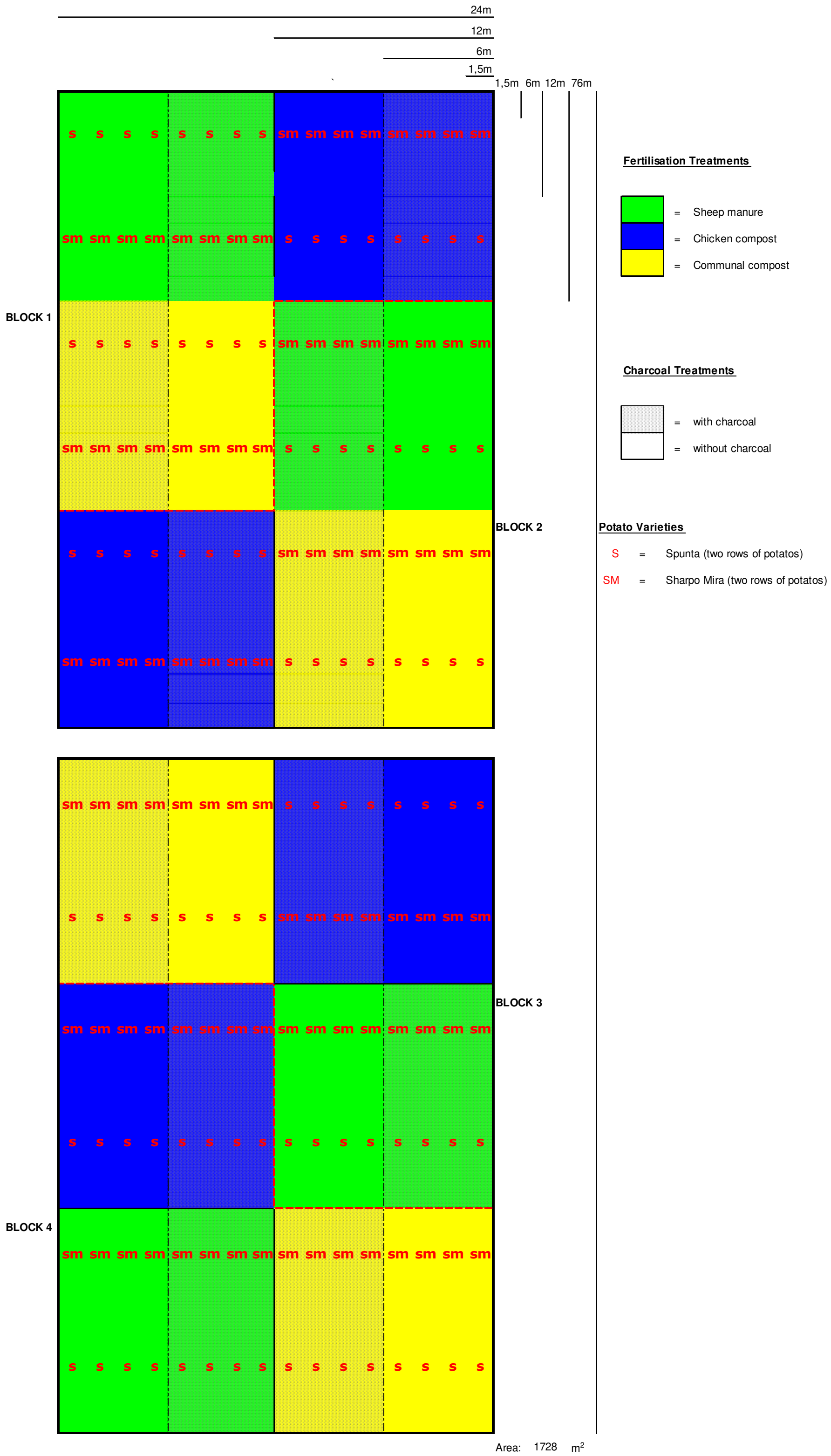


Figure 2.3 Experimental design, showing the location of potato experimental plots.

Table 2.1 Soil macro nutrient content before and after planting in Autumn 2011 growth season

(a) Before planting	**N %**	**C%**	**P mg/kg**	**K mg/kg**	**S mg/kg**	**Mg mg/kg**
Fertilisation						
1 Sheep manure	0.17±0.01	1.95±0.11	57.83±4.68b	365.1±23.81	47.67±3.01b	272.19±32.86
2 Chicken manure	0.16±0.01	2±0.2	318.82±85.51a	511.02±58.48	113.04±21.5a	323.29±56.73
3 Communal waste	0.17±0.01	2.03±0.15	132.84±50.6b	388.98±33.2	79.99±14.3ab	275.47±14.8
Biochar 1 -Biochar	0.16±0.01	1.79±0.06	167.72±55.29	426.57±34.12	80.45±13.84	290.33±30.18
2 +Biochar	0.17±0.01	2.2±0.14	171.94±57.69	416.83±41.63	80.02±14.98	290.31±33.24
ANOVA						
Fertilisation treatment (ft)	0.9687	0.7511	**0.026**	0.0731	**0.0387**	0.2885
Biochar (ch)	0.617	**0.0132**	0.9537	0.8513	0.9821	0.9994
FT x CH	0.9074	0.6264	0.9847	0.9186	0.996	0.9203
(b) After planting	**N %**	**C%**	**P mg/kg**	**K mg/kg**	**S mg/kg**	**Mg mg/kg**
Fertilisation (FT)-						
Sheep manure	0.15±0.01	1.93±0.09	22.33±2.79b	207.53±6.25b	55.01±2.66b	290.92±21.86
2 Chicken manure	0.18±0.01	2.21±0.13	151.05±17.71a	331.83±24.08a	68.38±3.7a	301.17±22.92
3 Communal waste	0.16±0.01	2.02±0.07	18.29±1.94b	213.83±12.37b	53.33±3.41b	270.46±17.84
Biochar 1 -Biochar	0.17±0.01	2.08±0.07	66.62±16.15	250.85±14.57	61.68±2.76	281.55±16.67
2 +Biochar	0.16±0.01	2.03±0.09	61.16±14.5	251.26±20.19	56.13±3.13	293.49±17.54
Variety Spunta	0.16±0.01	2±0.1	63.57±13.94	251.38±16.37	57.6±3.26	284.75±15.2
Sarpo Mira	0.17±0.01	2.11±0.06	64.21±16.66	250.74±18.76	60.21±2.7	290.29±18.9
ANOVA						
Fertilisation treatment (ft)	0.567	0.8337	**0.0053**	**0.0105**	**0.0258**	0.3627
Biochar (ch)	0.8683	0.5114	0.6469	0.9833	0.1034	0.3884
Variety (vr)	0.8342	0.183	0.9554	0.9731	0.3879	0.6057
FT x CH	0.6335	0.5609	0.8186	0.6188	0.8048	0.6999
FT x VR	**0.0258**	**0.0146**	0.985	0.8587	0.3791	0.0565
CH x VR	0.2199	0.3208	0.9288	0.6471	0.362	0.6632
FT x CH x VR	0.4976	0.6146	0.9473	0.4072	0.6206	0.4342

2.3 Crop and tuber assessment

2.3.1 Emergence

Emergence of plants from seed tubers was assessed on daily basis when at least 75% of plants had emerged in all plots.

2.3.2 Growth stages

The growth stage of plants in each plot was determined twice a week using the protocol published by Hack (1993). The nine principal growth stages of potatoes according to Hack *et al*. (1993), are provided in the Appendix.

2.3.3 Leaf greenness assessment

Leaf greenness, which is closely correlated to leaf chlorophyll content, was measured on 5 plants per plot using a chlorophyll meter (SPAD-502, Konica Minolta Sensing Inc.-Japan). The SPAD-502 chlorophyll meter was initially developed by Minolta Corporation to determine the nitrogen status of plants, since chlorophyll content is closely correlated with the N-status in crop (Markwell *et al*, 1995; Richardson *et al*., 2002).

For each plant, SPAD values were taken from five fully developed leaves, including recently emerged leaves, and then average values were calculated. During measurement, the SPAD sensor was placed randomly on the leaflet's mesophyll tissue, avoiding veins or leaf areas with discolorations/disorders (Pinkard *et al.*, 2006).

2.3.4 Harvest dates and tuber assessments

The foliage was removed when plants started to senesce. Tubers were harvested manually, two weeks after defoliation, using a pinch fork and a shovel (Figures 2.4 & 2.5). In the experiment accomplished the spring of 2011, there was only one planting and harvest date, while in the autumn of 2011 the experiment included one planting and two harvest dates. In the spring experiments of 2012, there were compared two planting and two harvest dates.

Figure 2.4 Harvest of Spunta variety

Figure 2.5 Harvest of Sarpo Mira variety

After harvest, potato tubers from each plot were placed into separate sacks and transferred to a sorting shed for tuber assessment. Tubers that were waste by soil-borne diseases and pests, as well as damaged tubers (mechanical damage by the tools and tractor) were separated and counted. Healthy tubers were then separated into four size categories: very small (<4.5cm), small (4.5-6.5cm), medium (6.5-8.5cm) and large (>8.5cm). The size of both varieties was measured considering the tubers' equatorial diameter by using a caliper. After separation into size categories, the weight of tubers in each size category was determined for each plot and converted to % of total tuber weight.

Marketable yield was calculated by removing the sum of the weight of the small tubers (<4.5cm) and of rotten tubers, from the total yield. Dry matter (DM) content was determined by weighing a sub-sample (100g) of tubers before and after oven drying (at 80°C for 48 hours) prior to calculation of the % DM. Tubers used for DM-determination were cleaned and washed to remove dirt and little stones and cut into pieces. Homogenization was carried out before oven drying (Rempelos, 2013).

2.3.5 Leaf damage by Tuta absoluta

The leaf area damaged by the tomato leaf miner (*Tuta absoluta*) was recorded one time per week, after the first foliar symptoms (Figure 2.6 & 2.7) were detected. To quantify leaf damage recorded in a leaf area, a scoring system developed by (James, 1971) for foliar blight was used. Results obtained concerned % leaf damage on the whole foliage**.** This scoring system used, is provided through Table 2.2.

Table 2.2 Scoring system used to estimate/compare Tuta absoluta leaf damage

Estimated % leaf area affected	Observed leaf miner severity
0.001%	1 lesion per plot
0.01%	2-5 leaves per 10 plants affected.
0.1%	About 5-10 infected leaflets / plant; OR about 2 affected leaves / plant
1.0%	About 20 lesions / plant OR 10 leaves affected / plant; 1 in 20 leaves affected
5.0%	About 100 lesions / plant; 1 in 10 leaflets affected
25%	Nearly every leaflet infected but plants retain normal form; plants may smell of blight. Field looks green although every plant is affected
50%	Every plant is affected and about 50% of the leaf area is destroyed. Field appears green flecked with brown
75%	About 75% of the leaf area destroyed; field appears neither predominantly green nor brown
95%	Only a few leaves on plants, but stems are green
100%	All leaves dead, stems dead or dying

Adapted from: (James 1971).

In Figure 2.5 and 2.6, is shown the appearance of potato leaves according to the % leaf covered by *Tuta absoluta*, as given by James (1971).

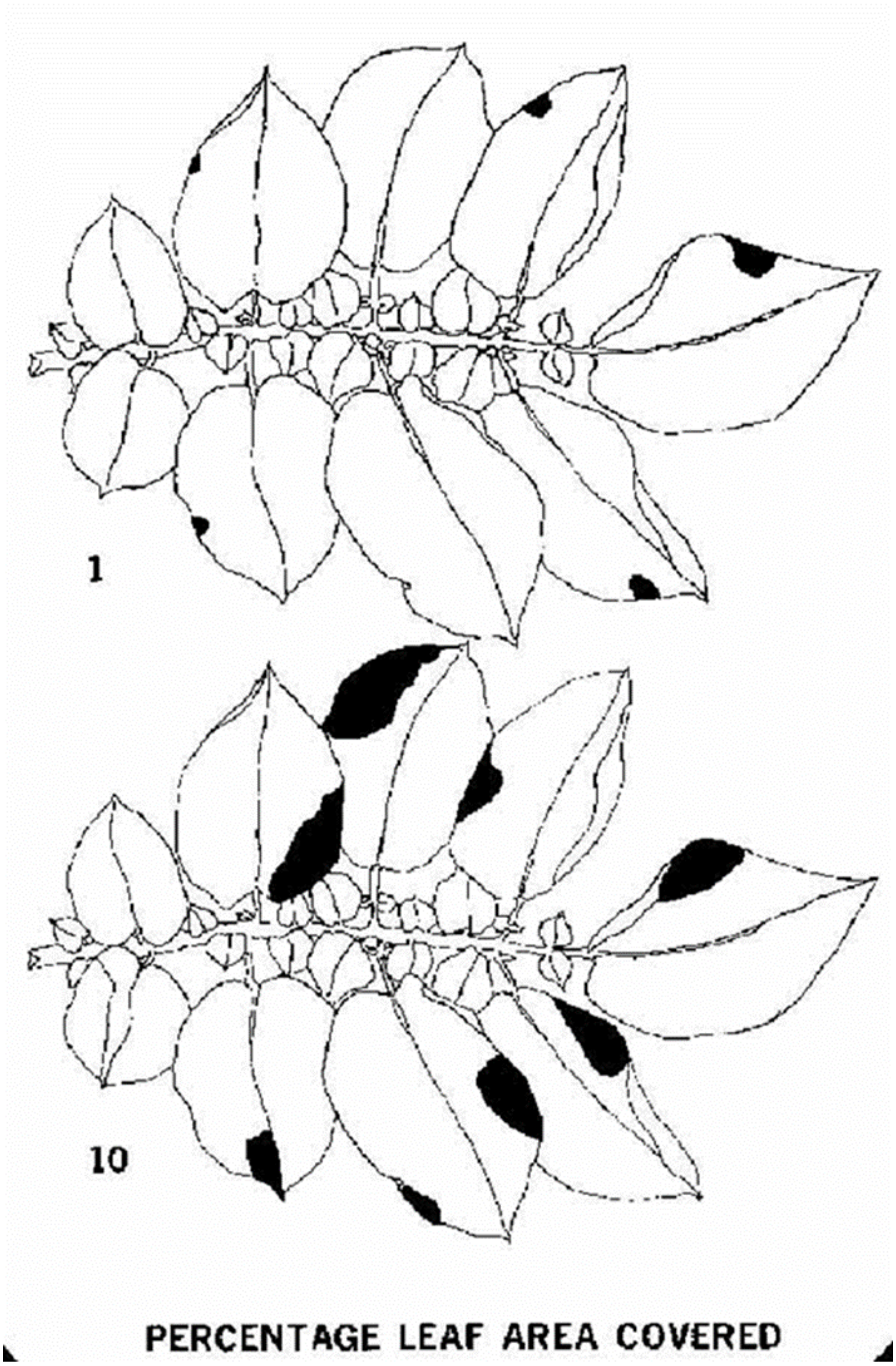


Figure 2.6 Percentage leaf area covered (1% &10%) of potato leaves by *Tuta absoluta* (Adopted by James, 1971)

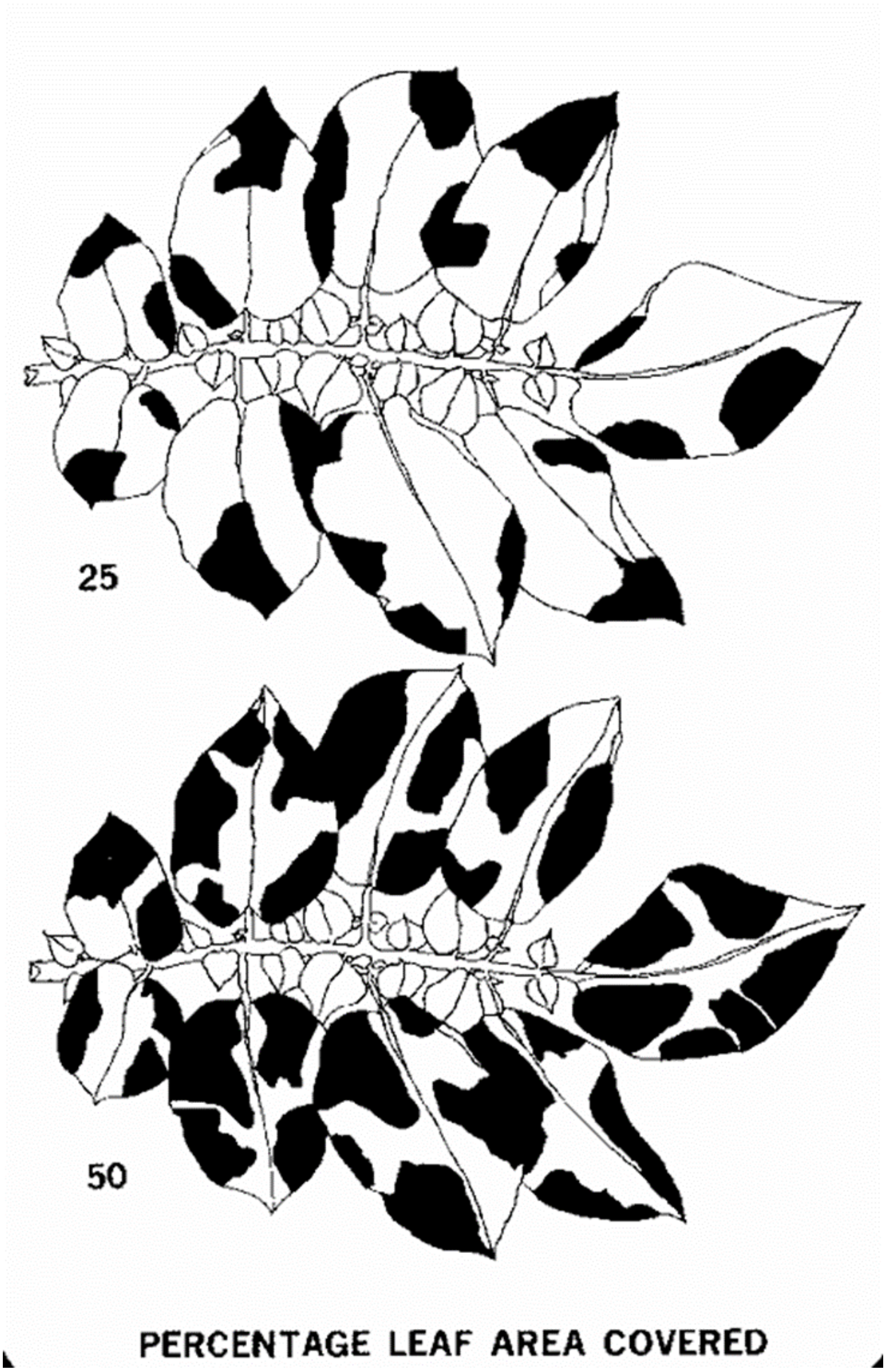


Figure 2.7 Percentage leaf area covered (25% &50%) of potato leaves by *Tuta absoluta*

2.4 Insect diversity

2.4.1 Experimental design and assessments

See Section 2.1 Materials and Methods for a detailed description of the field experimental design.

2.4.2 Insect monitoring

Several standard methods for assessing insect activity on the soil surface and in the crop canopy, were used in all three experiments. The aim was to monitor epigeal (soil surface), aerial and plant canopy insects. Insect monitoring was only carried out in sub plots with the variety Spunta.

Pitfall traps - epigeal insects' monitoring

For the monitoring of epigeal (soil surface) insects pitfall traps were established in the centre of each Spunta sub-plot (24 traps in total). Each set of traps (a set of five pots) consisted of a plastic pot-based traps (8cm diameter, 10cm deep) which was buried up to the rim in the soil. Traps were placed between plant rows at the bottoms of the ridges as showed in (Figure 2.8) Traps when then buried just below the soil surface so that surface active insects moving across the trap, would fall in. The exact place of each set was in the middle of the potato rows of each subplot, with each subplot having 6-metre-long rows. Each pitfall trap was part-filled (3-4cm from the trap lip) with a saturated salt (NaCl) solution, to which a drop of detergent was added, as a preservative. Traps were regularly checked (every 2-4 days) and when necessary additional water or salt solution was added.

Image of the pitfall traps used for this experiment, is given in (Figure 2.8).

Sampling took place every two weeks. The trap contents were strained through a sieve. The insects caught in the trap were placed in plastic bags which were then stored in a refrigerator until sampling and further analysis. After sampling all traps were re-filled again with salted water until the next sample was taken. A total of 24 samples were obtained.

Figure 2.8 Set of Pitfall traps for epigeal insect

Pan-traps - aerial insect monitoring

Aerial insect activity was monitored using 24 pan traps, one in each of the Spunta sub-plots. The traps were plastic pan traps (20cm high, 25cm width, and 35cm length) and coloured bright yellow to optimise attraction of insects. Traps where placed next to the plant rows as shown in (Figure 2.9). The traps were half buried with their top approximately 20cm above ground level so that epigeal insects could not fall in. The exact trap placement was in the middle of the potato rows of each sub-plot Figure 2.10. Each pan trap was part-filled with salt and detergent preservative, to 3-4cm from the top, with the level regularly checked. 24 samples were taken, with caught insects strained and placed in plastic bags as previously described.

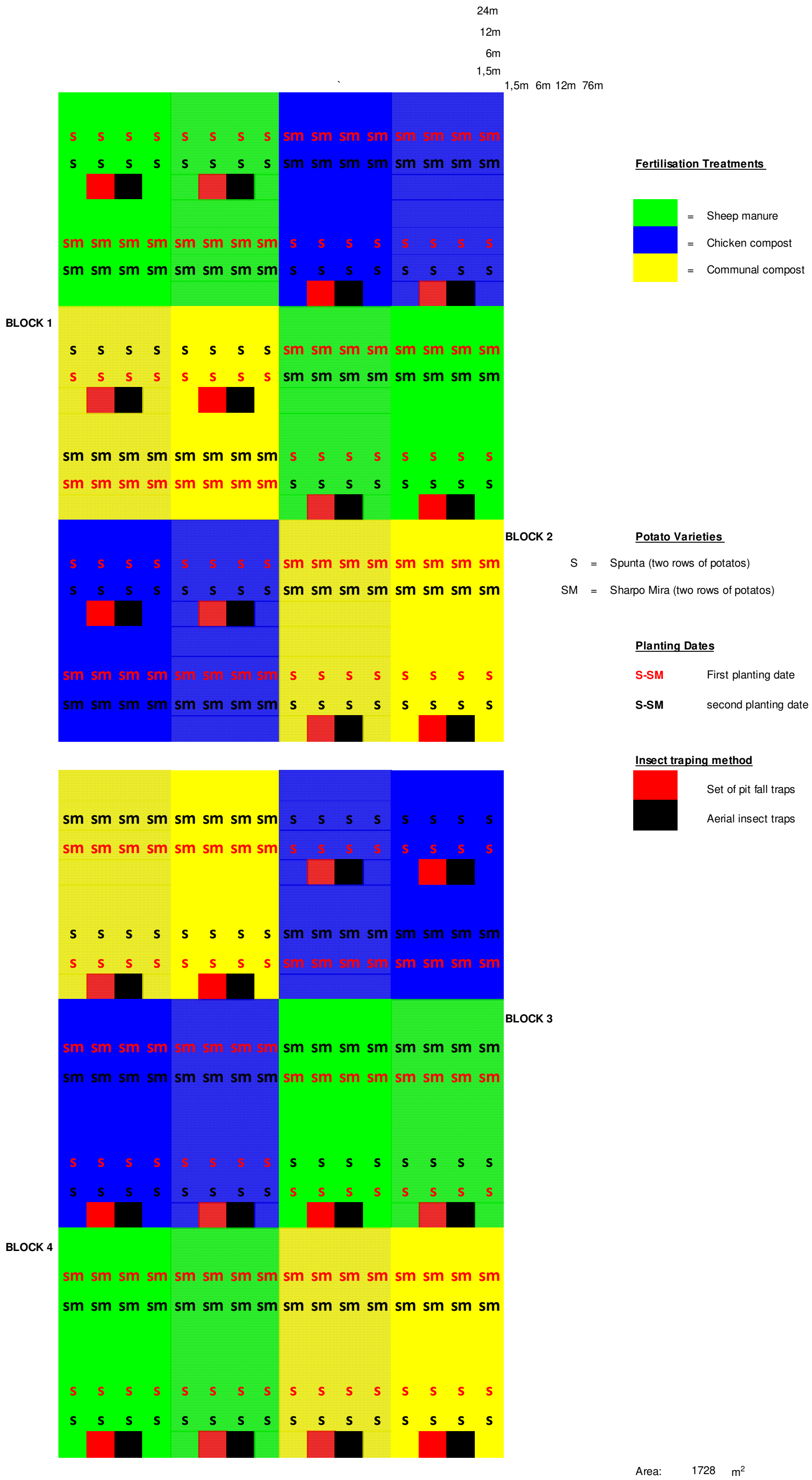


Figure 2.9 Experimental design showing location of epigeal and aerial traps

Figure 2.10 Yellow pan trap for aerial insect

Suction sampling - plant canopy insect monitoring

In order to monitor the insect activity in the plant canopy, a suction sampler was used. This was an adapted leaf-blower, using suction instead of blowing. The instrument was catching insects in a bag at the end of a long sampling tube (Figure 2.11). Each sub-plot was sampled for 1 minute, and the insects caught were placed into plastic bags with salt solution as preservative. 24 samples from each sub-plot were generated.

Figure 2.11 Adapted leaf-blower for Suction sampling

2.4.3 Sorting and identification of insects

Insect samples collected in the field, were transported into the laboratory in plastic bags. In the laboratory the samples were put through a strainer and the sample was then emptied on to a white plastic tray. Water was used to separate insects from extraneous material such as leaves and soil. Insects were then collected and placed into plastic tubes with alcohol as a preservative.

<u>Identification</u>

All insects were identified macroscopically in the level of order. There were 8 main orders/groups. When the identification was difficult to be completed macroscopically, it was done stereoscopically.

More intense attention was given to the identification of *Tuta absoluta*, which was based in their external morphological characteristics as described in a recent study of Visser *et al.*

(2017). In particular and in agreement with the previously mentioned researchers, in the current study the individuals of *Tuta absoluta* were identified considering that should have narrow forewings characterised by black, grey and brown mottling. A photo where the external characters of Tuta absoluta are visible, has already be given in subchapter 1.6 (Figure 1.11). Visser *et al.* (2017), also suggested a method to avoid any confuse between individuals of *Tuta absoluta* and *Phthorimaea operculella*, because these two species have many similarities. In particular, as reported in their study, the most prominent difference between these two species, is their size. Individuals of *Tuta absoluta* have smaller size (ca. 6 mm in length, which means about 2mm smaller that the size of the potato tuber moth). Additionally, the valvae of *Phthorimaea operculella* were not only slenderer but also had an apical curve in comparison to *Tuta absoluta*. Another characteristic that was used to differentiate the individuals between the two species, was their antennae that in the case of *Tuta absoluta*, were more clearly banded.

2.4.5 Statistical analysis

All the entomological data from the experiments were analyzed by analysis of variance ANOVA General Linear Model (main effect means, SE and P-values) and where significant effects were found, Tukey's test was accomplished to compare individual main effect means. In all three Experiments, there was a 3-factor analysis (a) Sampling date, (b) Fertilisation treatment (c) biochar treatment.

In all the experiments, block was a random factor. Insect monitoring was carried out only for Spunta variety.

