Effect of variety, fertilisation, rotation, crop protection and growing season on yield and nutritional quality of potato (*Solanum tuberosum* L.)

Thesis submitted for the degree of Doctor of Philosophy

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Abstract

Potatoes (*Solanum tuberosum* L.*)* are the most important food crop in the world after rice and wheat. Potato tubers contain many types of essential nutrients. They contain high concentrations of carbohydrates and also vitamins, minerals and protein. They also contain toxic compounds called glycoalkaloids. Potato is classed as a protective vegetable because of its high vitamin C content. The objectives of this study were to determine the effects of different fertiliser types (composted cattle manure, mineral NPK fertiliser), pre-crop (beans, barley) crop protection protocols (organic, conventional) and growing season on the nutritional quality of vitamin C, glycoalkaloids and minerals and yield of different varieties of potato (Sante, Sarpo Mira, Nicola, Fontane, Agria and Cara). Field experiments were carried out during the 2010 and 2011 growing seasons at Nafferton Farm (Newcastle University).

The experiment was a split split split plot-design. The main plot was crop rotation, the sub-plot was crop protection, the sub-sub plot was fertility management and sub-sub-sub plot was variety. The vitamin C content was determined by two different methods of analyses; colorimetric titration and high- performance liquid chromatography (HPLC). Mineral content was assessed by the Dumas combustion method at Sabanci University, Turkey. Total glycoalkaloids were determined according to the AOAC method 997. 13.
A significant effect of fertilisation was detected for potato yield for both of years. In plots treated with NPK fertilisers, higher yield, compared to compost was obtained for both seasons. In addition conventional crop protection increased yield in both years.

Pre-crop significantly affected yield in both years, with higher yields being recorded after beans than barley in 2010 while, a pre-crop of barley resulted in the significantly higher yield than beans in 2011. However, no significant difference between varieties was detected. Also, no significant interactions were detected for tuber yield in 2010. However a significant 2-way interaction between crop protection and pre-crop was observed in 2011, with a pre-crop of beans resulting in the highest yields under conventional crop protection, while a pre-crop of barley resulted in the significantly higher yield under organic crop protection systems.

Results of the second growing season (2011) were based on the NUE potato experiment and showed that there was significant difference ($P < 0.05$) in yield between varieties, fertilisation

and crop protection. A significant interaction between fertilisation and variety was detected for the yield.

There was a significant effect of variety on tuber vitamin C content ($P < 0.001$), in 2010 and 2011. The concentrations were higher in Sante than Sarpo Mira. There were no significant influences of other treatments (fertility, rotation, crop protection). However, a 2-way interaction between fertilisation and variety was detected in 2011.

In 2011 there was a significant effect of varieties on vitamin C content, but no significant effect of fertility and crop protection treatments. However, a significant interactions between fertility, variety and crop protection treatments was detected but only for the titration analysis for vitamin C content. There were no significant effects ($P > 0.05$) of fertilisation, pre-crop and crop protection on glycoalkaloid concentrations. However, a significant 3-way interaction between fertilisation, variety and rotation was detected for alpha solanine in 2011. A significant 3-way interaction between crop protection, fertilisation and variety was detected for alpha chaconine in 2010.

In 2010 the mineral content (N, P, K, Na and Ca) of potatoes was significantly affected by fertilisation treatments. N, P and Ca contents were significantly increased by NPK application while the K and Na contents were significantly increased by compost application. In 2011 Ca contents were affected by fertilisation treatments only. Effects of variety, rotation and crop protection and interactions between factors were also detected for macro mineral contents. However, in 2011 no effect of pre-crop on tuber macronutrient concentration was detected. There was a significant difference in micronutrient concentration between variety, fertilisation and crop protection. No significant effect of rotations was detected for micronutrient concentrations in both of seasons.

In conclusion, in both years, 2010 and 2011, variety significantly affected vitamin C content of potato tubers, but there were no significant effects of fertility, pre-crop and crop protection treatments irrespective of the analytical method (titration and HPLC) analysis. Sante tubers contained about 20% more vitamin C than Sarpo Mira. Therefore, it appears that variety choice is a reliable means of manipulating vitamin C as a component of tuber quality compared with other agronomic treatments. In addition, mineral content was also affected by treatments (fertility, variety, rotation and crop protection) and was highly variable.

For the two years, similar results were obtained in alpha solanine and alpha chaconine content. Significant interactions between rotation, fertilisation and variety were only detected on alpha solanine content during 2011. Also, significant interactions between variety, fertility and crop protection were observed on alpha chaconine content during 2010.

The 2010 and 2011 growing seasons appeared to have a significant effect on alpha solanine, macro minerals and micro minerals but did not appear to affect yield, vitamin C and alpha chaconine contents.

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Abbreviations

HPLC	High performance liquid chromatography
N	Nitrogen
P	Phosphorus
K	Potassium
S	Sulphur
Mg	Magnesium
Na	Sodium
Fe	Iron
Zn	Zinc
Ca	Calcium
Cd	Cadmium
B	Boron
Mn	Manganese
DW	Dry weight
FW	Fresh weight
VAR	Variety
FE	Fertilisation
CP	Crop protection
PC	Pre-crop
GS	Growing seasons
α	Alpha
Rt	Retention time

CHAPTER 1 Literature Review

1.1 Introduction

Vegetables and fruits require a balanced fertilisation in order to achieve higher yield and to improve their nutritional quality. These issues are very important for the environment and human health and are closely related to the fertilisation ratio of N/ P/ K (Krinsky and Johnson, 2005). In recent years great interest has been focused on improving the quality of vegetables and fruits by developing different mechanisms and methods for the production of agricultural crops, in order to improve nutritional value and make them attractive to the consumer and simultaneously decreasing the environmental risks (Sansavini, 2006). Recently many consumers have come to believe that vegetables grown without the use of chemical fertilisers, pesticides, fungicides and herbicides are more nutritious and flavoursome, of better quality, healthier and less damaging to the environment than those are that (Lehesranta *et al.*, 2007).

Fertilisation management is one of the most important factors that plays a vital role in achieving satisfactory yield and plant growth and at the same time improving the quality of vegetables and fruits. Previous studies examined different kinds of vegetables, fruits and rates of fertilisation which vary in different regions of the world. Several studies have shown that the use of organic material (compost) in agriculture has many physical, chemical and biological benefits to the crops, soil and environment (Mkhabela and Warman, 2005).

Potato, *Solanum tuberosum* L., is the most popular food crop in the world after rice and wheat and seems to be the most consumed vegetable in Europe and probably in many other countries (Han *et al*., 2004). Furthermore, potato is described as healthy, edible and pro-health plant. Potato tuber is a basic component of the everyday diet in many countries. In most of Europe potato consumption ranges from about 34 to 96 kg per capita, but reaches 121 kg per capita per year in Poland (Gugała and Zarzecka, 2012).. In the USA potato consumption averages 63 kg per capita. Of 34 vegetables and fruits commonly consumed, potato is the third highest source of antioxidants (Gugała and Zarzecka, 2012).
Potato tubers are approximately 20% solids and 80% water, but these values can differ by several percentage points depending on the cultivar (Navarre et al., 2009).

Potato tubers also contain 13-30% carbohydrates, 13-37% dry matter and 0.7-4.6% proteins. In addition, vitamin C and other vitamins, minerals and phenolic substances are present (Liu et al., 2009). Dry matter content is one of the most important factors with regard to the texture of potatoes.

Potato tubers contain many types of essential nutrients, for instance: vitamins, carbohydrate, minerals and dry matter and in the human diet are classed as a protective vegetable because of their high vitamin C content (Wheeler, 2009).

Vitamin C is the most important vitamin in vegetables and fruits for human nutrition. In the human diet more than 90% of the vitamin C is supplied by fruits and vegetables (including potato). Vitamin C is necessary for the prevention of scurvey and maintenance of gums and healthy skin. Vitamin C, as an antioxidant, reportedly decreases the risk of cardiovascular diseases and some forms of cancer (Seung, 2000).

The chemical content of potato tubers such as ascorbic acid (vitamin C) and phenolic compounds are influenced by different factors. Important factors to be considered are variety, period and temperature of storage, soil and climatic conditions, maturity of tubers, and damage to tubers (Hamouz *et al.*, 1999). Potato growth response to organic and inorganic fertiliser depends highly on genotype and environmental conditions (Ukom, 2009).

Nutritionally fruits and vegetables are the major source of vitamin C (Bénard *et al.*, 2009). Relatively few reports exist on pre and postharvest factors that influence the vitamin C content of food crops, although these factors are responsible for the wide variation in vitamin C level of fruits and vegetables (Seung, 2000). As potatoes become staples in the diets of an increasing number of humans, small differences in potato nutritional composition will have major influence on population health. Potatoes are a good source of potassium and B vitamins and are particularly high in vitamin C. Several compounds in potatoes contribute to antioxidant activity and the rising interest in cultivars with pigmented flesh (Burgos *et al.*, 2007).

Organic agriculture is a system that prohibits the use of mineral fertilisers and synthetic pesticides. Interest from both consumers and producers has grown considerably in the past decade throughout the world (Paull 2011). Paull has reviewed the improvement of sustainable agriculture (mainly organic agriculture) for 71 countries. He indicated that between 2001 and 2011 the consumption and global growing production area increased at a rate of approximately 9% per annum. In the UK the land area used for organic agriculture (fully organic and in conversion) increased to a maximum of 743516ha in 2008 although has since declined to just over 605000ha in 2012. As with other commodities, the increasing demand for organic foods is explained mainly by consumers concerns about the safety and quality of foods and their perception that organically produced foods are healthier and safer than conventional foods.

A study by Brandt and Molgaard (2001) observed that organic fruits and vegetables most likely contained more of these compounds (minerals, vitamins, carbohydrates and proteins) than conventional ones, allowing for the possibility that organic plant foods may in fact benefit human health more than corresponding conventional ones.

The beliefs and attitudes of people towards the consumption of organic vegetables and fruits have been studied by Baniuniene *et al.*, (2008) where they noticed that the subjects tend to have positive attitudes towards consumption of vegetable and fruits produced from organic agriculture. Most of the study subjects claimed that organic vegetables and fruits were environmentally friendly, healthy more tasty and nutritious when compared with conventionally grown foods.

Vegetables and fruits are considered good sources of minerals (Barminas *et al.*, 1998). Generally minerals can classified as major minerals such as potassium (K), calcium (Ca), magnesium(Mg), phosphorus (P), sodium (N), chlorine (Cl) nitrogen (N), manganese (Mn) and nutritionally important minor and trace mineral for example copper (Cu) iron (Fe), nickel (Ni), sulphur (S), lead (Pb), and boron (B).

The importance of optimal mineral intake to preserve good health is widely documented (Navarre *et al.*, 2009). Potato is an essential source of different dietary minerals. Potato is well known as providing 18% of the recommended daily allowance (RDA) of potassium, and 2% calcium and zinc, 6% of iron, phosphorus and magnesium. Retention of most minerals is high in cooked potato with skin and boiled potato (True *et al.*, 1978).

Andre *et al.* (2007) found that most potato genotypes were balanced in terms of mineral contents and antioxidant compounds (vitamin C, phenolics and carotenoids) but some of them could still differ in the level of micronutrients. They also observed that after four months of postharvest storage at 4 °C the vitamin C losses ranged from 20- 60% in 33 potato genotypes and that this difference among the genotypes seemed to be lower after storage.

1.2 Nutrient composition of potato

1.2.1 Vitamin C

Bergquist *et al.* (2006) observed in a study that vitamin C content in spinach decreased during postharvest storage. Similar results were also observed by other experimental studies (Abushita *et al.,* 1997). In a different study Seung (2000) pointed that the most important factor to maintain vitamin C after harvest is temperature management. Haase and Weber (2003) showed that vitamin C content in potato samples was different due to varieties investigated.

lisiewska and Kmiecik (1996) observed that directly after harvesting, broccoli contained 116.3-116.4 mg of vitamin C in 100 mg of fresh matter, and cauliflower contained 60.5- 64.7 mg. Increasing the amount of nitrogen fertiliser from 80 to 120 kg N/ha decreased the content of vitamin C only in cauliflower by 70% but increased nitrate content by 44% and 33% in broccoli and cauliflower respectively. During the course of processing, the greatest losses in vitamin C content happened during blanching in cauliflower by 28-32% and in broccoli by 41-42%.

Another research by Zarzecka and Gugała (2003) showed that application of herbicides to potato tubers field caused an increase in the content of vitamin C compared with the control treatment. Ismail and Cheah (2003) demonstrated that not all organically grown vegetables (without pesticides) were higher in vitamins compared to the conventionally grown ones. In this study they found that only swamp cabbage grown organically was highest in vitamin C, riboflavin and β carotene contents between all the samples studied. In another study by Bénard *et al.* (2009) mentioned that for accurate determination of quantitative values of vitamin C in agricultural samples and in pharmaceutical preparations the cyclic voltammetric method can be used in quality control laboratories. They revealed that low contents of vitamin C in the range of 6-10 mg/100 g (cyclic voltammetric determination) were found in potato, lemon grass, carrot, cucumber and yam.

Asami *et al.* (2003) compared the total vitamin C and phenolic content of air-dried and freeze-dried strawberry and corn grown using organic, conventional and sustainable agricultural practice in 2003 and their results showed that the concentration of vitamin C in sustainably grown and organically grown samples were consistently higher than the conventionally grown crops. A statistically significant decrease in vitamin C level was also observed in air-dried and freeze-dried samples as compared to frozen samples.

1.2.2 **Glycoalkaloids (alpha solanine & alpha chaconine)**

Glycoalkaloids present in potato tubers are natural toxins. They play a role in host-plant resistance and hence protection against pests and diseases. Alpha solanine and alpha-chaconine are the two most important types of glycoalkaloids in the family Solanaceae including potatoes, eggplants and tomatoes (Navarre *et al.*, 2009). Whilst glycoalkaloids are beneficial for the potato crop, their presence in plants at levels above 20 mg/100 g of fresh tuber is toxic for human consumption (Sotelo and Serrano, 2000). It is very important to examine the concentration of potato tuber glycoalkaloids destined for human consumption. Several experimental studies determined the glycoalkaloid content of potato tubers by using different analytical methods including HPLC, titration and enzyme- linked immunosorbent-assay (ELISA).

Morgan *et al.* (1985) mentioned that the ELISA method employed much simpler sample preparation, was technically easier to carry out, and it would find wider application in the future for the determination of glycoalkaloid contents. Study by Griffiths and Dale (2001) showed that light exposure increased the concentration level of both alpha solanine and alpha chaconine in all eleven *S. phureja* genotypes studied. The large increase was noticed in alpha-solanine content, which increased on average by 2.8 mg/100 g as compared with an average increase of only 0.7 mg/100 g FW in alpha chaconine content. The total glycoalkaloid content was significantly higher in the leaf samples compared with the tuber samples.

Zrůst *et al.* (2001) exposed three Slovakian varieties to the light during post-harvest storage (one week and 14 days) during years 1996 and 1998 and measured the concentration of the two most important glycoalkaloids (alpha solanine and alpha chaconine). Results showed that after exposure to one week of lighting the average content of alpha solanine increased more than the content of alpha chaconine in all the groups of varieties. The increase in the total glycoalkaloid content in tubers after 14 days of lighting was approximately double in all the varieties.

Zrůst (1997) found that year has greater effect on content of glycoalkaloid than the variety. In all three varieties (Krystala, Karin, Arnika) mechanical damage of tubers increased highly significantly the total glycoalkaloid content compared with undamaged tubers. A study by Elżbieta (2012) reported that the industrial processes of manufacturing potato granules significantly reduced the content of glycoalkaloids (solanine and chaconine) and nitrate in finished and intermediates products compared with raw material. The highest decrease in glycoalkaloids was caused by peeling (50%) and blanching (63%).

A very recent study by Deußer *et al.* (2012) mentioned that contents of glycoalkaloid were highest in the peel of potato and lowest in the inner flesh, values in the flesh potato were below guideline limits in all varieties. Another study by Şengül *et al.* (2004) found out that the tuber content of alpha solanine ranged from 0.01 to 6.46 mg/kg FW, and alpha chaconine content from 0.35 to 28.12 mg/kg FW and total glycoalkaloid content from 0.66 to 32.76 mg/kg FW. Results of a study by Chuda *et al.* (2004) showed that there was no significant difference in content of glycoalkaloid between mature and immature tubers among all the varieties tested. The light exposure increased content of glycoalkaloid in long-term stored tubers of all four potato varieties tested except for Sayaka potato.

Total glycoalkaloid content of alpha chaconine and alpha solanine was determined for different potato varieties under different environmental conditions by Nitithamyong et al 1999 who found that the ratio of alpha chaconine to solanine was close to 60:40 under all growing conditions (Nitithamyong *et al.*, 1999).

Study results by Ankumah *et al.* (2003) revealed that the glycoalkaloid contents can be affected by environmental conditions during growth, storage and harvest. The N P K + Mg fertilisation produced further significant increase of total glycoalkaloid content before flowering and at harvest time. Potassium used as a fertiliser significantly decreased total glycoalkaloid content at flowering and after flowering time. The relative humidity (RH), ±95% and temperature, 4 °C caused total glycoalkaloids content from all tubers after six months of storage to be much lower than after harvest time.

Knuthsen *et al.* (2009) indicated that very few potato samples (only 3 of 386 samples) contained more than 200 mg/kg total glycoalkaloids. On the other hand, as levels of glycoalkaloids in potato tubers differ among varieties and are influenced by environmental factors during harvest, growth and storage, levels in both old and new cultivars should be surveyed to reflect the development of the market.

Research results by Cabello *et al.* (2009) of an analysis of random samples of potatoes (*S. tuberosum*) from local markets in Jordan showed that several whole tubers had solanine levels above the recommended level of 20 mg/100 g (fresh weight) of potato, whereas the maximum level in the skins was 128 mg/100 g. They also suggested that rapid removal of tubers from the field immediately after harvest and storage of crop in the dark is more important to keep the level of glycoalkaloids in potatoes low.

Schuphan (1974) measured that the alkaloid contents of *S. chacoense* and *S. tuberosum* tubers and leaves using capillary gas chromatography (GC) method. The leaves contained higher content of glycoalkaloids than tubers in both *S tuberosum* and *S. chacoense*, which is consistent with previous studies.

1.2.3 **Minerals**

Baking a potato with skin is the best cooking method to keep minerals (True, 1979). Many factors influence the mineral composition of potato for instance, weather, location, irrigation, fertilisation, soil type, soil pH, stage of development (Barminas *et al.*, 1998). Soil organic matter is also an important factor and can affect the mineral content of potatoes (Vreugdenhil *et al.*, 2004).

Conventional crop protection resulted in significantly lower Al (15%), Cu (6%), and Zn (10%) concentrations in wheat compared to organic crop protection but had no effect on Cd, Ni or Pb (Cooper *et al.*, 2011). The concentrations of mineral elements in potato tubers are affected by both genetic and environmental factors. One of the most important environmental factors is the phytoavailbility of mineral elements in the soil (White *et al.*, 2009). Nitrogen and potassium are found in the largest quantities in potato plants, followed by calcium (Ca) and magnesium (Mg).

According to (Westermann, 2005) nutrients can be applied in different ways to meet the requirement for production of potato. Frossard *et al.* (2000) showed that the total concentration of Zn, Fe and Ca in edible parts of plants can be increased in three ways namely by plant breeding and/ or by genetic engineering and by the application of fertilisers to the crop or to the soil.

A field experimental study by Wurr *et al.* (2001) revealed that the crop gave increased yields with irrigation and N fertiliser. N fertiliser increased the weight of embryonic tubers and leaves as early as 6 weeks after planting though it had little influence on water use. At 4-6 weeks after crop emergence that was when the highest uptake rates of K, P and N (g/m^2 / day) which were 0.62, 0.071 and 0.88 respectively. The tubers of potato at harvest contained 11.7-27.2 g/m^2 of K, 1.5-2.8 g/m^2 of P and 8.7-21.1 g/m^2 of N. The uptake of all the nutrients was increased by irrigation and by application of N fertiliser.

1.3 Effect of variety on nutritional quality and yield of potato

1.3.1 **Effect on vitamin C**

It is very important to determine the changes in chemical composition because they can represent significant loss in nutritional value of the potato. According to several research reports, vitamin C content of fruit and vegetables, which is considered to be an important quality characteristic, is affected by many agronomic management and environmental factors such as cultivar choice, time of harvest and maturity, location, and seasonal conditions (Griffiths and Dale, 2001 Mullin *et al.*, 1991). Nutrient composition of the tubers can be influenced not only by choice of variety but also by the environment in which it is grown, and conditions of storage (Phillips *et al.*, 2002).

Kolbe *et al.* (1995) demonstrated that potato quality response to fertilisation is negligible when compared to the response of climatic conditions and other factors. Quality is better controlled by choice of appropriate variety, soil and climatic condition rather than by fertiliser management (Anac and Martin-Prével, 1998). A previous study by Panigrahi *et al.* (1996) revealed that variety and processing temperature and their interactions as significant factors affecting the nutritive value of sweet potato tubers.

Horst *et al.* (2002) showed that the effect of variety was very significant; Marable variety showed the highest vitamin C content (207.2 mg/kg FW) and exceeded the level in other seven varieties by 15-49%.