In all different experiments three main different categories were analyzed, which were:

I. Epigeal insect populations
II. Aerial insect populations
III. Crop canopy insect populations

2.5 Materials and methods of potato sensory test

2.5.1 Production of potato for sensory evaluation

Disease-free potato tubers of both varieties, were harvested at the late harvest date in the 2012 spring trial and used for sensory analyses, as described in section 1.10. Equal numbers of medium tubers from all fertiliser and biochar treatments were pooled and a large enough number of tubers for the sensory analyses was obtained.

2.5.2 Sensory analysis

The methodology for the sensory evaluation survey was adapted from different protocols previously described by Hassanpanah (2011).The consumer sensory evaluation survey was carried out in the prefecture/area of Heraklion in Crete, Greece.

Families (=16) consisting of four adult members were asked to complete the questionnaire used for the purposes of this research. The individuals who participated in the survey were from different social and age groups in order to cover a cross section of Greek society and socio-economic groups.

The participants involved in the survey were asked to assess both the (a) visual quality/appearance of tubers prior to processing and (b) the visual and taste characteristics after processing into chips, oven-cooking and boiling of potato. Participants were provided with a structured questionnaire and asked to record cooking times and sensory quality parameters on a scale from 1 to 9. The questionnaire is provided in Table 2.3.

Each participant was supplied with the same amount of healthy and disease-free potato tubers of the same size from each variety. Tubers involved in sensory evaluation had been harvested at the later harvest date of the 2012 spring trial.

Figure 2.12 Professional stainless-steel potato cutter

All pieces of potatoes used for this survey were from parts of medium tubers of both varieties and had been cut in same size (1cm x 1.5 cm). For that purpose, a professional stainless-steel potato cutter was used (Figure 2.12). According to each way of cooking (fried, boiled and oven-cooked potatoes), potatoes were cooked at the same temperature (140ºC) for 10 minutes (when fried), for 45 minutes (when boiled at 100ºC) and 90 minutes when were oven-cooked at 200ºC.

Table 2.3a Questionnaire for the sensory evaluation of potato tubers (Questions 1-8)

No.	Parameter assessed by consumers	Description of scored in a range of 1-9			Scoring
1	Did you like the fried potatoes/chips? (Like-Did not like)	1 – Like extremely	4 – Like slightly	7 – Dislike moderately	
		2 – Like very much	5 – Neither like or dislike	8 – Dislike very much	
		3 – Like moderately	6 – Dislike slightly	9 – Dislike extremely	
2	What you believe about the colour of the chips? [natural colour of raw potato-black (like burnt/very black)]	1 – Extremely natural	4 – Slightly natural	7 – Moderately black	
		2 – Very much natural	5 – Neither natural or very black	8 – Very much black	
		3 – Moderately natural	6 – Slightly black	9 – Extremely black	
3	Do you believe that fried time was short or long?	1 – Extremely short	4 – Slightly short	7 – Moderately long	
		2 – Very much short	5 – Neither short or long	8 – Very much long	
		3 – Moderately short	6 – Slightly long	9 – Extremely long	
4	Did you like the boiled potatoes or not?	1 – Like extremely	4 – Like slightly	7 – Dislike moderately	
		2 – Like very much	5 – Neither like or dislike	8 – Dislike very much	
		3 – Like moderately	6 – Dislike slightly	9 – Dislike extremely	
5	Do you believe that boiling time was short or long?	1 – Extremely short	4 – Slightly short	7 – Moderately long	
		2 – Very much short	5 – Neither short or long	8 – Very much long	
		3 – Moderately short	6 – Slightly long	9 – Extremely long	
6	Did you like the potatoes baked in the oven or not?	1 – Like extremely	4 – Like slightly	7 – Dislike moderately	
		2 – Like very much	5 – Neither like or dislike	8 – Dislike very much	
		3 – Like moderately	6 – Dislike slightly	9 – Dislike extremely	
7	Do you believe that baking time was short or long?	1 – Extremely short	4 – Slightly short	7 – Moderately long	
		2 – Very much short	5 – Neither short or long	8 – Very much long	
		3 – Moderately short	6 – Slightly long	9 – Extremely long	
8	Do you believe that the potatoes were sweet or bitter?	1 – Extremely sweet	4 – Slightly sweet	7 – Moderately bitter	
		2 – Very much sweet	5 – Neither sweet or bitter	8 – Very much bitter	
		3 – Moderately sweet	6 – Slightly bitter	9 – Extremely bitter	

Table 2.4b Questionnaire for the sensory evaluation of potato tubers (Questions 9-14)

9	Did you like the taste or not?	1 – Like extremely	4 – Like slightly	7 – Dislike moderately	
		2 – Like very much	5 – Neither like or dislike	8 – Dislike very much	
		3 – Like moderately	6 – Dislike slightly	9 – Dislike extremely	
10	Do you believe the potatoes were crunchy or smooth?	1 – Extremely crunchy	4 – Slightly crunchy	7 – Moderately smooth	
		2 – Very much crunchy	5 – Neither crunchy or Smooth	8 – Very much smooth	
		3 – Moderately crunchy	6 – Slightly smooth	9 – Extremely smooth	
11	Do you think that the colour of the potatoes was white or red?	1 – Extremely white	4 – Slightly white	7 – Moderately red	
		2 – Very much white	5 – Neither white or red	8 – Very much red	
		3 – Moderately white	6 – Slightly red	9 – Extremely red	
12	Did you like the colour of the potatoes or not?	1 – Like extremely	4 – Like slightly	7 – Dislike moderately	
		2 – Like very much	5 – Neither like or dislike	8 – Dislike very much	
		3 – Like moderately	6 – Dislike slightly	9 – Dislike extremely	
13	Do you think that the potatoes were soft or hard?	1 – Extremely soft	4 – Slightly soft	7 – Moderately hard	
		2 – Very much soft	5 – Neither soft or hard	8 – Very much hard	
		3 – Moderately soft	6 – Slightly hard	9 – Extremely hard	
14	What is your general opinion about the potatoes you tasted?	1 – Extremely good	4 – Slightly good	7 – Moderately bad	
		2 – Very much good	5 – Neither good or bad	8 – Very much bad	
		3 – Moderately good	6 – Slightly bad	9 – Extremely bad	

Chapter 3 Effect of interaction between fertiliser type biochar and potato variety choice on potato crop performance and parameters

3.1 Spring Crop: Field Experiments; 2011

Effect of fertiliser, biochar, variety and of harvest date on potato crop performance parameters;

3.1.1 Introduction

In Greece, the spring crops of potato are planted between December and February and harvested between May/June. In commercial practice, the seed tubers used for planting spring crops are usually imported certified seed tubers produced in Northern Europe (mainly the Netherlands).

In spring crops soil temperature continuously increases during the growing season. As long as sufficient soil moisture is available (e.g. through precipitation and/or irrigation) this increase in soil temperature is thought to result in a continuous increase of soil microbial activity and mineralisation capacity of soils (Tejada *et al*., 2002; Agehara and Warncke, 2005). Nutrients and especially Nitrogen's release pattern from organic fertilisers is therefore thought to be more closely matched with crop demand in spring crops rather than in autumn crops. The reason for this thought is based on the reduction of soil's temperature during the growing period of autumn crops. Chapter 1.4, supports this thought and discusses it in more detail.

The major crop protection challenges in spring planted organic potato crops are the late blight (*Phytophthora infestans*), the foliar damage by potato beetle and later on (June/July) also lepidopteran pests.

In Crete, which has a semi-arid climate, the weather is usually dry in May and June (the period when spring crops become susceptible to foliar blight) and foliar blight infections are usually found primarily in sprinkler irrigated crops. In contrast late blight symptoms are rarely found in drip irrigated crops in Crete.

Sarpo Mira is thought to have significant potential for use in organic production systems in Greece since it was shown to be more resistant/tolerant to late blight than Spunta; the main potato variety currently grown in Greece in both conventional and organic production (Speiser *et al*., 2006; Orlowska *et al.* 2012; Rietman *et al.*, 2012).

Spunta, is usually harvested in late May/early June before high temperatures increase the risk of damage by lepidopteran pests. Sarpo Mira is known to be a very late maturing variety, which is thought to result in a later tuber maturation and harvest compared to Spunta, (Speiser et al., 2006; Orlowska *et al.* 2012; Rietman *et al.*, 2012).

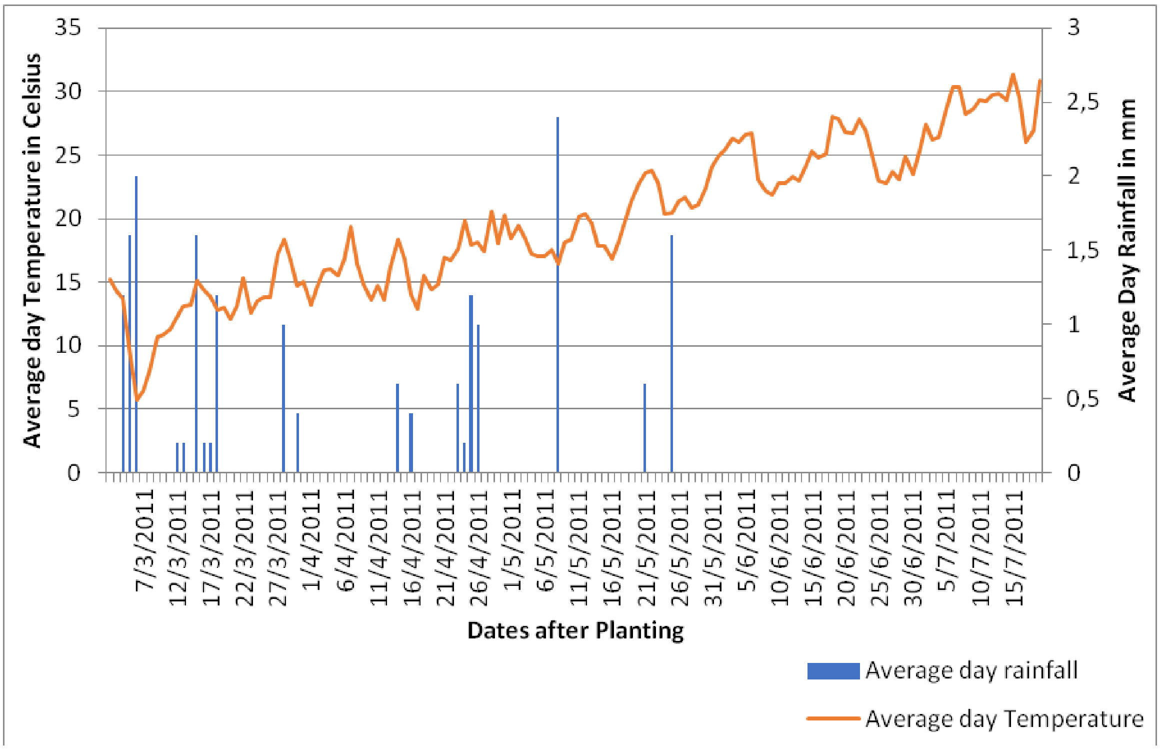
Therefore, the specific objectives for the spring crop focused field experiments were to:

1. Quantify the effect of different organic fertilisers and biochar available in Crete on crop health, yield and quality parameters of the cultivars Spunta and Sarpo Mira. Spunta was selected for that purpose considering that is the main potato cultivar grown and consumed in Greece Sarpo Mira was selected considering that is a more Late blight resistant/tolerant cultivar than Spunta.
2. Quantify pest resistance in Spunta and Sarpo Mira and the extent of lepidopteran pest damage if potato harvest in Crete is delayed until late June/July (when there is a high risk of lepidopteran pest attack). The aim is to allow maximum yields to be achieved from late maturing cultivars such as Sarpo Mira, if possible.

3.1.2. Environmental conditions in the spring cropping seasons of 2011 and 2012

Figure 3.1 shows the average daily temperatures and rainfall in the 2011 and 2012 spring cropping season.

2011 Growing season



2012 Growing season

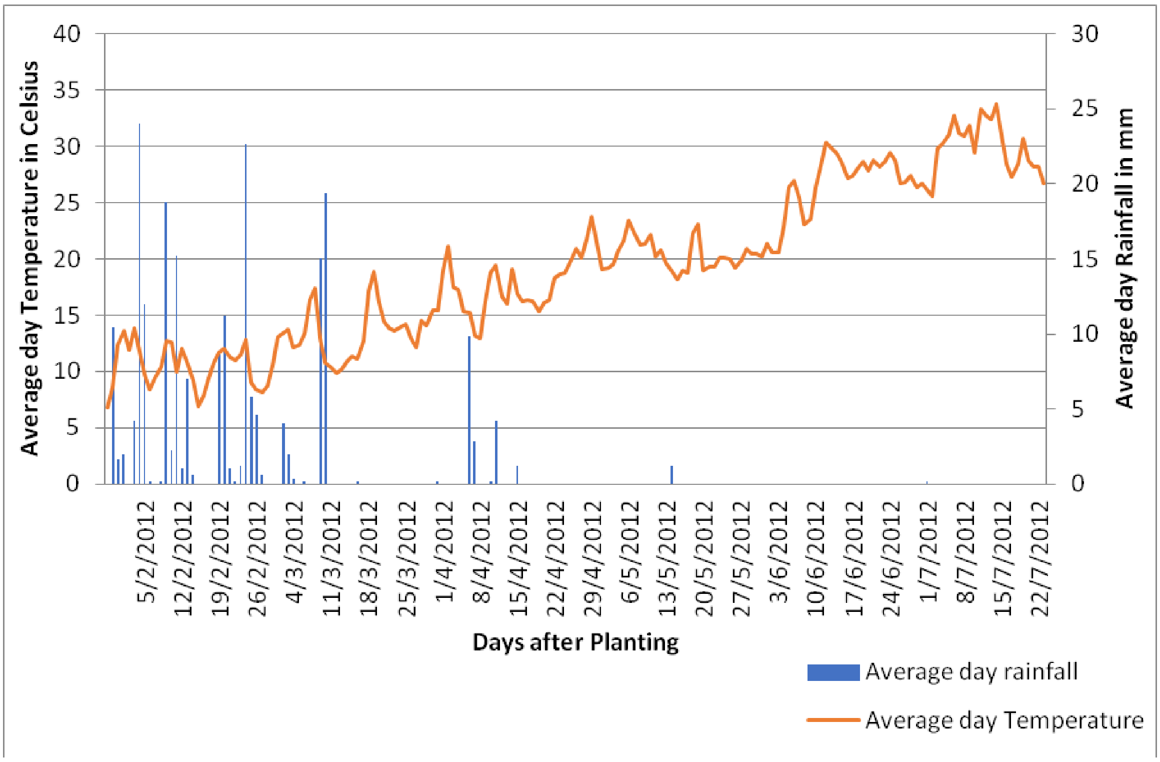


Figure 3.1 Average daily temperatures and rainfall in the 2011 and 2012 spring growing seasons

In the factorial analysis reported here results obtained for the standard planting (09/03/2011) and harvest (19/07/2011) dates of the 2011 experiment were also used for 2012 late planting (15/3/2012) and late harvest (26/7/2012).

In the experiment carried out in 2012, two planting and harvest dates were compared and the results of the factorial analysis comparing both are presented in Section 5 below.

3.1.3 Emergence rate (days to 50% and 75% emergence)

There were significant main effects of production year and potato variety choice on the days to 50% and 75% emergence. Emergence was more rapid for the variety Spunta in 2011 (Table 3.1).

There were significant 2-way interactions between year and variety for the time to 50% and 75% emergence. Spunta emerged more rapidly in both years, but the difference in time for 50% emergence between the 2 varieties, was greater in 2012 than in 2011 (Table3.1). However, when the time of 75% emerged plants was compared in the 2 years, Sarpo Mira reached 75% emergence earlier in 2011, and Spunta in 2012 (Table 3.2).

Spunta is known to be a main crop variety with a relatively short growing season (NIAB, 2013). The finding that it emerged earlier than Sarpo Mira, which is a relatively late maturing crop variety in only one of the 2 seasons, is therefore surprising.

The most likely explanation for these differences may be the contrasting weather conditions after planting (e.g. temperature and/or rainfall pattern) in 2011 and 2012. Average temperatures in the 2-3 weeks after planting were slightly higher in 2011 (except for a short cold period after planting) compared to 2012 (Figure 3.1). However, average daily rainfall was substantially (10 times) higher in 2012 than 2011 (Figure 3.1). This makes it more likely, that soil moisture was the main environmental factor responsible for the contrasting emergence pattern between the two varieties in 2011 and 2012, and not the soil temperature. Soil moisture was maintained more to the field due to the higher rainfall in 2012. However, further field experiments and/or controlled greenhouse of growth chamber studies are required to test this hypothesis.

Table 3.1 Effect of, and interactions between production year (spring season), fertiliser type, biochar and potato variety choice on the days to 50% and 75% emergence and % *Tuta absoluta* damage on potato leaves**.**

Factor	Time to emergence 50%	75%	*Tuta absoluta* % leaf damage
Year			
2011	25.4 ±0.2	23.8 ±0.2	7.7 ±0.6
2012	21.1 ±0.2	23.3 ±0.2	3.3 ±0.5
Fertiliser type			
Sheep manure	23.1 ±0.5	25.6 ±0.4	5.7 ±0.8
Chicken manure	23.3 ±0.5	25.4 ±0.5	4.8 ±0.5
Communal waste compost	23.4 ±0.5	25.7 ±0.5	5.9 ±0.5
Biochar			
Without	23.2 ±0.4	25.6±0.4	5.5 ±0.6
With	23.3 ±0.4	25.6 ±0.4	5.5 ±0.6
Variety			
Spunta	22.4 ±0.4	25.2 ±0.5	8.5 ±0.5
Sarpo Mira	24.2 ±0.3	26.0 ±0.3	2.4 ±0.3
ANOVA results (p-values)			
Main effects			
Year (YR)	0.0033	0.0011	0.0084
Fertiliser types (FT)	Ns	ns	ns
Biochar (BC)	Ns	ns	ns
Variety (VA)	**<0.001**	**<0.001**	**0.0001**
Interactions			
YR x FT	Ns	ns	ns
YR x BC	Ns	0.0369 [1]	ns
FT x BC	Ns	0.0055 [2]	ns
YR x VA	0.0061 [3]	**<0.001** [4]	0.0061 [5]
FT x VA	Ns	ns	ns
BC x VA	Ns	ns	ns
YR x FT x BC	Ns	ns	ns
YR x FT x VA	Ns	ns	*0.0741*
YR x BC x VA	Ns	ns	ns
FT x BC x VA	Ns	*0.0874*	ns
YR x FT x BC x VA	Ns	ns	ns

The values represent means (SE)

[1] See table 3.3 for interaction means and SE

[2] See table 3.4 for interaction means and SE

[3] See table 3.5 for interaction means and SE

[4] See table 3.2 for interaction means and SE

[5] See table 3.6 for interaction means and SE

Table 3.2 Effect of, and interactions between production year (spring season) and potato variety choice on 75% emergence

	Time of 75% plants emerge (in days)	
	2011	2012
Spunta	28.1±0.3 A a	22.2±0.2 B b
Sarpo Mira	27.5±0.2 B a	24.5±0.2 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

In addition, for the time of 75% emergence significant interactions between (a) year and biochar and (b) fertilization treatment and biochar, were found.

In 2011, the addition of biochar resulted in a slightly, but significantly faster emergence, while no significant effect of biochar on emergence was detected in 2012 (Table 3.3).

Table 3.3 Effect of, and interactions between production year (spring season) and biochar treatment on 75% emergence of the plants

	Time of 75% plants emergence (in days)	
	2011	**2012**
- biochar	28.0 ±0.3 A a	23.1 ±0.3 B b
+ biochar	27.7 ±0.2 B a	23.6 ±0.3 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Biochar treatment significantly delayed emergence when used in soil fertilised with sheep manure, but had no effect on emergence in soils fertilised with chicken manure or communal waste compost (Table 3.4).

Table 3.4 Effect of, and interactions between production years (spring season), fertiliser type, and biochar treatment on 75% emergence of the plants

	Time of 75% plants emerge (in days)		
	Sheep manure	Chicken manure	Communal waste compost
- biochar	25.1±0.6 B b	25.8±0.8 B a	25.7±0.7 B a
+ biochar	26.1±0.6 A a	25.1±0.6 A b	25.8±0.6 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

In 2011, biochar treatment resulted in a delay of the emergence of Spunta, but not of Sarpo Mira in compost fertilized plots. In contrast, biochar treatment resulted in earlier emergence of Spunta, but not of Sarpo Mira in chicken manure treated plots. When communal waste compost was used no significant difference between varieties and biochar treatments could be detected in 2011 (Table 3.4).

Table 3.5 Effect of, and interactions between production year (spring season) and potato variety choice on the days of emergence to 50%

	Time of 50% plants emerge (in days)	
	2011	2012
Spunta	24.8±0.4 B a	19.9±0.2 B b
Sarpo Mira	26.0±0.2 A a	22.3±0.2A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

In disagreement with the results derived in 2011, in 2012, biochar treatment resulted in earlier emergence of Sarpo Mira, but not of Spunta in compost fertilised plots. Biochar had no effect on emergence when chicken manure and communal waste compost was used as fertiliser.

Sarpo Mira showed later emergence than Spunta regardless the type of the fertiliser used (Table 3.4).

The effect of biochar on the emergence of potato seed tubers was to our knowledge not previously studied. However, biochar inhibited potato emergence only when used in combination with sheep manure and the reasons for this are unknown. Results confirm previous studies reporting inhibitory effects of biochar on the germination of true seeds. For example, inhibition of wheat, mung bean and clover seed germination by certain types of biochar has been reported, but the effect differs greatly between crops species (Solaiman, 2012).

3.1.4 Leaf damage caused by Tuta absoluta

No symptoms of late blight, other significant fungal diseases and of insect pests other than *Tuta absoluta* were detected in both spring growing seasons.

There were significant effects of production year and potato variety choice on the severity of leaf damage by the lepidopteran pest *Tuta absoluta*. Leaf damage was approximately 2 times more severe in 2011 than in 2012 and more than 4 times lower in tubers of the variety Sarpo Mira than of the variety Spunta (Table 3.6). There was also a significant interaction between year and variety (Table 3.6), with the relative difference between varieties found to be greater in 2012 than 2011 (Table 3.3).

The finding that foliar damage caused by *T. absoluta* was between 2 and 4 times lower in Sarpo Mira than in Spunta tubers, suggests that the two potato varieties differ significantly in lepidopteran pest resistance. However, there is a lack of knowledge in the relevant literature regarding this issue.

T. absoluta is not known to cause significant economic damage in potato (Viggiani *et al.*, 2009) . Significant damage by this insect, has been mainly reported for field and greenhouse tomato and to a lesser extent for eggplant (Viggiani *et al.*, 2009; Deleva and Hariznova, 2014).

However, *T. absoluta* was used as an indicator pest, since other more important pests were not detected in both years.

Other studies has shown that the potato plant is the target of several other pests that have an important economic impact, such as the Colorado potato beetle (*Leptinotarsa decemlineata L.)* (CPB), potato tuber moths (*Phthorimaea operculella* [Zell.], T*ecia solanivora Polovny,* *Symmetrischema tangolias* [Gyen]), and potato weevil (Premnotrypes spp.) (Flanders *et al*., 1992; Wale, 2008). These pests differ in relative commercial importance and type of damage to the crop.

Table 3.6 Effect of, and interactions between production year (spring season) and potato variety choice on % damage caused by *Tuta absoluta* on potato leaves

	Tuta absoluta % leaf damage	
	2011	2012
Spunta	11.1±0.4 A	5.9±0.4 A
Sarpo Mira	4.3±0.3 B a	0.6±0.2 B b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

The most damaging pest is thought to be the Colorado beetle in many regions (Alyokhin e*t al*., 2002). It can cause complete defoliation with adult beetles consuming up to 9.65cm of foliage per day and approximately 40cm^2 of potato leaves when exist in the form of larvae (Ferro, 1985). Depending on the environmental conditions and plant growth stage, when infestations occur the beetle may cause great economic damage and incidences of total crop losses are frequently reported (Hare, 1990). For Sarpo Mira which it is known to have great late blight resistance (Speiser *et al*., 2006) there is limited information on pest resistance/tolerance.

Future experiments (Mass trapping of the pest with scoring the plant damage and comparison of the results) should study whether the pest resistance/tolerance in Sarpo Mira also have the same positive action with regards to other economically more important lepidopteran pests or Colorado beetle.

3.1.5 Chlorophyll concentrations (SPAD readings)

There were significant main effects of production year and potato variety choice on chlorophyll concentrations in potato leaves of 53 (GS 1, end of elongation), 61 (GS 2, canopy closed), 77 (GS 4, end of bud formation), 93 (GS 6, end of flowering), 101 (GS 7, first berries drop off) and 109 (GS 8, Plant has fully died back) days after emergence (Table 3.7 and 3.8).

Table 3.7 Effect of, and interactions between production years (spring season), fertiliser type, biochar and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves at different days after planting.

	SPAD readings (in days after planting)			
	53	**61**	**69**	**77**
Factor				
Year				
2011	49.0 ±0.4	47.1 ±0.3	46.5 ±0.3	44.7 ±0.3
2012	53.3 ±0.4	53.9 ±0.5	49.7 ±1.0	47.5 ±0.4
Fertiliser type				
Sheep manure	51.0 ±0.5	49.9 ±0.6	47.8 ±0.6	46.2 ±0.5
Chicken manure	50.1 ±0.6	50.1 ±0.8	47.3 ±1.5	46.2 ±0.6
Communal waste compost	51.1 ±0.7	51.1 ±0.9	49.0 ±0.5	45.8 ±0.4
Biochar				
Without	51.4±0.5	50.1±0.6	47.7±1.0	46.1±0.4
With	50.9 ±0.5	50.2 ±0.6	48.4 ±0.5	46.1 ±0.5
Variety				
Spunta	50.2 ±0.5	49.5 ±0.6	47.1 ±1.0	44.8 ±0.3
Sarpo Mira	52.2 ±0.5	51.6 ±0.6	49.0 ±0.4	47.3 ±0.4
ANOVA results (p-values)				
Main effects				
Year (YR)	0.0048	0.0038	*0.0666*	0.0366
Fertiliser types (FT)	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns
Variety (VA)	**0.0002**	**0.0002**	*0.0756*	**<0.001**
Interactions				
YR x FT	ns	*0.0770*	ns	ns
YR x BC	ns	ns	ns	ns
FT x BC	ns	ns	ns	ns
YR x VA	ns	ns	ns	0.0018 [2]
FT x VA	ns	ns	ns	ns
BC x VA	ns	ns	ns	ns
YR x FT x BC	ns	ns	ns	ns
YR x FT x VA	ns	ns	ns	*0.0565*
YR x BC x VA	ns	ns	*0.0617*	ns
FT x BC x VA	ns	ns	ns	ns
YR x FT x BC x VA	ns	ns	ns	ns

The values represent means (SE)

[2] See table 3.9 for interaction means and SE

Table 3.8 Effect of, and interactions between production years (spring season), fertiliser type, biochar and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves at different days after planting

Factor	**SPAD readings** (in days after planting) **85**	**93**	**101**	**109**
Year				
2011	41.4 ±0.3	40.6 ±0.3	37.4 ±0.4	35.1 ±0.4
2012	43.0 ±0.7	37.4 ±0.4	33.5 ±0.4	28.5 ±0.4
Fertiliser type				
Sheep manure	41.9 ±0.7	39.3 ±0.6	34.9 ±0.8	31.5 ±0.8
Chicken manure	43.1 ±0.7	39.9 ±0.5	36.4 ±0.5	32.7 ±0.7
Communal Waste Compost	41.5 ±0.7	37.9 ±0.6	35.1 ±0.5	31.2 ±0.8
Biochar				
Without	42.1±0.6	39.1±0.5	35.5±0.5	31.5±0.6
With	42.3±0.6	39.0±0.4	35.4±0.5	32.1±0.6
Variety				
Spunta	39.6 ±0.3	37.4 ±0.4	34.3 ±0.5	30.5 ±0.5
Sarpo Mira	44.8 ±0.5	40.7 ±0.3	36.6 ±0.5	33.1 ±0.6
ANOVA results (p-values)				
Main effects				
Year (YR)	*0.0819*	0.0041	0.0063	**0.0008**
Fertiliser types (FT)	Ns	**0.0129**	ns	*0.0618*
Biochar (BC)	Ns	ns	ns	ns
Variety (VA)	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interactions				
YR x FT	Ns	ns	0.0248 [1]	ns
YR x BC	Ns	ns	ns	ns
FT x BC	*0.0737*	ns	ns	ns
YR x VA	**<0.001** [3]	ns	ns	0.0072 [4]
FT x VA	Ns	ns	ns	ns
BC x VA	Ns	ns	ns	ns
YR x FT x BC	Ns	ns	ns	ns
YR x FT x VA	Ns	ns	ns	ns
YR x BC x VA	Ns	ns	ns	ns
FT x BC x VAR	Ns	Ns	ns	ns
YR x FT x BC x VA	Ns	Ns	ns	ns

The values represent means (SE)

[1] See table 3.12 for interaction means and SE

[3] See table 3.10 for interaction means and SE

[4] See table 3.11 for interaction means and SE

There was also significant main effect of (a) variety 85 (GS 5 full flower) days after emergence and fertiliser type 93 (GS 6, end of flowering) days after planting on SPAD readings (Table 3.8).

Chlorophyll levels were found to be higher in Sarpo Mira throughout the growth period. However, in 2012, chlorophyll levels in plants were higher during the early growth stages (between 53 and 85 days after emergence). However, during the later growth stages (between 93, 101 and 109 days after emergence) chlorophyll levels were higher in 2011 (Table 3.7 and 13.8). Chlorophyll levels were higher in sheep and chicken manure fertilised plants, 93 days after planting than in plants fertilised with communal waste compost (Table 3.8).

Significant 2-way interactions were detected between (a) planting year and variety choice on 77 after planting (Table 3.9), 85days after planting (Table 3.10) and 109 days after planting (Table 3.11) and (b) planting year and fertility treatment on 101 days after planting (Table 3.12).

Table 3.9 Effect of, and interactions between production year (spring season) and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves on days 77 after planting (GS 4)

	SPAD on 77 day	
	2011	**2012**
Spunta	44.1±0.4 B b	45.5±0.6 B a
Sarpo Mira	45.2±0.4 A b	49.4±0.4 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.10 Effect of, and interactions between production year (spring season) and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves on days 85 after planting (GS5)

	SPAD on 85 day	
	2011	**2012**
Spunta	40.3±0.4 B a	38.9±0.5 B b
Sarpo Mira	42.5±0.4 A b	47.1±0.6 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.11 Effect of, and interactions between production year (spring season) and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves on days 109 after planting (GS 8)

	SPAD on 109 day	
	2011	**2012**
Spunta	33.2±0.4 B a	27.8±0.6 B b
Sarpo Mira	37.0±0.3 A a	29.2±0.4 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Table 3.12 Effect of, and interactions between production year (spring season) and fertiliser type, on chlorophyll concentrations (SPAD readings) in potato leaves on day 101 after planting (GS 7)

	SPAD on 101 day		
	Sheep manure	Chicken manure	Communal waste compost
2011	38.1±0.7 A a	37.8±0.6 A a	36.4±0.6 A b
2012	31.7±0.8 B b	34.9±0.7 B a	33.8±0.5 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

When chlorophyll measurements were taken 77 or 85 days after planting, the relative differences between Spunta and Sarpo Mira were greater in 2012 than in 2011. However, when chlorophyll levels were assessed 109 days after planting the relative difference between Sarpo Mira and Spunta were greater in 2011 (Table 3.11). When chlorophyll concentrations were assessed 101 days after planting there were no significant differences between fertiliser types in 2011. In 2012, plants fertilised with chicken manure and communal waste compost were reported to have higher chlorophyll concentrations in their leaves, than plants fertilised than sheep manure (Table 3.12).

The finding that Sarpo Mira also had higher chlorophyll levels than Spunta throughout the growing season, may indicate that it has a higher N-use efficiency, since leaf greenness/ chlorophyll levels were shown to be correlated with N-availability/uptake by crops (Hassan *et al*., 2009). This finding confirms previous studies regarding the performance of Sarpo Mira compared to other varieties carried out in the UK. Thus, it can be said that Sarpo Mira has higher nutrient utilisation efficiency than other potato varieties especially when organic fertilisers inputs are used (Juntharathep, 2004). For example, it has been shown that Sarpo Mira has higher yields and nutrient use efficiency (NUE) compared to other main crop varieties such as Sante (Swain *et al.*, 2014) but this may be due to the late maturity of the variety.

The higher N-use efficiency usually reported for Sarpo Mira potatoes, can probably be explained considering that this variety have been initially bred for and selected under relatively low input conditions in Eastern Europe (Santos, 2006).

3.1.6 Total tuber numbers and % weight of tubers in different size categories

There were significant main effects of (a) production year and (b) potato variety choice on total tuber numbers per m^2 and % weight but there were no interactions between the different treatments.

Considering these two quantification parameters between different years, it can be said that 2012 resulted in higher % weight of total yield on medium (6.5-8.5cm) tubers (Table 3.13).

On variety choice Sarpo Mira resulted in higher number of tubers per m^2 and %weight of total yield on very small (<4.5cm) and small (4.5-6.5cm) tubers. Regarding the Spunta variety, they were the large (>8.5cm) tubers that shown the highest % weight of total yield (Table 3.13).

Results showed that the Sarpo Mira produce higher total yields in organic production systems with drip irrigation, which is thought to have prevented negative impacts on potato yields by late blight in both growing seasons. This suggests that Sarpo Mira may provide a suitable alternative to the use of Spunta in spring grown organic crops in Greece.

The finding that the type of fertiliser did not affect tuber yield is surprising, since other studies reported higher crop yield for chicken manure pellets compared to other organic fertilisers (e.g. composted cattle manure and communal waste compost) (Juntarathep, 2004; Santos, 2006).

Table 3.13 Effect of, and interactions between production years (spring season), fertiliser type, biochar and potato variety choice on total tuber numbers and the numbers of tubers on different size categories. Wt: % of the total weight

	No Tubers	**Wt % <45**	**Wt % 45-65**	**Wt % 65-85**	**Wt % 85**	**Ware Wt %**
Factor /Year	m^2	<45	45-65	65-85	85	All Grades
2011	20.9±1.05	7.8±0.89	22.9±1.64	38.4±0.92	30.8±2.46	90.1±1.35
2012	21.7±0.52	6±0.37	24.5±1.24	55.3±1.14	14.2±1	83.5±0.87
Fertilisation treatment						
Sheep manure	21.7±1.02	7.3±1	25.6±1.87	44.4±1.9	22.6±2.92	85.6±1.7
Chicken manure	22±1.09	7±0.92	20.5±1.27	48.8±1.92	23.7±2.55	88.5±1.22
Communal waste	20.3±0.92	6.3±0.6	25±2	47.4±2.04	21.2±2.76	86.4±1.54
Without Biochar	21.2±0.87	7±0.74	23.9±1.37	46.9±1.69	22.3±2.23	86.5±1.28
With Biochar	21.4±0.78	6.9±0.66	23.6±1.53	46.8±1.53	22.7±2.24	87.2±1.17
Spunta	18.7±0.65	5±0.39	18.7±1.4	47.7±1.96	28.6±2.74	83.6±1.24
Sarpo Mira	23.9±0.82	8.8±0.82	28.7±1.09	46±1.14	16.4±0.97	90±1.03
ANOVA						
Year (yr)	Ns	ns	ns	**0.0011**	ns	ns
Fertilisation (Ft)	Ns	ns	ns	*0.0888*	ns	ns
Biochar (ch)	Ns	ns	ns	ns	ns	ns
Variety (vr)	**<0.001**	**<0.001**	**<0.001**	ns	**<0.001**	**<0.001**
yr:ft	Ns	ns	ns	ns	ns	ns
yr:ch	Ns	ns	ns	ns	ns	ns
ft:ch	Ns	ns	ns	ns	ns	ns
yr:vr	Ns	ns	ns	ns	ns	ns
ft:vr	Ns	ns	ns	ns	ns	ns
ch: vr	Ns	ns	ns	ns	ns	ns
yr: ft:ch	Ns	ns	ns	ns	ns	ns
yr: ft:vr	Ns	ns	ns	ns	ns	ns
yr:ch: vr	Ns	ns	ns	ns	ns	ns
ft:ch: vr	Ns	ns	ns	ns	ns	ns
yr:ft:ch:vr	Ns	ns	ns	ns	ns	ns

The values represent means (SE)

3.1.7 % Weight of waste tubers, per size category

There were significant differences on % weight of waste tubers, per size category in different (a) planting year and (b) variety choice. In 2012, the % weight of waste tubers on very small (<4.5cm), medium (6.5-8.5cm) tubers was higher than in 2011. Large (>8.5) tubers were found to have higher % weight of waste tubers in 2011 (Table 3.14).

Regarding the effects of the variety in the % weight of waste tubers, it was found that Spunta resulted in higher % weight of waste tubers regardless the size of the tubers (Table 3.14).

The addition of biochar and the type of fertiliser used, showed to have significant 2-way interactions, affecting the parameter for which, this subchapter refers to (Table 3.14 & Table 3.15). When biochar was combined with sheep manure, higher % weight of waste tubers on very small (<4.5cm) tubers were found. When biochar was combined with communal waste compost, the % weight of waste tubers was found to be significantly lower.

The findings that Sarpo Mira potatoes had lower % weight in all size categories of waste tubers, shows a very good performance on crop production and suggest that it can be used as an alternative to Spunta.

Table 3.14 Effect of, and interactions between, production years (spring season), fertiliser type, biochar and potato variety choice on % weight of waste tubers on different size categories. Wt: % of the total weight

	Waste Wt %	**Waste Wt %**	**Waste Wt %**	**Waste Wt %**	**Waste Wt %**
	<45	**45-65**	**65-85**	**85**	**All Grades**
Year					
2011	0.3±0.07	1.2±0.2	3.4±0.39	5±0.97	9.9±1.35
2012	1.3±0.13	5.6±0.45	8.1±0.46	1.4±0.26	16.5±0.87
Fertilisation treatment					
Sheep manure	0.9±0.16	3.8±0.62	6.2±0.68	3.6±1.05	14.4±1.7
Chicken manure	0.7±0.16	2.5±0.4	5.5±0.74	2.7±0.55	11.5±1.22
Communal waste	0.8±0.15	4±0.67	5.6±0.6	3.3±1.09	13.6±1.54
Biochar	0.8±0.12	3.4±0.43	5.9±0.58	3.5±0.83	13.5±1.28
Without	0.8±0.14	3.5±0.52	5.6±0.52	2.9±0.67	12.8±1.17
With					
Spunta	0.9±0.14	3.6±0.51	6.7±0.54	5.3±0.95	16.4±1.24
Sarpo Mira	0.7±0.12	3.3±0.43	4.8±0.53	1.2±0.25	10±1.03
ANOVA					
Year (yr)	**0.0229**	**0.0133**	**0.0040**	**0.0443**	**0.0175**
Fertilisation (ft)	Ns	ns	ns	ns	ns
Biochar (ch)	Ns	ns	ns	ns	ns
Variety (vr)	Ns	ns	**0.0021**	**<0.001**	**<0.001**
yr:ft	Ns	ns	ns	ns	ns
yr:ch	*0.0698*	ns	ns	ns	ns
ft:ch	**0.0358**[1]	ns	ns	ns	ns
yr:vr	Ns	ns	ns	ns	ns
ft:vr	Ns	ns	ns	ns	ns
ch: vr	Ns	ns	ns	ns	ns
yr: ft:ch	*0.0708*	ns	ns	ns	ns
yr: ft:vr	Ns	ns	ns	ns	ns
yr:ch: vr	*0.0700*	ns	ns	ns	ns
ft:ch: vr	Ns	ns	ns	ns	ns
yr:ft:ch:vr	Ns	ns	ns	ns	ns

The values represent means (SE)

[1] See table 3.15 for interaction means and SE

Table 3.15 Effect of, and interactions between fertiliser type and biochar treatment on % weight of waste tubers on very small (<4.5cm) size tubers.

	Waste Wt % <4.5cm		
	Sheep manure	Chicken manure	Communal waste compost
- biochar	0.6 ±0.1 B b	0.7 ±0.2 Aab	1.0 ±0.2 A a
+ biochar	1.1 ±0.3 A a	0.7 ±0.2 A ab	0.6 ±0.2 B b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

3.1.8 Fresh-marketable yield and % tuber dry matter

There were significant main effects of (a) fertilisation treatment (b) planting year and of (c) potato variety choice on the fresh-marketable yield and % tuber dry matter. Between the different fertilisation treatments used, chicken manure showed significant the lowest amount of % dry matter on tubers (Table 3.16). In terms of variety choice, Sarpo Mira resulted in higher marketable yield, % dry matter and total marketable dry mater of tubers (Table 3.16).

There was only one significant 2-way interaction of the parameters monitored for their effect on fresh-marketable yield and % tuber dry matter, which was between fertilisation treatment and variety choice (Table 3.16). In more detail, when Spunta was combined with chicken manure and communal waste compost, showed significantly lower amounts of % dry matter of the tubers tested (Table 3.17).

The findings that Sarpo Mira resulted in higher marketable final yield and higher dry matter content, also showed a very good performance of this variety on crop production (not only on waste tubers) and suggest that it can be used as an alternative to Spunta.

Table 3.16 Effect of, and interactions between production year (spring season), fertiliser type, biochar and potato variety choice on fresh yield, marketable yield, % tuber dry matter and marketable tuber dry matter

	Fresh Yield t/ha	Marketable yield t/ha	Tuber DM %	DM Yield t/ha
	t ha	t ha		
Year				
2011	23±0.79	19.1±0.83	21.6±0.36	5±0.22
2012	23.4±0.66	18.5±0.63	22.8±0.38	5.3±0.16
Fertilisation treatment				
Sheep manure	23.2±0.96	18.6±0.99	22.8±0.5 **a**	5.3±0.25
Chicken manure	24.3±0.92	20.1±0.89	21.6±0.5**b**	5.3±0.25
Communal waste	22±0.74	17.9±0.78	22.3±0.4**a**	4.9±0.2
Biochar	23±0.79	18.6±0.78	22.4±0.38	5.2±0.2
Without	23.3±0.66	19.1±0.68	22.1±0.37	5.2±0.18
With				
Spunta	22.3±0.61	17.9±0.64	20.5±0.33	4.6±0.14
Sarpo Mira	24±0.81	19.8±0.79	23.9±0.22	5.7±0.2
ANOVA				
Yr	Ns	ns	0.0872	ns
Ft	Ns	ns	0.0474	ns
Ch	Ns	ns	ns	ns
Vr	0.0825	0.0287	**<0.001**	**<0.001**
yr:ft	Ns	ns	ns	ns
yr:ch	Ns	ns	ns	ns
ft:ch	Ns	ns	ns	ns
yr:vr	Ns	ns	ns	ns
ft:vr	Ns	ns	0.0471[1]	ns
ch: vr	Ns	ns	ns	ns
yr: ft:ch	Ns	ns	ns	ns
yr: ft:vr	Ns	ns	ns	ns
yr:ch: vr	Ns	ns	0.0842	ns
ft:ch: vr	Ns	ns	ns	ns
yr:ft:ch:vr	Ns	ns	ns	ns

The values represent means (SE)

[1] See table 3.17 for interaction means and SE

Table 3.17 Effect of, and interactions between fertiliser type and variety choice on % of tuber dry matter

	Tuber DM %		
	Sheep manure	Chicken manure	Communal waste compost
Spunta	21.6 ±0.8 B a	19.4 ±0.4 B b	20.5 ±0.4 B b
Sarpo Mira	23.9 ±0.4 A a	23.8 ±0.5 A a	24.1 ±0.3 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

3.2 Autumn Crop – Field Experiments

Autumn Crop: Field Experiments; 2011

Effect of fertiliser, biochar, variety and of harvest date, and interactions between fertiliser type, biochar soil amendment and variety choice and harvest date on potato crop performance parameters.

3.2.1 Introduction

In Greece, autumn crops of potato are planted between August and September and harvested in December and January. In commercial practice, the seed tubers used for planting spring crops are "saved" small tubers from spring crops since certified seed tubers are usually not available or deemed too expensive by farmers in August. As a result, the quality of seed tubers used for planting autumn crops is usually lower, often due to higher levels of seed borne diseases.

In autumn, soil temperature continuously decreases during the growing season and this is thought to result in a continuous decrease of soil microbial activity and mineralisation capacity of soils (Tejada *et al.*, 2002; Agehara and Warncke, 2005) Nutrients and among them especially nitrogen's release pattern from organic fertilisers, is therefore thought to decrease over time, resulting in insufficient nutrients (especially N), being available during later stages of crop development. There may also be significant nutrient losses at later stages of crop development, since there is usually significant rainfall in Crete from October and especially in November and December.

The most important crop protection challenges in autumn planted organic potato crops is late blight (*Phytophthora infestans*), since the crop matures and becomes blight susceptible during November and December. These months are more beneficial for this pathogen because this period of the year, the temperatures are cooler and high humidity and rainfall provide ideal environmental conditions for both foliar and tuber blight development (Henfling, 1987). Foliage damage by pest (including *T. absoluta)* is not usually a problem in autumn crops in Crete (Volakakis, 2013).

Sarpo Mira, which is known to be highly resistant to late blight is therefore thought to have significant potential for autumn potato production in Greece, in both organic and conventional systems (Speiser *et al.*, 2006; Orlowska *et al.* 2012; Rietman *et al.,* 2012). However, Sarpo Mira is known to be a very late maturing variety and thus a later tuber maturation and harvest compared to Spunta is expected (Speiser *et al.*, 2006; Orlowska *et al.* 2012; Rietman *et al.*, 2012). Delaying harvest in the autumn season may therefore be a strategy to increase Sarpo Mira's yield in the autumn cropping season, where tuber damage by lepidopteran pests are not a major crop protection challenge.

In the trials reported here, drip irrigation was therefore used to minimise Late Blight pressure and allow the yield potential and susceptibility of varieties produced under different fertilization regimes to insect pests to be assessed with minimum confounding effect of foliar blight.

Objectives

The specific objectives focused for the autumn crop field experiment was therefore to:

1. Quantify the effect of different **organic fertilisers** available in Crete on crop health, yield and quality parameters of the cultivars **(a)** Spunta (the main potato cultivar grown and consumed in Greece) and **(b)** Sarpo Mira (a more Late Blight resistant/tolerant cultivar)
2. Quantify the effect of **harvest date** on crop health, yield and quality parameters of the cultivars **(a)** Spunta and **(b)** Sarpo Mira
3. Compare foliar **disease resistance** (especially against *Phytophthora infestans*) between two varieties (Spunta and Sarpo Mira).

3.2.2 Environmental conditions in the 2011 autumn cropping seasons

Since environmental conditions are expected to significantly affect several biotic and abiotic factors related to major characteristics of potato crops, in this sub-chapter are provided environmental data regarding the period of this experiment.

Figure 3.2 shows the average daily temperatures and rainfall in the 2011 autumn cropping season.

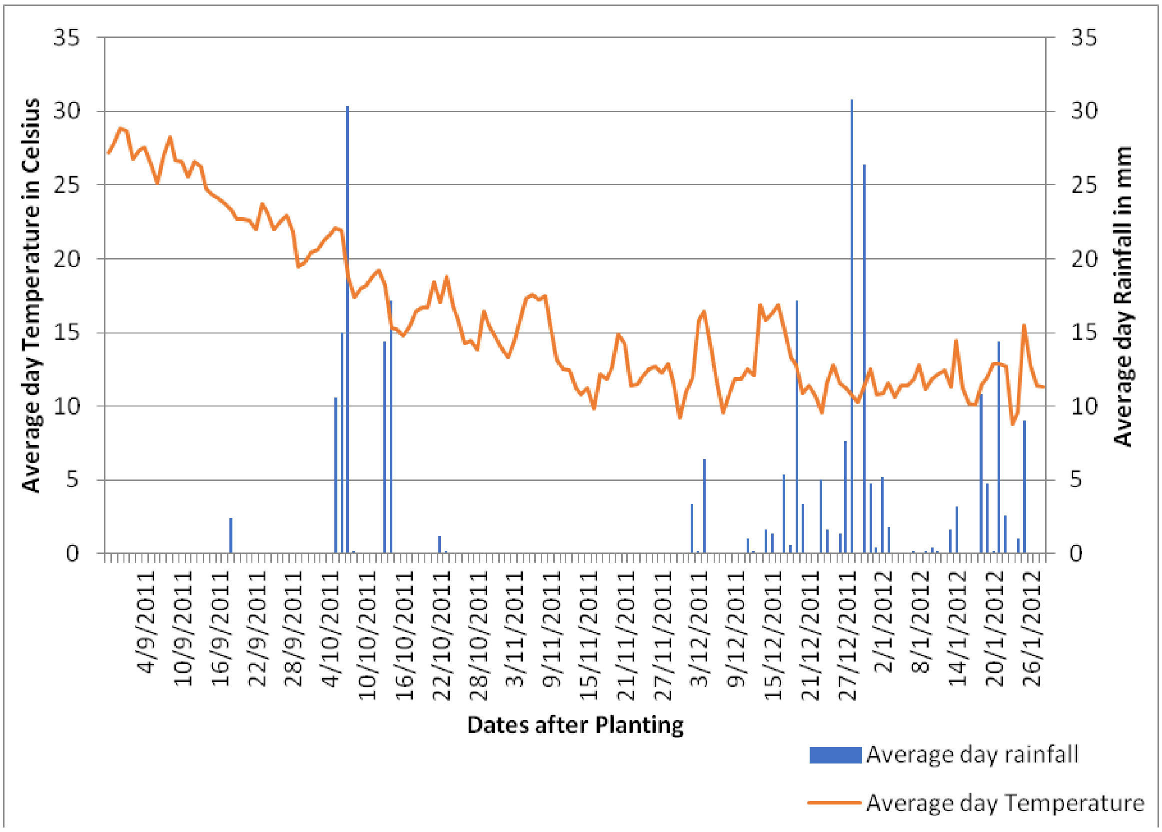


Figure 3.2 Average daily temperatures and rainfall in the 2011 autumn growing seasons

In the factorial analysis reported here, were results obtained for the standard planting (09/03/2011) and harvest (19/07/2011) dates of the 2011 experiment.

3.2.3 Emergence rate (days to 50% and 75% emergence)

There were no main effects of fertiliser type, biochar soil amendment and potato variety choice on the days to 50% emergence. However, when the final % age of emerged plants was compared, Sarpo Mira showed significantly higher emergence than Spunta (Table 3.18).

There was only one significant 2-way interaction between fertiliser type and variety choice for the time to 50% emergence. Spunta showed a slightly delayed emergence in plots fertilised with chicken manure, while the time to 50% emergence was not significantly different when different fertiliser types were used for the cultivation of Sarpo Mira (Table 3.19).

Table 3.18 Effect of, and interactions between fertiliser type, biochar and potato variety choice on the days to 50% and 75% emergence

Factor	Time to 50%emergence (days)	Total number of plants emerged per plot ($9m^2$)	% of plants that emerged
Fertiliser type			
Sheep manure	40.6±0.5	31.25±1.20	78.13±2.99
Chicken manure	42.2±0.7	27.69±1.58	69.22±3.94
Communal waste compost	41.8±0.6	27.88±1.17	69.69±2.92
Biochar			
Without	41.6±0.5	28.58±1.12	71.46±2.79
With	41.3±0.5	29.29±1.13	73.23±2.81
Variety			
Spunta	41.6±0.7	26.96±1.00	67.40±2.50
Sarpo Mira	41.4±0.4	30.92±1.09	77.29±2.73
ANOVA results (p-values)			
Main effects			
Fertiliser types (FT)	Ns	ns	ns
Biochar (BC)	Ns	ns	ns
Variety (VA)	Ns	**0.0077**	**0.0077**
Interactions			
FT x BC	Ns	ns	ns
FT x VA	**0.0467** [1]	ns	ns
BC x VA	Ns	ns	ns
FT x BC x VA	Ns	ns	ns

The values represent means (SE)

[1].See table 3.19 for interaction means and SE.

Table 3.19 Effect of, and interactions between fertiliser type and potato variety choice on the days to 50% emergence

	Sheep manure	Chicken manure	Communal Waste compost
Spunta	40.8±1.0 A b	43.7±0.8 A a	40.6±1.3 A b
Sarpo Mira	40.5±0.4 A a	41.1±0.9 A a	42.5±0.5 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05).

3.2.4 Chlorophyll concentrations (SPAD readings)

There were no significant main effects of (and interactions between) fertiliser type, biochar amendment and cultivar choice on chlorophyll concentrations (SPAD readings) in potato leaves (Table 3.20 & 3.21) in the autumn experiment, in 2011.

However, when compared to spring crops (see Section 3.1), chlorophyll levels were lower in both varieties throughout the growing period. The only exception were the readings taken at 92/93 days after planting which were similar. This suggest that N-supply/availability was lower in the autumn cropping season. This decrease, was expected as soil temperatures (and associated mineralisation capacity) are known to decrease between August and December in Crete. Therefore, a negative effect on nutrient (especially N) release and availability from organic fertilisers was expected (Tejada *et al.*, 2002; Agehara and Warncke, 2005).

Table 3.20 Effect of, and interactions between fertiliser types, biochar and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves at different days after planting.

	SPAD readings (days after planting)			
	60	**68**	**76**	**84**
Factor				
Fertiliser type				
Sheep manure	48.2±0.6	46.0±0.6	46.6±0.8	45.0±0.7
Chicken manure	46.8±0.7	46.2±0.6	45.8±0.5	43.8±0.9
Communal waste compost	47.1±0.7	46.3±0.9	45.9±0.7	44.4±1.0
Biochar				
Without	47.4±0.6	45.8±0.6	46.2±0.6	44.2±0.8
With	47.3±0.6	46.5±0.5	46.1±0.5	44.6±0.6
Variety				
Spunta	47.9±0.7	46.0±0.7	46.3±0.6	43.9±0.9
Sarpo Mira	46.9±0.4	46.3±0.3	45.9±0.5	44.9±0.5
ANOVA results (p-values)				
Main effects				
Fertiliser types (FT)	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns
Variety (VA)	ns	ns	ns	ns
Interactions				
FT x BC	ns	ns	ns	ns
FT x VA	ns	ns	ns	ns
BC x VA	ns	ns	ns	ns
FT x BC x VAR	ns	ns	ns	ns

The values represent means (SE)

Table 3.21 Effect of, and interactions between fertiliser types, biochar and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves at different days after planting.