1.3.2 **Effect on glycoalkaloids**

Pedro *et al* (2007) compared the glycoalkaloid content by using HPLC analysis for two kinds of potato varieties (Sante and Raja) of marketed Portuguese potato from conventional integrated and organic crop systems. The results showed that the total amount of these glycoalkaloids was identical in Sante tubers, while in the Raja variety there was a lower concentration of total glycoalkaloids (Clark *et al.*, 1999)

Wang *et al.* (1972) the glycoalkaloid analyses on the slices of the potato varieties revealed that the glycoalkaloid of B5141-6 variety was much higher than that found in either Russet Burbank or Kennebec varieties. The distribution studies indicated that the glycoalkaloid was more concentrated in the cortical region of Russet Burbank and Kennebac. While in B5141-6 variety it was distributed throughout the tuber.

1.3.3 **Effect on minerals**

Conditions of the locality have different effect on vitamin C content of potato tubers. A study by Horst *et al.* (2002) showed that though location and variety had different effects on mineral content and other quality parameters of some potato cultivars, location had a higher influence.

1.3.4 **Effect on yield**

Roshani *et al.* (2009) reported that varieties affected yield of tubers significantly. Yield increase in some varieties is because of bigger tubers and more weight in the other varieties. Results also showed that Aimera variety is recommended for potato tilling in Mashhad, Iran, because of high yielding ability.

1.3.5 **Effect of storage and cooking methods on vitamin C**

The change in vitamin C content during storage at 12°C and 90% relative humidity was evaluated by Rivero *et al* (2003). Their results showed that vitamin C content reduced significantly after 20 weeks of storage, where the concentration had decreased by more than 50% (Rivero *et al.*, 2003). Burgos *et al.* (2007) observed that boiled tubers had higher vitamin C content than baked or microwaved tubers and the vitamin C concentration reduced as the storage time increased, the degree of retention after storage under farmer conditions and cooking was highly variable between varieties.

An old study by Hester and Bennett (1956) showed that differences in the cooking pressure (5, 10 or 15 pounds pressure) seem to affect only the time of cooking and not the quality of the product. In another study by Oba *et al.* (1998) in which six potato varieties were stored at

4°C for 10 days after harvest at 23°C both vitamin C content and the activity of L-galactono-Y-lactone dehydrogenase increased after two days and reduced thereafter.

Han *et al.* (2004) revealed that vitamin C content of 33 potato genotypes grown in Europe decreased significantly during storage. Unpeeled potatoes lose less vitamin C during cooking than peeled potatoes. Water content and presence of air in the cooking atmosphere increased the rate of destruction of vitamin C during home processing.

1.3.6 **Effect of storage and cooking methods on glycoalkaloids**

Vreugdenhil *et al.* (2004) illustrated that the levels of glycoalkaloids of potato tubers of four varieties generally decreased during controlled storage at 4.5 and 10 °C. Most of the decrease happened during the first two months of storage. Rivero *et al.* (2003) recommended that future research must focus on choice of storage conditions, cultivation and post-harvest treatment, providing a maximal decrease in the levels of alkaloid in potato, and improvement of existing potato varieties by protein and genetic engineering.

Mondy and Gosselin (2006) studied three methods of cooking; (1) steaming; (2) boiling in distilled water; and (3) boiling in 16% NaCl solution. The results in all three methods showed that potatoes cooked without the peel were lower in total glycoalkaloid contents and phenolic content, less bitter and discoloured less compared with potatoes cooked with the peel. During cooking phenols migrated from the peel into both the internal tissues and cortex of the potato. Glycoalkaloids were less mobile compared to phenols, and migrated only into the cortex. The movement of glycoalkaloid and phenols into the cortex increased both bitterness and discoloration in potatoes cooked with the peel.

Buono *et al.* (2009) reported that glycoalkaloids content of potato tubers depended on N rates used during cultivation and the potato cultivar. Doubling nitrogen rates increased glycoalkaloids content by 10% after peeling and cooking. The glycoalkaloids level in potato decreased from 75% to 80% depending on potato cultivar. After peeling the losses of glycoalkaloids were twice higher than after cooking. After cooking and peeling of the potatoes the losses of alpha solanine were higher than those of alpha chaconine.

Twelve samples of cooked potato peels and raw peels from commercial potato varieties were analysed for their alpha solanine and alpha chaconine content by high performance liquid chromatography (HPLC). Raw peels contained 0.5-50.16 mg/100 g peel (wet weight) alpha solanine and 1.30-56.67 mg/100 g peel (wet weight) alpha chaconine. From the same potatoes raw flesh contained 0.01-2.18 mg/100 g flesh (wet weight) of alpha solanine and 0.02-2.32 mg/100 g flesh (wet weight) of alpha chaconine. Peels were cooked by frying and baking-frying, baking. The two kinds of fried peels contained more alpha chaconine (2.18 92.82 mg/100 g cooked peel) and alpha solanine (1.09-72.09 mg/100 g cooked peel) (Bushway *et al.*, 1983).

1.4 Effect of fertilisation on nutritional quality and yield

1.4.1 **Effect on vitamin C**

A previous study indicated that vitamin C content of potato and the yield were not affected by fertilisation treatments (Warman and Havard, 1998). This study also indicated that seasonal variations in weather have a greater influence on plant production than the source and amount of compost applied. The results of the study by Clough (1994) showed that potato quality could be improved by supplementing Ca fertilisation with an internal brown spot (IBS) susceptible variety for instance Frontier pre plant and side-dressed Ca fertiliser raised tuber Ca content and improved tuber quality of potato.

Mondy and Gosselin (2006) found that the vitamin C content and yield of carrots and cabbage were not influenced by treatments. In carrot leaves (Na, S) and five elements in carrot roots (S, N, Cu, Mn, B) were affected by treatments ($P < 0.11$); in cabbages, N, Zn and Mn were affected.

Mondy *et al* (1979) examined the effect of nitrogen fertilisation on potato discoloration in relation to chemical composition of two phenols and vitamin C and found a significant positive relationship between phenolic content and enzymatic discoloration, vitamin C increased significantly with increased nitrogen levels (Mondy *et al.*, 1979).

Rosen and Allan (2007) illustrated that varied supply of other nutrients and limited N availability may contribute to the differences occasionally observed in tissue NO_3 and mineral concentration, dry matter, vitamin C and other phytochemicals, and taste. Phytonutrient content can also be influenced by differences in pest control strategies between cropping systems regardless of nutrient source. There is a slight, but significantly, increased risk of produce contamination by *Escherichia coli* and other enteric bacteria contamination on the crop when organic fertilisers are used. Appropriate management of organic inputs is critical to achieving potential benefits for soil quality and crop production.

A negative effect on vitamin C content in potato tubers was noticed in the case of increased intensity of N fertilisation at 180 kg N/ha - it was decreased by 6.1% compared to doses of 100 kg N/ha. On the other hand, a favourable effect was observed at increased levels of magnesium and potassium fertilisation at 166 kg K /ha and 60 kg Mg/ha by 6.2% compared to the lower levels of 30 kg Mg/ha and108 kg K/ha (Hamouz and Lachman, 2007).

1.4.2 **Effect on glycoalkaloids**

Najm *et al.* (2012) showed that total glycoalkaloid content in tubers was increased by the application of N fertiliser as compared with cattle manure.

Application of NPK caused increasing total glycoalkaloids concentration. Higher concentrations stated after NPK fertilisers used with magnesium. Potassium used as a fertiliser significantly decreased total glycoalkaloids content at flowering and after flowering time (Zolnowski *et al.*, Date unknown).

1.4.3 **Effect on minerals**

Another study by Jeong *et al.* (2009) found that application of highest level of municipal solid waste compost significantly increased the concentrations of most extractable soil mineral elements except for Ni which was raised in the highest application rate of compost tea. Notable compost application resulted in increased fruit Na levels perhaps due to raised uptake of Na by leaves as compared with roots. The composts and compost teas produced fruit of equal quality in terms of vitamin C and total antioxidant; consequently, with reduced yield.

Effects of seven treatments of fertiliser (organic manure and N P K fertilisers) on fruit quality and yield of Khudari date palm variety, demonstrated that chemical fertilisers increased the yield of trees compared to the organic manure. Some of chemical and physical characteristics of the fruits were also affected by the chemical fertilisers during both seasons. Soil fertilisation did not produce significant effects on the mineral content (P, N, K, Mg and Ca) of the fruits and the leaves (Bacha and Abo-Hassan, 1982).

White *et al.* (2009) mentioned that for maximum efficiencies and crop yield, nitrogen fertiliser application should be based on the N required by the crop during its various growth stages. The application of pre plant nitrogen fertiliser between 67 and 137 kg N/ ha gave maximum early potato tuber growth because plant up take was between 78 and 100 kg N/ ha at the start of growth stage. They claimed that the optimum amount of N fertiliser needed to be applied depended on the amount of N mineralised and the residual soil NO_3- N content between planting and start of growth stage. Also their results indicated that the response of the potato crop to the available nitrogen supply is an important determinant for accurate N fertiliser recommendations.

The results of the study also showed that the vitamin C contents and yield of the carrots were not influenced by treatment of the element evaluated, the treatments significantly influenced only the S content of both edible and leaf tissue with organically grown carrots being higher in S, while conventionally grown carrot roots were significantly higher in Mn, Cu and N and organically grown carrot leaves were higher in Na with the roots were higher in B.

Karlsson *et al.* (2006) elucidated that calcium applications can mitigate black spot bruising in commercially grown potato varieties. Another important result of their study is that varieties vary significantly in response to bruise mitigation by calcium. Potato varieties with the lowest inherent calcium concentration in their tuber tissue responded most to supplemental calcium applications. The results of this study proposed that in season application of water-soluble calcium during the bulking period significantly increased tuber tissue calcium content and may have led to a concomitant decrease in tuber black spot. This is the first study providing evidence for decreasing bruise by improving tuber calcium.

Černý *et al.* (2010) reported that applying K fertiliser decreased the Ca content in potato tuber dry matter but increased Mg content more than when Mg was applied. The application of Mg did not increase the K content in potato tubers. The increased amounts of Mg in potato tubers (18 to 50% of that in the plant) resulting from the addition of K could have caused a decrease in the amounts in the leaves and stems because of the little alteration in the total Mg uptake. During the formation of the tubers Mg moved from the stems if much K was applied but not from the leaves; but when K fertiliser was added it appeared to cause Mg to be diverted to the tubers of potato without reaching the leaves.

Study by Srikumar and öckerman (1990) indicated that the content of iron was 11-45% lower in inorganically fertilised potato samples as compared to those treated with organic manure. The content of zinc was lower in samples treated with a higher amount of inorganic fertiliser (NPK). The combination of inorganic fertiliser NPK and raw manure decreased the content of copper, zinc and iron. Higher application of NPK fertiliser resulted in an increase in the content of iron but with a decrease in the concentrations of the zinc while the content of copper and manganese remained unchanged.

Another study by Kandil *et al.* (2011) found that application of 40% organic chicken manure (158 kg N/ha) plus 60% mineral nitrogen fertiliser (238 kg N/ ha) produced the highest averages of tuber diameter and tuber length. In addition they produced the highest average of nitrogen content in foliage and protein content in tubers.

1.4.4 **Effect on yield**

It is widely known that one of the most important factors influencing plant growth and productivity is fertilisation. A number of experimental studies have investigated the influence of different fertiliser treatments on the number of vegetables, fruits and on the yield. Low N and K (two times below the standard) fertilisation rates caused a 28% decrease in the yield of tomato fruits compared to standard application of 198 mg/ lt N, 375 mg/lt K. (Serrano - Megías *et al.*, 2006).

Cabello et al in 2009 observed that N treatments of standard 112 kg/ha increased yield of water melon than with N treatments two times above and two times below the standard by 18% and 13% respectively. standard applications of N (160 k/ha) increased the number of potato tubers compared with non-fertilised treatments and with N doses 40% above the standard by 23% and 18% respectively (Cabello *et al.*, 2009). Similar results have been observed in another study (Belanger *et al.*, 2002).

A study by Jamaati-e-Somarin *et al.* (2008) mentioned that application of the 80 kg/ ha nitrogen and plant density of 11 plants/m^2 is recommended to obtain highest potato yield with the most nitrogen use efficiency. Marzouk and Kassem (2011) noticed that applying organic manure alone or in mixture with mineral NPK raised palm yield more than mineral fertiliser alone. Overall, application of organic manure alone or in mixture with mineral NPK did not vary from each other in their influence on yield and quality.

Hachicha *et al.* (2006) showed that field experiments using compost made of poultry manure and olive mill waste resulted in an increase in potato production to 31.5- 35.5 t/ha, compared to 30.5t /ha using compost of cattle manure. The compost made of poultry manure and olive mill products seems therefore as a promising ecological alternative to classical fertilisers. An earlier study by Thybo *et al.* (2002) revealed that potatoes manured with slurry had a slightly higher moisture content and seemed to have high discoloration. Joern (1995) found that increasing rate of N application up to 112 kg/ha generally led to increased total tuber yield and there was no effect on tuber specific gravity of N rate (Joern and Vitosh, 1995).

Demirer *et al.* (1999) showed that fertilisation type and rates markedly affected the crops and highest yield was observed with ammonium sulphate at the level of 150 kg N/ha. Fertilisation rates were also effective on dry matter contents which were decreased with increasing rates of fertilisations.

Another study by Jarvan (2009) showed that there were no significant differences in the effect of mineral fertilisers and compost on the biological quality of potato tubers. Maticic and Avbelj (1994) showed that nitrogen fertilisation and watering increased crop yield by 44 t/ ha and 7 t/ ha respectively. The maximal yield was 96 t/ha and was achieved with 150 kg N/ha and 1119 mm of water after the growing period.

A study by Campiglia *et al.* (2009) illustrated that mechanical weed control compared to a weed free crop that received supplementary hand-weeding consistently decreased potato crop yield and the reduction averaged over years was larger in N-P-K mineral fertilised control (-23.6%) compared with a crop that followed a cover crop of ryegrass (-7.9%). Recently Biswas (2011) showed that yield and uptake of N, P and K by potato tubers was considerably raised due to application of inorganic fertiliser and enriched compost over control. The results clearly showed that enriched compost might be an alternative and cost effective option to prepare a value added product using agricultural wastes and low-grade minerals instead of costly chemical fertiliser for maintaining soil fertility and crop protection.

Najm *et al.* (2012) showed that N fertiliser, cattle manure, and their combination had very significant effects on tuber yield. Maximum tuber yield (36.8 t/ha) was obtained by utilization of 150 kg N + 20 t/ha manure per hectare. Hachicha *et al.* (2008) demonstrated that as a result of compost application potato productivity increased 10-23%. Application of manure and sewage sludge increased the yield of potatoes by 30% over control. The highest yield was obtained after application of mineral fertilisers. Average yield increased by 59, 50 and 36% in winter wheat, spring barley and potatoes respectively.

Ankumah *et al.* (2003) found that total and marketable yields of early maturing potato varieties were significantly higher compared to late maturing varieties. Moreover a single application of nitrogen resulted in significantly higher yield in storage roots compared with split application ($P < 0.05$). Zandstra *et al.* (1969) found that yields of potato harvested at maturity were significantly raised by potassium fertiliser in Nipawin soil type than in a Melfort soil; potassium fertiliser did not increase yields when potatoes were harvested at maturity.

A related study conducted during the spring and winter months of 2000 and 2002 at Hatay, Turkey to investigate the effects of farmyard manure (0, 10, 20, 30, 40 and 50 tonnes/ha) and mineral fertilisation (0 or 200, 90, 90 kg/ha N-P-K respectively) on the growth and yield of early potato crop indicated that NPK fertilisation significantly increased the yield of tuber and morphological traits while it affected negatively affected dry matter content of potato tubers. The application of farmyard manure also had positive effects on yield and growth with or without mineral fertilisation (Caliskan *et al.*, 2004).

Kumar *et al.* (2007) showed that a higher N fertilisation resulted in a positive effect on plant growth parameters, and increased yield and tuber number. Another study by Mkhabela and Warman (2005) reported that highest yields were obtained after the application of the combined organic N and mineral K (potassium sulphate) source.

Freyman *et al.* (1991) used different rates of (N) fertilisation (0, 100, 200, 300, 400 and 500 kg N/ha and reported that the highest rate resulted in obviously higher yield of cabbage, though this resulted in a decrease in vitamin C content. Another study by Saue *et al.*, (2010) showed that, both tillage and fertilisation affect the influence of weather on yields. They noticed that application of fertiliser had an effect on potato yields, while tillage methods had no effect on the yield.

Del Amor (2007) reported that organic farming raised antioxidant activity but decreased both β-carotene and chlorophylls. Pericarp thickness, fruit firmness, pH and total soluble solids content of sweet paper exhibited higher values with the organic method however; these differences were not significant with respect to the conventional method. No significant differences in total marketable yield were noticed between organic and conventional farming.

1.4.5 **Effect on dry matter of the tuber and specific gravity**

The specific gravity of potato has been given great attention due to its relation to cooking quality and starch content. Specific gravity depends on the amount of starch, dry matter content mineral constituents present. Generally, high specific gravity is associated with high cooking quality and high starch content in potato. Due to the subjective nature of cooking tests and the several factors affecting quality in potato, some exceptions to this general rule have been reported, so that potatoes that are relatively low in specific gravity are not always of poor quality (Liu et al., 2009).

Kadaja (2004) in a study revealed that fertilisation reduced the maximum of root growth function and moved the maximum of leaf growth functions forward. Another study conducted by Maclean (1984) indicated that mean crops for two years period showed a significant response to 135 kg/ha of N at planting. In addition the specific gravity of tubers was lesser with high rates of N at planting.

Another study by Baniuniene *et al.* (2008) reported that fertiliser combinations with potassium tended to decrease dry matter and starch content in potato tubers. The results also showed that potato crops applied with only mineral fertilisers contained higher dry matter and starch contents in tubers than with those applied with mineral fertilisers and farmyard manure.

A study by Roinila *et al.* (2003) illustrated that the high application rate of the mineral fertiliser increased the content of nitrogenous compounds (free amino acid and nitrate) in potato. The slurry fertilisation caused a similar but lesser effect. Dry matter content of potato differed more strongly than the starch content as a result of the type of fertiliser (mineral/ organic) and the application rate. The minerally- fertilised potatoes had a lower dry matter content compared with organically-fertilised but, the starch yield and dry matter showed no significant difference between the organic and mineral treatments, even though the fresh matter was higher in those which had mineral fertilisation.

Research by Krinsky and Johnson (2005) determined response of potato (*S. tuberosum* L.) to different rates of phosphorus and nitrogen fertilisation and showed that nitrogen fertilisation significantly decreased tuber dry matter content and specific gravity without affecting stem number. They also showed that the increase in tuber yield in response to the fertilisation was because of the increase both in the weight and in tuber number. It was noticed that application of 138 kg N and 20 kg P/ha was required for optimum productivity of Gorebiella variety in the centre highlands of Ethiopia under rain fed conditions. However, contrary to these results, no significant response in average tuber weight was observed when P treatment rates were increased.

1.5 Comparison between organic and conventional methods of production and protection on nutritional quality and yield

1.5.1 **Effect on vitamin C**

Magkos *et al.* (2003) mentioned that there is little evidence that conventional and organic production differs in respect to the concentrations of various micronutrients (minerals, vitamins and trace elements), but there seems to be a slight trend towards higher vitamin C content in organically grown potatoes and leafy vegetables. However, it seems that although with this difference, a well-balanced diet can equally improve health regardless of its conventional or organic origin.

1.5.2 **Effect on minerals**

A study by Herencia *et al.* (2007) reported that the use of organic fertiliser resulted in higher soil N content, soil organic matter and available K and P. However, few differences were found in the macronutrient concentration in the edible part of the crops, as a result of the kind of fertilisation. For the crops grown in the organically fertilised plots the nitrate content in the edible parts was low. Crop yield was not statistically different among fertiliser treatments. This study also showed that long-term use of organic compost in greenhouse soil improved soil fertility and produced similar nutrient composition and yields in the edible portion of crops as compared to mineral fertilisation.

1.5.3 **Effect on yield**

Several studies have reported the effect of different organic and conventional methods on plant growth and yield of potato. Results of a study by Rembialkowska (2003) showed that organic vegetables had lower yields; however, most of their nutritive sensory and storage quality characteristics were better compared to conventional crop products.

Results from study by Lehesranta *et al.* (2007) found that the yields were higher with conventional fertilisation and crop protection. On the other hand the proportion of dry matter was considerably higher when crop protection and fertilisation were carried out to organic farming standards. The total N, P, and K contents in tubers were mainly affected by fertility management. Another study by Mohammed and Salem (2010) reported that incorporation of compost in soil will not only protect the environment, but also take advantage of the nutrients and organic matter contained in the compost to improve crop production and soil fertility.

An alternative study by Granstedt and Kiellenberg (1997) showed that organic treatments resulted in higher yielding crops with higher quality protein, and higher soil fertility, a greater ability to tolerate stressful conditions and long term storage and higher starch content in comparison with the inorganic treatments. According to the results of a study conducted by Cooper *et al.*, (2011) there was a significant main effect for crop protection in all four seasons and on average, conventional crop protection resulted in 35% higher yields. Grain yields were highest were conventional fertility management and crop protection practices were used.

Abbott (1999) reported that the nutritional value of food, as the absolute content of individual nutrients, is only one aspect of food quality. Quality of the crop is not a single, well- defined attribute but includes many properties or characteristics; it encompasses sensory attributes (texture, appearance, taste and aroma), nutritive values, chemical constituents, safety determinants, functional properties and defects.

A study by Oba *et al.* (1998) showed that preference for organic foods is associated with a variety of factors that reflect both a concern for natural environment and personal health. This study supports other results that consumer interest in organic foods is influenced to a large measure by their concerns about pesticide residues. Also this research demonstrated that a general attitude towards food shopping and preparation is a significant factor that influences preference for organic foods.