	SPAD readings (days after planting)		
	92	**100**	**109**
Factor			
Fertiliser type			
Sheep manure	41.5±1.1	34.5±1.6	29.4±1.1
Chicken manure	41.0±0.9	34.1±1.2	30.4±1.1
Communal waste compost	40.7±0.9	33.1±0.9	28.5±0.9
Biochar			
Without	41.5±0.8	34.2±1.1	29.4±0.9
With	40.6±0.7	33.6±0.8	29.5±0.8
Variety			
Spunta	41.1±0.8	34.0±0.9	29.9±0.9
Sarpo Mira	40.9±0.8	33.8±1.1	29.0±0.8
ANOVA results (p-values)			
Main effects			
Fertiliser types (FT)	ns	ns	ns
Biochar (BC)	ns	ns	ns
Variety (VA)	ns	ns	ns
Interactions			
FT x BC	ns	ns	ns
FT x VA	ns	ns	ns
BC x VA	ns	ns	ns
FT x BC x VAR	ns	ns	ns

The values represent means (SE)

3.2.5 Total tuber numbers and % weight of tubers in different size categories

There were significant main effects (a) of harvest date, (b) of biochar effect and (c) of variety choice on total tuber numbers and % weight of tubers in different size categories.

At the first harvest date (late January) there was a significant higher number of tubers per m^2 and on % weight of total yield on medium (6.5-8.5cm) and large (>8.5cm) tubers (Table 3.22).

On biochar effect, when biochar added there was significant higher number of tubers per m^2 (Table 3.22).

Regarding the effects of the variety choice on total tuber numbers and % weight of tubers in different size categories, it was found that Sarpo Mira resulted in higher number of tubers per m^2 and %weight of total yield on very small size (<4.5cm), small (4.5-6.5cm), medium (6.5-8.5cm), while Spunta resulted in higher on large (>8.5cm) tubers (Table 3.22).

There was only one significant 2-way interaction, which was between harvest time and variety choice (Table 3.23) with Spunta on late planting time resulting significant lower % weight of ware all grades of tuber

Results in autumn experiment also indicated that Sarpo Mira produce higher total yields in organic production systems with drip irrigation, which is thought to have prevented negative impacts on potato yields Late Blight in both growing seasons. This suggests that Sarpo Mira may provide a suitable alternative to the use of Spunta also in autumn grown organic crops in Greece.

Table 3.22 Effect of, and interactions between harvest date, fertiliser type, biochar and potato variety choice on total tuber numbers and the numbers of tubers in different size categories (Wt: % of total weight).

	No of Tubers	Wt % <45	Wt % 45-65	Wt % 65-85	Wt % 85	Ware Wt %
Harvest date (hd)	m^2	<45	45-65	65-85	85	All Grades
Late January	16.0 ±0.6	4.6 ±0.3	14.4 ±0.8	59.1 ±1.5	21.9 ±1.7	97.2 ±0.4
Late February	13.0 ±0.6	4.4 ±0.3	16.7 ±1.3	37.9 ±1.5	40.9 ±2.3	95.4 ±1.0
Fertilisation treatment (FT)						
Sheep manure	15.6 ±0.6	4.4 ±0.4	13.1 ±1.0	50.6 ±2.2	31.9 ±2.4	97.2 ±0.74
Chicken manure	15.1 ±0.9	4.4 ±0.4	15.6 ±1.2	45.3 ±2.5	34.8 ±3.0	95.7 ±1.31
Communal waste	12.9 ±0.8	4.7 ±0.4	18.0 ±1.7	49.7 ±3.1	27.5 ±3.4	96.2 ±0.64
Biochar (ch)						
Without	13.7 ±0.6	4.4 ±0.3	15.0 ±1.0	50.0 ±2.3	30.6 ±2.6	96.0 ±0.9
With	15.4 ±0.7	4.6 ±0.3	16.1 ±1.2	47.0 ±2.0	32.2 ±2.3	96.7 ±0.7
Variety (vr)						
Spunta	13.3 ±0.7	3.5 ±0.2	12.6 ±1.1	46.0 ±2.1	37.9 ±2.3	95.4 ±1.0
Sarpo Mira	15.7 ±0.6	5.5 ±0.3	18.5 ±1.0	51.1 ±2.2	24.9 ±2.2	97.3 ±0.5
hd	0.0418	ns	ns	0.0040	0.0053	ns
ft	Ns	ns	ns	ns	ns	ns
ch	0.0465	ns	ns	ns	ns	ns
vr	**0.0005**	**<0.001**	**0.001**	0.0150	**<0.001**	0.0625
hd: ft	ns	ns	ns	ns	ns	ns
A hd: ch	ns	ns	ns	ns	ns	ns
N ft:ch	ns	ns	ns	ns	ns	ns
O hd: vr	ns	ns	ns	ns	ns	0.0251[1]
V ft:vr	ns	ns	ns	ns	ns	ns
A ch: vr	ns	ns	ns	ns	ns	ns
hd: ft:ch	ns	ns	ns	ns	ns	ns
hd: ft: vr	ns	ns	ns	ns	ns	ns
hd: ch: vr	ns	ns	ns	ns	ns	ns
ft:ch: vr	ns	ns	ns	0.0607	ns	ns
Hd: ft: ch: vr	ns	ns	ns	ns	ns	ns

[1] See table 3.23 for interaction means and SE

Table 3.23 Effect of, and interactions between harvest date and variety choice on ware weight (Wt) % All Grades

	Ware Wt % All Grades	
	1st harvest date	2nd harvest date
Spunta	97.5 ±0.5 A a	93.3 ±1.8 A b
Sarpo Mira	97.0 ±0.6 A a	97.6 ±0.7 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

3.2.6 % Weight of waste tubers, per size category

There were no significant differences on % weight of waste tubers between different treatments. However, there were significant 2way interactions on harvest time and on variety choice with Spunta on second harvest date showing significantly higher % weight of waste tubers on large size (>8.5cm) category (Table 3.25) and on ware of all grades tubers (Table 3.26).

The finding that the number of waste tubers increased between harvest dates for Spunta, while for Sarpo Mira is consistent with the later maturity and greater disease resistance previously reported for Spunta. Given the very variable weather conditions in Greece in winter, the use of Sarpo Mira may therefore increase the flexibility of farmers to delay harvest if there are unsuitable conditions for harvest in January.

Table 3.24 Effect of, and interactions between, harvest date, fertiliser type, biochar treatment and potato variety choice on waste tubers, per size category (Wt: % of total weight)

	Waste Wt % <45	**Waste Wt % 45-65**	**Waste Wt % 65-85**	**Waste Wt % 85**	**Waste Wt %**
	<45	45-65	65-85	85	All Grades
Harvest date (hd)					
Late January	0.2 ±0.1	0.9 ±0.2	1.0 ±0.3	0.7±0.3	2.8±0.4
Late February	0.1 ±0.1	0.8 ±0.2	2.0 ±0.4	1.7±0.7	4.6±1.0
Fertilisation treatment (ft)					
Sheep manure	0.1±0.1	0.5 ±0.1	1.0 ±0.3	1.2 ±0.6	2.8 ±0.7
Chicken manure	0.2 ±0.1	0.9 ±0.3	1.3 ±0.4	1.9 ±1.0	4.3 ±1.3
Communal waste	0.3 ±0.1	1.0 ±0.3	2.1 ±0.5	0.5 ±0.3	3.8 ±0.6
Biochar (ch)					
Without	0.2±0.08	0.7±0.19	1.6 ±0.4	1.4 ±0.7	4.0 ±0.9
With	0.1±0.04	0.9±0.23	1.3 ±0.3	1.0 ±0.4	3.3 ±0.7
Variety					
Spunta	0.2 ±0.1	0.9 ±0.2	1.8 ±0.4	1.8 ±0.7	4.6 ±0.1
Sarpo Mira	0.2 ±0.1	0.7 ±0.2	1.2 ±0.3	0.6 ±0.2	2.7 ±0.5
ANOVA					
hd	ns	ns	ns	ns	ns
ft	ns	ns	ns	ns	ns
ch	ns	ns	ns	ns	ns
vr	ns	ns	ns	ns	0.0625
hd: ft	ns	ns	ns	ns	ns
hd: ch	ns	ns	ns	ns	ns
ft:ch	ns	ns	ns	ns	ns
hd: vr	ns	ns	ns	**0.0155**[1]	**0.0251**[2]
ft: vr	ns	ns	ns	ns	ns
ch: vr	ns	ns	ns	ns	ns
hd: ft:ch	ns	ns	ns	ns	ns
hd: ft: vr	ns	ns	ns	ns	ns
hd: ch: vr	ns	ns	0.0854	ns	ns
ft:ch: vr	ns	ns	ns	ns	ns
hd: ft: ch: vr	ns	ns	ns	ns	ns

The values represent means (SE)
[1] See table 3.25 for interaction means and SE

[2]See table 3.26 for interaction means and SE

Table 3.25 Effect of, and interactions between harvest date and variety choice on Waste Weight % 85

	Waste Weight % 85	
	1st harvest date	2nd harvest date
Spunta	0.4 ±0.2 A b	3.2±0.4 A
Sarpo Mira	1.0±0.4A a	0.2±0.1 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.26 Effect of, and interactions between harvest date and variety choice on total Waste Weight % All grades

	Waste Wright % All grades	
	1st planting date	2nd planting date
Spunta	2.5 ±0.5 Aa	6.7±1.8 A a
Sarpo Mira	3.0±0.6 A a	2.4±0.7B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

3.2.7 Fresh-marketable yield and % tuber dry matter

There were significant effects of (a) biochar applications and (b) of variety on fresh-marketable yield and % tuber dry matter.

On biochar application, when biochar was added in the soil, it resulted in higher marketable dry matter, and on variety choice Sarpo Mira resulted in higher % dry matter of the tubers (Table 3.27). The finding that biochar increased the dry matter indicates a positive effect of biochar. This could have been due to the increase of the action exchange capacity of soils caused by biochar. Biochar, actually minimises the leaching losses and/or optimises the availability of $NH4^+$ and K^+ to potato crops. This view is supported by previous studies which reported that biochar inputs increase the (a) cation exchange capacity and (b) N, K, P, Mn and Ca concentrations and/or availability in soil and crop yields (Liang *et al.*, 2006; Chan *et al*, 2007; Novak, 2009). All the above results show that there is a potential of Sarpo Mira and the application of biochar to promote higher dry matter of tubers and that Sarpo Mira can be used as an alternative to Spunta variety.

Table 3.27 Effect of, and interactions between harvest date, fertiliser type, biochar and potato variety choice on fresh-marketable yield and % tuber dry matter (DM)

	Fresh Yield t/ha	**Mark yield t/ha**	**Tuber DM %**	**DM Yield t/ha**
Harvest date (hd)				
Late January	16.0 ±0.8	15.0±0.8	22.2±0.3	3.6±0.17
Late February	13.2 ±0.7	12.0 ±0.7	21.5±0.3	2.8±0.15
Fertilisation treatment (ft)				
Sheep manure	16.0 ±0.6	14.9 ±0.6	21.9 ±0.3	3.5 ±0.15
Chicken manure	14.9 ±1.0	13.6 ±1.0	21.9 ±0.4	3.3 ±0.22
Communal waste	12.9 ±1.1	11.9 ±1.0	21.7 ±0.3	2.8 ±0.23
Biochar (ch)				
Without	13.7 ±0.7	12.6 ±0.7	21.8 ±0.3	3.0 ±0.2
With	15.5 ±0.7	14.4 ±0.7	21.9 ±0.3	3.4 ±0.2
Variety (vr)				
Spunta	14.9 ±0.8	13.8 ±0.8	20.6 ±0.2	3.1 ±0.2
Sarpo Mira	14.3 ±0.7	13.2 ±0.6	23.1 ±0.2	3.3 ±0.2
ANOVA				
Hd	ns	0.0659	ns	0.0541
Ft	ns	ns	ns	0.0871
Ch	0.0665	0.0725	ns	0.0457
Vr	ns	ns	**<0.001**	ns
hd: ft	ns	ns	ns	ns
hd: ch	ns	ns	ns	ns
ft:ch	ns	ns	ns	ns
hd: vr	ns	ns	0.0972	ns
ft: vr	ns	0.0604	ns	0.0623
ch: vr	ns	ns	ns	ns
hd: ft:ch	ns	ns	ns	ns
hd: ft: vr	ns	ns	ns	ns
hd:ch: vr	ns	ns	ns	ns
ft:ch: vr	ns	ns	ns	ns
hd: ft:ch: vr	ns	ns	ns	ns

The values represent means (SE)

3.3 Spring Crop Planting Date – Field Experiment

Effect of, and interactions between planting date, harvest date, fertiliser type, biochar soil amendment and cultivar choice on potato crop performance;

2012 cropping season

3.3.1 Introduction

Results from the first spring crop experiment in 2011, indicated that earlier planting and/or later harvest dates may increase potato yield potential in the Messara plain, especially of the later maturing variety Sarpo Mira. In the repeat experiment in 2012, two planting and harvest dates were therefore introduced into the experimental design as additional factors.

Objectives

The specific objectives for the spring crop focused field experiment in 2012 were therefore to:

1. Quantify the effect of **planting and harvest date** on crop health, yield and quality parameters of the cultivars **(a)** Spunta (the main potato cultivar grown and consumed in Greece) and **(b)** Sarpo Mira (a more Late Blight resistant/tolerant cultivar).
2. Quantify the effect of different **organic fertilisers** and **biochar** available in Crete on crop health, yield and quality parameters of the cultivars **(a)** Spunta and **(b)** Sarpo Mira.
3. Quantify **pest resistance** in Spunta and Sarpo Mira and the extent of lepidopteran pest damage if potato harvest in Crete is delayed until late June/July. In June/July there is a high risk of lepidopteran pest attack, and the aim was to investigate whether maximum yields can be achieved from late maturing cultivars such as Sarpo Mira.

3.3.2 Environmental conditions in the 2012 spring cropping seasons

In Figure 3.3, data regarding the average daily temperatures and rainfall in the 2012 spring cropping season are provided.

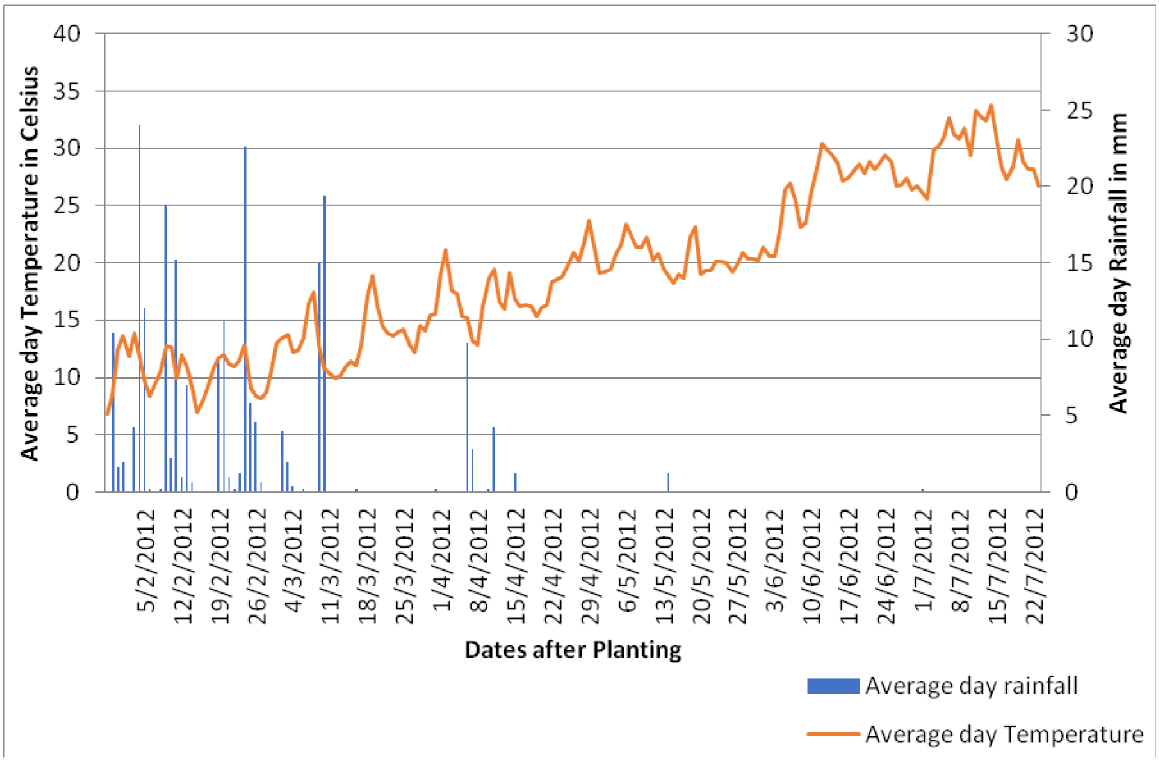


Figure 3.3 Average daily temperatures and rainfall in the 2012 spring growing seasons

3.3.3 Emergence rate (days to 50% and 75% emergence)

There was a significant main effect of cultivar on the days to (a) 50% emergence and (b) 75% emergence with Spunta emerging more rapidly than Sarpo Mira (Table 3.28).

There were significant 2-way interactions between planting date and variety for the time to 50% and 75% emergence. Spunta variety emerged more rapidly on both planting dates and the difference in time to 50% emergence (Table 3.29) and 75% emergence (Table 3.30) between the 2 varieties was greater in the first planting date than the second one.

Table 3.28 Effect of, and interactions between planting date (spring season 2012), type of fertiliser, biochar and potato variety choice on the days to 50% and 75% emergence and % Tuta absoluta damage on potato leaves

Factor	Time to emergence 50%	75%	*Tuta absoluta* % leaf damage
Planting Date			
First planting date	21.1±0.2	23.3±0.2	3.3±0.5
Second planting date	22.0±0.2	24.1±0.2	3.2±0.5
Fertiliser type			
Sheep manure	21.6±0.2	23.9±0.2	3.4±0.6
Chicken manure	21.2±0.3	23.5±0.3	2.6±0.4
Communal waste compost	22.0±0.3	23.8±0.3	3.8±0.6
Biochar			
Without	21.7±0.2	23.6±0.2	3.3±0.5
With	21.5±0.2	23.9±0.2	3.2±0.5
Variety			
Spunta	20.7±0.2	23.0±0.2	5.6±0.4
Sarpo Mira	22.5±0.1	24.5±0.2	0.9±0.3
ANOVA results (p-values)			
Main effects			
Planting date (PD)	*0.0507*	*0.0543*	ns
Fertiliser types (FT)	ns	ns	ns
Biochar (BC)	ns	ns	ns
Variety (VA)	**<0.001**	**<0.001**	**<0.001**
Interactions			
PD x FT	ns	ns	ns
PD x BC	ns	ns	ns
FT x BC	ns	ns	ns
PD x VA	0.0065[1]	0.0014 [2]	0.0213 [3]
FT x VA	ns	ns	0.0046 [4]
BC x VA	ns	ns	ns
PD x FT x BC	ns	ns	ns
PD x FT x VA	ns	ns	ns
PD x BC x VAR	ns	ns	ns
FT x BC x VAR	ns	ns	ns
PD x FT x BC x VA	ns	ns	ns

The values represent means (SE)

[1]See table 3.29 for interaction means and SE
[2]See table 3.30 for interaction means and SE
[3]See table 3.31 for interaction means and SE
[4]See table 3.32 for interaction means and SE

Table 3.29 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on the days to 50% emergence of potato plants

	Time to 50% emerged plants (in days)	
	First planting date	Second planting date
Spunta	19.9±0.2 B b	21.4±0.2 B a
Sarpo Mira	22.3±0.2 A a	22.6±0.2 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Table 3.30 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on the days to 75% emergence of potato plants

	Time to 75% emerged plants (in days)	
	First planting date	Second planting date
Spunta	22.2±0.2 B b	23.8±0.2 A a
Sarpo Mira	24.5±0.2 A a	24.5±0.3 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

These results suggest that Spunta has the capacity to grow and develop more rapidly than Sarpo Mira under colder conditions (winter planting dates).

3.3.4 Tuta absoluta leaf damage

There was a significant main effect on potato variety choice on the severity of leaf damage by the lepidopteran pest *Tuta absoluta* with Spunta variety showing greater leaf damage on the foliage, than Sarpo Mira (Table 3.28).

There were significant 2 - way interactions between (a) planting date and variety choice and (b) fertilisation treatment and variety choice. When potatoes were planted at the earlier planting date, leaf damage in Spunta tubers was 10 times higher than in Sarpo Mira. In potatoes planted at the later date, these ones from Spunta variety had only 4 times higher leaf damage than Sarpo Mira (Table 3.31).

Table 3.31 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on % *Tuta absoluta* damage on potato leaves

	***Tuta absoluta* % leaf damage**	
	First planting date	Second planting date
Spunta	5.9±0.4 A a	5.2±0.5 A b
Sarpo Mira	0.6±0.2 B a	1.3±0.5 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Figure 3. 4 Sample of *Tuta absoluta l*eaf damage (lesion 1-5%)

It was also indicated a significant interaction between fertilisation treatment and variety choice. While Sarpo Mira showed similar leaf damage with all 3 fertiliser types; leaf damage in Spunta was highest in communal compost fertilised plots and lowest in chicken manure fertilised plots (Table 3.32).

Results provide further evidence for the conclusion that Sarpo Mira is more pest resistant/tolerant than other potato varieties, they also indicate that the crop development stage and nutrient supply have no, or only a limited effect, on the level of resistance/tolerance of Sarpo Mira against *T. absoluta*. In contrast, the susceptibility of Spunta to *T. absoluta* damage, appears to be affected by nutrient supply pattern, since damage was lowest in plots fertilised with chicken manure. The damage caused by this insect in Spunta tubers, was highest in plots fertilised with household waste compost (the fertiliser with lowest available N, P and K content). Fertilisation treatments as applied in the soil can have several effects on plant quality, considering that can affect insect abundance and subsequent levels of herbivore damage. The reallocation of mineral amendments in crop plants can influence the growth rates, survival and reproduction in the insect populations (Altieri and Nicholls, 2003). Future studies should evaluate the relative pest resistance of both varieties in regions with high Colorado beetle pest pressure (e.g. the Kalamata region of the Peloponnese).

Table 3.32 Effect of, and interactions between type of fertiliser type and potato variety choice on *Tuta absoluta* damage on potato leaves

	***Tuta absoluta* % leaf damage**		
	Sheep manure	Chicken manure	Communal waste compost
Spunta	5.9±0.7 A b	4.2±0.4 A c	6.6±0.6 A a
Sarpo Mira	0.9±0.4 B a	0.9±0.4 B a	0.9±0.4 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

3.3.5 Chlorophyll concentrations (SPAD readings)

There was a significant main effect of variety choice on chlorophyll concentration throughout the growth period with Sarpo Mira having higher chlorophyll levels (Table 3.33 & 3.34).

There was also a significant main effect of planting date at day 69 (GS 3, Plant starts to form the first buds), 77 (GS 4, end of bud formation), 93 (GS 6, end of flowering), 101 (GS 7, first berries drop off) and 109 (GS 8, Plant has fully died back) days after planting, (Table 3.33 & 3.34). Earlier planted crops showed higher levels of chlorophyll concentrations at the same development stage (days after planting).

Table 3.33 Effect of, and interactions between planting date (spring season 2012), fertiliser type, biochar and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves at different days after planting.

	SPAD readings (in days after planting)			
Factor	**53**	**61**	**69**	**77**
Planting Date				
First planting date	53.3±0.4	53.9±0.5	49.6±1.0	47.5±0.4
Second planting date	53.3±0.4	54.9±0.4	45.6±0.6	44.5±0.7
Fertiliser type				
Sheep manure	53.3±0.5	54.0±0.5	47.5±0.7	46.4±0.7
Chicken manure	52.9±0.4	54.7±0.5	47.3±1.6	46.3±0.9
Communal waste compost	53.6±0.5	54.6±0.6	48.0±0.7	45.3±0.6
Biochar				
Without	53.3±0.4	54.5±0.5	47.3±1.1	46.1±0.6
With	53.3±0.3	54.3±0.4	47.8±0.6	45.9±0.6
Variety				
Spunta	52.1±0.3	53.9±0.5	45.5±1.1	43.5±0.5
Sarpo Mira	54.4±0.3	55.0±0.4	49.7±0.4	48.5±0.5
ANOVA results (p-values)				
Main effects				
Planting date (PD)	ns	ns	0.0352	0.0368
Fertiliser types (FT)	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns
Variety (VA)	**<0.001**	0.0487	**0.0003**	**<0.001**
Interactions				
PD x FT	ns	0.0254 [1]	ns	ns
PD x BC	ns	ns	ns	ns
FT x BC	ns	ns	ns	ns
PD x VA	ns	ns	0.0886	0.500
FT x VA	ns	ns	0.0498 [2]	0.0027 [3]
BC x VA	ns	ns	ns	ns
PD x FT x BC	ns	ns	ns	ns
PD x FT x VA	0.0507	0.0886	ns	0.0555
PD x BC x VA	ns	ns	ns	ns
FT x BC x VA	ns	ns	ns	ns
PD x FT x BC x VA	ns	ns	ns	ns

The values represent means (SE)

[1]See table 3.35 for interaction means and SE

[2]See table 3.37 for interaction means and SE

[3]See table 3.38 for interaction means and SE

Table 3.34 Effect of, and interactions between planting date (spring season 2012), fertiliser type, biochar and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves at different days after planting.

	SPAD readings (in days after planting)			
Factor	**85**	**93**	**101**	**109**
Planting Date				
First planting date	43.0±0.7	37.4±0.4	33.5±0.4	28.5±0.4
Second planting date	40.4±0.8	33.6±0.7	30.9±0.4	26.8±0.3
Fertiliser type				
Sheep manure	42.2±0.9	35.8±0.7	31.5±0.6	27.5±0.4
Chicken manure	42.4±1.0	36.0±0.9	32.7±0.6	27.9±0.5
Communal waste compost	40.6±1.0	34.8±0.7	32.4±0.4	27.6±0.4
Biochar				
Without	41.8±0.8	35.3±0.7	32.2±0.5	27.5±0.3
With	41.6±0.8	35.7±0.6	32.2±0.4	27.8±0.4
Variety				
Spunta	37.8±0.5	33.2±0.6	31.1±0.4	26.9±0.3
Sarpo Mira	45.7±0.6	37.9±0.5	33.3±0.4	28.4±0.4
ANOVA results (p-values)				
Main effects				
Planting date (PD)	*0.0507*	**0.0127**	**0.0246**	**0.0270**
Fertiliser types (FT)	Ns	ns	ns	ns
Biochar (BC)	Ns	ns	ns	ns
Variety (VA)	**<0.001**	**<0.001**	**0.0002**	**0.0007**
Interactions				
PD x FT	Ns	ns	**0.0452** [4]	*0.0539*
PD x BC	Ns	ns	ns	ns
FT x BC	Ns	ns	ns	ns
PD x VA	Ns	ns	ns	ns
FT x VA	Ns	ns	ns	ns
BC x VA	Ns	ns	ns	ns
PD x FT x BC	Ns	ns	ns	ns
PD x FT x VA	Ns	ns	ns	ns
PD x BC x VA	Ns	ns	ns	ns
FT x BC x VA	Ns	ns	ns	ns
PD x FT x BC x VA	Ns	ns	ns	ns

The values represent means (SE)

[4] See table 3.38 for interaction means and SE

In contrast, when SPAD meter readings were taken at day 53 (GS 1, end of elongation) and at day 61 (GS 2, canopy closed), there was no significant differences in chlorophyll levels between planting dates (Table 3.33 & 3.34).

Significant 2-way interactions were detected between (a) planting date and fertility treatment (61 and 101 days after planting) and (b) fertilisation treatment and cultivar choice (69 and 77 days after planting) (Table 3.33 & 3.34).

When chlorophyll measurements were taken 61 days after planting in the earlier planted crops, plants fertilised with communal compost had higher chlorophyll concentration than plants fertilized with chicken and sheep manure. In contrast, in later planted crops chicken and sheep manure resulted in higher chlorophyll concentration than communal compost (Table 3.35).

Table 3.35 Effect of, and interactions between planting date (spring season 2012), fertiliser type on chlorophyll concentrations (SPAD readings) in potato leaves on day 61 (GS 2)

	SPAD readings on 61 day		
	Sheep manure	Chicken manure	Communal waste compost
First planting date	52.5±0.6 A b	53.8±0.9 B b	55.5±0.7 B a
Second planting date	55.6±0.5 A a	55.5±0.5 A a	53.7±1.0 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

When chlorophyll measurements were taken 101 days after planting in the earlier planted crops, plants fertilised with sheep manure had significantly lower chlorophyll concentration than plants fertilised with chicken manure and communal waste compost. In contrast, in the later planted crops there was no significant effect of fertiliser type on chlorophyll levels (Table 3.36).

Table 3.36 Effect of, and interactions between planting date (spring season 2012), fertiliser type on chlorophyll concentrations (SPAD readings) in potato leaves on day 101 (GS 7) after planting.

	SPAD readings on 101 days after planting		
	Sheep manure	Chicken manure	Communal waste compost
Early planting date	31.7±0.8 A b	34.9±0.7 A a	33.8±0.5 A a
Late planting date	31.3±0.8 A a	30.4±0.7 B a	31.0±0.5 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

When chlorophyll measurements were taken 69 days after planting Sarpo Mira had significantly higher chlorophyll levels than Spunta in chicken manure and communal waste compost fertilised plots. No significant difference was indicated between the varieties, in plots fertilised with sheep manure. However, when chlorophyll measurements were taken 77 days after planting, Sarpo Mira had significantly higher chlorophyll concentrations than Spunta in all three fertilisation treatments although the relative difference between varieties varied between fertiliser types (Table 3.37). There was also a significant interaction between planting date, fertiliser type and cultivar (Table 3.38). No significant differences between planting date on both the varieties were found when chicken manure was applied.

Table 3.37 Effect of, and interactions between fertiliser type and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves on day 69 (GS 3) after planting

	SPAD meter readings on the 69th day after planting		
	Sheep manure	Chicken manure	Communal waste compost
Spunta	46.9±1.1 A a	43.4±2.9 B b	46.2±1.3 B a
Sarpo Mira	48.1±0.8 A a	51.2±0.5 A a	49.8±0.5 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

Table 3.38 Effect of, and interactions between fertiliser type and potato variety choice on chlorophyll concentrations (SPAD readings) in potato leaves on day 77 (GS 4) after planting

	SPAD meter readings on 77th day after planting		
	Sheep manure	Chicken manure	Communal waste compost
Spunta	44.8±0.9 B a	42.3±1.0 B b	43.4±0.5 B b
Sarpo Mira	48.0±0.8 A b	50.2±0.7 A a	47.3±0.8 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

Since SPAD meter based chlorophyll content measurements were shown to be closely correlated with N-supply/availability to crops (Wang 2012; Basyouni, 2016), results indicate that: (a) an earlier planting date results in an improved N-supply/availability and (b) Sarpo Mira has a higher N-uptake/acquisition capacity compared to Spunta in spring season crops.

Results also indicate that there are complex interactions between planting date (and associated differences in environmental conditions and soil biological activities), fertiliser input types and cultivar choice with respect to chlorophyll content/N-supply pattern. However, it is difficult to understand/explain these results based on an individual field experiment.

Interestingly, the highest chlorophyll levels in Sarpo Mira and the greatest differences in chlorophyll levels between the 2 varieties were found in plots fertilised with chicken manure (the fertiliser type with the highest content of readily plant available nutrients). Hence, it can be said that Sarpo Mira has potentially a higher nutrient scavenging capacity or more widely distributed root system.

3.3.6 Total tuber numbers and % weight of tubers in different size categories

There were significant main effects of (a) planting date, (b) harvest date (c) fertiliser type and (d) of variety on total tuber numbers and % weight of tubers in different size categories. Early planting date resulted twice higher % weight on total production of larger tubers (>8.5cm) category (Table 3.39). On harvest, early harvest resulted significant higher % weight on small

(4.5-6.5cm), larger (>8.5cm) and on ware of total production. On late harvest, medium tubers (6.5-8.5cm) showed higher % weight of total production (Table 3.39). With regards to the type of fertiliser, communal waste compost resulted in significant lower number of tubers per m^2 compared to the other two fertilisers. No significant differences were found in total tuber numbers and % weight of tubers in different size categories, between the crops where sheep manure and chicken manure were added in the field (Table 3.39).

Table 3.39a Effect of, and interactions between planting dates (spring season 2012), harvest date, fertiliser type, biochar treatment and potato variety choice on total number of tubers and % weight (Wt) of tubers in different size categories.

Factor	No of Tubers/ m^2	Wt % <45	Wt % 45-65	Wt % 65-85	Wt % >85	Ware Wt %
Planting date (pd)						
1st planting	21.6 ±0.4	6.3 ±0.3	25.5 ±0.9	49.6 ±1.1	18.6 ±0.9	87.7 ±0.7
2nd planting	19.9 ±0.8	6.6 ±0.4	29.4 ±0.8	54.9 ±0.9	9.0 ±0.4	84.7±0.7
Harvest date (hd)						
1st harvest	21.6 ±0.7	7.0 ±0.4	29.3 ±0.9	48.1 ±1.0	15.6±1.0	88.1±0.7
2nd harvest	20.0 ±0.6	6.0 ±0.3	25.6±0.8	56.4±0.9	12.1±0.6	84.2±0.6
Fertilisation treatment (ft)						
Sheep manure	21.4 ±0.8 **a**	6.7 ±0.4	27.4±1.0	52.8±1.1	13.1 ±1.0	85.6 ±0.9
Chicken manure	22.4 ±0.8**a**	6.7 ±0.5	27.5 ±1.2	51.7 ±1.4	14.1 ±1.0	86.1 ±0.8
Communal waste	18.4 ±0.6 **b**	6.0 ±0.4	27.5 ±1.1	52.3 ±1.3	14.2 ±1.2	86.8 ±0.9
Biochar (ch)						
Without	20.4 ±0.6	6.6 ±0.4	27.7 ±0.9	52.4 ±1.0	13.3±0.86	86.0 ±0.7
With	21.1 ±0.6	6.4 ±0.3	27.2 ±0.9	52.1 ±1.0	14.3±0.86	86.3 ±0.7
Variety (vr)						
Spunta	18.8 ±0.5	5.6 ±0.3	26.1 ±0.9	55.2 ±1.1	13.1±0.8	85.6 ±0.7
Sarpo Mira	22.7 ±0.6	7.4 ±0.3	28.8 ±0.8	49.3 ±0.9	14.5±0.9	86.6 ±0.7

The values represent means (SE)

Table 3.39b Effect of, and interactions between planting dates (spring season 2012), harvest date, fertiliser type, biochar treatment and potato variety choice on total number of tubers and % weight (Wt) of tubers in different size categories.

Factor	**Tubers/ m²**	**Wt % <45**	**Wt % 45-65**	**Wt % 65-85**	**Wt % >85**	**Ware Wt %** All Grades
ANOVA						
Pd	ns	ns	0.0903	0.0744	0.0017	ns
Hd	ns	ns	0.0244	0.0005	0.0077	0.0041
Ft	0.0014	ns	ns	ns	ns	ns
Ch	ns	ns	ns	ns	ns	ns
Vr	**<0.001**	**<0.001**	0.0331	**<0.001**	ns	ns
pd: hd	**0.0424**[1]	ns	ns	0.0381[2]	**0.0010** [3]	**0.0018**[4]
pd: ft	ns	ns	ns	ns	ns	ns
hd: ft	ns	ns	ns	ns	ns	ns
pd:ch	ns	ns	ns	ns	ns	ns
hd: ch	ns	ns	ns	ns	ns	ns
ft:ch	ns	ns	ns	ns	ns	**0.0438**[5]
pd:vr	**<0.001**[6]	**0.0181**[7]	ns	ns	**0.0141**[8]	**0.0024**[9]
hd: vr	ns	ns	ns	ns	ns	ns
ft: vr	ns	ns	ns	ns	ns	ns
ch: vr	ns	ns	ns	ns	ns	ns
pd: hd: ft	ns	ns	ns	ns	ns	ns
pd: hd: ch	ns	ns	ns	ns	ns	ns
pd: ft: ch	ns	ns	ns	ns	0.0613	ns
hd: ft:ch	ns	ns	ns	ns	ns	ns
pd: hd: vr	ns	ns	ns	ns	ns	ns
pd: ft: vr	ns	ns	ns	ns	ns	ns
hd: ft: vr	ns	ns	ns	ns	ns	ns
pd:ch: vr	ns	ns	ns	ns	ns	ns
hd:ch: vr	ns	ns	ns	ns	ns	ns
ft:ch: vr	ns	ns	ns	ns	ns	ns
pd: hd: ft:ch	ns	ns	ns	ns	ns	ns
hd: ft:ch: vr	ns	ns	ns	ns	ns	ns

The values represent means (SE)

[1,2,3,4,5,6,7,8,9] See table 3.47, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45 and 3.46 repectively, for interaction means and SE

Sarpo Mira resulted in higher number of tubers per m^2 and % weight of total yield of very small (<4.5cm) and small (4.5-6.5cm) tubers. Spunta tubers were known to have higher % weight of total yield on medium tubers (6.5-8.5cm) (Table 3.39).

A significant 2 - way interaction between (a) planting time and harvest time (b) fertilisation and biochar treatment t and (c) planting time and variety choice on the parameters evaluated in this Section. Late harvest of the late planting time, resulted in significant lower number of tubers per m^2 (Table 3.47). The early harvest of the late planting and both the two harvest dates of the early planting time did not indicate difference between them. Early harvest of the early planting date resulted in lower % weight of total yield on medium tuber (Table 3.40) when it was higher on large tubers (Table 3.41) and on ware of all grades (Table 3.42).

Table 3.40 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of medium (6.5-8.5cm) tubers

	Wt % 6.5-8.5cm	
	1st planting date	2nd planting date
1st harvest date	43.8 ±1.4 B b	52.4 ±1.2 B a
2nd harvest date	55.3 ±1.1 A a	57.5 ±1.3 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.41 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of large (>8.5cm) tubers

	Wt % >8.5cm	
	1st planting date	2nd planting date
1st harvest date	23.0 ±1.3 A a	8.1 ±0.5 A b
2nd harvest date	14.2 ±1.0 B a	9.9 ±0.6 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.42 Effect of, and interactions between planting date (spring season 2012) and harvest date on % ware of all grades of total yield

	Ware Weight % All Grades	
	1st planting date	2nd planting date
1st harvest date	91.8 ±0.7 A a	84.4 ±1.1 A b
2nd harvest date	83.5 ±0.9 B a	84.9 ±0.8 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

When fertilisation treatments were combined with biochar treatment, chicken manure with biochar resulted in higher % weight of ware of all grades (Table 3.43). In contrast, when sheep manure and communal waste compost had no significant differences on their effect in the % weight of the tubers.

Table 3.43 Effect of, and interactions between fertility type and biochar treatment on % ware of all grades of total yield

	Ware Weight % All Grades		
	Sheep manure	Chicken manure	Communal waste compost
- biochar	86.2 ±1.2 A ab	84.5 ±1.2 B b	87.3 ±1.3 A a
+ biochar	84.9 ±1.3 A b	87.7 ±1.0 A a	86.4 ±1.3 A ab

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

The interaction of planting time and variety choice, indicated that Spunta resulted in higher number of tubers per m^2 on early planting time while Mira on late planting time (Table 3.48). Also, Sarpo Mira resulted in higher % weight of very small tubers (Table 3.44) on late planting time while early planting time resulted in higher on large tubers (Table 3.45) and on ware of all grades (Table 3.46).

Table 3.44 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on %weight (Wt) of very small (<4.5cm) tubers

	Wt % <4.5cm	
	1st planting date	2nd planting date
Spunta	5.9 ±0.4 A a	5.2 ±0.5 B a
Sarpo Mira	6.8 ±0.4 A b	24.1 ±1.1 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.45 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on % weight (Wt) of large (>8.5cm) tubers

	Wt % >8.5cm	
	1st planting date	2nd planting date
Spunta	16.8 ±1.3 A a	9.5 ±0.5 A b
Sarpo Mira	20.4 ±1.2 B a	8.6 ±0.6 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.46 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on % ware of all grades of total yield

	Ware Weight % all grades	
	1st planting date	2nd planting date
Spunta	86.0 ±1.0 A a	85.4 ±1.0 A a
Sarpo Mira	89.3 ±0.9 B a	83.9 ±0.8 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.47 Effect of, and interactions between planting date (spring season 2012) and harvest date on number of tubers per m^2

	No of Tubers m^2	
	1st planting date	2nd planting date
1st harvest date	21.4 ±0.6 A a	21.7 ±1.2 A a
2nd harvest date	21.7 ±0.5 A a	18.2 ±1.0 B b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.48 Effect of, and interactions between planting date (spring season 2012) and potato variety choice on number of tubers per m^2

	No of Tubers/m^2	
	1st planting date	2nd planting date
Spunta	21.8 ±0.6 A a	15.8 ±0.7 B b
Sarpo Mira	21.4± 0.6 A b	24.1 ±1.1 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Early planting and early harvest that showed higher percentage of total tubers, indicate that this may be the best time period for planting and harvest in order to obtain higher percentage of tuber weight. However, further experiments are required so that more accurate results for the best combination, will be provided. Moreover, the finding that Sarpo Mira had higher weight percentage of tubers in early planting date, indicate that Sarpo Mira can be used as an alternative of Spunta on early planting potato crop.

3.3.7 % Weight of waste tubers, per size category

There were significant main effects of (a) planting date, (b) harvest date and (c) variety choice on the weight of waste tubers, per size category. On different planting dates early planting time, resulted in higher % weight of waste tubers on large tubers.

On different harvest dates early harvest resulted in higher %weight of waste tubers on large tubers when late harvest resulted in higher % weight of waste medium tubers and on ware of all grades. The research about the effects of the cultivar in the weight of waste tubers, showed that Spunta had higher % weight of waste medium tubers and on ware of all grades.

There was significant 2 - way interaction between (a) planting time and harvest time (b) harvest time and fertilisation treatment (c) fertilisation treatment and biochar amendment and (d) on planting time and variety. The interaction of planting time and harvest time, showed that early harvest time in combination with early planting time resulted in higher % weight of waste tuber on large tubers (Table 3.53). In very small (Table 3.50), small (Table 3.51) and medium tubers (Table 3.52), a significant ware of all grades (Table 3.54) and lower % weight of waste tubers was found.

Table 3.49a Effect of, and interactions between planting dates (spring season 2012), harvest date, fertiliser type, biochar treatment and potato variety choice on waste tubers, per size category.

Factor	No of Tubers/ m^2	Wt % <45	Wt % 45-65	Wt % 65-85	Wt % >85
Planting date (pd)					
1st planting	0.9 ±0.1	3.8 ±0.3	5.4 ±0.4	2.2 ±0.2	12.3 ±0.7
2nd planting	1.6 ±0.2	6.5 ±0.4	7.0 ±0.4	0.2±0.1	15.3±0.7
Harvest date (hd)					
1st harvest	1.2 ±0.2	4.3 ±0.4	4.8 ±0.4	1.6±0.2	11.9±0.7
2nd harvest	1.3 ±0.1	6.0 ±0.3	7.6±0.4	0.8±0.2	15.8±0.6
Fertilisation treatment (ft)					
Sheep manure	1.2 ±0.2	5.3 ±0.4	6.8±0.5	1.1±0.2	14.4±0.9
Chicken manure	1.3 ±0.1	5.2 ±0.4	6.3 ±0.5	1.2 ±0.2	13.9 ±0.8
Communal waste	1.2 ±0.2	5.1 ±0.5	5.5 ±0.5	1.4 ±0.3	13.2 ±0.9
Biochar (ch)					
Without	1.2 ±0.1	5.3 ±0.4	6.3 ±0.4	1.2 ±0.2	14.0 ±0.7
With	1.3 ±0.2	5.0 ±0.4	6.1 ±0.4	1.3 ±0.2	13.7 ±0.7
Variety (vr)					
Spunta	1.2 ±0.1	5.1 ±0.4	6.7 ±0.4	1.3 ±0.2	14.4 ±0.7
Sarpo Mira	1.3 ±0.1	5.2 ±0.4	5.6 ±0.4	1.3 ±0.2	13.4 ±0.7

The values represent means (SE)

Table 3.49b Effect of, and interactions between planting dates (spring season 2012), harvest date, fertiliser type, biochar treatment and potato variety choice on waste tubers, per size category.

Factor	**Tubers/ m²**	**Wt % <45**	**Wt % 45-65**	**Wt % 65-85**	**Wt % >85**
ANOVA					
Pd	ns	ns	*0.0992*	0.0036	ns
Hd	ns	ns	**0.0009**	0.0108	0.0041
Ft	ns	ns	ns	ns	ns
Ch	ns	ns	ns	ns	ns
Vr	ns	ns	0.0110	ns	0.0450
pd: hd	0.0064 [1]	0.0095[2]	0.0010 [3]	0.0063[4]	0.0018 [5]
pd: ft	ns	ns	ns	ns	ns
hd: ft	ns	0.0376[6]	ns	ns	ns
pd:ch	ns	ns	ns	ns	ns
hd: ch	ns	ns	ns	ns	ns
ft:ch	ns	ns	ns	ns	ns
pd:vr	0.0028 [8]	0.0027 [9]	ns	ns	0.0438 [7]
hd: vr	ns	ns	ns	ns	0.0024[10]
ft: vr	ns	ns	ns	ns	ns
ch: vr	ns	ns	ns	ns	ns
pd: hd: ft	ns	ns	ns	ns	ns
pd: hd: ch	ns	ns	ns	ns	ns
pd: ft: ch	ns	ns	ns	ns	ns
hd: ft:ch	ns	ns	ns	ns	ns
pd: hd: vr	ns	ns	ns	ns	ns
pd: ft: vr	ns	ns	ns	ns	ns
hd: ft: vr	ns	ns	ns	ns	ns
pd:ch: vr	ns	ns	ns	ns	ns
hd:ch: vr	ns	ns	ns	ns	ns
ft:ch: vr	ns	ns	ns	ns	ns

The values represent means (SE)

[1,2,3,4,5,6,7,8,9,10] See table 3.50, 3.51, 3.52, 3.53, 3.54, 3.55, 3.56, 3.57, 3.58 and 3.59 repectively, for interaction means and SE.

Mechanical damage from harvest Soil pest damage Potato early blight

Figure 3.5 Samples of waste tubers

When fertiliser inputs combined with harvest time, chicken manure on late harvest time resulted lower % weight of waste tubers on small tubers (Table 3.55) when in early harvest time resulted higher compared to sheep manure and the communal waste compost.
When fertiliser was combined with biochar amendment chicken manure without biochar resulted higher % weight of waste tubers of ware all grades than communal waste compost, with sheep manure combined with biochar showing higher results than chicken manure (Table 3.56).

When planting date combined with variety choice Sarpo Mira on late planting time resulted higher % weight on very small tubers (Table 3.57), small tubers (Table 3.58) and ware of all grades (Table 3.59) than Spunta and Sarpo Mira on early planting time.

Table 3.50 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of very small (<4.5cm) waste tubers

	Waste Wt % <4.5cm	
	1st planting date	2nd planting date
1st harvest date	0.5 ±0.1 A b	1.8 ±0.3 A a
2nd harvest date	1.3 ±0.1 A a	1.3 ±0.2 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.51 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of small (4.5-6.5cm) waste tubers

	Waste Wt % 45-65	
	1st planting date	2nd planting date
1st harvest date	2.0 ±0.3 B b	6.6 ±0.5 A a
2nd harvest date	5.6 ±0.5 A a	6.4 ±0.5 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Table 3.52 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of medium (6.5-8.5cm) waste tubers

	Waste Wt % 65-85	
	1st planting date	2nd planting date
1st harvest date	2.6 ±0.3 A b	7.0 ±0.5 A a
2nd harvest date	8.1 ±0.5 A a	7.1 ±0.5 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Table 3.53 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of large (>8.5cm) waste tubers

	Waste Wt % >8.5cm	
	1st planting date	2nd planting date
1st harvest date	3.1 ±0.3 A a	0.2 ±0.1 A b
2nd harvest date	1.4 ±0.3 B a	0.3 ±0.1 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Table 3.54 Effect of, and interactions between planting date (spring season 2012) and harvest date on % weight of waste tubers of all grades

	Waste Wt % all grades	
	1st planting date	2nd planting date
1st harvest date	8.2 ±0.7 B b	15.6 ±1.1 A a
2nd harvest date	16.5 ±0.9 A b	15.1 ±0.8 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.55 Effect of, and interactions between harvest date and fertiliser type on % weight of small (4.5-6.5cm) waste tubers

	Waste Wt % 4.5-6.5cm	
	1st harvest date	2nd harvest date
Sheep manure	4.2±0.6 A b	6.3±0.6 A a
Chicken manure	5.1±0.8 A a	5.2±0.5 Ba
Communal waste compost	3.6±0.6 A b	6.5±0.7 A a

Means followed by the same lower- case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.56 Effect of, and interactions between fertiliser type and biochar treatment on % weight of waste tubers of all grades

	Waste Wt % all grades		
	Sheep manure	Chicken manure	Communal waste compost
- biochar	13.8 ±1.2 A ab	15.5 ±1.2 A a	12.7 ±1.3 A b
+ biochar	15.1 ±1.3 A a	12.3 ±1.0 A b	13.6 ±1.3 A ab

Means followed by the same lower- case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.57 Effect of, and interactions between, between planting date (spring season 2012) and potato variety choice on % weight of very small (<4.5cm) waste tubers

	Waste Wt % <4.5cm	
	1st planting date	2nd planting date
Spunta	1.1 ±0.1 B a	1.2 ±0.2 B a
Sarpo Mira	0.8 ±0.1 B a	1.9 ±0.2 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

Table 3.58 Effect of, and interactions between, between planting date (spring season 2012) and potato variety choice on % weight of small (4.5-6.5cm) waste tubers

	Waste Wt % 4.5-6.5cm	
	1st planting date	2nd planting date
Spunta	4.4 ±0.5 A b	5.7 ±0.6 B a
Sarpo Mira	3.2 ±0.4 B b	7.1 ±0.4 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

Table 3.59 Effect of, and interactions between, between planting date (spring season 2012) and potato variety choice on % weight (Wt) of waste tubers of all grades

	Waste Wt %	
	1st planting date	2nd planting date
Spunta	14.0 ±1.0 A a	14.6 ±1.0 A a
Sarpo Mira	10.7 ±0.4 B b	16.1 ±0.8 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

Results derived from early planting and early harvest showed the lowest percentage of waste tubers. It is thus indicated that this may be the best period of time for planting and harvest because it is believed that the yield losses will be minimized. However, further experiment will give more accurate conclusions for the best combination.

The finding that Sarpo Mira had lower percentage of waste tubers in early planting date but had no effects on late planting, indicates that Sarpo Mira may can replace the use of Spunta on early planting potato crop.

3.3.8 Fresh-marketable yield and % tuber dry matter

There were significant main effects of (a) planting date, (b) fertilisation treatment and (c) variety choice on the fresh-marketable yield and % tuber dry matter. On planting time early planting time resulted in higher amounts of fresh yield, marketable yield and marketable dry matter than the potatoes of the late planting time.

On fertiliser inputs, sheep and chicken manure resulted in higher fresh yield, marketable yield and marketable dry matter than communal waste compost. Sheep manure resulted in higher tuber dry matter than chicken manure and communal waste compost.

The comparison between the two varieties, showed that Sarpo Mira resulted in higher amounts of fresh yield, marketable yield, marketable dry matter and % of dry matter on tubers than Spunta.

There was significant 2 - way interaction between (a) fertilisation treatment and biochar amendment (b) planting time and fertilisation variety choice (c) fertilisation treatment and variety choice.

When fertiliser inputs were combined with biochar, chicken manure with biochar resulted in higher amount of marketable yield than the other inputs with or without biochar (Table 3.61).

When considered the interaction of variety and planting time, it was shown that early planting date resulted in greater amounts on fresh yield (Table 3.62) and marketable yield (Table 3.63) on both Spunta and Sarpo Mira potatoes. In more detail, Spunta had significant lower amounts of fresh yield (Table 3.62.) on late planting time. On early planting time, Spunta had significantly lower % dry matter on tubers (Table 3.64) than Sarpo Mira on both early and late planting time.

Table 3.60 Effect of, and interactions between planting date (spring season 2012), harvest date, fertiliser type, biochar treatment and potato variety choice on fresh and marketable yield on dry matter %.

Factor	Fresh Yield	Marketable	Tuber DM %	DM Yield t/ha
Planting date (pd)				
1st planting	22.6 ±0.5	18.7 ±0.5	22.9 ±0.3	5.1 ±0.1
2nd planting	14.6 ±0.5	11.6 ±0.4	22.9 ±0.2	3.4 ±0.1
Harvest date (hd)				
1st harvest	18.5 ±0.6	15.5 ±0.6	22.9 ±0.2	4.2 ±0.2
2nd harvest	18.6 ±0.7	14.8 ±0.6	22.9 ±0.2	4.3 ±0.2
Fertilisation (ft)treatment				
Sheep manure	19.0 ±0.8 **a**	15.3±0.7 **a**	23.7 ±0.3**a**	4.5±0.2 **a**
Chicken manure	20.0 ±0.8 **a**	16.3 ±0.8 **a**	22.3 ±0.3 **b**	4.5±0.2 **a**
Communal waste	16.8 ±0.7 **b**	13.8 ±0.6 **b**	22.7 ±0.3 **b**	3.8±0.2**b**
Biochar (ch)				
- Biochar	18.0 ±0.6	14.6±0.6	22.9±0.2	4.1±0.2
+ Biochar	19.2 ±0.7	15.7 ±0.6	22.9 ±0.2	4.4 ±0.2
Variety (vr)				
Spunta	17.7 ±0.7	14.5 ±0.6	21.7 ±0.2	3.8 ±0.1
Sarpo Mira	19.4 ±0.6	15.8 ±0.6	24.0 ±0.1	4.7 ±0.2
ANOVA				
Pd	0.0011	0.0012	ns	0.0014
Hd	ns	ns	ns	ns
Ft	0.0019	0.0052	**0.0007**	0.0025
Ch	0.0634	0.0724	ns	ns
Vr	0.0099	0.0225	**<0.001**	**<0.001**
pd: hd	0.0612	ns	ns	0.0592
pd: ft	ns	ns	ns	ns
hd: ft	ns	ns	ns	ns
pd:ch	ns	ns	ns	ns
hd: ch	0.0722	0.0532	ns	ns
ft:ch	0.0651	0.0196[1]	ns	ns
pd: vr	0.0016[2]	0.0417[3]	0.0109[4]	ns
hd: vr	ns	ns	ns	ns
ft: vr	ns	ns	0.0099[5]	ns
ch: vr	ns	ns	ns	ns
pd: hd: ft	ns	ns	ns	ns
pd: hd: ch	ns	ns	ns	ns
pd: ft: ch	ns	ns	ns	ns
hd: ft:ch	ns	ns	ns	ns
pd: hd: vr	ns	ns	ns	ns
pd: ft: vr	ns	ns	ns	ns
hd: ft: vr	ns	ns	ns	ns
pd:ch: vr	ns	ns	ns	ns
hd:ch: vr	ns	ns	ns	ns
ft:ch: vr	ns	ns	ns	ns

The values represent means (SE)

[1,2,3,4,5] See table 3.61, 3.62, 3.63, 3.64 and 3.65 respectively, for interaction means and SE.