Kotíková *et al.* (2007) indicated that there was no clear evidence for sensory differences among conventional and organic grown potatoes, vegetable products or vegetable, or apples. Also the review investigated studies that compared produce from animals that were fed conventionally grown feed to those that were fed organic feed. The products investigated were meats, eggs, milk and dairy products, and honey. None of the studies reviewed was able to establish a difference in the sensory properties of products from conventional or organically grown feed.

A study by Blatt (1991) indicated that soil and leaf nutrient values were not consistently influenced by the fertiliser material, soil type, rate of N or method of application. Plants receiving the chemical fertiliser had significantly higher yields compared to the plants receiving any of the organic treatments

1.5.4 **Effect on dry matter and starch**

Another study by Srikumar and öckerman (1990) showed that application of inorganic fertiliser (NPK) increased dry matter content of potato. Compost manure as compared with raw manure was more effective in the improvement of protein content. They did not find any significant difference in the concentrations of dietary fibre, crude fibre and fat between samples treated with inorganic fertiliser and organic manure. Also the results indicated that a higher application of inorganic NPK fertiliser increased the starch content.

Lee and Chung (2006) pointed out that in the soil after the application of compost the contents of NH_4 –N were much lower compared with those found in the soils of chemical fertiliser application. However, NH_4 -N was not found in the soils which had compost application after two weeks, and NH_4 –N was not found in the soils of chemical fertilisers application three weeks after lettuce transplant.

1.6 Effect of growing seasons on nutritional quality and yield of potato tubers

1.6.1 **Effect on vitamin C**

Although light is not essential for the synthesis of vitamin C in plants, intensity and the amount of light during the growing season have a definite effect on the content of vitamin C formed. In general, the lower the light intensity during growth, the lower the vitamin C content of plant tissues (Seung, 2000). Temperature also affects the composition of plant tissues during development and growth. Total available heat and the extent of low and high temperature are the most important factors in determining growth rate and chemical composition of horticultural crops (Seung, 2000). Reuther and Nauer (in published report, 1972) indicated that ‘Frost Satsuma’ contained more ascorbic acid when grown under cool temperature (20-22°C day, 11-13°C night) than hot temperature (30-–35°C day, 20–25°C night).

Seung (2000) also mentioned that selection of the genotype with the highest vitamin C concentration is a much more important factor for a given commodity than climatic conditions. The metal concentration of crops is reported to be affected by a range of factors, including climatic conditions, variety choice, soil type and crop species (Addiscott, 1974).

1.6.2 **Effect on glycoalkaloids**

A significant increase in glycoalkaloids (alpha solanine and alpha chaconine) was noticed under drought stress conditions in most varieties Average concentration rise of 43 and 50% were recorded in the improved and control varieties respectively (Bejarano *et al.*, 2000).

1.6.3 **Effect on minerals**

Drought can affect tuber mineral content by acting on mineral composition of different tissues and, as a consequence, on the redistribution of minerals within the plants (Hornick, 1992).

1.6.4 **Effect on yield**

Potato quality is affected by a wide range of factors, for instance climatic conditions, geographical location, pre- and post-harvesting practices and choice of cultivar (Gilsenan *et al.*, 2010). Growing seasons’ average temperature, rainfall and light have a strong effect on the chemical composition of vegetables and fruits (Campbell *et al.*, 2011). Temperature, rainfall and light intensity, which interact to affect the nutrient concentration of plants, can vary significantly depending on the specific growing conditions and season (Talley *et al.*, 1970).

Results of a study by (Zolnowski *et al.*, Date unknown) showed that drought caused yield losses between 39% and 92%. Moreover, stresses from drought and extreme temperatures, and nutrient deficiencies can noticeably affect growth of crops, yield and nutrient uptake.

Abreu *et al.* (2007) Showed that the effect of rainfall during growing season is that high rainfall sites have markedly higher yields compared to those with low rainfall.

According to published data it is clear that vitamin C, glycoalkaloids, minerals and yield are influenced by variety and the use of different types of fertilisation pre-crop, crop protection regimes and growing seasons in a range of different crops and crop products. As glycoalkaloids are highly toxic and undesirable compound in potato tubers for human consumption, it is important that varieties should have glycoalkaloid contents below the safety limits and pose no real threat to animals and humans. However, few field studies have considered the combined effects of these factors and their interactions. There appears to be limited information, and certainly very little recently published information in the literature about how the pre-crop and growing seasons affect the vitamin C, glycoalkaloids and mineral contents of potatoes, as well as their yield. There is also a lack of published studies comparing the results of titration and HPLC methods for determination of vitamin C in potato tubers to assess the extent to which the accuracy of results might be affected and the implications this might have.

This study was undertaken to fill in some of the gaps in knowledge by comparing the effects of variety, fertilisation, pre-crop, crop protection and growing season treatments on vitamin C, glycoalkaloid, mineral contents and yield of potato tubers. Moreover, the observations of the earlier studies indicate for any study of vitamin C and glycoalkaloids the choice of variety will obviously affect the results. Finally, the success of such an effort would enhance the value of potatoes as a high-quality food.

1.7 Aims of the study

Based on the information obtained in the literature review the hypothesis for the experimental work was as follows:

1. Growing seasons, crop protection regimes, fertilisation, pre-crop and potato cultivar will significantly affect the tuber yield and quality (vitamin C, glycoalkaloids, and minerals).

2. There will be significant interactions between growing seasons and agronomic factors with respect to tuber yield and quality parameters.

The objectives of this study, conducted at Nafferton Ecological Farm, Newcastle University (2010-2011), were to:

1. investigate the effect of different varieties on nutrient content of potato tubers (vitamin C, minerals, and glycoalkaloids).

2. examine the effect of two different types and rates of fertilisers (Compost, NPK) on nutritional quality of potato crop.

3. determine the effect of crop protection treatments (organic, conventional) on nutrient content of potato tubers.

4. evaluate the treatment effect of crop rotation following beans, barley (i.e. pre-crop) on nutrient content of potato tubers.

5. evaluate the effect of different treatments of fertilisation, varieties, pre-crop and crop protection on minerals content of potato tubers.

6. investigate the effect of growing seasons on yield and nutritional quality of potato.

7. identify the effect of variety, fertilisation, pre-crop, crop protection and growing seasons on tuber yield of potatoes.

8. compare two different methods of analysis (HPLC, colorimetric titration method) of nutritional quality of different potato varieties (vitamin C content) in two different seasons of year 2010, 2011.

A number of methods, for instance high-performance liquid chromatography (HPLC) and titration have been used for the determination of vitamin C and glycoalkaloid compounds in potato. HPLC is now becoming the most widely used method, because it is accurate, rapid and reproducible, but the titration method is still used and HPLC equipment is not always available. A comparison between titration method and a high-performance liquid chromatographic (HPLC) procedure was made using six potato varieties, two types of fertilisation, two pre-crops and two crop protection systems. Results from the two methods compared favourably.

Overall, the study seeks to understand major factors that influence the nutritional quality of potatoes with regards to the needs and demands of consumers and concerns about the environment and conflicting demands. In addition, findings from the study aimed to provide some recommendations which might beneficially influence future studies.

CHAPTER 2 Materials and Methods

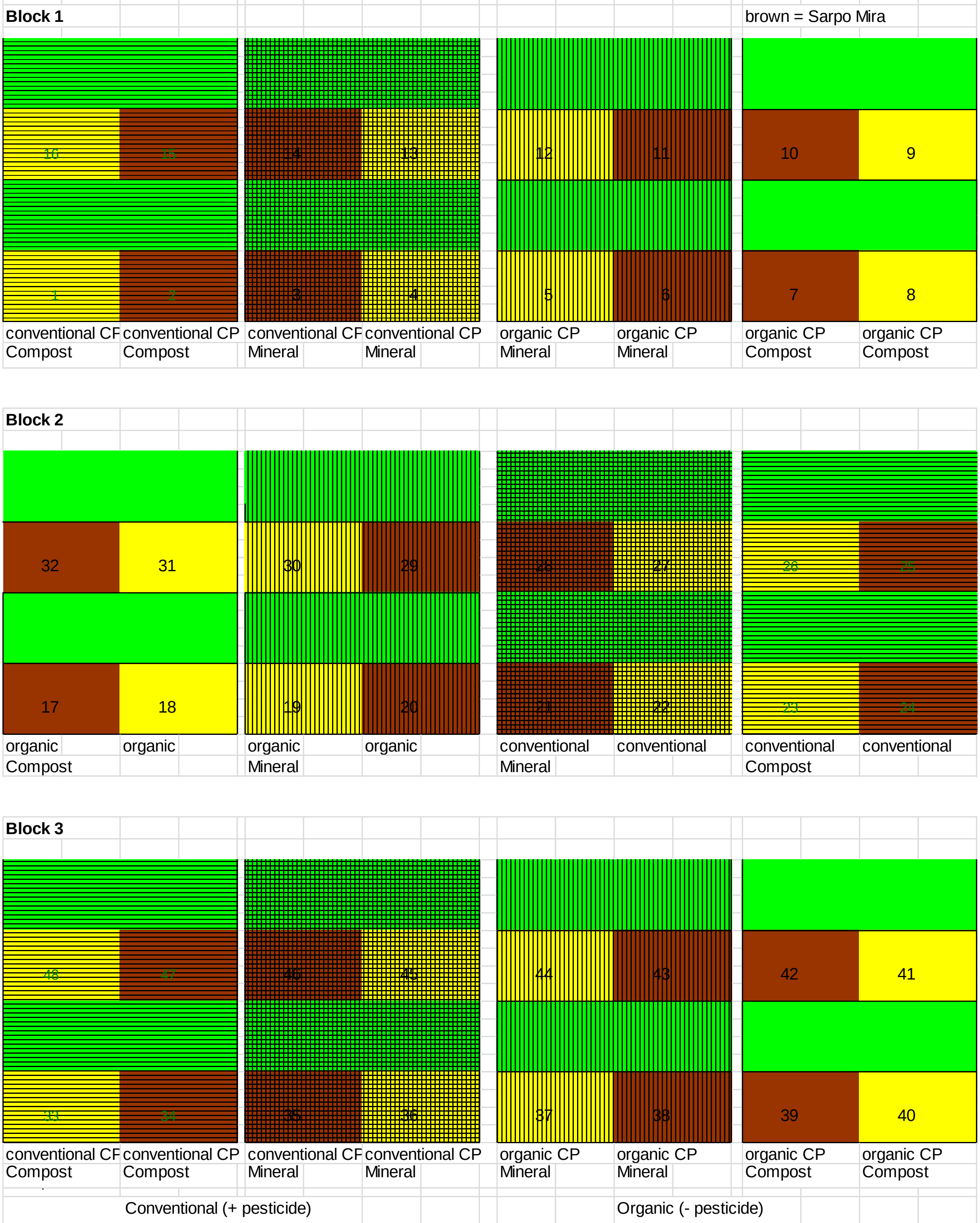
2.1 Experimental set-up

2.1.1 Location and experimental design

Two of the experiments (QLIF 2010 and QLIF 2011) were part of the Nafferton factorial systems comparison (NFSC) trial conducted at the Newcastle University's Nafferton Experimental Farm, Northumberland, U.K. (54:59:09 N; 1: 43:56 W), with a uniform sandy loam soil. Laboratory analysis was conducted in the Agriculture building, Newcastle University. The design of the experiment was a split split split- plot design. The main plot was crop rotation, the sub- plot was crop protection, the sub-sub plot was fertility management and the sub-sub sub plot was variety (Figure 1). The experiment was designed to identify the effect of, and interactions between, variety, fertility management, crop rotation and crop protection methods used in organic, low-input, and conventional production systems on yield and nutritional quality of potato crops.

The design generated four treatments: (1) compost fertility management (compost cattle manure) and 'organic' crop protection (mechanical weed control during ridging –up and late blight controlled with copper fungicides); (2) compost fertility management and 'conventional' crop protection (usage of herbicides and fungicides according to British Farm Assured practice); (3) mineral NPK fertilisation and 'organic' crop protection; (4) mineral NPK fertility and 'conventional' crop protection. All treatments were replicated four times, generating 16 plots. Non-chitted seed tubers were planted using a semiautomatic two-row potato planter. Potato seed tubers planted in plots treated with conventional crop protection were produced under conventional seed potato production conditions (Greenvale AP, Blairgowrie, UK). Potato seed tubers planted in plots treated with low-input crop protection were produced under organic seed potato production standards (Greenvale AP). All fertility treatments were applied 3 weeks prior to planting of tubers. No water irrigation was applied. Observations were made of disease in both 2010 and 2011. Late blight caused by the fungus *Phytophthora infestans* was at a low level of infection in both years and was unlikely to have had an effect on tuber yields or differences between varieties with different levels of resistance to the disease.

QLIF Potato Areas 2010



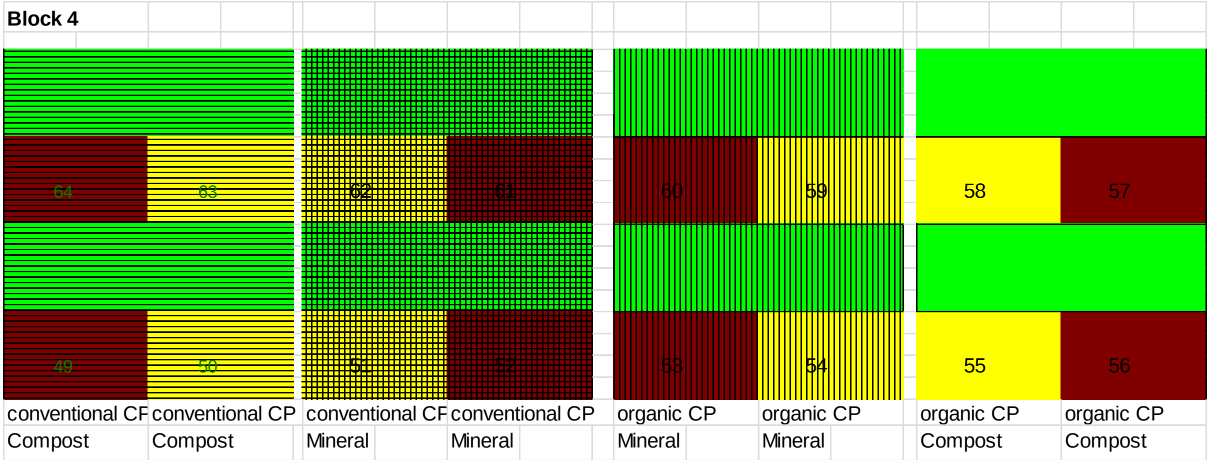


Figure 1 Design of the experiment

2.1.2 Experimental treatments and varieties used

2.1.2.1 QLIF (Quality Low Input Food) potato trial 2010

These research materials consisted of two varieties Sante and Sarpo Mira, two kinds of fertilisation compost and NPK 250 kg N. The potatoes were sampled from conventional rotation, following a cereal crop of barley and in the organic rotation, following a legume crop of beans. Crop protection sub plots are nested within the crop rotation main plots at two levels (organic and conventional) while fertility management (organic and conventional) is the sub-subplot factor. Two varieties in the first year (Sante and Sarpo Mira) are nested in each fertilisation plots so the total treatments are 16 plots ×4 replicates = 64 plots in total. Potatoes in the first experiment were planted on 29th April 2010 and harvested during the first week of October 2010 with a single row potato harvester. Potato plants were defoliated about a month before the target harvest date to allow the skins to set. Tuber yields were assessed by weighing tubers harvested from the central two rows of each plot. Tubers were bulked together into paper sacks and stored for about 3 weeks at ambient temperature prior to tubers being size graded.

2.1.2.2 QLIF potato trial 2011

The design of the potato trial and varieties, fertilisers and pre-crops were exactly the same in 2011 as described for 2010. However, planting was later, on in June 2011 and harvesting was between 3-7 October 2011.

2.1.2.3 NUE (Nutrient Use Efficiency) potato trial 2011

Another potato trial in 2011 was sampled. This was the NUE crops trial situated on a different field at Nafferton Farm. Potatoes followed a cereal crop (wheat), main plot factor was the fertilisation with 2 types (compost and mineral NPK applied 3 weeks before planting) and the 3 levels (0, 125, 250 kg/ha). Crop protection subplots are nested within the fertilisation main plots at two levels (organic and conventional) while the 6 varieties in the second year (Agria, Cara, Fontane, Nicola, Sante and Sarpo Mira Table 1 and Figure (2, a to f).) are the sub- subplot factor there were 60 plots × 4 replicates= 240 plots in total. Potatoes were planted on the 7 June 2011 and harvested between 3-7 October 2011. Late planting in the 2011 NUE crops trial may have been responsible for the generally lower yields of tubers that were observed in that trial in that year compared with the others that were assessed.

Table 1 Variety characteristics of potatoes used in the present studies

Name of variety	Tuber characteristics	Resistance to disease
Sante	Smooth skin, short-oval and light cream colour of skin.	High resistance to powdery scab (*Spongospora subterranea*).
Sarpo Mira	Smooth skin, oval-long shape and red colour of skin.	High resistance to late blight on tubers (*Phytophthora infestans*).
Cara	Medium smooth of skin, short-oval and red parti-coloured skin.	High resistance to late blight on tubers (*Phytophthora infestans*)
Nicola	Smooth of skin,oval-long shape and medium yellow colour of flesh	High resistance to potato cyst nematode (*Globodera pallida*)
Agria	Medium smooth of skin, oval-long shape and cream colour of skin	High resistance to potato cyst nematode (*Globodera rostochiensis*).
Fontane	Medium smooth of skin, oval shape and white colour of skin.	High resistance to potato cyst nematode (*Globodera rostochiensis*).

a. Sante potato

b. Sarpo Mira potato

c. *Cara potato*

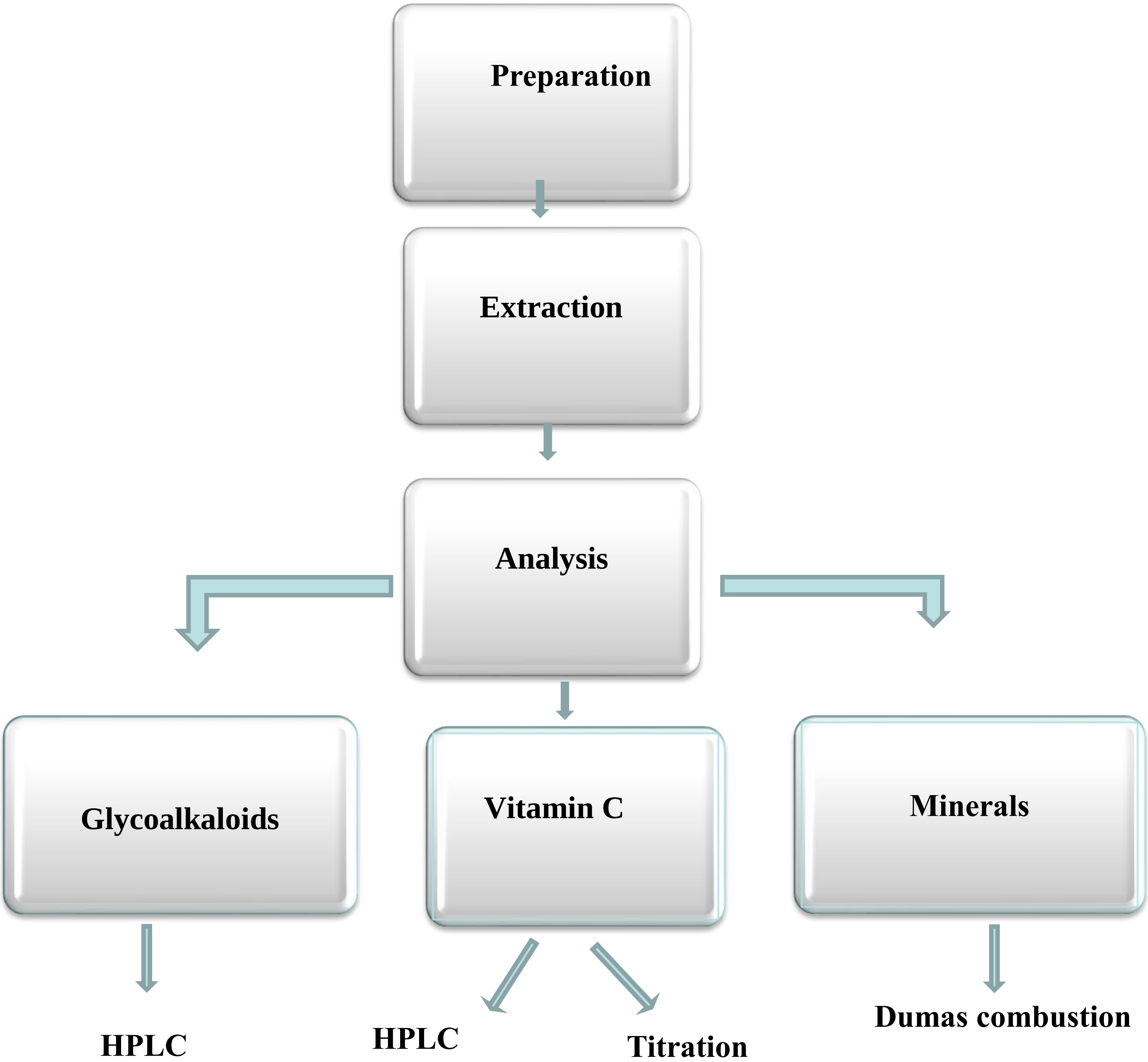
d. Nicola potato

e. *Agria potato*

f. Fontane potato

Figure 2 a, b, c, d, e, f. Potato varieties used in the experiment

Figure 3 Processing potatoes samples for nutritional analysis



2.1.3 Preparation of samples for vitamin C, glycoalkaloid and mineral analyses

Potatoes were washed, labelled, weighed and oven-dried for 15 minutes to remove surface moisture and then re-weighed. Samples of four to six tubers were selected with a combined weight of 800 g (Figure 3, 4 A).