Table 3.61 Effect of, and interactions between fertiliser treatment and biochar treatment on marketable yield t/ha

	Marketable yield t/ha		
	Sheep manure	Chicken manure	Communal waste compost
- biochar	15.8 ±1.0 A a	14.6 ±1.0 B a	13.4 ±0.9 A a
+ biochar	14.9 ±1.0 A b	18.0 ±1.0 A a	14.1 ±1.3 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.62 Effect of, and interactions between planting date and variety choice on fresh yield t/ha

	Fresh Yield t/ha	
	1st planting date	2nd planting date
Spunta	22.8 ±0.7 A a	12.7 ±0.5 B b
Sarpo Mira	22.4 ±0.8 A a	16.5 ±0.7 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 3.63 Effect of, and interactions between planting date and variety choice on marketable yield t/ha

	Marketable yield t/ha	
	1st planting date	2nd planting date
Spunta	18.6 ±0.7 A a	10.3 ±0.4 B b
Sarpo Mira	18.8 ±0.7 A a	12.9 ±0.6 A b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

According to the table above (Table 3.63), the marketable yields have a range of 18.6-18.8 ±0.7 t/ha. According to Table 2.3 and the information provided by the Ministry of Rural

Development and Food (Minagric, 2018), the average yields were 20.21 t/ha in 2011 and 19.91 t/ha in 2012. Considering that these yields include both organic and conventional farming, while the data given in Tables 3.61, 3.62 and 3.63, concern only organic yields, it can be assumed that the potato crops had good yields.

Table 3.64 Effect of, and interactions between planting date and variety choice on % of tuber dry matter

	Tuber DM %	
	1st planting date	2nd planting date
Spunta	21.4 ±0.4 B a	22.1 ±0.3 A a
Sarpo Mira	24.4 ±0.3 A a	23.7 ±0.2 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

The interaction of fertilisation treatment and variety choice, showed that Spunta tubers when grown in fields fertilised with chicken manure had lower % dry matter (Table 3.65) than Spunta tubers fertilised with sheep manure and Sarpo Mira combined with all the fertiliser inputs.

Table 3.65 Effect of, and interactions between fertiliser treatment and variety choice on % of tuber dry matter (DM)

	Tuber DM %		
	Sheep manure	Chicken manure	Communal waste compost
Spunta	23.1 ±0.5 B a	20.6 ±0.3 B b	21.6 ±0.3 B b
Sarpo Mira	24.4 ±0.3 A a	23.9 ±0.4 A a	23.8 ±0.2 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

The interaction of chicken and sheep manure showed greater levels of fresh and marketable yield and tuber dry matter and marketable dry mater. This may be due to the higher levels of

Nitrogen that these two fertilisers have, when compared to the communal waste compost. Finally, the indication that Sarpo Mira performed better than Spunta in all categories and that early planting date showed better results than late planting, allows it to be assumed that Sarpo Mira can replace Spunta in potato cultivations.

Chapter 4. Effect of and interactions between different sampling dates, fertiliser type and biochar amendment on tuber blights caused by fungi and bacteria, insect populations

4.1 Insect populations - spring season crop 2011

4.1.1 Epigeal insect populations

Significant main effects of sampling date were detected on the population of several insects such as: Diptera, Coleoptera, Orthoptera, Hymenoptera, Arthropoda, Lepidoptera Slugs and Ants, which are invertebrates that were detected/monitored by pitfall traps (Table 4.1).
The population of Diptera, Coleoptera and Slugs increased between the 3rd (6 June) and the 4th (20 June) sampling dates with the highest population detected on the 4th sampling date (20 June). The population of Orthoptera increased between the 1st (5 May) and the 2nd (20 May) sampling date and between 2nd (20 May) and 3rd (6 June) sampling date. The population of Hymenoptera, Ants and Arthropoda was increased between the 1st (5 May) and the 2nd (20 May) sampling date. However, Ants' population was decreased between the 2nd (20 May) and the 3rd (6 June) sampling date (Table 4.1).
No significant main effects of fertiliser type and biochar on invertebrate populations were detected (Table 4.1) and no significant interaction between experimental factors (sampling date, fertiliser type and/or biochar) could be detected (Table 2.3.1).

Table 4.1 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (pit fall traps) in the 2011 spring potato cropping season per subplot ($36m^2$)

	Diptera	*Coleoptera*	*Orthoptera*	*Hymenoptera*	*Arthropoda*	*Lepidoptera*	*Slugs*	*Ants*
Factor								
Sampling date								
1st 5/5/2011	0.00±0.00 b	3.00±0.65 b	1.04±0.26 c	0.29±0.19 b	0.29±0.17 b	0.00±0.00 b	1.08±0.36 ab	1.96±0.68 b
2nd 20/5/2011	0.42±0.15 b	2.00±0.40 b	4.17±1.05 b	1.21±0.31 a	2.42±0.43 a	0.17±0.08 a	0.25±0.14 b	4.46±1.64 ab
3rd 6/6/2011	0.04±0.04 b	1.79±0.36 b	6.63±0.90 a	1.79±0.48 a	3.33±0.81 a	0.29±0.11 a	0.33±1.16 b	5.63±1.21 a
4th20/6/2011	2.13±0.65 a	18.50±2.20 a	5.00±0.71 ab	2.41±0.75 a	3.04±0.70 a	0.00±0.00 b	1.58±0.48 a	5.42±1.50 a
Fertiliser type								
Sheep manure	1.00±0.44	5.63±1.48	3.91±0.55	1.69±0.59	2.19±0.55	0.09±0.07	0.66±0.20	4.71±1.26
Chicken manure	0.59±0.30	6.47±1.43	4.28±0.92	1.16±0.31	2.63±0.51	0.06±0.04	0.97±0.38	3.75±0.72
Communal waste compost	0.34±0.19	6.88±1.90	4.44±0.79	1.44±0.35	2.00±0.57	0.19±0.07	0.81±0.27	4.63±1.38
Biochar								
Without	0.69±0.26	6.42±1.42	3.96±0.65	1.58±0.28	2.44±0.47	0.06±0.04	0.90±0.27	4.10±0.74
With	0.60±0.27	6.23±1.20	4.46±0.60	1.27±0.41	2.10±0.41	0.17±0.06	0.73±0.19	4.63±1.11
ANOVA results (p-values)								
Main effects								
Date (SD)	**<0.001**	**<0.001**	**<0.001**	**0.0071**	**0.0001**	0.0022	0.0124	0.0239
Fertiliser types (FT)	ns	ns	ns	ns	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	*0.0924*	ns	ns	ns	ns
Interactions								
DT x FT	ns	ns	ns	ns	ns	ns	ns	ns
DT x BC	ns	ns	ns	ns	ns	ns	*0.0848*	ns
FT x BC	ns	ns	ns	ns	ns	ns	ns	ns
DT x FT x BC	ns	ns	ns	ns	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

4.1.2 Aerial insect populations

Significant main effects of sampling date were detected for 6 of the 8 invertebrate groups detected/monitored by yellow traps: Diptera, Coleoptera, Orthoptera, Hymenoptera, Lepidoptera and ants. The population of Diptera, Coleoptera, Orthoptera, Hymenoptera and of Lepidoptera, increased between the 1st (5/5/2011) and the 2nd sampling date (20/5/2011) and then decreased between the 2nd and the 3rd (20/5/2011 and 6/6/2011) sampling date. The highest population was detected at the 4th sampling date (20/6/2011). Ants' population was only detected at the 4th sampling date (20/6/2011) (Table 4.2).

Significant main effects of fertiliser type were detected in the population of four (Diptera, Orthoptera, Hymenoptera and slugs) of the eight invertebrate groups monitored. Population of all four groups was higher in sheep and chicken manure fertilised plots than when fertilised with communal waste compost. The difference in the insects' populations of Orthoptera and slugs detected, between sheep and communal waste compost fertilised plots, was not significant (Table 4.2).

No significant main effects of biochar on invertebrate populations were detected (Table 4.2). Only two significant interactions between experimental factors affecting the population of the insects monitored (sampling date, fertiliser type and/or biochar) could be detected.

For Lepidoptera, a significant interaction between sampling date and fertiliser type was detected regarding their effects on insects. In particular, sheep manure was associated with a higher population of insects than chicken manure and communal waste compost on sampling date 1(5/5/2011). In addition, fertilisation with chicken manure was associated with higher insect population than the fertilisation with communal waste compost on sampling date 2 (20/5/2011). No significant differences in population of insects was detected on sampling date 1(5/5/2011) and 4 (20/6/2011) (Table 4.3).

For Hymenoptera a significant interaction between fertiliser type and biochar treatment was detected, with biochar amendments resulting in higher population when used in combination with sheep and chicken manure. However, insects were found to have lower population when fertilisation combining biochar and communal waste compost was used (Table 4.4).

Table 4.2 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (yellow traps) in the 2011 spring potato cropping season per subplot ($36m^2$)

Factor	Diptera	Coleoptera	Orthopteran	Hemiptera	Hymenoptera	Arthropoda	Lepidoptera	Slugs	Ants
Sampling date									
1^{st} 5/5/2011	13.79±1.94 b	5.38±1.30 b	0.46±0.16 c	0.33±0.12	17.08±1.58 b	0.83±0.36	0.46±0.20 b	0.21±0.10	0.00±0.00 b
2^{nd} 20/5/2011	31.04±5.95 b	6.04±1.21 b	1.33±0.30 b	0.17±0.08	33.21±6.62 b	1.67±0.62	1.50±0.48 b	0.21±0.10	0.00±0.00 b
3^{rd} 6/6/2011	7.42±1.81c	0.67±0.17 c	1.75±0.52 b	0.04±0.04	15.71±2.56 b	1.71±0.52	1.17±0.35 b	0.25±0.12	0.00±0.00 b
4^{th}20/6/2011	44.79±5.10a	12.92±1.21 a	4.67±0.74 a	0.33±0.33	65.67±5.81 a	2.42±0.68	12.54±1.14 a	0.33±0.16	2.17±0.87 a
Fertiliser type									
Sheep manure	26.28±4.32 a	6.94±1.21	2.38±0.42 ab	0.09±0.05	37.38±4.81 a	1.97±0.57	3.72±0.88	0.25±0.11 ab	0.38±0.38
Chicken manure	27.03±4.48 a	6.25±1.07	2.44±0.67 a	0.22±0.07	32.22±4.48 a	1.44±0.46	4.22±1.11	0.47±0.13 a	0.38±0.23
Communal waste compost	19.47±4.38 b	5.56±1.34	1.34±0.33 b	0.34±0.17	29.16±6.56 b	1.56±0.42	3.81±1.16	0.03±0.03 b	0.88±0.55
Biochar									
Without	26.42±3.40	7.04±1.01	1.90±0.29	0.13±0.05	34.44±4.20	1.71±0.41	3.71±0.88	0.29±0.09	0.52±0.29
With	22.10±3.76	5.46±0.95	2.21±0.50	0.31±0.12	31.40±4.55	1.60±0.38	4.13±0.83	0.21±0.08	0.56±0.27
ANOVA results (p-values)									
Main effects									
Date (DT)	**<0.001**	**<0.001**	**<0.001**	ns	**0.0001**	0.0925	**<0.001**	ns	
Fertiliser types (FT)	**0.0422**	ns	**0.0271**	ns	**0.0104**	ns	ns	0.0235	
Biochar (BC)	ns	ns	ns	ns	ns	ns	ns	ns	
Interactions		ns	ns	ns	ns	ns	ns	ns	
DT x FT	ns	ns	ns	ns	ns	ns	0.0087[1]	ns	
DT x BC	0.0816	ns	ns	ns	ns	ns	ns	ns	
FT x BC	0.0659	ns	ns	ns	0.0288[2]	ns	ns	ns	
DT x FT x BC	ns	ns	ns	ns	ns	ns	ns	ns	

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

[1] See table 4.3 for interaction means and SE

[2] See table 4.4 for interaction means and SE

Table 4.3 Effect of and interaction of Insect sampling date and fertilisation treatment on Lepidoptera insect populations on spring experiment 2011 per subplot ($36m^2$)

	Sampling date			
	5/5/2011	20/5/2011	6/6/2011	20/6/2011
Fertiliser type				
Sheep manure	0.25±0.25 A c	3.38±1.08 A b	1.38±0.78 A c	9.88±1.97 B a
Chicken manure	0.38±0.26 A d	0.75±0.49 B cd	1.88±0.58 A bc	13.88±1.84 A a
Communal waste compost	0.75±0.49 A b	0.38±0.26 B b	0.25±0.25 B b	13.88±2.02 A a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

Table 4.4 Effect of and interaction of fertilisation treatment and biochar amendment on hymenoptera insect populations on spring experiment 2011per subplot ($36m^2$)

	Fertiliser type		
	Sheep manure	Chicken manure	Communal waste compost
Biochar amendment			
- biochar	34.38±5.22 B b	29.31±6.68 B c	39.63±9.49 A a
+ biochar	40.38±8.20 A a	35.13±6.09 A b	18.69±8.56 B c

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

4.1.3 Crop canopy insect populations

Significant main effects of sampling date, but not of fertiliser type and biochar amendment, were noted for all 4 invertebrate groups (Coleoptera, Orthoptera, Hymenoptera and Arthropoda) detected/monitored in the potato canopy (Table 4.5). The population of Coleoptera and Hymenoptera, increased between sampling date 1 (9/5/2011) and 2 (23/5/2011) and then decreased. Significant populations of Orthoptera was only detected on sampling date 4 (24/6/2011) and the population of Arthropoda increased over time (Table 4.5).

Only one significant interaction (between sampling date and fertiliser type for Coleoptera) could be detected (Table 4.5). No significant difference in Coleoptera population between fertiliser types was detected on sampling dates 1(9/5/2011) and 3 (8/6/2011) (Table 4.6). On sampling date 2 (23/5/2011) Coleoptera population was higher in plots fertilized with communal waste compost than plots that received sheep and chicken manure inputs. In contrast, on sampling date 4 (24/6/2011), population was higher in sheep and chicken manure fertilised plots than plots that received communal waste compost inputs (Table 4.6).

Table 4.5 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (canopy hovering) in the 2011 spring potato cropping season

Factor	*Coleoptera*	*Orthoptera*	*Hymenoptera*	*Arthropoda*
Sampling date				
1st 9/5/2011	0.29±0.18 c	0.00±0.00 b	2.42±0.25 ab	0.08±0.08 c
2nd 23/5/2011	2.66±0.48 a	0.04±0.04 b	2.88±0.32 a	0.79±0.22 b
3rd 8/6/2011	0.96±0.20 b	0.21±0.10 b	2.25±0.53 b	3.25±0.60 a
4th 24/6/2011	1.67±0.32 ab	0.32±0.28 a	1.58±0.31 b	3.88±0.48 a
Fertiliser type				
Sheep manure	1.19±0.24	0.38±0.13	2.28±0.28	1.97±0.45
Chicken manure	1.53±0.34	0.69±0.23	2.19±0.42	2.38±0.53
Communal waste compost	1.47±0.36	0.38±0.17	2.38±0.25	1.67±0.35
Biochar				
Without	1.42±0.25	0.52±0.15	2.15±0.23	1.96±0.31
With	1.38±0.27	0.44±0.14	2.42±0.30	2.04±0.41
ANOVA results (p-values)				
Main effects				
Date (SD)	**<0.001**	**<0.001**	**0.0103**	**<0.001**
Fertiliser types (FT)	Ns	Ns	Ns	Ns
Biochar (BC)	Ns	Ns	Ns	Ns
Interactions				
DT x FT	**0.0032**[1]	*0.0759*	Ns	Ns
DT x BC	Ns	Ns	Ns	Ns
FT x BC	Ns	Ns	Ns	Ns
DT x FT x BC	Ns	Ns	Ns	Ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

[1] See table 4.6 for interaction means and SE

Table 4.6 Effect of Insect sampling date and fertility treatment on Coleoptera insect populations on autumn experiment 2011/ per subplot (36m^2)

	Sampling date			
	9/5/2011	23/5/2011	8/6/2011	24/6/2011
Fertiliser type				
Sheep manure	0.00±0.00 A c	1.50±0.33 B b	1.00±0.27 A b	2.25±0.67 A a
Chicken manure	0.50±0.38 A c	2.50±1.09 B a	1.00±0.38 A b	2.13±0.44 A a
Communal waste compost	0.38±0.38 A b	4.00±0.73 A a	0.88±0.44 Ab	0.63±0.38 B b

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

4.2 Results and Discussion insect populations - autumn season crop 2011

4.2.1 Epigeal insect populations

Significant main effects of sampling date were detected for 4 (Coleoptera, Orthoptera, Arthropoda and ants) of the 6 invertebrate groups detected/monitored by pit fall traps (Table 4.7). Different population pattern was detected for the 4 groups with:

(a) Coleoptera population decreasing over time,

(b) Significant Orthoptera population only being detected at the 1st sampling date (10/11/2011)

(c) Arthropoda population being higher at the 2nd (25/11/2011) then the other three sampling dates, and

(d) Ant populations peaking on the 2nd and 4th (25/11/2011and 25/12/2011) sampling date (Table 4.7).

No significant main effects of fertiliser type and biochar amendment and no significant 2 or 3 - way interactions could be detected in the 2011 autumn season (Table 4.7).

Table 4.7 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (pit fall traps) in the 2011 autumn potato cropping season per subplot (36 m^2)

Factor	*Coleoptera*	*Orthoptera*	*Hymenoptera*	*Arthropoda*	*Slugs*	*Ants*
Sampling date						
1st 10/11/2011	3.33±0.65 a	4.54±0.92 a	0.13±0.07	1.17±0.39 b	0.54±0.22	4.54±1.78 c
2nd 25/11/2011	1.33±0.26 b	0.21±0.10 b	0.25±0.11	4.13±0.47 a	0.50±0.18	12.54±2.85 ab
3rd 9/12/2011	1.00±0.23 b	0.00±0.00 b	0.46±0.15	1.08±0.24 b	0.33±0.16	5.00±1.78 bc
4th 25/12/2011	0.38±0.16 c	0.08±0.06 b	0.38±0.13	0.54±0.19 b	0.33±0.16	14.21±2.54 a
Fertiliser type						
Sheep manure	1.50±0.39	0.81±0.34	0.22±0.09	1.66±0.40	0.44±0.15	6.31±1.56
Chicken manure	1.63±0.33	1.69±0.69	0.31±0.11	2.00±0.39	0.44±0.17	12.19±2.45
Communal waste compost	1.41±0.42	1.13±0.48	0.38±0.11	1.53±0.36	0.41±0.15	8.72±2.10
Biochar						
Without	1.48±0.27	1.17±0.38	0.31±0.09	1.86±0.35	0.29±0.11	9.10±1.51
With	1.54±0.35	1.25±0.47	0.29±0.08	1.60±0.27	0.57±0.14	9.04±1.91
ANOVA results (p-values)						
Main effects						
Date (SD)	**<0.001**	**<0.001**	ns	ns	Ns	**0.0003**
Fertiliser types (FT)	ns	ns	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns	ns	ns
Interactions						
DT x FT	ns	ns	ns	*0.0690*	ns	ns
DT x BC	ns	ns	ns	ns	ns	ns
FT x BC	ns	ns	ns	ns	ns	ns
DT x FT x BC	ns	ns	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

4.2.2 Aerial insect populations

Significant main effects of sampling date were detected for the aerial insect populations of 6 (Diptera, Orthoptera, Hemiptera, Hymenoptera, Arthropoda and Lepidoptera) of the 7 invertebrate groups detected/monitored by flying insect traps (Table 4.8). Different population patterns were detected for the 6 groups with:

(a) Diptera population decreasing over time,

(b) Orthoptera and Lepidoptera population being higher on sampling date 1 and 3,

(c) Significant Hemipteran population only being detected at the 3rd sampling date (9/12/2011),

(d) Hymenoptera population being higher at the 2nd (25/11/2011) then the other three sampling dates, and (e) Arthropoda population being higher at the 1st compared to the other 3 sampling dates (Table 4.8).

No significant main effects of fertiliser type and biochar amendment on aerial insect populations could be detected in the 2011 autumn season (Table 4.8).

Only one significant interaction (between sampling date and fertiliser type for Lepidoptera) could be detected (Table 4.8). No significant difference in the population of Lepidoptera upon different fertiliser types was detected on sampling dates 1 and 4 (Table 4.9). On sampling date 2, Lepidopterans' population was higher in plots fertilised with chicken manure than plots that received communal waste compost inputs. In contrast, on sampling date 3, population was higher in sheep manure or communal waste compost fertilized plots than plots that received chicken manure inputs (Table 4.9).

Table 4.8 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (flying insect traps) in the 2011 autumn potato cropping season per subplot ($36m^2$)

Factor/Insect	*Diptera*	*Coleoptera*	*Orthoptera*	*Hemiptera*	*Hymenoptera*	*Arthropoda*	*Lepidoptera*
Sampling date							
1st 10/11/2011	13.63±1.62 a	1.33±0.40	4.58±0.57 a	0.17±0.10 b	4.21±0.65 b	2.33±0.57 a	4.88±0.63 a
2nd 25/11/2011	1.17±0.30 b	1.13±0.26	0.42±0.12 c	0.08±0.06 b	8.25±0.97 a	0.33±0.13 b	1.75±0.40 b
3rd 9/12/2011	0.04±0.04 c	1.50±0.35	2.04±0.46 b	1.04±0.36 a	1.13±0.29 c	0.13±0.07 b	3.50±0.55 a
4th 25/12/2011	0.00±0.00 c	2.13±0.41	0.00±0.00 c	0.04±0.04 b	2.89±0.40 b	0.58±0.20 b	0.00±0.00 b
Fertiliser type							
Sheep manure	3.75±1.21	1.28±0.25	2.03±0.50	0.41±0.24	3.88±0.67	1.03±0.38	3.22±0.61
Chicken manure	3.59±1.21	1.25±0.25	1.66±0.48	0.31±0.18	4.22±0.72	0.91±0.31	2.41±0.49
Communal waste compost	3.78±1.34	2.03±0.40	1.59±0.37	0.28±0.09	4.25±0.77	0.59±0.21	1.97±0.42
Biochar							
Without	4.04±1.11	1.40±0.25	1.65±0.32	0.27±0.12	4.29±0.62	0.92±0.30	2.23±0.42
With	3.38±0.92	1.65±0.26	1.89±0.41	0.40±0.17	3.94±0.55	0.77±0.20	2.84±0.42
ANOVA results (p-values)							
Main effects							
Date (SD)	**<0.001**	ns	**<0.001**	**0.0002**	**<0.001**	**<0.001**	**<0.001**
Fertiliser types (FT)	ns	ns	ns	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns	ns	ns	ns
Interactions	ns	ns	ns	ns	ns	ns	ns
DT x FT	ns	ns	ns	ns	ns	ns	ns
DT x BC	ns	ns	ns	ns	ns	ns	ns
FT x BC	ns	ns	ns	ns	ns	ns	ns
DT x FT x BC	ns	ns	ns	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

[1] See table 4.9 for interaction means and SE

Table 4.9 Effect of Insect sampling date and fertilisation treatment on Lepidoptera insect populations for autumn experiment 2011 per subplot (36 m^2)

	Sampling date			
	10/11/2011	25/11/2011	9/12/2011	25/12/2011
Fertiliser type				
Sheep manure	5.38±1.25 A a	2.00±0.73 A b	5.50±1.13 A a	0.00±0.00 A c
Chicken manure	5.38±1.05 A a	2.50±0.82 A b	1.75±0.62 C b	0.00±0.00 A c
Communal waste compost	3.88±1.00 A a	0.75±0.41 B b	3.25±0.59 BC a	0.00±0.00 A c

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

4.2.3 Crop canopy insect populations

Significant main effects of sampling date, but not of fertiliser type and biochar amendment, were found on the insect populations of three (Diptera, Coleoptera, Hymenoptera) of the five invertebrate groups detected/monitored in the potato canopy (Table 4.10). The population of all three groups decreased over time (Table 4.10).

No significant main effects of fertiliser type and biochar amendment on the populations of the insects could be detected in the 2011 autumn season (Table 4.10).

Only one significant interaction (between sampling date and biochar amendment for Coleoptera) could be detected (Table 4.10). A significant difference in population between biochar treated and non-treated plots could only be detected on sampling date 1, when the populations of Coleoptera was higher in biochar treated plots (Table 4.11).

Table 4.10 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (canopy hovering) in the 2011 autumn potato cropping season per subplot (36 m^2)

Factor	*Diptera*	*Coleoptera*	*Hymenoptera*	*Arthropoda*
Sampling date				
1st 10/11/2011	0.83±0.24 a	0.96±0.24 a	3.63±0.34 a	0.42±0.12
2nd 25/11/2011	0.08±0.06 b	0.58±0.19 b	4.50±0.43 a	0.17±0.08
3rd 9/12/2011	0.04±0.04 b	0.21±0.12 b	2.00±0.38 b	0.13±0.07
4th 25/12/2011	0.00±0.00 b	0.42±0.17 b	1.21±0.24 b	0.17±0.08
Fertiliser type				
Sheep manure	0.19±0.07	0.47±0.16	2.53±0.35	0.22±0.07
Chicken manure	0.22±0.10	0.72±0.19	3.03±0.47	0.25±0.09
Communal waste compost	0.31±0.18	0.44±0.15	2.94±0.31	0.19±0.07
Biochar				
Without	0.31±0.13	0.58±0.14	3.00±0.35	0.21±0.06
With	0.17±0.06	0.50±0.13	2.67±0.27	0.23±0.07
ANOVA results (p-values)				
Main effects				
Date (SD)	**<0.001**	**0.0194**	**<0.001**	ns
Fertiliser types (FT)	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns
Interactions				
DT x FT	ns	ns	ns	ns
DT x BC	ns	**0.0352** [1]	ns	ns
FT x BC	ns	ns	ns	ns
DT x FT x BC	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

[1] See table 4.11 for interaction means and SE

Table 4.11 Effect of Insect sampling date and biochar amendment on Coleoptera insect populations on autumn experiment 2011 per subplot (36 m^2)

	Sampling date			
	10/11/2011	25/11/2011	9/12/2011	25/12/2011
Biochar amendment				
- biochar	1.33±0.36 A a	0.58±0.29 A b	0.33±0.22 A b	0.08±0.08 A b
+ biochar	0.58±0.29 B a	0.58±0.26 A a	0.08±0.08 A a	0.75±0.30 A a

Means followed by the same lower- case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

4.3 Results and Discussion insect populations - spring season crop 2012

4.3.1 Epigeal insect populations

Significant main effects of sampling date on epigaeal insect populations were detected for 4 (Diptera, Coleoptera, Orthoptera and ants) of the 9 invertebrate groups detected/monitored by pit fall traps (Table 4.12). Different population patterns were detected for the 4 groups:

(a) Population of Diptera was higher at 2nd sampling date (23/5/2012),

(b) Population of Coleoptera was higher at the 4th sampling date,

(c) Population of Orthoptera was higher on the 4th (24/6/2012) than the three earlier sampling dates (9/5/2012, 23/5/2012 and 8/6/2012),

(d) Population of Arthropoda was higher at the two early sampling dates (9/5/2012 and 23/5/2012) while

(e) Ant population was higher at the two later sampling dates (8/6/2012 and 24/6/2012) (Table 4.12).