Each tuber was chopped twice longitudinally, and placed face down. The four longitudinal sections were each cut then transversely to obtain eighth pieces (Figure 4 B, C, and D). One set of opposites was then placed into liquid nitrogen for 1 minute, placed into polystyrene boxes to keep them dry and finally freeze dried for 8 days at -40 °C to complete the drying process effectively.

Milled samples were placed in to plastic containers. All mill parts were washed and cleaned promptly after use. Freeze dried cubes or powders stored in labelled containers with information including: - Year of starting the experiment, type of crop, and number of the sample. Samples were prepared with the agreement of the methodology described by laboratory work at Nafferton Farm, Newcastle University.

Potato samples for minerals analysis were packaged, labelled and sent to Sabanci University, Istanbul, Turkey for analysis. Mineral content was determined by the Dumas combustion method using a LECO TruSpec Automated C/N Analyzer, LECO.

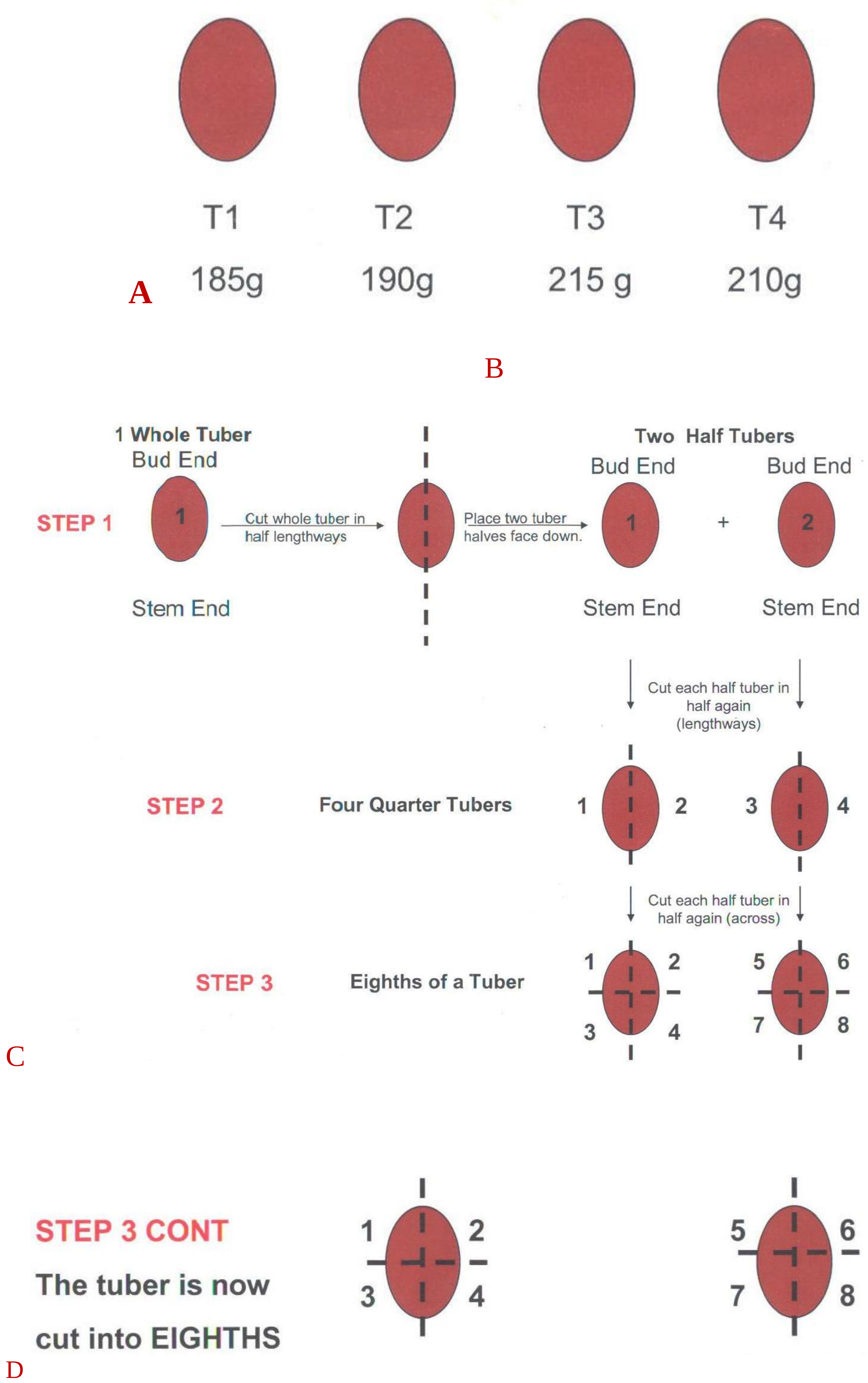


Figure 4 Preparation of samples for nutritional analysis

2.1.4 **Extraction procedure for nutrient contents**

2.1.4.1 Materials

The chemicals used for the methods in this study were sodium hydrogen sulphate, acetonitrile Fisher Scientific, UK. Alpha solanine (purity ≥ 99% by HPLC) and metaphosphoric acid were purchased from Sigma-Aldrich. Alpha chaconine (purity ≥ 99% by HPLC) obtained from Extrasynthese, solid phase extraction SPE cartridges were purchased from Agilent. The water used in the mobile phase was deionised water obtained from laboratory of Agriculture. All other reagents such as acetic acid, 2, 6 dichlorophenolindophenol were obtained from laboratory of Agriculture, Newcastle University and are filtered before used.

2.1.4.2 Sample extraction for Vitamin C

Potato tuber pieces were ground into powder and 1.0 g of each sample was extracted with 10 ml of 5% methaphosoric acid. Samples were then put through ultra-sonication for 10 minutes at room temperature and then centrifuged at 18000 g for 10 minutes with both procedures at room temperature. The residue was rinsed with 5 ml of 5% metaphosphoric acid and centrifuged again. The extracts were combined and made up to 25 ml. This solution was analysed by HPLC for vitamin C content. The extraction procedure was based on that of Jae-Sook (2004). Metaphosphoric acid solution for sample extraction was used in order to preserve the vitamin C and prevent oxidation of vitamin C by air.

1. 5 g + 100 ml of DW.
2. 10 g +200 ml of DW. This is dependent on the volume required.

2.1.4.3 Determination of vitamin C

There are a number of ways to determine amounts of vitamin C in crops, these include:

- The Classic 2, 6 dichlorophenolindophenol colorimetric titration method.
- HPLC method.

2.1.4.4 Determination of vitamin C content using colorimetric titration method

Determination of the vitamin C content was carried out using a colorimetric titration method according to the Newcastle University laboratory protocol. Titration is a simple form of analysis which relies on a reaction occurring between the substances to be analysed (the analyte) and a reagent added to it (the titrant).

2.1.4.5 Standardisation of reagent

2, 6- dichlorophenolindophenol (DCPIP) indicator was made up by dissolving 0.2 g of the dye in distilled water and made up to 250 ml to give a 0.08% solution. Then 10 ml of the solution was then taken and diluted to 100 ml and kept in the dark at room temperature.

2.1.4.6 Preparing standard solution and titration of vitamin C

A standard curve was prepared by dissolving a known weight 0.0055 g of vitamin C and made up to 25 ml with 5% methaphosoric acid and mixed thoroughly. 5 ml of this solution was transferred into a small flask and titrated quickly with dye dichlorophenolindophenol (DCPIP) to an end point at which the pink colouration was seen.

Using a graduate pipette, 1 ml solution of sulphuric acid in water was added to each of 25 ml extract and 2.9 ml of formaldehyde solution added to acidified extract. After thorough mixing, 10 ml aliquots were pipetted into small flask or beaker and allowed to stand for 8-10 minutes. The solution was then titrated with the standardised dye solution to an end point at which the pink colouration persisted for 5-10 seconds. The vitamin C content was then calculated using the formula below;

V*F*50*28.9*100/W*10*25 mg and to convert to g multiply by 1000.

- V- titre for each sample.
- F- dye factor (number of mg of vitamin C equivalent to 1 ml of dye solution.
- W- weight of potato sample (g).
- (28.9 ml) is total solution before titration with dye solution which contains 1 ml sulphuric acid +2.9 ml Formaldehyde + 25 ml extract solution of sample.
- 100, 10, 50 are constants.
- 25 ml… is the amount of metaphosphoric acid which added to sample.

2.1.4.7 Determination of vitamin C content using HPLC method

The vitamin C was determined by a reverse-phase HPLC technique using an ESA coularray system (ESA, Massachusetts USA). The HPLC conditions are outlined in Table 2 below.

2.1.4.8 *Identification and Quantification of vitamin C*

Quantification of vitamin C was accomplished by comparing integrated chromatographic peak areas from the test samples to peak areas of known amounts of standard vitamin C. Different concentration (1, 0.5, 0.25, 0.125, 0.06, 0.031 mg/ml) of vitamin C standard was prepared by dissolving 10 mg of vitamin C in 10 ml metaphosphoric acid (5%) solution at the final concentration of 1mg/1ml.

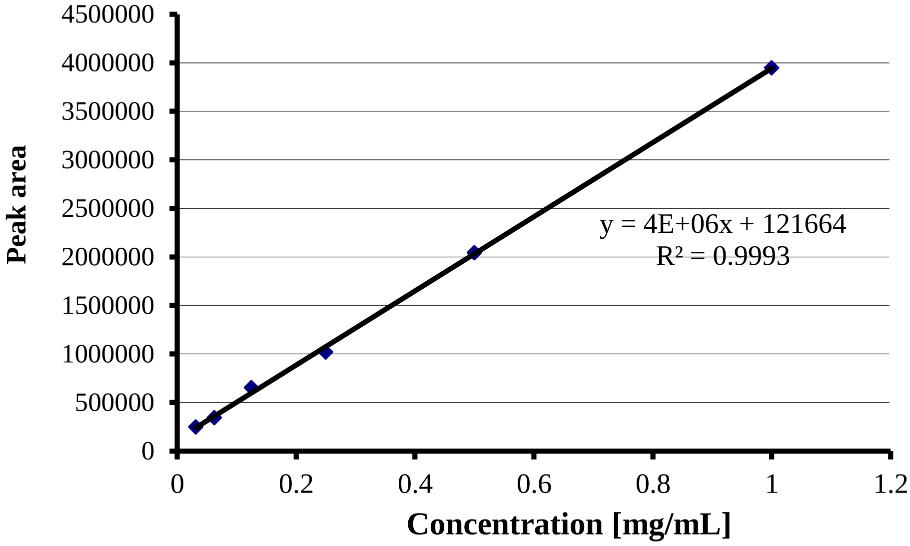


Figure 5 Vitamin C standard curve

2.1.4.9 *Extraction and HPLC analysis of glycoalkaloids alpha solanine and alpha chaconine*

Potato tubers were ground into powder and 1.0 g of sample was extracted immediately with 10 ml of extraction solution (1.0 L H_2O : 50 ml glacial acetic acid, add 5.0 g sodium hydrogen sulphite ($NaHSO_3$), and mixed for 2 minutes to dissolve). Clarify by centrifugation for 30 min at ≥40 000 g. Collect supernatant. Extract is stable at least 1 week at 4 °C. Place solid-phase extraction (SPE) column, on vacuum manifold, and conditioned each with 5 ml acetonitrile, followed by 5 ml extraction solution, pass 10 ml extract of sample through columns. Wash column with 4 ml SPE wash solution (15% acetonitrile. Mix 150 ml acetonitrile, with 850 ml H_2O. Elute with 4 ml mobile phase, (elution rate: 1-2 drops/s), and adjust volume to 5 ml with mobile phase, elute is stable at least 1 week at 4 °C. The extract procedure was based on that of AOAC Official Method 997.13 (1997**).** The HPLC conditions are outlined in Table 2 below.

Table 2 HPLC Conditions

	Vitamin C	***Glycoalkaloids*** *α solanine & α chaconine*
Column	18 reverse phase column, 3µm particle size 150mm× 3.2mm	Synerji,4 *µ* hydro-RP 80A, length: 2.50× 4.6mm (Phenomenex) UK
Eluent type	Isocratic	Isocratic
Eluent	2 % Ammonium phosphate pH 2.8	60% acetonitrile in 0.01M phosphate buffer pH 7.6
Flow rate	0.5 ml/ minute	1.5 ml/ minute
Temperature	37°C	(40 °C)
Detection	ESA coularray d etector at 100 mV	Shimadzu UV-Vis SPD-10A @ 280 nm; 2 AUFS
Injection volume	20 µl	20 µl
Calibration standard	Ascorbic acid 0-50 mg/ mL	Glycoalkaloids 0-150µg/ mL

2.1.4.10 Identification and Quantification of glycoalkaloids (α-solanine and α-chaconine)

Quantification of glycoalkaloids was performed by comparing integrated chromatographic peak areas from the test samples to peak areas of known concentrations of standard glycoalkaloid. (5, 10, 25, 50, 100, 150 μg/ml) of glycoalkaloid standard was prepared by dissolving 5 mg of (α-solanine and α-chaconine) in 10 ml of 0.1M KH_2PO_4 at the final concentration of 500 μg/ml. The injection volume was 20 μl and glycoalkaloid (solanine and chaconine) concentrations were quantified by absorbance at 202 nm.

2.2 Statistical analysis and data management

All data were subjected to statistical analysis using general liner model (GLM), (Minitab version, 16) or Microsoft Excel to determine the effects of the different experimental variables and interaction between them.

All data were checked for normal distribution of the residuals using the Anderson Darlington model and if data were not normally distributed, Log base 10 data transformation was employed before parametric test to meet the criteria of normal data distribution statistics. Significant level of differences between means was determined at the level of 0.05. Means comparisons were calculated using Tukey‘s test ($P \leq 0.05$).

CHAPTER 3 Results

Results obtained for yield and the 3 compositions parameters assessed are described in separate sections below:

3.1. Yield

3.2. Vitamin C

3.3. Glycoalkaloids

3.4. Minerals

3.1 Yield

3.1.1 Effect of variety, fertility, pre-crop and crop protection treatments on yield

All three main factors fertility, rotation and crop protection affected potato yield significantly, No significant difference between varieties was detected on tuber yield of potato. However, although not significant, Sarpo Mira produced higher yield compared to Sante (Table 3).

No significant interaction between variety, fertility, rotation and crop protection was observed on yield in 2010. However, in 2011 a significant interaction was observed between rotation and crop protection (Table 3, 4).

In a comparison of effect of fertilisation on potato yield, a significant difference was obtained between compost and NPK fertilized plots. On plots treated with NPK fertilisers, higher yield compared to compost was obtained for both seasons. In addition the effect of crop protection was greater on yield for both years, the highest yield was obtained under application of conventional crop protection than organic crop protection systems.

Pre-crop significantly affected yield in both years, with highest yield after a pre-crop of beans than barley in 2010 while, a pre-crop of barley resulted in the significantly higher yield than beans in 2011.

Table 3 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, pre-crop and crop protection on tuber yield of potato

Factor	Total tuber yield(t/ha) **2010**	**2011**	ANOVA results *P*-value **2010**	**2011**	Interactions **2010**	*P*-value	Interactions **2011**	*P*-value
Variety			0.060	0.163	PC × CP	0.298	PC× CP	0.005
Sante	28.29 ± 3.08a	30.23 ± 1.21a			PC × FE	0.121	PC × FE	0.462
Sarpo Mira	31.61 ± 2.64a	31.76 ± 1.29a			PC× VAR	0.946	PC × VAR	0.169
Fertiliser			<0.000	< 0.000	CP× FE	0.085	CP × FE	0.956
Compost	26.51 ± 0.983b	27.29 ± 1.06b			CP × VAR	0.921	CP× VAR	0.931
NPK	33.42 ± 1.44 a	34.70 ± 1.07a			FE× VAR	0.812	FE× VAR	0.456
Crop protection			<0.004	<0.000	PC × CP× FE	0.894	PC × CP × FE	0.176
Organic	27.78 ± 1.27 b	27.51 ± 1.13b					PC× CP× VAR	0.969
Conventional	32.15± 1.37a	34.48 ± 1.05a					PC × FE × VAR	0.757
Pre-crop			<0.000	<0.000			CP × FE × VAR	0.521
Beans	33.25± 1.47a	28.94± 1.33b					PC × CP× FE× VAR	0.914
Barley	26.67 ± 0.971b	33.05 ± 1.05a						

Variety: VAR, Fertilisation: FE, Crop protection: CP, Pre-crop: PC.

Means labelled with the different letter are significantly different (Tukey s' honestly significant difference test, P < 0.05).

Table 4 Interaction effect of pre-crop and crop protection management on yield of potato (t/ha), mean ± SE 2011

	Organic	Conventional	Means
Beans	23.86 ± 1.18 b	34.03 ± 1.58 a	28.94
Barley	34.93 ± 1.42 a	31.16 ±1.35 b	33.05
Means	27.51	34.48	

3.1.2 Effect of growing season on tuber yield of potato

In general, crop yield of potato tuber was not statistically different between growing seasons (UK yields of the crop were also quite similar in 2010 and 2011). However, yield was slightly higher in year 2011 compared with 2010 in the QLIF trials.

The interaction between three factors was significant on yield of potato with a pre-crop of beans resulting in the highest yields under organic and conventional crop protection during the season of 2010, while in 2011 a pre-crop of barley resulted in the highest yields under organic and conventional crop protection systems (Table 5).

Table 5 Interaction effect between growing seasons, rotation and crop protection on tuber yield of potato (t/ha) (mean ±SE)

Growing season	Crop protection **(Organic)**		Crop protection **(Conventional)**	
	Rotation (beans)	**Rotation** (barley)	**Rotation** (beans)	**Rotation** (barley)
2010	31.83± 1.82ab	23.72± 1.09b	34.67± 2.31a	29.62±1.25ab
2011	23.86± 1.18b	31.16±1.45a	34.03± 1.58a	34.93± 1.42a

3.1.3 **Effect of treatments on tuber yield of NUE potato (2011)**

The results showed that the effect of crop protection and fertility was significant on yield. Variety also had a significant effect on yield, the highest values of the yield presented by variety Sante compared with Fontane, Nicola and Agria. The interactions among the experimental factors revealed significant difference between variety and fertility on tuber yield of potato which is illustrated in (Tables 6 & 7). The highest effect on yield was observed in the case of NPK fertiliser application compared with compost and control treatments (Table 6).

Table 6 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility, and crop protection on tuber yield of potato (2011).

Factor	Total tuber yield (t/ha)	ANOVA result *P*-value	Interactions	ANOVA result *P*- value
Variety		<0.001	FT × CP	0.627
Agria	24.98± 1.13bc		FT × VAR	0.005
Cara	25.67 ± 0.891b		CP ×VAR	0.910
Sarpo Mira	25.95 ± 0.884b		FT × VAR	0.964
Fontane	22.60 ± 1.07d			
Nicola	22.94 ± 1.02cd			
Sante	28.63 ± 1.25a			
Fertilisation		<0.001		
Compost	22.55 ± 0.398b			
NPK	31.165 ± 0.531a			
Control	18.213 ± 0.596c			
Crop protection		<0.001		
Organic	23.40 ± 0.569b			
Conventional	26.85 ± 0.643a			

Means labelled with the different letter are significantly different (Tukey's honestly significant difference test, $P < 0.05$). Variety: VAR, Fertilisation: FE, Crop protection: CP

Table 7 Interaction effect between variety and fertility treatments on tuber yield of potato (t/ha) mean ±SE

	Agria	Cara	Sarpo Mira	Fontane	Nicola	Sante	Mean
Compost	24.9 ± 1.13[efg]	25.6 ±0.89[cde]	25.9 ±0.88[ef]	22.6±1.07[efg]	22.9±1.02[efgh]	28.6±1.25[de]	22.55
NPK	31.7 ± 0.99[b]	29.4 ±1.33[bc]	31.3±0.631[b]	28.49±1.36[bcd]	28.9 ±1.09[bcd]	37.0 ± 1.09[a]	31.16
Control	18.3 ± 1.80[fgh]	20.0±1.04[efgh]	20.3 ± 1.25[efgh]	14.5 ± 1.17[h]	15.9±1.13[gh]	20.1 ±1.21[efgh]	18.21
Mean	24.98	25.68	25.95	22.6	22.94	28.63	

3.2 Vitamin C

3.2.1 **Titration and HPLC analysis (2010)**

3.2.2 **Effect of variety, fertility, rotation and crop protection treatments on vitamin C content of potato**

Results from the field experiments in 2010 and 2011 show that variety Sante had significantly higher vitamin C content compared with Sarpo Mira ($P < 0.001$) (Table 8). There were no significant influences of other treatments (fertility, rotation, crop protection and their interactions) on vitamin C content of potato (Table 8, 9).

A comparison of vitamin C content of potato tubers for the two years 2010, 2011 and two varieties using calorimetric titration method showed similar trend results on vitamin C content in Sante and Sarpo Mira potato (Figure 6).

Table 8 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, crop rotation and crop protection on concentrations of total vitamin C content in potato tubers. **Titration analysis 2010**

Factors	Total vitamin C (mg/100g DW)	ANOVA results *P*-value
Variety (VAR)		<0.0001
Sante	55.65 ± 2.07a	
Sarpo Mira	43.11± 1.69b	
Fertilisation (FE)		0.5092
Compost	50.28± 2.29a	
NPK	48.31± 2.1a	
Crop protection (CP)		0.7280
Organic	48.74± 2.22a	
Conventional	49.81± 2.18a	
Pre-crop (PC)		0.422
Beans	50.61 ± 2.28a	
Barley	47.91± 2.08a	

Interactions	ANOVA results	*P*-value
CP × FE		0.9450
CP × VAR		0.7605

FE × VAR	0.8448
CP × FE× VAR	0.8178
PC ×FE	0.125
PC ×CP	0.124
PC ×VAR	0.352
PC ×FE ×CP ×VAR	0.833

Variety: VAR, Fertilisation: FE, Crop protection: Pre-crop: PC.

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

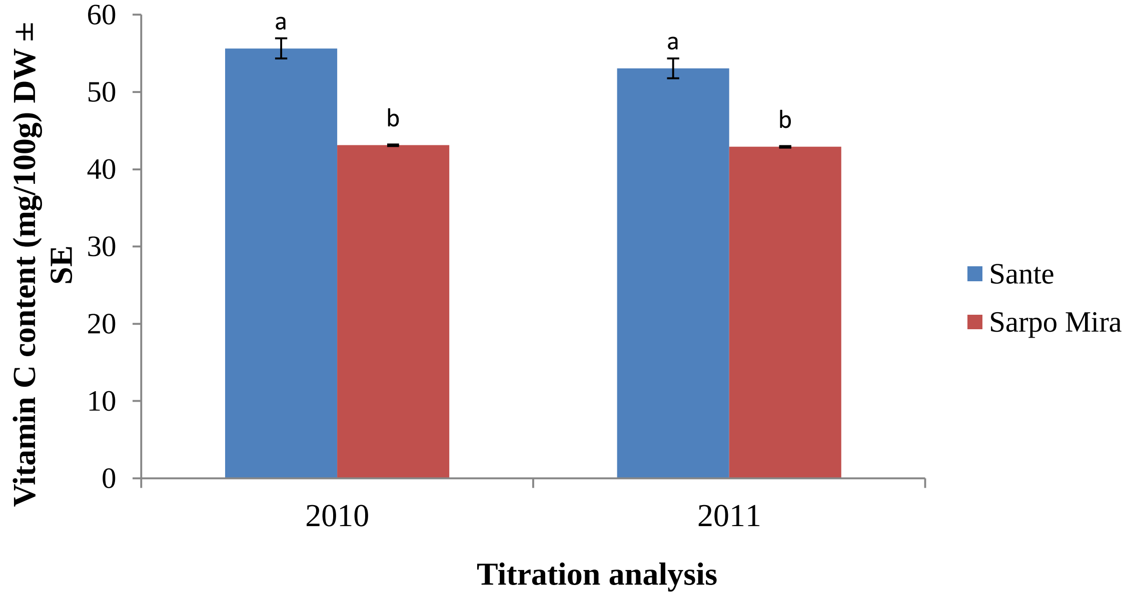


Figure 6 Comparison between effect of varieties on vitamin C content of potato in 2010, 2011. Titration analysis. Means that do not share a letter are significantly different.

Table 9 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, crop rotation and crop protection on concentrations of total vitamin C content in potato tubers. **HPLC analysis 2010**

Factors	**Total vitamin C (mg/100g DW)**	**ANOVA results**	***P*-value**
Variety			< .0001
Sante	46.23 ±1.21a		
Sarpo Mira	36.57 ± 0.951b		
Fertilisation			0.0947
Compost	42.70 ± 1.56a		
NPK	39.98 ± 1.17a		
Crop protection			0.3398
Organic	42.26 ± 1.23a		
Conventional	40.41 ± 1.51a		
Pre-crop			0.6956
Beans	41.71± 1.27a		
Barley	40.92 ±1.51a		

Interactions	**ANOVA results**	***P*-value**
PC ×CP		0.5549
PC ×FE		0.6393
CP ×FE		0.3581
PC ×VAR		0.9678

CP ×VAR	0.8227
FE ×VAR	0.8410
PC× CP× FE	0.7011
PC ×CP ×VAR	0.1168
PC ×FE ×VAR	0.4835
CP ×FE× VAR	0.8738
PC ×CP ×FE× VAR	0.4724

Means labelled with the same letter are not significantly different (Tukey's honestly significant difference test, P < 0.05). Variety: VAR, Fertilisation: FE, Crop protection: CP, Pre-crop: PC

3.2.3 **Titration and HPLC analysis (2011)**

3.2.3.1 Effect of variety, fertility, rotation and crop protection treatments on vitamin C content of potato

Based on two years of data the vitamin C results showed that variety Sante had significantly higher vitamin C content ($P < 0.001$) compared with Sarpo Mira. There were no significant influences of other treatments (fertility, rotation, crop protection and their interactions) on vitamin C content of potato tubers (Table 10, 11).

A comparison of vitamin C content of potato tubers for the two years 2010, 2011 and two varieties using HPLC analysis showed similar trend results on vitamin C content in Sante and Sarpo Mira potato (Figure 7).

Table 10 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, crop rotation and crop protection on concentrations of total vitamin C content in potato tubers. **Titration analysis 2011**

Factors	**Total vitamin C (mg/100g DW)**	**ANOVA results *P*-value**
Variety (VAR)		0.0079
Sante	53.07± 2.03a	
Sarpo Mira	42.91±1.25b	
Fertilisation (FE)		0.5292
Compost	39.40 ± 2.08a	
NPK	41.32 ±2.19a	
Crop protection (CP)		0.9746
Organic	42.30 ± 2.08a	
Conventional	38.42 ± 2.15a	
Pre-crop (PC)		0.554
Beans	41.05 ± 2.21a	
Barley	39.67 ± 2.07a	

Interactions	**ANOVA results**	***P*-value**
CP ×FE		0.7547
CP ×VAR		0.7302
FE ×VAR		0.2203

CP ×FE ×VAR	0.8638
PC× FE	0.056
PC ×CP	0.057
PC ×VAR	0.201
PC ×FE ×CP	0.951
PC× FE ×VAR	0.297
PC ×CP ×VAR	0.833
PC× FE ×CP ×VAR	0.961

Variety: VAR, Fertilisation: FE, Crop protection: CP, Pre-crop: PC.

Means with same letter are not significantly different at $P < 0.05$).

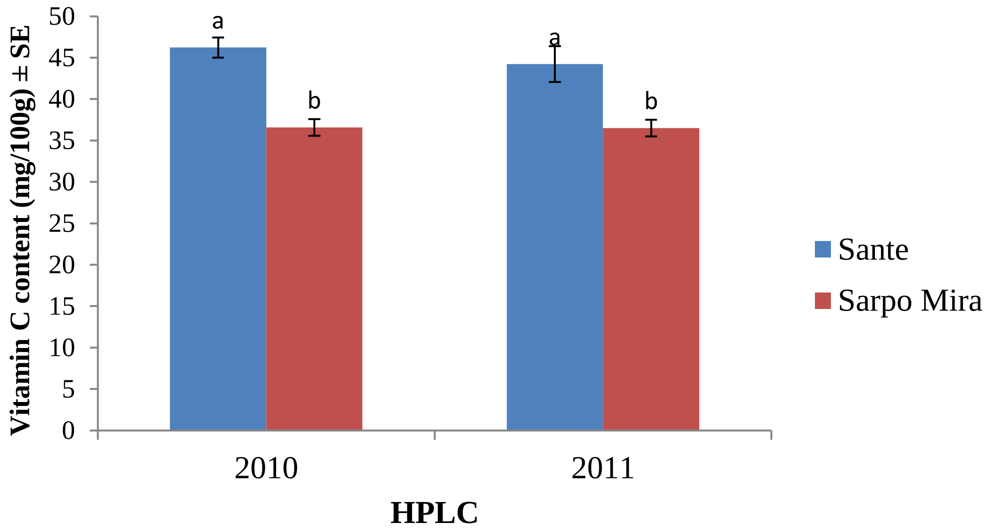


Figure 7 Comparison of effect of varieties on vitamin C content of potato in (2010, 2011). HPLC analysis. Mean ± SE. Bars with same letter are not significantly different.

Table 11 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, crop rotation and crop protection on concentrations of total vitamin C in potato tubers. **HPLC analysis 2011**

Factor	Total vitamin C (mg/100g DW)	*P*-value
Variety		< .0001
Santé	44.22 ± 2.16a	
Sarpo Mira	36.51± 1.89b	
Fertilisation		0.3269
Compost	39.40 ±2.08a	
NPK	41.32 ± 2.19a	
Crop protection		0.6646
Organic	42.30 ± 2.08a	
Conventional	38.42± 2.15a	
Pre-crop		0.6635
Beans	41.05 ±2.21a	
Barley	39.67 ± 2.07a	

Interactions	ANOVA results	*P*- value
PC× CP		0.5948
PC ×FE		0.0840
CP× FE		0.5721
PC× VAR		0.5133
CP ×VAR		0.8847
FE× VAR		0.0176
PC× CP ×FE		0.5855
PC× CP ×VAR		0.8889
PC× FE ×VAR		0.3922
CP× FE× VAR		0.7901
PC ×CP× FE× VAR		0.6081

Means labelled with the same letter are not significantly different (Tukey's honestly significant difference test, $P < 0.05$). Variety: VAR, Fertilisation: FE, Crop protection: CP, Pre-crop: PC.

3.2.3.2 Effect of growing seasons on vitamin C content

There was no significant difference between growing seasons on vitamin C content. No significant interaction was observed in vitamin C content between, variety, fertility, pre-crop, crop protection and growing season treatments of two years (Table 12).

There was a significant interaction between rotation and fertility for vitamin C over all two seasons as illustrated in Table 13. This shows that the vitamin C increase from fertility management was higher when beans was used compared with when barley was used.

The results of the study also recorded a significant interaction of vitamin C in potato tubers between crop protection and crop rotation (Table 14) with a pre-crop of beans resulting in the highest vitamin C under conventional treatment, while a pre-crop of barley resulted in the highest vitamin C under organic treatment.

Table 12 Main effect means ± SE and ANOVA *P*-values for the effects of variety, fertility management, crop rotation crop protection and growing season on concentrations of total vitamin C content of potato tubers.

ANOVA results				
Factor	Total vitamin C mg/100 g DW	*P*- value	Interactions	*P*-value
Growing season		0.420	GS ×PC	0.827
2010	49.28 ±1.55a		GS× FE	0.873
2011	47.99 ± 1.34a		GS× CP	0.993
Pre-crop		0.318	GS× VAR	0.485
Beans	49.66 ±1.52a		PC ×FE	0.015
Barley	47.59 ±1.35a		PC× CP	0.015
Fertilisation		0.268	PC× VAR	0.122
Compost	49.57 ±1.54a		FE ×CP	0.930
NPK	47.71 ±1.34a		FE× VAR	0.771
Crop protection		0.734	CP ×VAR	0.870
Organic	48.20 ±1.46a		GS ×PC× FE	0.912
Conventional	49.05 ±1.44a		GS × PC× CP	0.919
Variety		<0.000	GS ×PC ×VAR	0.887
Sante	54.34 ±1.45a		GS ×FE ×CP	0.906
Sarpo Mira	43.01 1.04b		GS× FE× VAR	0.633
			GS ×CP× VAR	0.846

GS ×FE× CP	0.903
PC× FE× VAR	0.127
PC ×CP× VAR	0.397
FE ×CP ×VAR	0.591
GS ×PC× FE× CP	0.839
GS× PC× FE ×VAR	0.878
GS ×PC× CP ×VAR	0.568
GS ×FE ×CP× VAR	0.934
PC× FE× CP×VAR	0.898
GS× PC× FE ×CP×VAR	0.848

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

Variety: VAR, Fertilisation: FE, Crop protection: CP, Pre-crop: PC, GS: Growing season.

Table 13 Effect of fertility and rotation on vitamin C content in 2 years 2010, 2011(mg/100g DW) mean ± SE

	Compost	**NPK**	**Mean**
Beans	48.41 ± 2.24a	50.91 ± 2.07a	49.66
Barley	50.76 ± 2.12a	44.51 ± 1.54a	47.59
Mean	49.57	47.71	

Table 14 Effect of crop protection and pre-crop on vitamin C content for 2 years 2010, 2011(mg/100g DW) mean ±SE

	Organic	**Conventional**	**Mean**
Beans			
	47.08 ± 2.00a	52.25 ± 2.24a	49.66
Barley			
	49.37 ± 2.14a	45.86 ± 1.66a	47.59
Mean			
	48.2	49.05	

3.2.3.3 Vitamin C results of NUE potato Titration method (2011)

3.2.3.4 Effect of variety, fertility and crop protection treatments on vitamin C content

Analysis of variance (ANOVA) of the effect of fertility on vitamin C content of potato indicated that there were no significant differences between fertility rate, types (High, Low, Compost, Mineral NPK, Control) and levels (0, 125, 250 kg /ha) on vitamin C content of potatoes (Table 15).

However, varieties showed significant effects on vitamin C content with vitamin C content of Nicola significantly higher than Agria, Cara, Sarpo Mira, Fontane and Sante. A significant interaction between fertility, variety and crop protection for vitamin C was recorded in 2011 (Table 15, 16).

The results as shown in Table 16, revealed that the application of high compost 250 kg/ha with organic crop protection significantly increased vitamin C content of variety Nicola compared with Sarpo Mira, Agria, Cara, and Fontane but was similar to Sante. Also application of low compost significantly increased vitamin C content in variety Nicola compared with Sarpo Mira and Fontane. There were no significant differences between Agria, Cara, Sarpo Mira and Fontane in vitamin C. High compost with conventional crop protection also significantly increased vitamin C content of variety Nicola compared with Sarpo Mira and Fontane, but not significantly different from Agria, Cara and Sante. The highest vitamin C content recorded was for Nicola with all fertility applications compared to Agria, Cara, Sarpo Mira and Fontane.

Table 15 Main effect means ± SE and ANOVA *P*-values for the effects of variety, fertility management and crop protection on concentrations of total vitamin C in NUE potato tubers. **Titration analysis 2011**

Factor	Total vitamin C (mg/100g DW)	ANOVA results *P*-value	Interaction	ANOVA results *P*-value
Variety		<0.0001	FE× CP	0.6749
Sante	48.67 ±1.39b		FE× VAR	0.0279
Sarpo Mira	29.6 ± 1.08d		CP ×VAR	0.5717
Nicola	66.96 ± 1.63a		FE ×CP ×VAR	0.0041
Agria	35.35 ± 1.75c			
Cara	30.08±0.906cd			
Fontane	33.3 ± 1.70cd			
Fertilisation		0.5898		
High compost	42.02 ± 2.14a			
Low compost	38.97± 2.38a			
High NPK	41.49 ±2.54a			
Low NPK	40.52± 2.32a			
Control	39.92 ± 2.32a			
Crop protection		0.8746		
Organic	40.67±1.52a			
Conventional	40.50±1.43a			

Variety: VAR, Fertilisation: FE, Crop protection: CP, Pre-crop: PC. Means with different letter are significantly different at P< 0.05).

Table 16 Interaction effect between fertility, variety and crop protection on vitamin C content of NUE potato (mg/100g) DW (2011), titration method

	High compost		Low compost		High NPK		Low NPK		Control	
Variety	Organic	Conventional	Organic	Conventional	Organic	Conventional	Organic	Conventional	Organic	Conventional
Agria	34.82$^{\mathbf{fgh}}$	41.33^{defgh}	28.9^{ghgh}	28.03^{gh}	48.39^{abcdefg}	32.8^{fgh}	30.49^{fgh}	50.41^{abcdefg}	26.15^{gh}	32.22^{fgh}
Cara	34.39f^{ghgh}	35.83^{efgh}	28.46^{gh}	30.06^{fgh}	27.74^{gh}	29.91^{fgh}	29.47^{fgh}	29.18^{gh}	27.02^{gh}	28.75^{gh}
Sarpo Mira	27.89^{gh}	35.58f^{gh}	28.32^{gh}	28.78^{gh}	29.91^{fgh}	24.39^{h}	27.6^{gh}	27.4^{gh}	31.78^{fgh}	33.85^{fgh}
Fontane	36.99^{efgh}	24.66^{gh}	29.61^{fgh}	28.31^{fgh}	31.93^{fgh}	52.39^{abcdefg}	32.37^{fgh}	25.23^{gh}	36.85^{efgh}	34.29^{efgh}
Nicola	68.76^{ab}	59.82^{abcde}	71.51$^{\mathbf{a}}$	63.57^{abcd}	63.15^{abcd}	68.92$^{\mathbf{ab}}$	68.76^{ab}	67.75^{abc}	68.77^{ab}	68.62^{ab}
Sante	51.73^{abcdefg}	49.7^{abcdef}	54.17^{abcdefg}	47.83^{abcdefgh}	50.99^{abcdefg}	44.35^{bcdefgh}	50.14^{abcdefg}	46.94^{abcdefgh}	43.05^{cdefgh}	47.82^{abcdefgh}

Means with different letter are significantly different.

3.2.3.5 Vitamin C results of NUE potato HPLC analysis (2011).

Analysis of variance (ANOVA) of the effect of fertility on vitamin C content indicated that there were no significant differences between fertility types and levels when averaged over all varieties (Table 17). However, the effect of varieties was significant. Vitamin C content of Sante was significantly higher than Agria, Cara and Fontane but similar to Sarpo Mira and Nicola when averaged over all fertility treatments. Response of all varieties to low NPK was similar except for Sante where the vitamin C content was significantly higher compared with Agria, Cara, Sarpo Mira and Fontane varieties.

Table 17 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total vitamin C of NUE potato tubers (2011). **HPLC analysis**

Factor	Total vitamin C (mg/100g) DW	ANOVA results *P*-value	Interactions	ANOVA results *P*-value
Variety		0.0015	FE ×CP	0.8871
Sante	297.5±40.1a		FE ×VAR	0.8613
Sarpo Mira	194.7±18.3b		CP× VAR	0.3560
Nicola	202.4±31.7ab		FE ×CP ×VAR	0.5680
Agria	89.6±4.18c			
Cara	106.4±12.4bc			
Fontane	164.6 ± 26.3bc			
Fertilisation		0.5851		
High compost	182.7 ±23.8a			
Low compost	209.7 ± 27.2a			
High NPK	182.8 ± 25.1a			
Low NPK	133.9 ± 21.0a			
Control	170.2±26.3a			
Crop protection		0.0828		
Organic	176.3 ±15.9a			
Conventional	175.4± 15.6a			

Variety: VAR, Fertilisation: FE, Crop protection: CP.

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

3.3 Glycoalkaloids results

Peak identification was achieved by comparing the retention times of the peaks in the samples to those of pure standards (Figure 8, 10). According to the AOAC official method the first peak was alpha solanine and appeared as a single peak at 5.9 ± SE min in the HPLC chromatogram, and the second peak was for alpha chaconine and appeared as a single peak at 7.3 ± SE min (Figure 8). Figure 9 illustrates the identification of alpha solanine and alpha chaconine for variety Sarpo Mira.