No significant main effects of fertiliser type and biochar amendment and no significant of 2 or 3 way - interactions on the populations of epigeal insects, was detected in the 2012 spring season (Table 4.12).

Table 4.12 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (pit fall traps) in the 2012 spring potato cropping season per subplot (36 m^2)

Factor	*Diptera*	*Coleoptera*	*Orthoptera*	*Hymenoptera*	*Arthropoda*	*Lepidoptera*	Neuroptera	*Slugs*	*Ants*
Sampling date									
1= 9/5/2012	0.25±0.11 c	17.00±1.61 b	3.04±0.35 b	1.67±0.34	7.17±1.68	0.17±0.10	0.58±0.20	5.79±1.80	22.25±11.79 b
2= 23/5/2012	0.50±0.16 a	7.95±0.87 c	0.92±0.18 c	0.92±0.22	9.38±1.17	0.21±0.10	0.21±0.12	13.79±8.44	9.54± 4.41 c
3= 8/6/2012	0.33±0.12 b	13.21±1.41 b	4.79±0.66 b	1.50±0.26	4.58±0.91	0.13±0.07	0.17±0.10	4.88±1.65	28.83±12.18 b
4= 24/6/2012	0.29±0.13bc	47.83±4.33 a	5.46±0.94 a	1.46±0.32	2.63±0.43	0.00±0.00	0.13±0.07	2.08±0.72	52.42±39.75 a
Fertiliser type									
Sheep manure	0.28±0.11	19.06±2.80	3.91±0.57	1.16±0.18	6.56±1.37	0.09±0.05	0.41±0.15	11.19±6.36	13.66±3.21
Chicken manure	0.28±0.08	22.41±3.08	3.25±0.55	1.47±0.27	6.16±1.01	0.09±0.05	0.19±0.11	4.94±1.51	46.94±29.91
Communal waste compost	0.47±0.13	22.47±4.28	3.50±0.69	1.53±0.30	5.09±0.76	0.19±0.09	0.22±0.09	3.78±1.15	24.19±12.25
Biochar									
without	0.42±0.11	22.02±3.16	3.50±0.51	1.17±0.17	4.96±0.65	0.06±0.05	0.21±0.08	5.06±1.15	32.00±19.98
with	0.27±0.07	20.60±2.40	3.60±048	1.60±0.24	6.92±1.04	0.19±0.06	0.33±0.10	8.21±4.29	24.52±8.49
ANOVA results (p-values)									
Main effects									
Date (SD)	ns	**<0.001**	**<0.001**	ns	**<0.001**	ns	ns	ns	**0.0010**
Fertiliser types (FT)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Interactions					ns				
DT x FT	ns	ns	ns	ns	ns	ns	ns	ns	ns
DT x BC	ns	ns	ns	ns	ns	ns	ns	*0.0834*	ns
FT x BC	ns	ns	ns	ns	ns	ns	ns	ns	ns
DT x FT x BC	ns	ns	ns	ns	ns	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test ($P<0.05$)

4.3.2 Aerial insect populations

Significant main effects of sampling date on aerial insect populations were detected for all the eight (Diptera, Coleoptera, Orthoptera, Hymenoptera, Arthropoda, Lepidoptera, slugs and ants) invertebrate groups detected/monitored by flying insect traps (Table 4.13). Different population patterns were detected for the eight groups studied with:

(a) Diptera, Coleoptera and Hymenoptera populations increasing over time,

(b) Orthoptera populations being higher on sampling date 4 (24/6/2012),

(c) Hemipteran and Neuropteran populations being higher on the two earlier sampling dates (9/5/2012 and 23/5/2012), and

(d) Arthropoda populations being higher at the 2nd (23/5/2012) sampling date (Table 4.13).

No significant main effects of fertiliser type and biochar amendment on the aerial insect populations, was detected in the 2011 autumn season (Table 4.13).

Only two significant interactions between experimental factors (sampling date, fertiliser type and/or biochar) was detected with the interactions between sampling date and fertiliser type being significant for both Diptera and ants (Table 4.13). For the populations of Diptera, significant differences were only be detected at sampling date 4, with their population found to be higher in plots fertilised with sheep manure than plots receiving chicken manure or communal waste compost inputs (Table 4.14)

Table 4.13 Effect of, and interaction between, different sampling dates, fertiliser types and biochar amendment on invertebrate populations (yellow traps) in the 2012 spring potato cropping season per subplot (36 m^2)

Factor	*Diptera*	*Coleoptera*	*Orthoptera*	*Hemiptera*	*Hymenoptera*	*Arthropoda*	*Lepidoptera*	Neuroptera
Sampling date								
1= 9/5/2012	0.71±0.44 ab	5.38±0.48 b	0.96±0.19 b	2.00±0.28 a	18.17±1.76 b	1.88±0.37 b	0.88±0.17	1.13±0.29 a
2= 23/5/2012	0.83±0.25 bc	2.04±0.39 c	1.38±0.25 b	1.63±0.31 ab	19.33±1.34 b	5.75±0.92 a	0.75±0.20	0.83±0.30 ab
3= 8/6/2012	1.13±0.21 c	10.50±0.71 a	0.79±0.16 b	1.17±0.22 b	20.25±2.19 b	2.29±0.40 b	0.54±0.21	0.21±0.08 b
4= 24/6/2012	2.46±0.56 a	13.75±0.96 a	3.88±0.57 a	0.67±0.24 c	29.92±3.02 a	1.67±0.29 b	1.04±0.29	0.33±0.14 b
Fertiliser type								
Sheep manure	1.91±0.43	8.38±0.87	2.31±0.45	1.59±0.25	25.16±2.76	2.50±0.41	0.97±0.22	0.44±0.11
Chicken manure	1.06±0.31	7.44±0.96	1.50±0.28	1.47±0.27	19.16±1.42	2.97±0.77	0.67±0.19	0.75±0.25
Communal waste compost	1.25±0.31	7.94±1.15	1.44±0.33	1.03±0.19	21.44±1.54	3.22±0.43	0.78±0.16	0.69±0.23
Biochar								
Without	1.42±0.29	8.25±0.85	1.85±0.34	1.38±0.21	21.81±1.81	3.00±0.52	0.92±0.17	0.69±0.17
With	1.40±0.30	7.58±0.76	1.65±0.24	1.35±0.18	22.02±1.50	2.79±0.38	0.69±0.15	0.56±0.16
ANOVA results (p-values)								
Main effects								
Date (SD)	**0.0010**	**<0.001**	**<0.001**	0.0007	0.0083	**<0.001**	ns	0.0202
Fertiliser types (FT)	ns	ns	ns	ns	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns	ns	ns	ns	ns
Interactions								
DT x FT	0.0492 [1]	ns	ns	ns	ns	ns	ns	ns
DT x BC	0.0701	ns	ns	ns	ns	ns	ns	ns
FT x BC	0.2054	ns	ns	ns	ns	ns	ns	ns
DT x FT x BC	*0.0681*	ns	ns	ns	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (*P*<0.05)

[1]See table 4.14 for interaction means and SE

Table 4.14 Effect of and interaction of insects' sampling date and fertilisation treatment on populations of Diptera populations during 2012 spring potato cropping season per subplot (36 m^2)

	Sampling date			
	9/5/2012	23/5/2012	8/6/2012	24/6/2012
Fertiliser type				
Sheep manure	1.13±0.40 A b	1.25±0.65 A b	0.88±0.48 A b	4.38±1.15 A a
Chicken manure	2.13±1.09 A a	0.88±0.23 A a	0.38±0.26 A a	0.88±0.35 B a
Communal waste compost	1.88±0.67 A a	0.38±0.26 A a	0.63±0.32 A a	2.13±0.88 B a

Means followed by the same lower-case letter within the same row and with the same capital letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

4.3.3 Crop canopy insect populations

Significant main effects of sampling date, but not of fertiliser type and of biochar amendment on crop canopy populations of insects, were detected for five (Diptera, Coleoptera, Orthoptera, Arthropoda and Lepidoptera) of the eight invertebrate groups detected/monitored in the potato canopy (Table 4.15). Different population patterns were detected for the five groups with:

(a) Significant populations of Diptera population only being detected at the 3rd sampling date (8/6/2012),

(b) The populations of Coleoptera and Lepidoptera increasing over time,

(c) The population of Orthoptera being highest at the 4th sampling date (24/6/2012) and lowest at the 3rd sampling date (8/6/2012) and

(d) The population of Arthropoda being highest on the 1st sampling date (9/5/2012) (Table 4.15).

No significant main effects of fertiliser type and biochar amendment on crop canopy populations of insects and no significant 2 or 3-way interactions could be detected in the 2012 spring season (Table 4.15).

Hence, it can be said that in both spring sampling seasons, the insect populations increased through the sampling date in most of the insect orders. In autumn, sampling season decreased the insect populations and this may have to do with the increase and decrease of the temperature that it is known that affects the insect populations. Coleoptera had the higher populations in all three sampling seasons (both spring and autumn). It's one the most important order as it includes Colorado beetle, that it is known to be one of the most important potato pests.

Table 4.15 Effect of sampling dates, fertiliser types and biochar amendment on invertebrate populations (canopy hovering) in the 2012 spring potato cropping season per subplot (36 m^2)

Factor	*Diptera*	*Coleoptera*	*Orthoptera*	*Hemiptera*	*Hymenoptera*	*Arthropoda*	*Slugs*
Sampling date							
1= 9/5/2012	0.08±0.08 b	3.00±0.45 c	1.13±0.36 b	0.04±0.04	3.58±0.33 a	2.17±0.24 b	0.17±0.10
2= 23/5/2012	0.17±0.10 b	3.92±0.37 b	0.50±0.15 bc	0.08±0.06	0.96±0.22 c	1.29±0.19 c	0.08±0.06
3= 8/6/2012	0.88±0.25 a	7.38±0.53 a	0.29±0.11 c	0.29±0.15	2.58±0.51 b	2.58±0.33 b	0.46±0.16
4= 24/6/2012	0.25±0.11 b	8.79±0.51 a	2.25±0.45 a	0.33±0.14	2.96±0.38 ab	5.25±0.56 a	0.21±0.13
Fertiliser type							
Sheep manure	0.28±0.13	6.22±0.62	0.88±0.26	0.19±0.10	2.69±0.33	3.28±0.51	0.25±0.10
Chicken manure	0.53±0.18	5.25±0.52	0.97±0.24	0.28±0.12	2.31±0.42	2.66±0.27	0.19±0.08
Communal waste compost	0.22±0.10	5.84±0.61	1.28±0.37	0.09±0.05	2.56±0.34	2.53±0.39	0.25±0.13
Biochar							
Without	0.23±0.09	5.94±0.48	0.98±0.24	0.17±0.06	2.56±0.29	2.75±0.37	0.27±0.09
With	0.46±0.14	5.60±0.47	1.10±0.24	0.21±0.09	2.48±0.31	2.90±0.29	0.19±0.08
ANOVA results (p-values)							
Main effects							
Date (SD)	0.0019	**<0.001**	**<0.001**	ns	**<0.001**	**<0.001**	0.0852
Fertiliser types (FT)	ns	ns	ns	ns	ns	ns	ns
Biochar (BC)	ns	ns	ns	ns	ns	ns	ns
DT x FT	ns	ns	ns	*0.0548*	ns	ns	ns
DT x BC	ns	ns	ns	ns	ns	ns	ns
FT x BC	ns	ns	ns	ns	ns	ns	ns
DT x FT x BC	ns	ns	ns	ns	ns	ns	ns

The values represent means (SE); Means with the same letter within the same column are not significantly different according to Tukey's Honestly Significant Difference Test (P<0.05)

Chapter 5. Potato taste and characteristic survey panel on two different potato varieties

5.1 Objectives

The specific objectives for the sensory analyses were to:

1. Carry out a comparative sensory analysis of the two varieties included in field trials (Spunta and Sarpo Mira), using untrained taste panels.

2. Assess the relative suitability/acceptability of Sarpo Mira as an alternative to Spunta for the Greek market, and especially in terms of organic production, based on both agronomic and sensory evaluation results.

5.2 Effect of cultivar on the time needed to prepare potato by frying, boiling and oven-cooking

Figure 5.1 shows the average consumers scores for three processing methods (deep fat frying, boiling in water, and oven cooking/baking) recorded by volunteers recruited for sensory evaluation. There was no significant difference in processing time by deep fat frying. However, when boiling and oven - cooking were compared in the two varieties studied, it was found that the processing time in both cases was scored as being significantly longer for Sarpo Mira than for Spunta.

In more detail, the results in this sub-chapter refer to answers given in the questionnaire (Table 2.3/ Chapter 2) used, for the sensory evaluation of the potatoes studied. Figure 5.1, provides answers regarding the question 3 (Do you believe that fried time was short or long?), 5 (Do you believe that boiling time was short or long?) and 7 (Do you believe that baking time was short or long?). Thus, according to the scale (1-9) used (see Table 3.2/ Chapter 2), it can be said that:

- The time required for frying was not influenced by the factor “variety”.
- The time required for boiling was influenced by the factor “variety”. In particular, the time required for the boiling of potatoes of Spunta variety it can be said that the closer characterisation matching with the scale used, is as “moderately short”. The time required

for the boiling of potatoes of Sarpo Mira variety was greater than for Spunta and was characterised as “slightly short”.

- The time required for baking the potatoes in the oven, was influenced by the factor “variety”. In particular, the time required for the baking of potatoes of Spunta variety it can be said that the closer characterization matching with the scale used, is as “moderately short”. The time required for the baking of potatoes of Sarpo Mira variety was greater than for Spunta and was characterised as “slightly short to neither short nor long”.

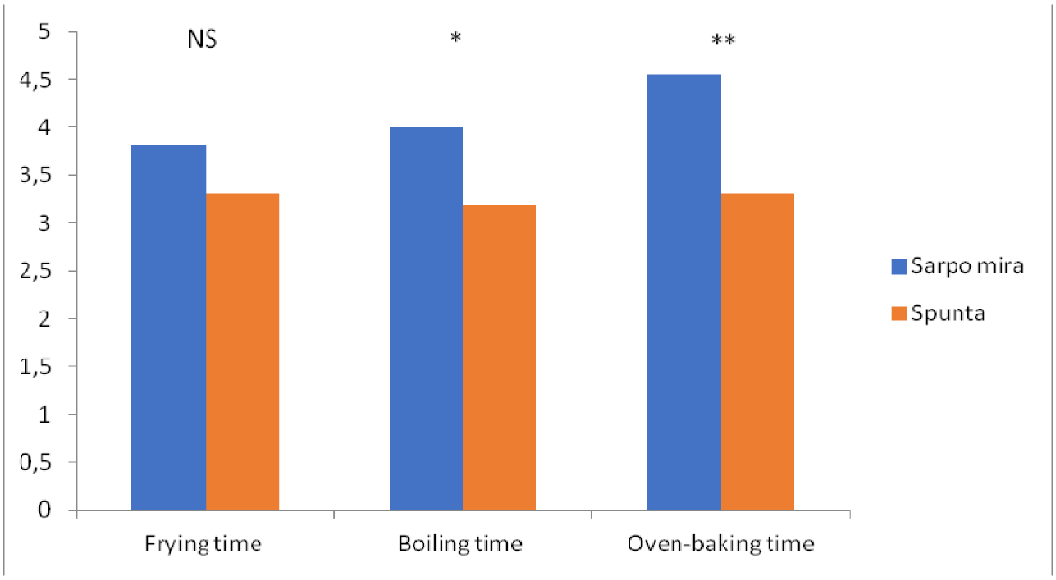


Figure 5.1 Effect of potato variety on the frying, boiling and oven baking time needed (relative cooking time scores given by consumers).

*The horizontal axis refers to question 3, 5 and 7, respectively

ANOVA results (p-values): NS, not significant; P<0.1; *, P<0.05; **, P<0.01; ***, P<0.001

5.3 Effect of cultivar on taste parameters

The results for the taste parameters studied in the sensory evaluation (including an overall taste preference score), of the two varieties following processing by three different methods (frying, boiling in water, oven cooking/baking) are provided in Figure 5.2.

No significant differences in overall taste/preference could be detected between the two varieties, when the potatoes processed by the three specific processing methods were compared. However, Spunta was perceived as being sweeter than Sarpo Mira. When participants in taste panels were asked to score the overall sensory quality of the two varieties (irrespectively of processing method) Spunta was preferred by potato consumers.

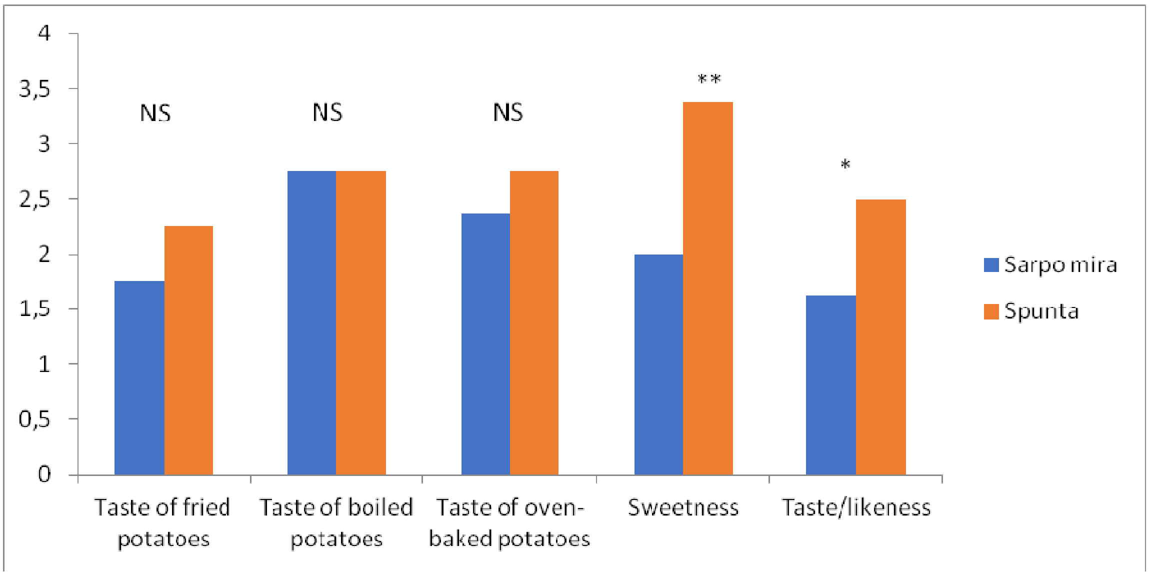


Figure 5. 2 Effect of variety on taste preference scores by consumers

*The horizontal axis refers to question 1, 4, 6, 8 and 9 respectively

ANOVA results (p-values): NS, not significant; P<0.1; *, P<0.05; **, P<0.01; ***, P<0.001

The results in this sub-chapter refer to answers given in the questionnaire (Table 2.3/ Chapter 2) used, for the sensory evaluation of the potatoes studied. Figure 5.2, provides answers regarding the following questions:

- 1: Did you like the fried potatoes/chips?

- 4: Did you like the boiled potatoes or not?

- 6: Did you like the potatoes baked in the oven or not?

- 8: Do you believe that the potatoes were sweet or bitter?

- 9: Did you like the taste or not?

Thus, according to the scale (1-9) used (see Table 3.2/ Chapter 2), it can be said that:

- The factor "variety" did not influence significantly the consumers in terms of taste. They liked the same the two varieties studied, regardless the way of cooking.
- In the sensory evaluation scale used, according to the most appropriate evaluation matching with the scale used for fried potatoes is that consumers "like very much" the taste of the potatoes.
- For the boiled and the oven-baked potatoes, it can be said that the taste panel like the potatoes "very much" to "moderately".
- The Sarpo Mira potatoes were characterised as "very much sweet" while the Spunta ones as "moderately sweet" to "slightly sweet".
- It can be said that the taste panel used for the purposes of the current study liked "extremely" to "very much" the Sarpo Mira potatoes.
- The taste panel used for the purposes of the current study liked "very much" to "moderately" the Spunta potatoes.

5.3 Effect of variety on other sensory parameters

Results regarding the other sensory parameters assessed (frying colour, texture and overall preference) are provided through Figure 5.3. Spunta received higher scores for frying colour and texture, while Sarpo Mira had higher scores for flesh colour and hardness (which is linked to "easy of peeling" quality characteristic). There was no significant difference in the score for colour overall preference.

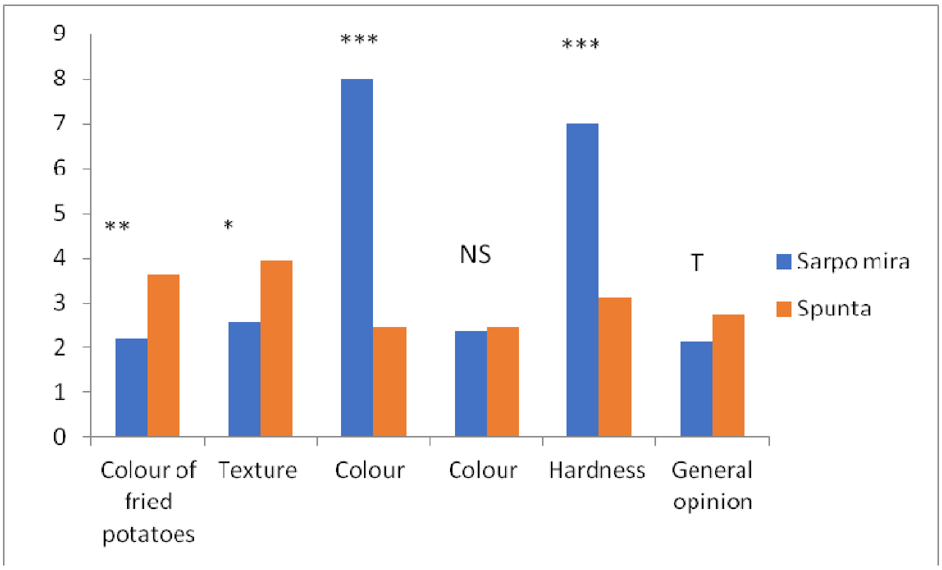


Figure 5.3 Effect of variety on scores for other parameters by consumers

*The horizontal axis refers to question 2, 10, 11, 12, 13 and 14 respectively.

ANOVA results (p-values): NS, not significant; Trend (T), P<0.1; *, P<0.05; **, P<0.01; ***, P<0.001

The results in this sub-chapter refer to answers given in the questionnaire (Table 2.3/ Chapter 2) used, for the sensory evaluation of the potatoes studied. Figure 5.3, provides answers regarding the following questions:

- 2: What you believe about the colour of the chips? [natural colour of raw potato-black (like burnt/very black)]
- 10: Do you believe the potatoes were crunchy or smooth?
- 11: Do you think that the colour of the potatoes was white or red?
- 12: Did you like the colour of the potatoes or not?
- 13: Do you think that the potatoes were soft or hard?
- 14: What is your general opinion about the potatoes you tasted?

Thus, according to the scale (1-9) used (see Table 3.2/ Chapter 2), it can be said that:

➢ The factor "variety" influenced significantly the consumers' perception regarding the colour of the fried potatoes. In particular, the panel thought that the colour of the Sarpo

Mira potatoes was “very much natural” while of Spunta potatoes, almost “moderately natural”.

- The factor “variety” influenced significantly the consumers’ perception regarding the texture of the potatoes. In particular, the panel thought that the texture of the Sarpo Mira potatoes was “very much crunchy” while of Spunta potatoes, almost “moderately crunchy”.
- The factor “variety” influenced significantly the consumers’ perception regarding the colour of the potatoes. In particular, the panel thought that the colour of the Sarpo Mira potatoes was “very much” red while of Spunta potatoes, “very much” white. However, they did not “like” or “dislike” the colour of the potatoes in a significantly different way.
- The factor “variety” influenced significantly the consumers’ perception regarding the texture, in terms of hardness, of the potatoes. In particular, the panel thought that the Sarpo Mira potatoes was “very much hard” while of Spunta potatoes, “moderately soft” white.
- The general opinion of the panel used for this study about the potatoes, was “very good”, with Spunta having a little lower score that Sarpo Mira potatoes and in particular scores closer to “moderately good general opinion”.

5.4 Short Discussion

The overall results from the Sensory evaluations indicated that Greek consumers preferred Spunta over Sarpo Mira, especially with respect to taste. However, in that case the difference for most sensory parameters were not very large. Besides Sarpo Mira had also higher scores than Spunta for some sensory parameters (colour, hardness).

It is therefore possible that Sarpo Mira could achieve a significant share of the organic potato market. However, the survey reported here was based on only a relatively small sample of consumers and only included consumers from one region of Crete.

It would be prudent to carry out further more substantial sensory evaluations to gain a more detailed understanding of the likely market potential of Sarpo Mira in the Greek market.

Chapter 6. General Discussion

6.1. The influence of different organic fertilisers and biochar on crop health, yield and quality parameters of the cultivars (a) Spunta and (b) Sarpo Mira.

Potato (*Solanum tuberosum*) is a crop of great importance because of its contribution to the requirements of the world for food (Karam *et al.*, 2009). While several researches have been carried out for potato crops because of their importance, there is still lack of information regarding the quality characteristics for lots of cultivars and the way these can be influenced by different kind of fertilisers or can be negatively affected by pests.

Especially, the effects of biochar application in this crop have been reported through scientific studies in a very limited extent. Thus, a main objective of this thesis, was to investigate the effect of different organic fertilisers and of biochar on crop health, yield and quality parameters of the potato cultivars Spunta and Sarpo Mira. The choice of the variety, as has been previously mentioned has been made considering the popularity of Spunta variety in Greece and the resistance of Sarpo Mira to Late Blight, which creates the thought that Sarpo Mira can probably replace Spunta in the Greek potato production, providing higher sales.

For that purpose, the fertilisers used were: chicken manure, sheep manure and communal waste compost. Nair *et al.* (2014), mention that the application of biochar can potentially be advantageous in cropping systems in terms of nutrient recycling, soil conditioning, and long-term carbon sequestration. They stated the lack of information regarding the potential benefits of biochar application in cropping systems and they investigated the potential use of biochar for commercial potato production. The results of their study indicated that biochar may increase the pH of the soil, the yield and may promote visibly better plant growth. However, these observations/increases were not always considered statistically significant. It worth noting that the same authors mentioned that these results are promising since no decrease in the potato yields was detected in contrast with other cropping systems. Hence, since biochar can be used in order to facilitate the management of degraded soils or soils poor in nutrients, by reducing the bulk density, it can fairly be considered as a potential valuable tool for increasing potato yields. The prospective to use biochar as an amendment in horticultural crops providing an avenue for soil management system through its regulative abilities with regards to soil's pH and electrical conductivity, is also suggested by Upadhyay *et al.*, (2014). In agreement with all the above, previous research of Akhtar *et al*. (2014), also suggests that the application of biochar can be used for enhancing soil water storage and therefore crop productivity may be benefited.

In agreement with Nair *et al.* (2014), according to the results given in the previous Chapter, indeed biochar application in the cropping systems used, indicated beneficial effects of biochar on the potato quality characteristics studied. As such, there was evidence that in spring potato crops, the addition of biochar can influence the emergence of the plants. In particular, emergence of Spunta crops can be delayed when biochar is added to compost fertilised crops. On the other hand, emergence occurred earlier for Spunta, when biochar was added to chicken manure treated plots. It can therefore be assumed that biochar may be potentially used to "regulate" the emergence of Spunta plants in the desirable period of time and according to the weather conditions expected.