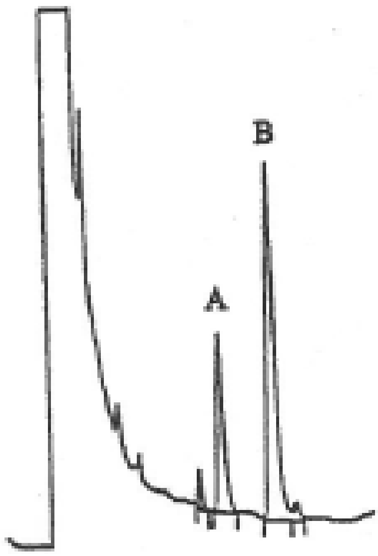


Figure 8 Chromatogram of potato tuber extract. Peaks: A = alpha solanine (R_t = 5.9 min) and B = alpha chaconine (Rt = 7.3 min). AOAC Official Method 997.13

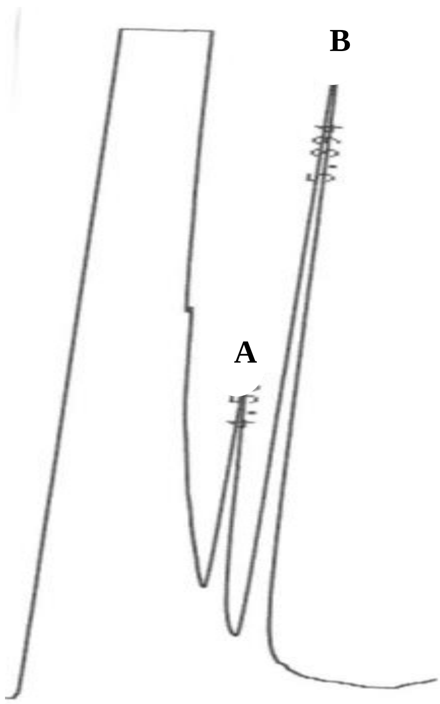


Figure 9 Chromatogram of potato tuber extracts (Variety. Sarpo Mira). Peaks: A= alpha solanine (Rt ± 4.5 min) and B = alpha chaconine (Rt ± 5.3 min), corresponding to potato tuber concentration at 150 mg/kg, respectively

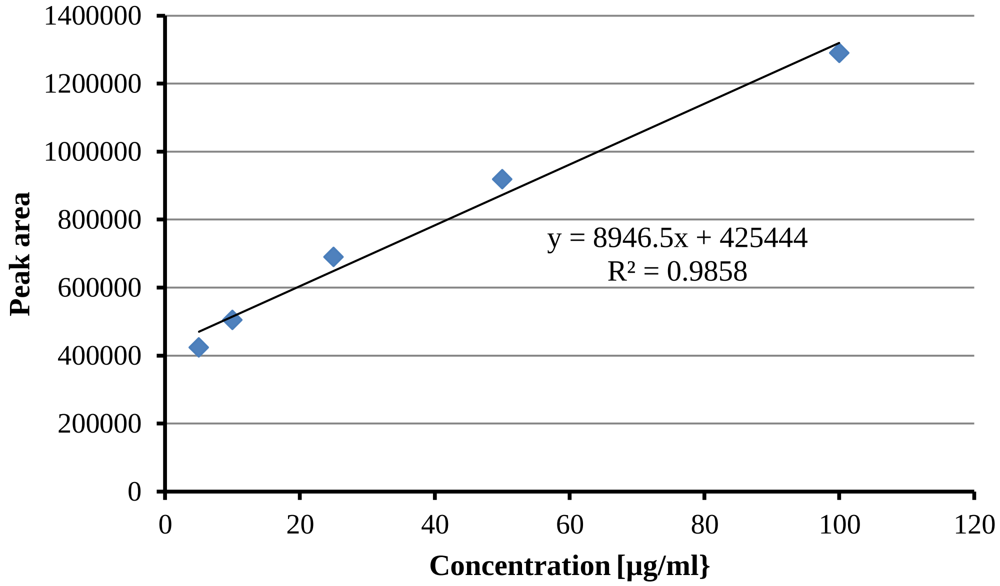


Figure 10 Standard curve for alpha solanine

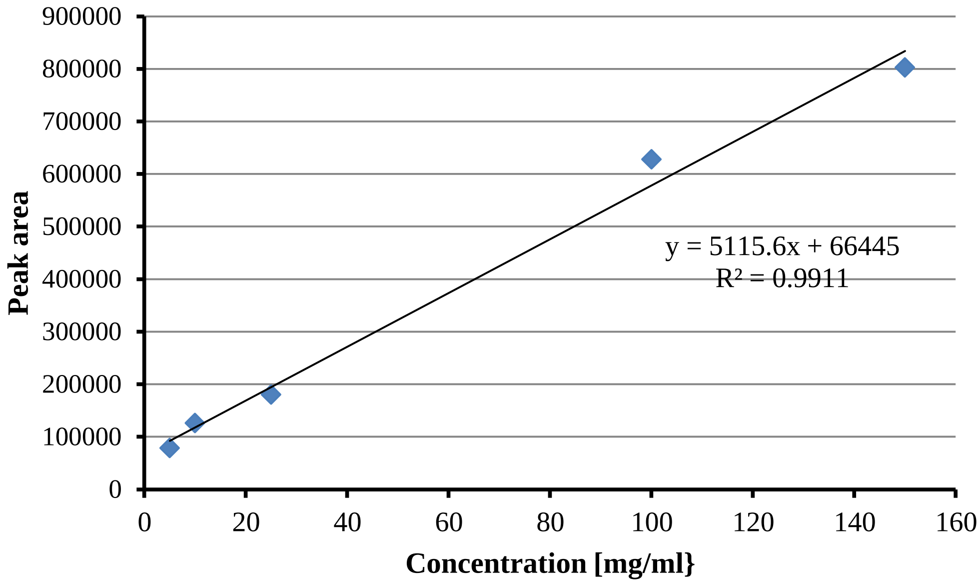


Figure 11 Standard curve for alpha chaconine

3.3.1 **Alpha solanine results 2010**

3.3.1.1 Effect of variety, fertility, rotation and crop protection treatments on alpha solanine content of potato

Data from the field experiments in 2010, 2011 was not normally distributed, hence subjected to logarithmic transformation prior to analysis. Results indicated that the effects of variety, fertility, rotation and crop protection on alpha solanine content were not significant (P >0.05) (Table 18). However, although not significant, Sante produced higher solanine content compared with Sarpo Mira.

No significant interaction effect on alpha solanine content between all previous treatments was observed during the 2010 season. The interaction effect between variety, fertility, rotation and crop protection treatments was also not significant on alpha solanine content (Table 18).

Table 18 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, pre-crop, and crop protection on concentrations of total alpha solanine content of potato (2010). **HPLC analysis**

Factor	**Total alpha solanine (mg/kg) DW**	**ANOVA results *P*-value**
Variety		0.871
Sante	244.5±79.7a	
Sarpo Mira	235.0±65.3a	
Fertilisation		0.093
Compost	329.7± 98.8a	
NPK	152.6 ±23.8a	
Crop protection		0.585
Organic	194.6±57.0a	
Conventional	283.4± 83.9a	
Pre-crop		0.589
Beans	283.2±84.5a	
Barley	230.0±58.4a	

Interactions	**ANOVA results**	***P*- value**
PC ×CP		0.270
PC ×FE		0.661
PC ×VAR		0.176
CP ×FE		0.672
CP ×VAR		0.646
FE ×VAR		0.919
PC ×CP× FE		0.671
PC× CP× VAR		0.697
PC ×FE ×VAR		0.101
CP ×FE× VAR		0.605
PC ×CP ×FE ×VAR		0.635

PC: pre-crop, VAR: variety, FE: fertilisation, CP: crop protection

Means with same letter are not significantly different at $P < 0.05$).The data were subjected to logarithmic transformation and means are expressed on a logarithmic scale ($P < 0.05$).

3.3.2 **Alpha solanine results 2011**

3.3.3 **Effect of variety, fertility, rotation and crop protection treatments on alpha solanine content of potato**

Statistical analysis of the effect of fertility, pre-crop and crop protection treatments on alpha solanine content also showed no significant impact during 2011 (Table 19). However, varieties showed significant effect on alpha solanine content as compared with 2010.

Analysis of data revealed that the interaction effect between variety, fertility, and crop rotation treatments was significant ($P < 0.05$) (Table 19). However, opposite results with variety were noticed in 2011. Sarpo Mira variety tended to be higher in alpha solanine content compared with Sante (Figure 12).

In general, comparing between two years of data alpha solanine content was found to be significantly higher in 2011 than 2010 (Figure 13).

Table 19 Main Effect Means ± SE and ANOVA *P*-values for the effects of Variety, Fertility Management, and Crop protection on concentrations of total alpha solanine content of potato (2011) **HPLC analysis**

Factor	**Total alpha solanine (mg/kg) DW**	**ANOVA results *P*-value**
Variety		0.037
Sante	469.3 ± 81.9b	
Sarpo Mira	817 ± 141a	
Fertilisation		0.802
Compost	622.7± 126a	
NPK	663.8 ± 112a	
Crop protection		0.881
Organic	656 ±123a	
Conventional	631 ± 116a	
Pre-crop		0.353
Beans	501.6± 76.6a	
Barley	401.0 ±70.3a	

Interactions	**ANOVA results**	***P*-value**
PC× FE		0.073
PC ×CP		0.395
PC× VAR		0.186
FE × CP		0.410
FE × VAR		0.647
CP× VAR		0.857
PC× FE× CP		0.684
PC× FE ×VAR		0.041
PC× CP× VAR		0.968
FE× CP ×VAR		0.414
PC ×FE ×CP ×VAR		0.427

See Table 18, for interactions means ± SE. PC: rotation. FE: fertility. VAR: variety. CP: crop protection.

Means with same letter are not significantly different at P <0.05).

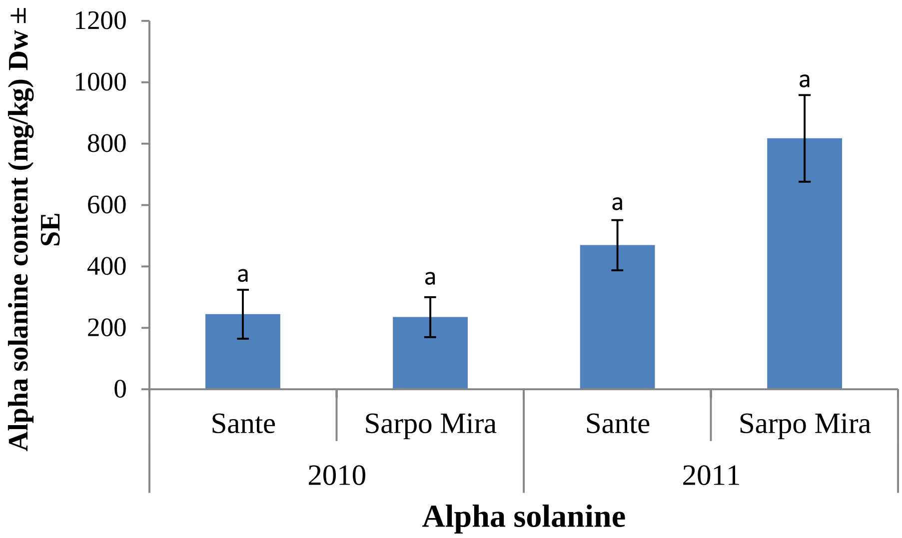


Figure 12 Comparison of effect of varieties on alpha solanine content of potato in (2010, 2011). HPLC analysis. Mean ± SE. Bars with same letter are not significantly different.

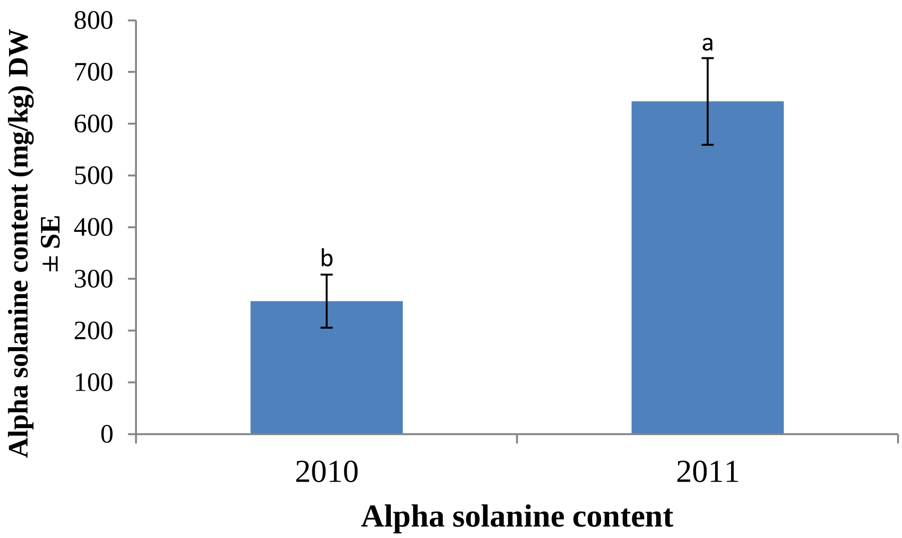


Figure 13 Comparison between two years on alpha solanine content. Means that do not share a letter are significantly different.

3.3.4 **Effect of growing season on alpha solanine content**

To determine the effect of growing season, year was used as a factor to detect the effect of growing season on alpha solanine content over two years of the experimental studies.

Growing season had a significant effect on the alpha solanine content of potato tubers. Alpha solanine content was significantly higher in year 2011 as compared with year 2010 (Table 20).

Variety interacted with fertility and crop rotation management factors as illustrated in Table 20, 21 which showed that the highest concentrations of alpha solanine was exhibited in Sarpo Mira potato when NPK fertiliser was applied with beans crop rotation as a compared to when compost was applied after barley cultivation.

Table 20 Main Effect Means ± SE and ANOVA P-values for the effects of Variety, Fertility, pre-crop, crop protection and growing season on concentrations of total alpha solanine content

Factor	**Total alpha solanine content (mg/kg) DW**	**ANOVA result *P*-value**	**Interactions**	**ANOVA result *P*-value**
Growing season		<0.000	GS× PC	0.627
2010	257.0 ± 51.3b		GS ×FE	0.257
2011	643.3 ± 83.7a		GS ×CP	0.672
Pre-crop		0.283	GS ×VAR	0.065
Beans	501.6 ± 76.6a		PC ×FE	0.201
Barley	401.0 ± 70.3a		PC× CP	0.189
Fertilisation		0.473	PC ×VAR	0.065
Compost	490.5 ± 81.6a		FE ×CP	0.357
NPK	413.4 ± 65.1a		FE× VAR	0.661
Crop protection		0.863	CP× VAR	0.688
Organic	446.0 ± 73.4a		GS× PC × FE	0.080
Conventional	457.2 ± 74.3a		GS× PC× CP	0.914
Variety		0.095	GS× PC ×VAR	0.710
Sante	370.7 ±58.5a		GS ×FE ×CP	0.645
Sarpo Mira	531.4± 85.0a		GS× FE ×VAR	0.743
			GS× CP ×VAR	0.920
			PC× FE× CP	0.567
			PC× FE ×VAR	0.009

PC× CP ×VAR	0.806
FE× CP ×VAR	0.335
GS× PC× FE× CP	0.914
GS× PC ×FE× VAR	0.402
GS× PC ×CP× VAR	0.858
GS× FE ×PC× VAR	0.687
PC ×FE ×CP× VAR	0.684
GS× PC× FE ×CP× VAR	0.356

GS: growing season, VAR: variety, FE: fertilisation, PC: pre-crop, CP: crop protection.

Means with same letter are not significantly different at $P < 0.05$) Tukey's honestly test.

Table 21 Effect of interaction of rotation, fertility and variety for the two years (2010, 2011) on alpha solanine content of potato tubers (mg/kg) DW, means ± SE

	Compost		**NPK**	
	Sante	**Sarpo Mira**	**Sante**	**Sarpo Mira**
Beans	634.4 ± 183	313.2 ± 98.7	386.1 ± 99.1	672.6 ± 198
Barley	220.4 ± 53.9	777.1 ± 222	232.5 ± 50.5	362.6 ± 113

3.3.5 **Alpha chaconine results 2010**

3.3.5.1 Effect of variety, fertility, rotation and crop protection treatments on alpha chaconine content of potato

In 2010 the experimental results demonstrated that the effect of variety, fertility, rotation and crop protection treatments on alpha chaconine content of potato tubers was not significant ($P > 0.05$) (Table 22). There was also no significant interaction between the fertility and variety treatments on alpha chaconine content. In contrast, the interaction effect was significant and more obvious between variety, fertility and crop protection on alpha chaconine content of potato tubers (Table 22, 23).

Table 22 Main Effect Means ± SE and ANOVA P-values for the effects of Variety, Fertility Management, pre-crop and crop protection on concentrations of total alpha chaconine content of potato tubers (2010)

Factor	Total alpha chaconine content (mg/kg) DW	ANOVA results *P*-value
Variety		0.667
Sante	307.7 ±70.2a	
Sarpo Mira	355.2 ± 92.7a	
Fertilisation		0.416
Compost	383.6 ± 56.6a	
NPK	378 ± 100a	
Crop protection		0.869
Organic	344.9 ±79.4a	
Conventional	319.2 ±85.5a	
Pre-crop		0.437
Beans	376.4± 87.3a	
Barley	285.8± 76.6a	

Interactions	ANOVA result	*P*-value
PC× CP		0.426
PC× FE		0.648
PC× VAR		0.701
CP × FE		0.244
CP × VAR		0.254
FE× VAR		0.808
PC× CP× FE		0.996
PC × CP × VAR		0.540
PC × FE × VAR		0.939
CP × FE× VAR		0.029
PC× CP × FE × VAR		0.846

PC: pre-crop, CP: crop protection, VAR: variety, FE: fertility.

Means with same letter are not significantly different at P < 0.05).

Table 23 Interaction effect between fertility, variety and crop protection on alpha chaconine content of potato tubers (mg/kg) DW) mean± SE

	Compost		**NPK**	
	Sante	**Sarpo Mira**	**Sante**	**Sarpo Mira**
Organic	300.6 ± 112	438.2 ± 165	481.8 ±236	153.2± 56.0
Conventional	253.8± 92.6	144.0± 40.8	193± 39.3	685.3± 302

3.3.6 **Alpha chaconine results 2011.**

3.3.6.1 Effect of variety, fertility, pre-crop and crop protection treatments on alpha chaconine content of potato

Statistical results indicated that the effect of treatments variety, fertility, pre-crop and crop protection was not significant (P>0.05) (Table 24).

Furthermore, there was no significant interaction detected between previous treatments on alpha chaconine content (Table 24). Generally, the effect of the treatments was similar across the two years.

In 2010 and 2011 although the difference between varieties was not significant, alpha chaconine content was found to be slightly higher in Sarpo Mira compared with Sante in both years (Figure 14). There was no significant difference between two years on alpha chaconine content (Figure 15).

Table 24 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total alpha chaconine content of potato tubers. **HPLC analysis 2011**

Factor	**Total alpha chaconine content (mg/kg) DW**	**ANOVA results *P*-value**
Variety		0.940
Sante	473.4±94.4a	
Sarpo Mira	483.4±86.1a	
Fertilisation		0.538
Compost	437.6±80.1a	
NPK	519.2± 99.0a	
Crop protection		0.107
Organic	586 ±102a	
Conventional	370.3± 71.2a	
Pre-crop		0.813
Beans	494.0±82.9a	
Barley	482.8±79.1a	
Interactions	**ANOVA results**	***P*-value**
PC ×CP		0.132
PC× FE		0.569
PC ×VAR		0.870
CP× FE		0.268
CP× VAR		0.897
FE× VAR		0.417
PC ×CP ×FE		0.914
PC× CP ×VAR		0.285
PC× FE× VAR		0.550
CP× FE ×VAR		0.577
PC ×CP× FE ×VAR		0.357

PC: rotation, CP: crop protection, VAR: variety, FE: fertility.

Means with same letter are not significantly different at P < 0.05).

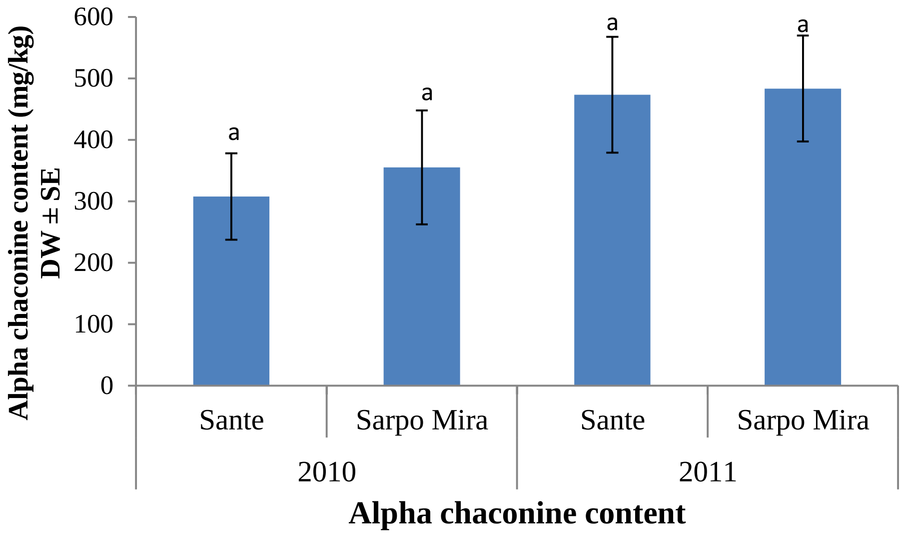


Figure 14 Comparison of effect of varieties on alpha chaconine content of potato in (2010, 2011). HPLC analysis. Mean ± SE. Bars with same letter are not significantly different.

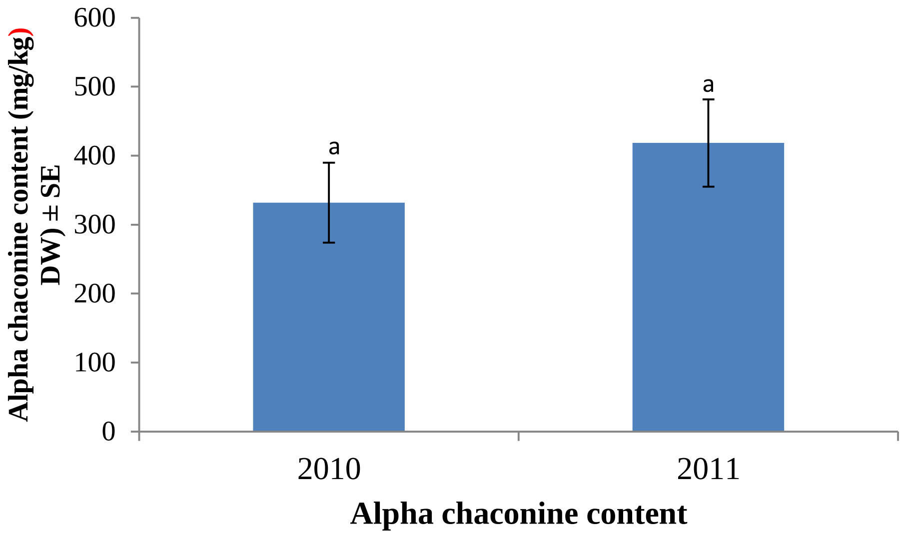


Figure 15 Comparison between two years on alpha chaconine content. Means ± SE. Bars with same letter are not significantly.

3.3.6.2 Effect of growing season on alpha chaconine content of potato

No significant difference between two years was detected on alpha chaconine content of potato (*P*> 0.05) (Table 25). No significant interactions were observed for alpha chaconine content in potato tubers between the two growing seasons.

Table 25 Main Effect Means ± SE and ANOVA P-values for the effects of Variety, Fertility, pre-crop, crop protection and growing season for the two years (2010, 2011) on concentrations of total alpha chaconine content of potato

Factor	**Total alpha chaconine content (mg/kg) DW**	**ANOVA results *P*-value**	**Interactions**	***P*-value**
Growing season		0.098	GS× PC	0.724
2010	331.8 ±58.0a		GS ×CP	0.274
2011	478.4 ± 63.4a		GS ×FE	0.924
Pre- crop		0.483	GS× VAR	0.814
Beans	435.2±60.2a		PC ×CP	0.559
Barley	375.7±62.6a		PC× FE	0.466
Fertilisation		0.315	PC ×VAR	0.704
Compost	361.8± 49.9a		CP ×FE	0.108
NPK	448.9±70.5a		CP× VAR	0.497
Crop protection		0.189	FE ×VAR	0.662
Organic	467.6±66.3a		GS ×PC ×CP	0.098
Conventional	344.8 ±55.3a		GS ×PC ×FE	0.911

Variety		0.729	GS ×PC× VAR	0.890
Sante	391.9±59.5a		GS× CP ×FE	0.976
Sarpo Mira	419.3±63.3a		GS× CP× VAR	0.384
			GS ×FE× VAR	0.444
			PC× CP ×FE	0.933
			PC× CP× VAR	0.228
			PC× FE ×VAR	0.696
			CP× FE× VAR	0.271
			GS× PC× CP FE	0.939
			GS× PC ×CP× VAR	0.704
			GS× PC× FE× VAR	0.621
			GS ×CP× FE× VAR	0.056
			PC ×CP ×FE ×VAR	0.416
			GS× PC ×CP ×FE ×VAR	0.581

GS: growing season, VAR: variety, FE: fertilisation, PC: pre-crop, CP: crop protection.

Means with same letter are not significantly different at $P < 0.05$).

3.3.7 **Alpha solanine results of NUE potato 2011**

3.3.7.1 Effect of variety, fertility, and crop protection on alpha solanine content

The results from this study show that there were no significant effects of variety, fertility and crop protection on alpha solanine content of potato ($P>0.05$). No significant interaction between variety, fertility and crop protection were detected for alpha solanine content (Table 26).

Table 26 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total alpha solanine content of NUE potato tubers (2011) **HPLC analysis**

Factor	**Total alpha solanine content (mg/kg) DW**	***P*-value**
Variety		0.127
Sante	270.9± 40.8 a	
Sarpo Mira	239.8± 42.8 a	
Agria	376.6 ±79.1 a	
Cara	371.3 ±95.7 a	
Fontane	424.7 ± 80.1 a	
Nicola	301.8 ± 61.4 a	
Fertilisation		0.462
High compost	356.6 ± 61.0 a	
Low compost	241.8 ± 37.7 a	
High NPK	327.0 ± 75.7 a	
Low NPK	287.9 ± 55.5 a	
Control	421.7 ± 74.2 a	
Crop protection		0.886
Organic	312.0 ± 32.2 a	
Conventional	342.0 ± 45.8 a	

Interactions	**ANOVA results *P*-value**
FE× CP	0.712
FE× VAR	0.340
CP ×VAR	0.745
FE ×CP ×VAR	0.239

Means that do not share a letter are significantly different at P < 0.05)

FE: fertiliser, CP: crop protection, VAR: variety

3.3.8 **Alpha chaconine results of NUE potato 2011**

3.3.8.1 Effect of variety, fertility, and crop protection on alpha chaconine content

The data presented in Table 27 show that alpha chaconine content was not significantly affected by fertility, variety and crop protection treatments in potato tubers in 2011 ($P>0.05$). However, results indicated that there was a significant interaction between fertility and crop protection treatments on alpha chaconine content of potato tubers (Table 27).

Table 27 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total alpha chaconine content of NUE potato tubers (2011) **HPLC analysis**

Factor	Total alpha chaconine content(mg/kg) DW	ANOVA results *P*-value
Variety		0.449
Sante	229.9± 21.4 a	
Sarpo Mira	282.7 ± 25.6 a	
Agria	277.7± 20.9 a	
Cara	243.4 ± 26.4 a	
Fontane	256.9 ± 28.5 a	
Nicola	292.6 ± 24.6 a	
Fertilisation		0.465
High compost	233.1±19.9 a	
Low compost	267.8± 22.7 a	
High NPK	262.1± 20.6 a	
Low NPK	282.2±24.1 a	
Control	276.7± 25.3 a	
Crop protection		0.560
Organic	257.5± 13.2 a	
Conventional	271.3 ± 15.2 a	
Interactions	**ANOVA results P-value**	
FE ×CP	0.045	
FE ×VAR	0.912	
CP× VAR	0.621	
FE ×CP ×VAR	0.203	

FE: fertilisation, VAR: variety, CP: crop protection

Means with same letter are not significantly different at P < 0.05)

3.4 Minerals results 2010

3.4.1 **Effect of variety, fertility, rotation and crop protection on macronutrient contents of potato tubers**

3.4.2 **N, P, K and S**

Analysis of the data showed that mineral contents (N, P, and K) of potatoes were significantly affected by fertility treatments (P < 0.0001, 0.0006 and 0.0338, respectively) (Table 28). There was no significant difference in S levels between the compost and NPK treated plots. N, P contents were significantly increased by NPK application. However, K content was increased significantly by compost application.

Differences in N, K and S contents of organic and conventional potatoes were not significant (P>0.05) but significant difference in the level of P was recorded between organic and conventional regimes (P< 0.05) with organic crop protection producing higher P level compared with conventional crop protection system.

The results as shown in table 28 revealed that N, P and S levels in potato tubers were significantly affected by variety treatments (P <0.05). On the other hand, the effect of variety on K levels was not significant (P> 0.05) (Table 28).

When total N was assessed, a significant mean effect of pre-crop was detected, (Table 28).In addition, a significant interaction between pre-crop and fertilisation was detected for total S content. S content was higher after barley cultivation with compost treatment than beans. However, S content was higher after beans than after barley in NPK treatment (Table 30).

There was significant interaction between rotation and crop protection in tuber content of phosphorus. P content after bean was significant higher in organic than conventional treatment (Table 31). However, there was no significant difference between organic and conventional after barley cropping.

3.4.3 **Mg, Na and Ca**

There was a significant effect of variety for total Na and Ca contents in 2010, but no significant mean effects of variety for total Mg content (Table 28). Concentrations of Na were highest in Sante and lowest in Sarpo Mira. However, opposite results were found for total content of Ca where Sante was highest compared with Sarpo Mira.

There were significant effects of fertilisation on total Na and Ca concentrations but no significant mean effects of fertilisation for total Mg contents were detected. Concentrations of Na were higher in tubers under compost fertilised plots as compared with NPK plots. The concentrations of Ca were higher under NPK fertilised plots compared with compost plots (Table 28).

Significant effects of crop protection were observed for total Na contents, while there were no significant effects of crop protection for any of the Mg and Ca contents.

The results of a more detailed analysis that included the effects of pre-crop are shown in Table 28. A significant effect of pre-crop was only detected for total Na contents.

There was also a significant interaction between variety and crop protection for total Na content (Table 28). In addition, a significant interaction between pre-crop, fertilisation and variety was detected for total Mg content.

Table 28 Main effect means ± SE and ANOVA *P*-values for the effects of variety, rotation, fertility management, and crop protection on concentrations of total macronutrient contents N, P, K and S of potato tubers (2010)

Factor	**N (g/100g DW)**	***p-value***	**P (g/100g DW)**	***p-value***	**K (g/100g DW)**	***P-value***	**S (g/100g DW)**	***p-value***
Variety		0.03		0.04		0.17	0.11 ±0.00a	**0.00**
Sante	1.13 ± 0.03 a		0.16 ± 0.00b		1.53± 0.04a		0.10± 0.00b	
Sarpo Mira	1.03±0.04 b		0.17 ± 0.00a		1.62 ± 0.04a			
Fertilisation		<0.000		<0.000		0.03		0.34
Compost	0.94±0.03b		0.15± 0.00b		1.64 ± 0.05a		0.10 ±0.00a	
NPK	1.22±0.03a		0.17± 0.00a		1.52± 0.03b		0.10 ±0.00a	
Crop protection		0.64		0.01		0.45		0.67
Organic	1.07±0.03a		0.17 ±0.00a		1.59 ± 0.04a		0.10 ±0.00a	
Conventional	1.09±0.04a		0.16 ± 0.00b		1.55 ± 0.04a		0.10± 0.00a	
Pre-crop		<0.00		0.45		0.02		0.43
Beans	1.02± 0.04a		0.16±0.00a		1.64 ± 0.03a		0.10 ±0.00a	
Barley	1.15 ±0.03b		0.16±0.00a		1.51 ± 0.04b		0.10 ±0.00a	

Interactions				ANOVA *p*-values			
N	***p*-value**	**P**	***p*-value**	**K**	***p*-value**	**S**	***p*-value**
PC× FE	0.32	PC ×FE	0.58	PC ×FE	0.72	PC× FE	0.01
PC× CP	0.29	PC ×CP	0.04	PC× CP	0.92	PC ×CP	0.12
PC× VAR	0.74	PC ×VAR	0.77	PC× VAR	0.70	PC× VAR	0.10
FE ×CP	0.43	FE× CP	0.78	FE ×CP	0.29	FE ×CP	0.89
FE ×VAR	0.52	FE ×VAR	0.33	FE ×VAR	0.77	FE ×VAR	0.21
CP ×VAR	0.95	CP× VAR	0.75	CP× VAR	0.85	CP× VAR	0.10
PC ×FE ×CP	0.51	PC ×FE ×CP	0.96	PC× FE× CP	0.49	PC ×FE ×CP	0.38
PC ×FE ×VAR	0.21	PC× FE ×VAR	0.40	PC ×FE ×VAR	0.11	PC ×FE× VAR	0.00
PC ×CP ×VAR	0.82	PC ×CP ×VAR	0.89	PC ×CP× VAR	0.87	PC× CP ×VAR	0.13
FE ×CP× VAR	0.23	FE ×CP ×VAR	0.46	FE× CP× VAR	0.53	FE× CP ×VAR	0.03
PC× FE ×CP ×VAR	0.40	PC FE CP VAR	0.43	PC× FE ×CP ×VAR	0.52	PC× FE ×CP ×VAR	0.26

Means that do not share a letter are significantly different at P < 0.05). FE: fertiliser, CP: crop protection, VAR: variety, PC: pre-crop

Table 29 Main effect means ± SE and ANOVA P-values for the effects of variety, rotation, fertility management, and crop protection on concentrations of total macronutrient contents Mg, Na**,** and Ca of potato tubers. 2010

Factor	**Mg (g/100g DW)**	***p*-value**	**Na (g/100g DW)**	***p*-value**	**Ca (g/100g DW**	***p*-value**
Variety		0.09		0.04		<0.000
Sante	0.08 ±0.00 a		42.7 ±2.30 a		0.02 ± 0.00a	
Sarpo Mira	0.07 ±0.00 a		38.2 ±1.55 b		0.03 ±0.00b	
Fertilisation		0.43		0.01		0.00
Compost	0.08 ±0.00 a		43.3 ± 2.05 a		0.025± 0.00a	
NPK	0.08± 0.00 a		37.7 ±1.81 b		0.028± 0.00b	
Crop protection		0.76		0.02		0.14
Organic	0.08 ±0.00 a		37.6 ±1.52 b		0.02 ±0.00a	
Conventional	0.08 ± 0.00 a		43.2 ±2.24 a		0.02± 0.00a	
Pre-crop		0.21		<0.000		0.36
Beans	0.08 ± 0.00 a		35.6 ± 1.29 b		0.02 ±0.00a	
Barley	0.07±0.00 a		45.4 ±2.20 a		0.02± 0.00a	

Interaction		ANOVA p-value			
Mg	***P-value***	**Na**	***P-value***	**Ca**	***P-value***
PC× FE	0.73	PC ×FE	0.97	PC× FE	0.38
PC× CP	0.78	PC× CP	0.20	PC ×CP	0.77
PC× VAR	0.17	PC× FE	0.17	PC ×VAR	0.41
FE CP	0.42	FE× CP	0.72	FE ×CP	0.95
FE× VAR	0.57	FE× VAR	0.74	FE× VAR	0.06
CP ×VAR	0.79	CP ×VAR	0.01	PC ×VAR	0.53
PC× FE× CP	0.79	PC ×FE ×CP	0.91	PC ×FE ×CP	0.45
PC× FE ×VAR	0.01	PC ×FE ×VAR	0.66	PC× FE ×VAR	0.24
PC× CP× VAR	0.62	PC ×CP ×VAR	0.22	PC× CP ×VAR	0.79
FE ×CP ×VAR	0.13	FE ×CP ×VAR	0.48	FE ×CP× VAR	0.28
PC× FE ×CP ×VAR	0.83	PC ×FE ×CP ×VAR	0.42	PC ×FE× CP ×VAR	0.75

Means with different letter are significantly different at P < 0.05)

FE: fertilisation, VAR: variety, PC: pre-crop, CP: crop protection.

Table 30 Interaction between pre-crop and fertility on S content of potato tubers (g/100g DW) mean ± SE

	Compost	**NPK**	**Means**
Beans	0.1036 a ± 0.003	0.1066 a ± 0.002	0.1051 A
Barley	0.11 *a* ± 0.002	0.1033 *a*± 0.003	0.1065 A
Means	0.1067 a	0.105 a	

Means with different letter are significantly different.

Table 31 Interaction between rotation and crop protection on P content of potato tuber (g/100g) DW

	Organic	**Conventional**	**Means**
Beans	0.1766 *a*	0.1570 *b*	0.1668 A
Barley	0.1703 *ab*	0.1691 *ab*	0.1697 A
Means	0.1736 a	0.1630 b	

Means with different letter are significantly different.

3.4.4 Effect of growing season on N content of potato tubers

Both agronomic and environmental parameters (especially contrasting climatic conditions in different growing seasons) may influence nutritional quality of potato tubers.

Growing season had a significant effect ($P < 0.05$) on the level of N in potato tubers (Figure 16). The 2010 season resulted in higher N concentrations compared with 2011. Growing season also interacted with fertility management factors (Figure 17).

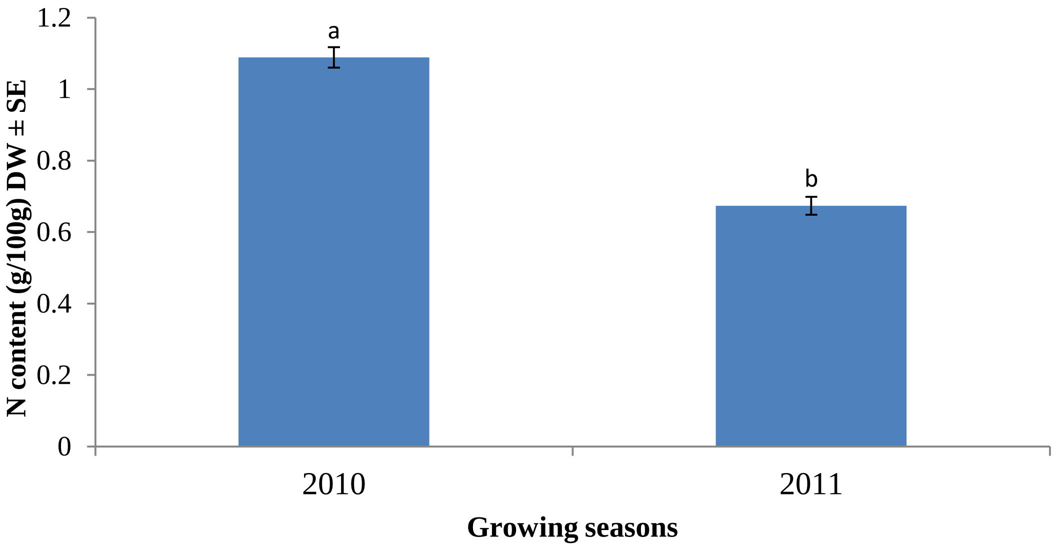


Figure 16 Effect of growing season on N content of potato. Mean ± SE. Bars with different letters are significantly different

There were significant interactions between growing season and fertilisation on N concentrations. N concentrations were highest after application of NPK and lowest after compost application. It is also obvious from Figure 17 that N content in 2010 was only affected significantly by fertility treatments while there was no significant effect between fertility treatments on N content in 2011.

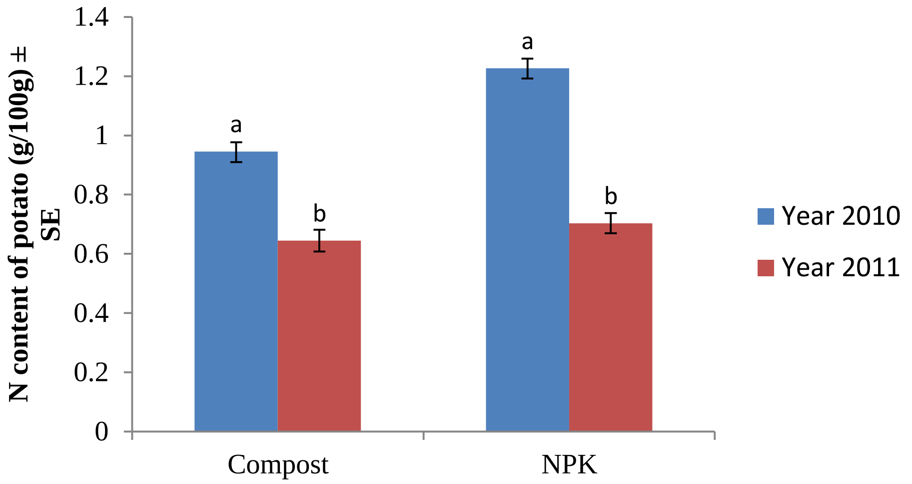


Figure 17 Interaction effect between fertility and growing season on N content of potato. Mean ± SE. Bars with same letter are not significantly different

3.4.5 Effect of growing seasons on P content of potato tubers

The results revealed that growing seasons had no significant effect on P content as compared with the N content. On the other hand, a significant interaction between growing season and fertilisation was observed on P content of potato. P concentrations were higher under compost fertility management in each year compared with NPK (Figure 18).

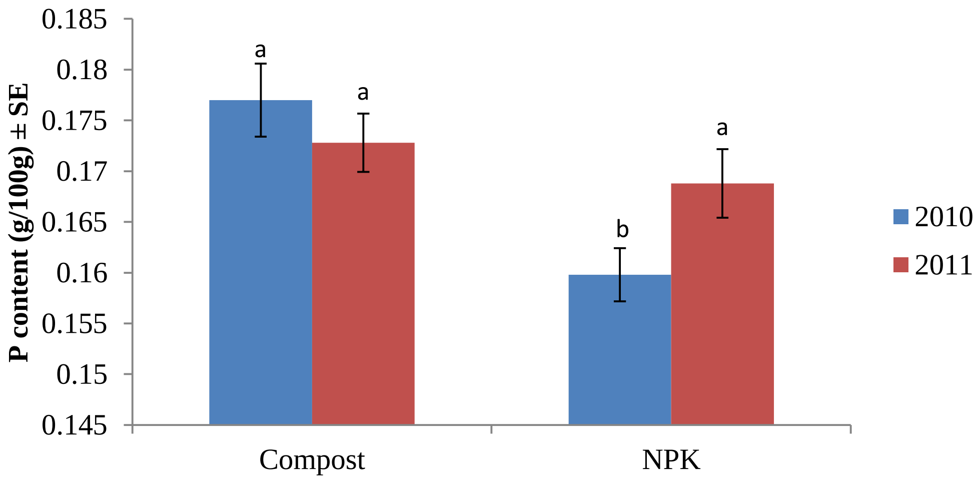


Figure 18 Interaction between fertility and growing season on P content of potato. Mean ± SE. Bars with same letter are not significantly different

3.4.6 **Effect of growing season on K content of potato tubers**

The results of a more detailed analysis that included the effects of growing season are shown in Figure 19. The results for K content where growing seasons had a significant effect on K level of potato tubers, but no significant interaction in the content of K was recorded between growing seasons.

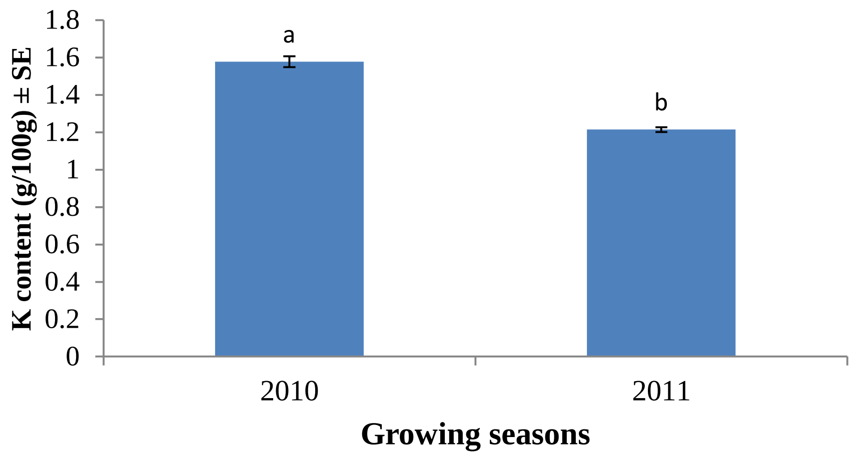


Figure 19 Effect of growing season on K content of potato. Mean ± SE. Bars with different letters are significantly different

3.4.7 **Effect of growing season on S content of potato**

Analysis of data showed that there was no significant difference between the two growing seasons on S content of potato tubers. Nevertheless, the results revealed that the interaction between growing season, fertility, rotation and variety was significant.