There was also evidence that in spring crop of 2012, when chicken manure was combined with biochar, the results in marketable yield were even better. In addition, the dry matter of autumn Sarpo Mira tubers were significantly higher when biochar was applied and thus it is indicated a positive effect of biochar in this variety. The reason of this finding probably relies on the limitation of leaching losses and/or on the optimisation of the availability of NH_4^+ and K^+ to potato crops, as already described in the relevant chapter. Better results upon the application of biochar in the potato systems studied were shown and when biochar was combined with communal waste compost, as it was found significantly lower % weight of waste small tubers in comparison to fertilization treatments without the application of biochar. In addition, rresults from autumn experiments showed that the addition of biochar in the soil resulted in higher number of tubers/m^2. These findings supported the theory of Nair et al. (2014) who suggested that potato yield can potentially be positively influenced by the application of biochar.

Communal waste compost when used for fertilisation purposes without being combined with biochar, was shown as factor of influence for the emergence only for the plants of the Sarpo Mira variety. In more detail, these plants emerged earlier than expected. However, in all different treatments of fertilisation, Sarpo Mira showed later emergence than Spunta in all experiments conducted, indicating that in cold conditions Spunta has better adaptation than Sarpo Mira. Therefore, it can be said that the type of fertilisation does not affect the earlier emergence of Spunta in comparison to Sarpo Mira when talking for either spring or autumn crops. Thus, it can be assumed that Sarpo Mira can replace in potato-cropping systems the variety Spunta when earlier emergence is required. Such a case can be when inappropriate weather conditions can be foreseen and must be avoided.

Chicken and sheep manure treatments were found to increase the levels of fresh and marketable yield and tuber' dry matter as well as the marketable yield, probably due to the higher levels of Nitrogen they have in comparison to the communal waste compost. This assumption is based on knowledge derived in the past. Amara *et al.* (2015) found through their research that the organic manure and the level of nitrogen fertiliser increased the positive impacts on the vegetative physiological proprieties of potato plants.

In the case of the field experiments carried out in autumn, no main effects of fertiliser type, biochar soil amendment and potato variety choice on the days to 50% emergence, were observed. Still, Sarpo Mira plants had higher emergence that those of Spunta variety when the final percentage of emerged plants was measured.

The type of the fertiliser, was also shown to affect in interaction with variety the chlorophyll content of potato leaves but only in experiments carried out in spring. Plants of Spunta variety had lower concentration of chlorophyll on their leaves than those of Sarpo Mira during the whole growing period in both years (2011 & 2012). In must, be mentioned that the effects of nitrogen in leaf chlorophyll and potato yield are usually positive (except if added in excess) and are positively correlated (Guler, 2009). Results also indicated differences in chlorophyll levels of potatoes planted in different dates, under different types of fertilisation. In earlier planted crops fertilised with communal compost there was higher chlorophyll content in the leaves of the plants in comparison to those of plants fertilised with chicken and sheep manure. In contrast chlorophyll levels of plants fertilised with communal waste compost were lower than in plants treated with chicken and sheep manure in later planted crops. Probably these patterns are related to Nitrogen's losses occurring between the two planting and harvest dates.

Chicken manure also affected negatively the amount of % dry matter of the tubers. Sheep and chicken manure resulted in higher fresh and marketable yield and in dry matter than communal waste compost.

An unexpectable result, was this that concerned the slight effect of the type of fertiliser on tuber yield since other researchers have indicated that it does affect it (Juntarathep 2004; Santos 2006). This result, it can possibly be explained by the different types of soil that researchers who support the opposite opinion, carried out their experiments.

With regards to chicken manure, it was found that at late harvest time this type of fertiliser beneficially resulted in lower % weight of waste small tubers, while at early harvest time the addition of chicken manure resulted in higher % weight of waste tubers compared to sheep manure and the communal waste compost. However, when this fertiliser was combined with biochar the % weight of waste tubers was more limited, indicating once more the beneficial effects of biochar in the potato systems studied.

6.2. Pest resistance in Spunta and Sarpo Mira and the extent of pest damage caused by Lepidoptera attacking potatoes.

Spring growing season in Crete, proved to be appropriate for potato cultivation in terms of damage by pests as no insect attacks were observed other than from *Tuta absoluta*. Sarpo Mira showed greater resistance to that pest than the variety Spunta. In particular, the damage on leaves of potatoes caused by *T. absoluta* was 2-10 times more severe in Spunta spring crops, depending on the year of cultivation and the harvest date.

Sarpo Mira has been mentioned to be a potato cultivar resistant to Late Blight (Cock, 2015). The current study showed that Sarpo Mira was also more resistant than Spunta to Late Blight and thus can probably replace it in spring grown organic crops in Greece, where the cultivation of Spunta is very popular. The same assumption can be made for autumn crops, as the results of the present study indicated that Sarpo Mira produce higher total yields in organic production systems with drip irrigation, which have probably prevented potential decrease on potato yields by Late Blight. This assumption, relies on the thought that the epidemics of Late Blight are benefited by high humidity (490%) and low temperatures (Olanya *et al.*, 2007) and that through drip irrigation humidity is not spread in the same extent as through other methods of irrigation.

The fertilisers used for the purposes of the current research, was shown to influence the damages caused by pests but not in the extent expected. It can be said that results indicated that for Spunta plants, fertilisation with communal compost can have negative effects in contrast to fertilization with chicken manure. Poultry manure's (and therefore also chicken manure) have high nitrogen content, and for that reason is considered to be a very desirable manure (Davis et al., 2017). On the other hand, when nitrogen input is decreased, the performance of herbivore insects is also decreased (Inbar *et al.*, 2001). Thus, considering that according to the analyses of the fertilisers used for this study it was found that chicken manure had higher concentration of nitrogen, the differences in the effects of chicken manure and communal waste compost on damages caused by pests can be explained.

The reason that fertilisation was expected to influence more extensively the insect population is because Nitrogen plays a very important role in the development of herbivore populations. In more detail when a fertiliser with Nitrogen is applied to crops, usually the preference of the herbivores for the fertilised plants is increased. Consequently, it is assumed that food consumption is increased and therefore the health of the insects, their survival and their growth. Moreover, the reproduction and the density of the population of the insects is also expected to be increased (Zhong-xian *et al*., 2007). Due to these reasons and considering that the fertilisers used had high levels of Nitrogen, it was surprising that generally the insects' population was not affected by the fertilisers to the extent expected.

For Hymenoptera a significant interaction between fertiliser type and biochar was detected, with biochar amendments resulting in higher aerial populations when used in combination with sheep and chicken manure, but lower populations when used with communal waste compost. The finding that the combination of biochar with sheep and chicken manure resulted in earlier emergence of the plants while when combined with communal compost the emergence of plant was delayed may explain the influence of fertilisation on the population of insects. In particular, later emergence means smaller plants in the dates of trapping the insects and therefore less food for them while earlier emergence means bigger plants and higher amounts for food the insects. For the same reason probably, most of the populations monitored in the spring crops were greater in June which means closer to the period of harvest time.

With regards to autumn season, the populations of crop canopy insects (Diptera, Coleoptera, Hymenoptera) were decreased over time. Thus, it can be said that in both spring sampling seasons, the insect populations increased over time in most of the insect orders. In autumn sampling season the population of the insect studied decreased over time, probably due to the changes in temperature. Coleoptera had the higher populations in all three sampling seasons (both spring and autumn), which was expected as several of them and especially the potato beetle (*Leptinotarsa decemlineata*) are known for their preferences in potatoes (Jacques and Fasulo, 2015). At this point, it must be mentioned that the abundance of potato beetle has been reported not to be increased significantly after the increasing application of poultry manure (Boiteau *et al*., 2007) which indicates similarities with the results of the current study.

The type of fertilisation didn't show many significant differences in population of the incest orders except in few orders in aerial and canopy insect in 2011 spring crop season and in aerial in autumn 2011 and 2012 spring crop season experiments. Thus, further research is required so to have more accurate information about how fertilisation and biochar amendments affect incest orders.

Finally, as it shown in the results 2012 spring season sampling, results showed even higher populations through the sampling dates which confirms previous statements that higher temperatures increase the insect activity. More specifically, it is said that the local weather influences significantly the populations of insects and among the weather components that have this ability, temperature and moisture are the main ones. The reason that in increased temperatures, insect activity also tends to increase, relies on the poikilothermal or in other words cold –blooded conditions of insects. That means that insects cannot regulate the temperature of their body which in turn means that their temperature depends on the ambient temperature of the environment. Therefore, insects such as life miners have better development in temperatures ranging between 27^{o}C and 31 ^{o}C and worse development in the cool winter conditions (Palumbo, 2011). Consequently, the results of this study that indicated an increase of the populations of insects, was expected and especially in the case of *Tuta absoluta* which is considered to be a leaf miner. Of course, insect development also depends on other factors as well, such as the availability of food and light. Greek climate provides greater light in the same period that the temperature increases. On the other hand, when temperature is increased in a rational level (up to 32 ^{o}C) growth development of plants it is also increased and thus the food quantities available for insects are greater, which in turn means that the damage the insects cause to the plants through eating is greater, which is also shown in the current results concerning the waste tubers.

Behinds, considering that potatoes are grown better at about 20 ^{o}C (Rykaczewska, 2013), it becomes obvious from the results and the weather monitoring data that the potatoes grown in this study benefited from the Greek climate and offered higher quantities of food to insects in comparison to the periods where temperature was not optimum.

6.3 Sensory characteristics

Since *Solanum tuberosum* L., is daily consumed by millions of people (Chiavaro *et al*., 2006), several researches have focused on its nutritional value and its contribution to human health. From this point of view, is considered to be low in fat and healthy while it is also economical (Abu-Ghannam and Crowley, 2006). The current study provides new data for the perception of consumers with regards to some main sensory characteristics of potato, such as colour, texture and taste.

According to the results provided in Chapter 5, the type of cultivar was not found to affect the time required for frying but it did affect the time required for the boiling and oven-baking of the potatoes studied. In particular, Spunta potatoes were found to require shorter period of boiling and baking time than Sarpo Mira potatoes. However, since this period of time was characterised as "moderately short" for Spunta and as "slightly short" for boiling or "slightly short to neither short nor long" (with regards to baking) for Sarpo Mira, it can be assumed that in both cases consumers were not dissatisfied regarding the time required for cooking, as this time was not long.

The overall taste of the potatoes studied, was not affected by the cooking method and according to the questionnaire used, the panel "liked very much" the potatoes. However, in terms of sweetness, Spunta was perceived as being sweeter than Sarpo Mira. For the boiled and the oven-baked potatoes, it can be said that the taste panel like the potatoes "very much" to "moderately" and therefore it can be assumed that the varieties studied may be preferred fried than boiled or baked.

The Sarpo Mira potatoes were characterised as "very much sweet" while the Spunta ones as "moderately sweet" to "slightly sweet". It can be said that the taste panel used for the purposes of the current study liked "extremely" to "very much" the Sarpo Mira potatoes. The taste panel used for the purposes of the current study liked "very much" to "moderately" the Spunta potatoes.

Spunta received higher scores for frying colour and texture, while Sarpo Mira had higher scores for flesh colour and hardness. The factor "variety" influenced significantly the consumers' perception regarding the texture, in terms of hardness, of the potatoes. In particular, the panel thought that the Sarpo Mira potatoes was "very much hard" while of Spunta potatoes, "moderately soft". In terms of texture, good-quality potatoes are firm (Bahlol, 2005) and therefore the results from the sensory evaluation of the potatoes studied show that Spunta may be preferred than Sarpo Mira in terms of texture. However, it must be noticed that well-cooked potatoes are never hard.

The mild heat processing in the temperature range 45–55 °C can affect the texture and causes softening of the plant tissues (Lebovka *et al*., 2004). Of course, all sensory evaluation parameters, it is well known that are influenced by several parameters such as storage time and variety. The difference between the two cultivars studied in terms of texture, is probably related with the different influence the temperature of cooking has on the potatoes. An alternative point of view for explaining the results considering the hardness, is related to the dry matter. As previously mentioned Sarpo Mira was found to have significantly greater amounts of dry matter, in comparison to Spunta and thus it can be said that it was expected to be perceived as "harder" from the consumers. The starch content which is also probably correlated with the results, was not measured as it was not part of the objectives of this thesis.

As far as the consumers acceptability, Maskan (2001), states that is correlated with colour which is a very important appearance attribute. However, there was no significant difference in the score for colour overall preference, which means that consumers did not prefer –in terms of colour-either of the cultivars studied opposed to the other.

The general opinion of the panel used for this study about the potatoes, was "very good", with Spunta having a little lower score that Sarpo Mira potatoes and in particular scores closer to "moderately good general opinion".

The overall results from the sensory evaluations indicated that Greek consumers preferred Spunta over Sarpo Mira, especially with respect to taste. However, in that case the difference for most sensory parameters were not very big. Besides Sarpo Mira had also higher scores than Spunta for some sensory parameters (colour, hardness).

It is therefore possible that Sarpo Mira could achieve a significant share of the Greek organic potato market. However, due to small sample of consumers that evaluated the potatoes there is not strong evidence for the above-mentioned results. Further investigation regarding the consumer acceptability for Spunta and Sarpo Mira potatoes is required, as explained in the following subchapter.

6.4. Suggestions for future work and conclusions

The reason that Sarpo Mira was one of the cultivars used for the experiments of the current research, was that there is evidence that has higher resistance to Late Blight than the cultivar Spunta (Speiser *et al.*, 2006; Rietman *et al.*, 2012). Therefore, it was thought that in Greece where Spunta is most used cultivar, can be replaced by Sarpo Mira which would benefit especially the organic production of potato, due to the avoidance of crop protection by conventional methods.

The results of this study showed that Sarpo Mira in agreement with the previous hypothesis, had higher resistance in main pests that are harmful for potatoes, and more specifically it was significantly more resistant than Spunta, against the insect *Tuta absoluta*. However, with regards to spring crops, as previously mentioned, Sarpo Mira matures later than Spunta and this results in the harvest of the potatoes after the increase of infestation levels of Lepidopteran pests due to the increased environmental temperature. The results of the present study are in agreement with the previously mentioned reports, as according to them the emergence rates (at 50%) of Spunta were higher than those of Sarpo Mira. However, since the emergence rate of 75%, was reached earlier by Sarpo Mira in the 2nd year of the experiments (2012), it cannot be said that this variety has definitely later emergence rate in comparison to Spunta.

As Spunta is reported to have a relatively short growing season (NIAB, 2013), while according to the present experiments in 2012 it matured later than Sarpo Mira further investigation in future is required. In case, that Sarpo Mira can indeed mature later than Spunta in some cases such as in the present one that happened in Greece, then the whole concept of variety choice can be changed. This change might be beneficial for the farmers, the seasonal Greek market and in turn for the imports/exports of the country also influencing the market of other countries. For that reason, the influence of the soil and the climatic conditions should be further investigated, while experiments in greenhouse conditions would clarify better the possible explanation of early maturity of Sarpo Mira due to weather conditions.

As far as the effect of biochar on the emergence of potato tubers is concerned, it can be said that it can possibly delay or speed the emergence of Spunta but further research is required especially in the case of biochar's combination with sheep manure in cultivated areas with the variety Sarpo Mira, where the emergence can be delayed. The reason triggering this delay is still unknown due to the lack of literature regarding biochar as a fertiliser in potato cultivation. Yet, if the emergence with the combination of biochar and sheep manure can be delayed, then this knowledge can benefit farmers as in the case that producers know that harmful weather conditions that will last for some days and want to delay the emergence of their potatoes. Besides, the conclusion of the potential success of the replacement of Spunta by Sarpo Mira, is also indicated from the results suggesting that upon addition of biochar, the dry matter of tubers of this variety is increased.

The obviously greater resistance of Sarpo Mira in comparison to Spunta, to important harmful pests, contributes the knowledge required to make decisions regarding the choice of variety for plantation. The already known resistance of Sarpo Mira to Late Blight, indicates that suggestions for future research regarding the possibly of Sarpo Mira's resistance to other pest species as well.

As expected, there were significant main effects of production year and potato variety choice on chlorophyll concentrations in potato leaves depending on the length of the period before emergence started. As Sarpo Mira had higher chlorophyll content than Spunta, it is assumed to have greater N-use efficiency, according to Hassan (2009). Sarpo Mira also had better results than Spunta, in terms of fresh yield, % dry matter and total marketable yield of tubers and therefore has the potential to replace the use of Spunta variety in both spring and autumn cultivations. Best results on fresh yield, marketable yield and marketable dry matter were also found when crops were early planted. In that point, it is worth mentioning that results of the experiment conducted the spring of 2011, indicated that harvest date also influences the concentration of chlorophyll in potato leaves. Earlier harvested crops had higher levels of chlorophyll concentrations.

In spring crops, the size category seemed to significantly affect the weight of waste tubers. Results were clearer in the case of Spunta, of which the weight of waste tubers was higher for those of medium (6.5-8.5cm) and large size (>8.5cm). The results for the weight of waste tubers of Sarpo Mira varied from year to year.
Sarpo Mira, can probably be used as an alternative to Spunta and in terms of waste tubers, as it was found to have the lower weight in total and larger size categories of waste tubers. In autumn crops, it was observed that harvest date also influences the weight of waste tubers, in contrast to Sarpo Mira tubers that were not influenced. As the weather conditions in this crop period vary a lot in Greece, it can be said that Sarpo Mira may be more suitable to be used, as it will allow a delayed harvest in case of unsuitable conditions in terms of weather. In spring crops, early

planting time also resulted in higher % weight of waste tubers but only for the large ones, suggesting that late planting would be more beneficial. Early harvest was shown to be negative in terms of % weight of waste large tubers and late harvest for the waste medium tubers. Early planting and early harvest that showed less percentage of waste tubers indicates that this may be the best time period for planting and harvest so to minimize the yield losses but further experiments will give more accurate result for the best combination. Also, the finding that Sarpo Mira had lower percentage of waste tubers in early planting date make but no difference on late planting may make Sarpo Mira an alternative to Spunta for early planting potato crop.

The comparison of spring and autumn crops in terms of chlorophyll content of leaves, shows that chlorophyll levels of autumn crops were lower in both varieties almost the whole growing period. As mentioned earlier, it can therefore be assumed that N-supply/availability was lower in the autumn cropping season due to the decreased soil temperatures.

Autumn experiments, indicated that harvest date is also a factor that influences the total tuber numbers and % weight of tubers in different size categories as the earlier the harvest date the higher was the number of tubers per m^2. Late harvest of the late planting time resulted in lowered number of tubers per m^2, also in spring experiments. Additionally, the earlier the harvest date the greater was the weight (%) of total yield on medium and large tubers. Harvest time also affected negatively the weight of Spunta tubers of all sizes. In spring experiment of 2012, the % weight of total production of large tubers (>8.5cm), was approximately twice higher for early planted than later ones, while early harvest was found to affect positively the total production of small and large tubers. In contrast, medium tubers were positively affected in terms of total production by late harvest. The number of tubers, was also affected by the date of harvest. The best combination of planting and harvest date also requires further investigation as results indicate early planting and early harvest showed higher percentage of total tubers.

Once more, it was indicated that Sarpo Mira can replace the use of Spunta, since it resulted in higher number of tubers per m^2 and in higher %weight of total yield on very small, small and medium tubers. However further investigation is required as Spunta resulted in higher number of large (>8.5cm) tubers according to the results of 2011 and in large tubers according to the results of 2012. The investigation suggested to be carried out shall also include research on market needs and consumers' preferences regarding the size of potatoes.

Another suggestion for future work concerns the potential resistance of both varieties studied here in *Tuta absoluta*, under several types of fertilisation.

Spunta crops were used as an indicator to see the insect severity in the variety. In the future, experiments shall also include as a factor a different variety. In addition, future experiments must record the Colorado beetle and *Phthorimaea Opercula* population as major potato pests and how biochar and fertility amendments affect the populations. However, according to the current results, it is suggested that fertilisation cannot be used as a tool for the management of pests.

With regards to the sensory characteristics of the potato cultivars studied it is also considered to be necessary to carry out further more substantial sensory evaluations to gain a more detailed understanding of the likely market potential of Sarpo Mira in the Greek market.

Therefore, considering all the previously mentioned issues, it can be said that the answer to the hypothesis that Sarpo Mira can replace Spunta in the Greek potato market might be positive. The importance of the evidence for these positive results is great, as Sarpo Mira can be characterised as more "environmentally-friendly" than Spunta not only because is more resistant to the pest enemies of potatoes but also because conventional farming is harmful for the environment. Besides, the use of pesticides increases pesticide resistance. Further research should be carried out to investigate the positive effects of the replacement of Spunta by Sarpo Mira, as environment, consumers and farmers may be benefited by this replacement.

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Appendix

Table A.1 The nine principal growth stages of potatoes

(adopted from Hack *et al*., 1993)

Code		Description of development from tuber	Description of development from seed
2- and 3digit			
Principal growth stage 0: Sprouting/Germination			
00	000	Innate or enforced dormancy, tuber not sprouted	Dry seed
01	001	Beginning of sprouting: sprouts visible (< 1 mm)	Beginning of seed imbibition
02	002	Sprouts upright (< 2 mm)	
03	003	End of dormancy: sprouts 2–3 mm	Seed imbibition complete
05	005	Beginning of root formation	Radicle (root) emerged from seed
07	007	Beginning of stem formation	Hypocotyl with cotyledons breaking
08	008	Stems growing towards soil surface, formation of scale leaves in the axils of which stolons will develop later	Hypocotyl with cotyledons growing towards soil surface
09	009	Emergence: stems break through soil surface	Emergence: cotyledons break through soil surface
	021–029[1]		

Code		Description of development from tuber and seed
2- and 3digit		
Principal growth stage 1: Leaf development		
10	100	From tuber: first leaves begin to extend From seed: cotyledons completely unfolded
11	101	1st leaf of main stem unfolded (> 4 cm)
12	102	2nd leaf of main stem unfolded (> 4 cm)
13	103	3rd leaf Auf main stem unfolded (> 4 cm)
1 .	10 .	Stages continuous till . . .
19	109	9 or more leaves of main stem unfolded (> 4cm) (2digit);[2] 9 leaves of main stem unfolded (> 4 cm) (3digit)
	110	10th leaf of main stem unfolded (> 4 cm)
	11 .	Stages continuous till . . .
	119	19. leaf of main stem unfolded (> 4 cm)
	121	First leaf of 2nd order branch above first inflorescence unfolded (> 4 cm)
	122	2nd leaf of 2nd order branch above first inflorescence unfolded (> 4 cm)
	12 .	Stages continuous till . . .
	131	First leaf of 3rd order branch above 2nd inflorescence unfolded (> 4 cm)
	132	2nd leaf of 3rd order branch above 2nd inflorescence unfolded (> 4 cm)
	13 .	Stages continuous till . . .
	1NX	Xth leaf of nth order branch above n-1th inflorescence unfolded (> 4 cm)

Codes		Description
2- and 3digit		
Principal growth stage 2: Formation of basal side shoots below and above soil surface (main stem)		
21	201	First basal side shoot visible (> 5 cm)
22	202	2nd basal side shoot visible (> 5 cm)
23	203	3rd basal side shoot visible (> 5 cm)
2 .	20 .	Stages continuous till . . .
29	209	9 or more basal side shoots visible (> 5 cm)

2- and 3digit

Principal growth stage 3: Main stem elongation (crop cover)

31	301	Beginning of crop cover: 10% of plants meet between rows
32	302	20% off plants meet between rows
33	303	30% of plants meet between rows
34	304	40% of plants meet between rows
35	305	50% of plants meet between rows
36	306	60% of plants meet between rows
37	307	70% of plants meet between rows
38	308	80% of plants meet between rows
39	309	Crop cover complete: about 90% of plants meet between rows

2- and 3digit

Principal growth stage 4: Tuber formation

40	400	Tuber initiation: swelling of first stolon tips to twice the diameter of subtending stolon
41	401	10% of total final tuber mass reached
42	402	20% of total final tuber mass reached
43	403	30% of total final tuber mass reached
44	404	40% of total final tuber mass reached
45	405	50% of total final tuber mass reached
46	406	60% of total final tuber mass reached
47	407	70% of total final tuber mass reached
48	408	Maximum of total tuber mass reached, tubers detach easily from stolons, skin set not yet complete (skin easily removable with thumb)
49	409	Skin set complete: (skin at apical end of tuber not removable with thumb) 95% of tubers in this stage

Principal growth stage 5: Inflorescence (cyme) emergence

51	501	First individual buds (1–2 mm) of first inflorescence visible (main stem)
55	505	Buds of first inflorescence extended to 5 mm
59	509	First flower petals of first inflorescence visible

2- and 3digit

Principal growth stage 5: Inflorescence emergence (continuation)

	521	Individual buds of 2nd inflorescence visible (second order branch)
	525	Buds of 2nd inflorescence extended to 5 mm open (main stem)
	529	First flower petals of 2nd inflorescence visible above sepals
	531	Individuell buds of 3rd inflorescence visible(3rd order branch)
	535	Buds of 3rd inflorescence extended to 5 mm
	539	First flower petals of 3rd inflorescence visible above sepals
	5N .	Nth inflorescence emerging

2- and 3digit

Principal growth stage 6: Flowering

60	600	First open flowers in population
61	601	Beginning of flowering: 10% of flowers in the first inflorescence open (main stem)
62	602	20% of flowers in the first inflorescence open
63	603	30% of flowers in the first inflorescence open
64	604	40% of flowers in the first inflorescence open
65	605	Full flowering: 50% of flowers in the first inflorescence open
66	606	60% of flowers in the first inflorescence open
67	607	70% of flowers in the first inflorescence open
68	608	80% of flowers in the first inflorescence open
69	609	End of flowering in the first inflorescence

Principal growth stage 6: Flowering (continuation)

621	Beginning of flowering: 10% of flowers in the 2nd inflorescence open (second order branch)
625	Full flowering: 50% of flowers in the 2nd inflorescence open
629	End of flowering in the 2nd inflorescence
631	Beginning of flowering: 10% of flowers in the 3rd inflorescence open (third order branch)
635	Full flowering: 50% of flowers in the 3rd inflorescence open
639	End of flowering in the 3rd inflorescence
6N .	Nth inflorescence flowering
6N9	End of flowering

2- and 3digit

Principal growth stage 7: Development of fruit

70	700	First berries visible
71	701	10% of berries in the first fructification have reached full size (main stem)
72	702	20% of berries in the first fructification have reached full size
73	703	30% of berries in the first fructification have reached full size
7 .	70 .	Stages continuous till . . .
	721	10% of berries in the 2nd fructification have reached full size (second order branch)
	7N .	Development of berries in nth fructification
	7N9	Nearly all berries in the nth fructification have reached full size (or have been shed)

2- and 3digit

Principal growth stage 8: Ripening of fruit and seed

81	801	Berries in the first fructification still green, seed light-coloured (main stem)
85	805	Berries in the first fructification ochre-coloured or brownish
89	809	Berries in the first fructification shrivelled, seed dark
	821	Berries in the 2nd fructification still green, seed light-coloured (second order branch)
	8N .	Ripening of fruit and seed in nth fructification

Phenological growth stages and BBCH-identification keys of potato

Codes		Description
2- and 3digit		

Principal growth stage 9: Senescence

91	901	Beginning of leaf yellowing
93	903	Most of the leaves yellowish
95	905	50% of the leaves brownish
97	907	Leaves and stem dead, stems bleached and dry
99	909	Harvested product