3.4.8 **Effect of growing season on Mg content of potato tubers**

Figure 20 indicates that there was a significant difference between the two growing seasons on Mg content of potato tubers. No significant interaction between growing season, rotation, fertility and variety was observed on Mg content of potato tubers.

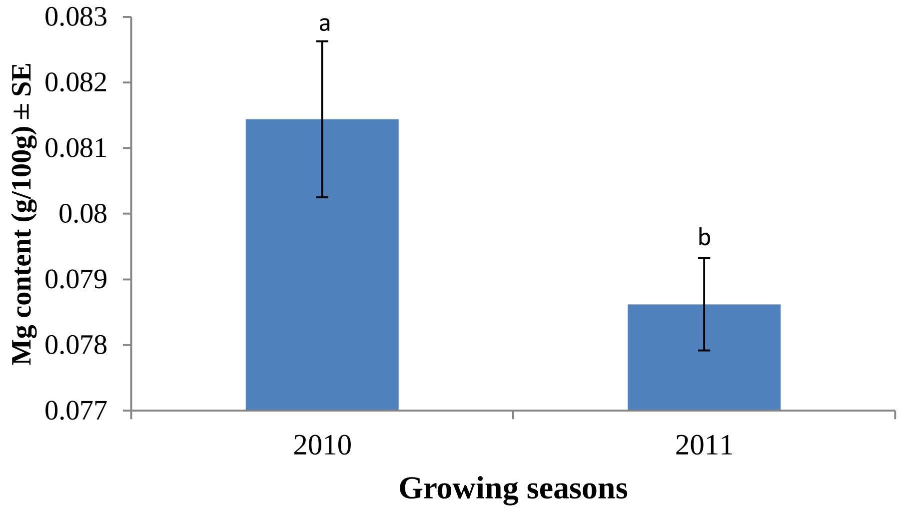


Figure 20 Effect of growing season on Mg content of potato. Mean ± SE. Bars with different letters are significantly different

3.4.9 **Effect of growing season on Na content of potato tubers**

The data presented in Figure 21 shows that growing season significantly affected Na content of potato tubers, with the highest Na content recorded in 2011 as compared to 2010.

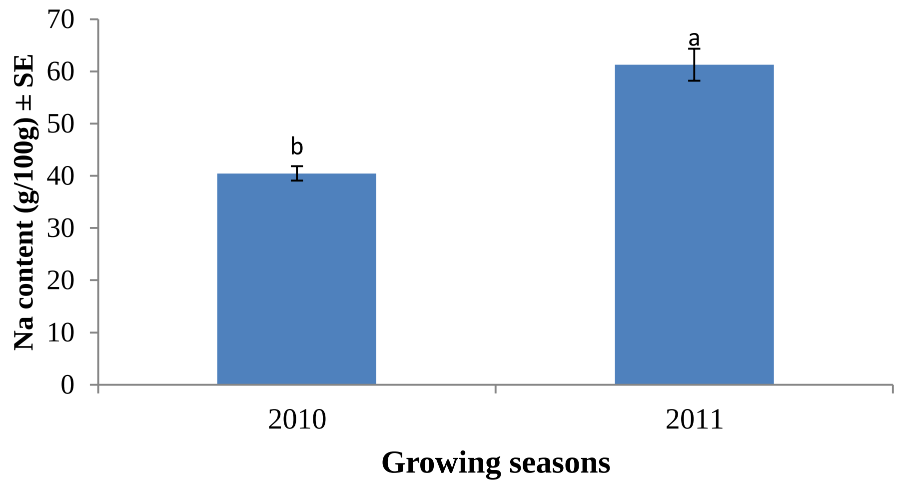


Figure 21 Effect of growing season on Na content of potato. Mean ± SE. Bars with different letters are significantly different

There was a significant interaction between the two growing seasons and crop rotation. In the 2010 Na concentrations were highest after a pre-crop of barley and lowest after a pre-crop of beans. On the other hand, in 2011 highest Na concentrations occurred after a pre-crop of beans compared with after a pre-crop of barley (Figure 22).

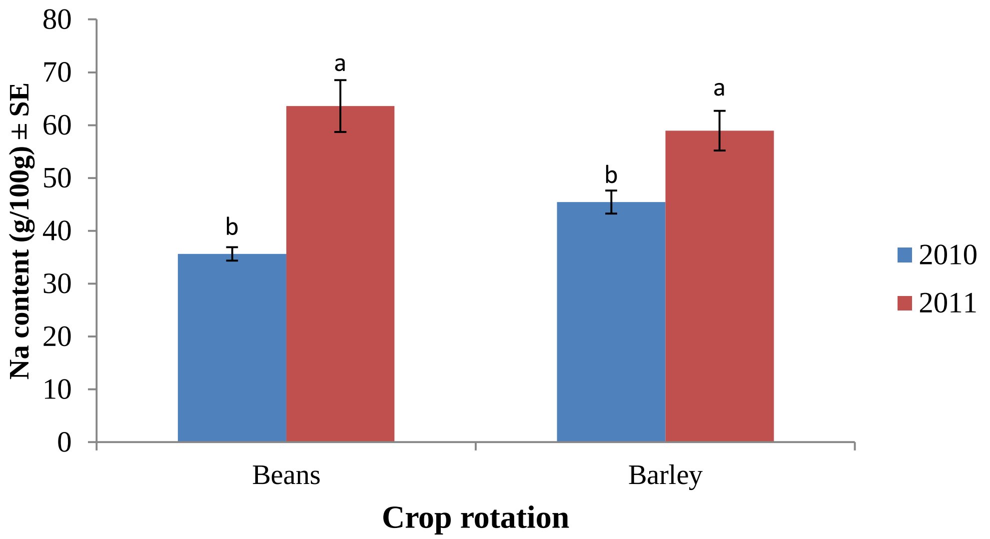


Figure 22 Interaction effect between growing season and pre-crop on Na content of potato. Mean ± SE. Bars with same letter are not significantly different

Table 32 shows that in 2010 Na concentrations were higher after a pre-crop of barley when conventional crop protection was applied compared with pre-crop of beans under organic crop protection. However, in 2011 Na concentrations were higher after a pre-crop of beans compared with barley when organic crop protection was applied.

Table 32 Interaction between growing season, rotation and crop protection on Na content of potato (g/100g) DW, mean ± SE

	Organic		Conventional	
	Beans	**Barley**	**Beans**	**Barley**
2010	34.45 ± 1.85d	41.01 ± 2.19cd	36.82 ± 1.80cd	49.60 ± 3.48bcd
2011	53.38 ± 4.83bcd	62.47 ± 6.27ab	73.83 ± 7.83a	55.43 ± 4.22abc

3.4.10 Effect of variety, fertility, rotation and crop protection on micronutrient contents of potato tubers

3.4.11 Fe, Mn, Zn, Cu and B

Fe and Zn contents of tuber were significantly affected by fertility and variety treatments. However, Mn was not affected by all the treatments (Table 33).

Fe and Zn were also observed to be higher in NPK treatment than compost. More Fe was found in variety Sarpo Mira than Sante, but Sante has more Zn than Sarpo Mira. Mn content was comparable in both Santé and Sarpo Mira. There was no significant difference between variety, fertility, rotation and crop protection on Mn content of potato tubers. However, a significant interaction was observed in the level of Mn between variety, rotation and fertility treatments (Table 33, 34).

The interaction effect of potato varieties, type of fertilisers and crop protection on mineral contents of Mn, Zn and Cu, was statistically significant (Table 33, 34). In both Sante and Sarpo Mira, the highest contents were found for Na, followed by K and N. while for micro minerals for all varieties, the highest levels were found for Fe, followed by Zn, B, Mn and Cu.

The levels of Cu were also observed to be significantly higher under ($P< 0.05$) organic treated plots than under conventional plots. However, there was no significant difference between varieties, fertilisation and crop rotation for the level of Cu (Table 33).

Table 33 Main effect means ± SE and ANOVA P-values for the effects of variety, pre-crop, fertility management, and crop protection on concentrations of total micronutrient contents **Fe, Mn, Zn, Cu** and **B** of potato tubers (2010)

Factor	**Fe** (g/100g DW)	***P*-value**	**Mn** (g/100g DW)	***P*-value**	**Zn** (g/100g DW)	***P*-value**	**Cu**(g/100g DW)	*P*-value	**B** (g/100g DW)	***P*-value**
Variety		<0.001		0.566		0.002		0.89		<0.001
Sante	34.6 ±0.9b		4.7±0.07a		11.8 ±0.23a		4.4 ± 0.23a		5.5±0.11b	
Sarpo Mira	41.9± 1.5a		4.6±0.11a		10.5 ±0.36b		4.6 ± 0.36a		6.3±0.11a	
Fertilisation		0.003		0.564		0.009		0.123		0.799
Compost	35.7±1.0b		4.4± 0.09a		10.6± 0.36b		4.4 ± 0.62a		5.9±0.12a	
NPK	40.9±1.7a		4.9±0.08a		11.7± 0.26a		4.6 ± 0.69a		5.8±0.14a	
Crop protection		0.406		0.476		0.813		0.001		0.951
Organic	37.7±1.7a		4.7± 0.09a		11.2 ±0.32a		4.87 ± 0.11a		5.9±0.12a	
Conventional	39.0±1.2a		4.7±0.10a		11.1 ±0.33a		4.17 ±0.09b		5.9±0.14a	
Pre-crop		0.315		2.275		0.144		0.08		0.869
Beans	37.4± 1.5a		4.6± 0.10a		10.9± 0.36a		4.6 ± 0.77a		5.8±0.12a	
Barley	39.3±1.3a		4.7 ±0.09a		11.4± 0.28a		4.4 ± 0.51a		5.9±0.13a	

Interactions	**Fe**	***P*-value**	**Mn**	***P*-value**	**Zn**	***P*-value**	**Cu**	***P*-value**	**B**	***P*-value**
	PC× FE	0.450	PC ×FE	0.062	PC ×FE	0.042	PC× FE	0.276	PC ×FE	0.623
	PC× CP	0.448	PC ×CP	0.084	PC× CP	0.520	PC× CP	0.003	PC ×CP	0.961
	PC × VAR	0.582	PC× VAR	0.880	PC× VAR	0.061	PC ×VAR	0.786	PC× VAR	0.454
	FE× CP	0.503	FE ×CP	0.941	FE× CP	0.491	FE× CP	0.851	FE× CP	0.847
	FE× VAR	0.003	FE ×VAR	0.042	FE ×VAR	0.115	FE ×VAR	0.052	FE× VAR	0.861
	CP× VAR	0.390	CP× VAR	0.910	CP× VAR	0.760	CP× VAR	0.896	CP ×VAR	0.970
	PC × FE × CP	0.900	PC× FE× CP	0.852	PC ×FE ×CP	0.835	PC× FE× CP	0.253	PC× FE ×CP	0.808
	PC × FE× VAR	0.370	PC× FE ×VAR	0.000	PC ×FE ×VAR	0.012	PC× FE× VAR	0.033	PC ×FE× VAR	0.094
	PC × CP × VAR	0.714	PC× CP ×VAR	0.919	PC ×CP ×VAR	0.165	PC× CP× VAR	0.931	PC ×CP× VAR	0.346
	FE× CP × VAR	0.323	FE ×CP ×VAR	0.011	FE× CP ×VAR	0.287	FE ×CP× VAR	0.134	FE× CP ×VAR	0.885
	PC× FE × CP × VAR	0.591	PC×FE× CP ×VAR	0.650	PC ×FE× CP ×VAR	0.266	PC× FE× CP ×VAR	0.091	PC ×FE× CP ×VAR	0.349

VAR: ***V****ariety, FE: Fertilisation, CP: Crop protection, PC: Pre-crop*

Means with same letter are not significantly different at P< 0.05)

3.4.12 **Effect of growing season on Mn, Fe, Zn and Cu contents of potato tubers**

There was no significant difference (*P*> 0.05) between growing seasons on Mn content of potato (Figure 23). On the other hand, there was significant interaction between growing season, rotation, fertility and variety on Mn content of potato.

There was significant difference (*P* < 0.05) between growing seasons on Fe content of potato (Figure 23). There was also significant interaction between variety and growing season on Fe content (Table 33). The results also revealed that in 2010 Fe levels in potato tubers were significantly higher in Sarpo Mira variety in each year compared with Sante.

There was also a significant difference (*P* < 0.05) between two years on Cu content.

Data in Table 35 showed that there was a significant interaction between growing season and crop protection factors on Cu content of potato tubers. Also, in 2010 the level of Cu in potato tubers was noted to be significantly higher under organic treated compared with conventional treatments. In 2011 K level was observed to be higher under conventional compared with organic treatment.

Growing season had a significant effect (*P*< 0.05) on Zn content of potato with higher content of Zn recorded in 2010 as compared to 2011 (Figure 23). There was also a significant interaction between growing season and crop protection treatments for Zn content (Table 36), with Zn content in 2010 higher under organic treated plots compared with conventional plots.

On the contrary, the Zn content was observed to be higher under conventional treated plot than organic plot in 2011.

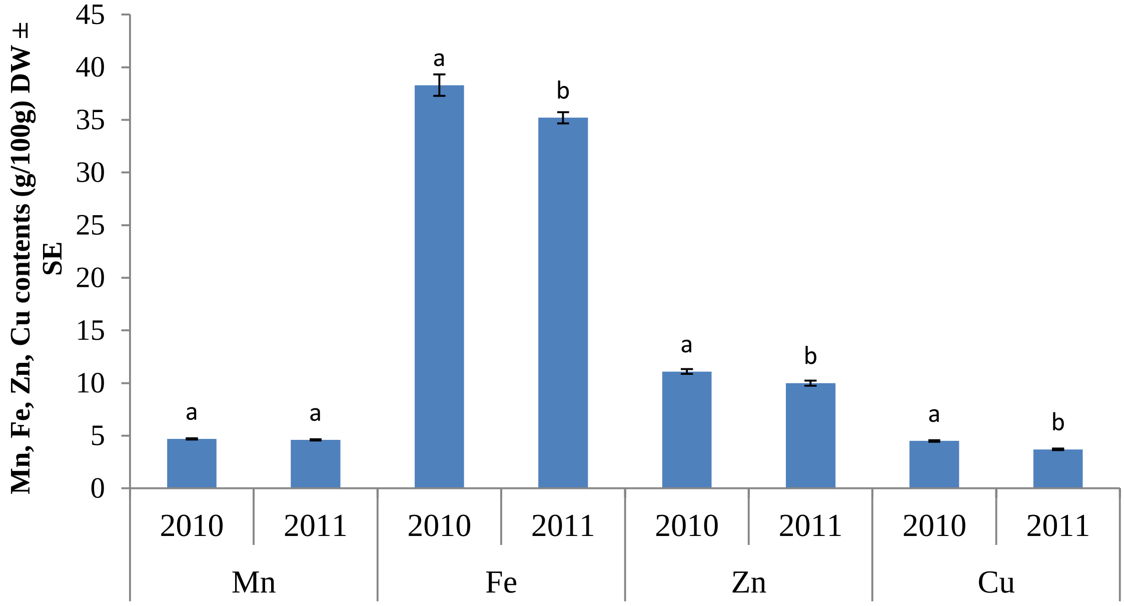


Figure 23 Effect of growing season of two years on Mn, Fe, Zn and Cu contents of potato. Mean ± SE. Bars with same letter are not significantly different

Table 34 Interaction between variety and growing season on Fe content of potato (g/100g) DW, mean ± SE

Growing season	Sante	Sarpo Mira	Mean
2010	34.63 ± 0.941	41.96 ± 1.59	38.36a
2011	34.16 ± 0.748	36.31 ± 0.694	35.24b
Mean	34.4b	39.14a	

Table 35 Interaction between growing season and crop protection on Cu content (g/100g) DW, mean ± SE

Growing season	Organic	Conventional	Mean
2010	4.87 ± 0.105	4.171 ± 0.0958	4.51a
2011	3.67 ± 0.811	3.848 ± 0.113	3.75b
Mean	4.26a	4.00b	

Table 36 Interaction between growing season and crop protection on Zn content (g/100g) DW, mean ± SE

Growing season	Organic	Conventional	Mean
2010	11.17 ± 0.320	11.09 ± 0.335	11.13a
2011	9.46 ±0.262	10.65 ±0.391	10.05b
Mean	10.3a	10.8a	

3.4.13 **Effect of treatments on Cd content of potato tubers 2010**

Analysis of data of potato minerals indicated that Cd content was affected significantly ($P < 0.05$) by variety and fertility treatments, while there was no significant difference between other treatments (Figure 24).

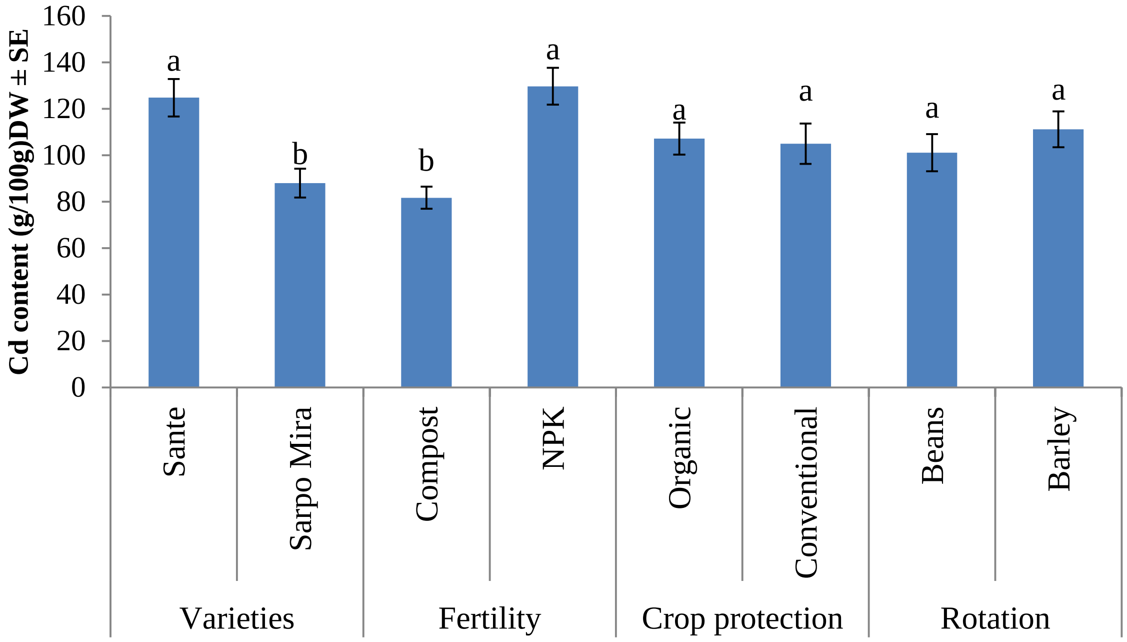


Figure 24 Effect of variety, fertility, crop protection and rotation on Cd content of potato. Mean ± SE. Bars with same letter are not significantly different.

3.4.14 **Effect of growing seasons on Cd content of potato tubers**

There was no significant difference ($P > 0.05$) between the growing seasons on Cd content of potato tubers. A significant interaction was however observed between fertility and growing season (Figure 25).

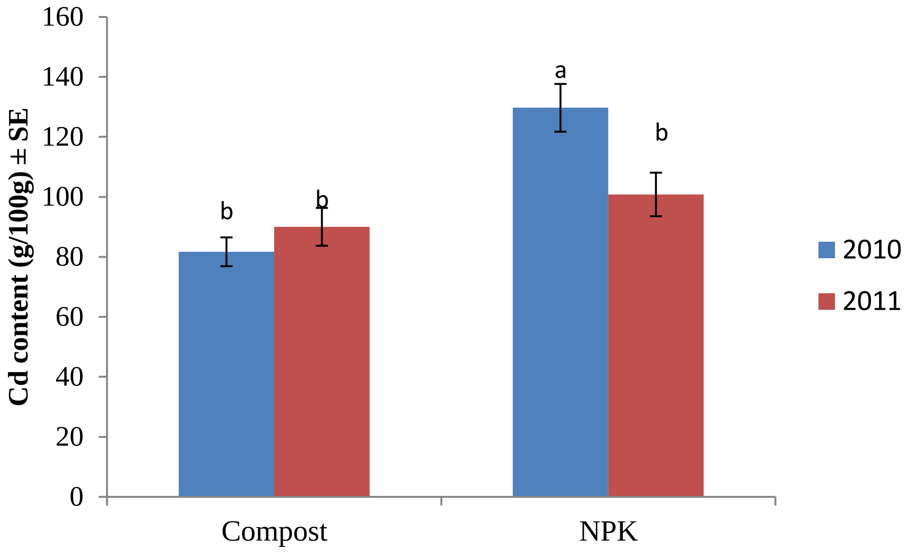


Figure 25 Interaction between fertility and growing season of two years on Cd content of potato tubers. Mean ± SE. Bars with same letter are not significantly different

3.5 Minerals results 2011

3.5.1 **Effect of variety, fertility, rotation and crop protection on macronutrient content of potato tubers**

3.5.1.1 N, P, K and S

The majority of QLEF potato minerals in 2011 were affected significantly only by variety (Table 37). Comparing between two years of data, opposite results was observed for total N content in 2011, where there was no significant difference between varieties and fertilisation on N content (Table 37).

There was significant difference between varieties on P and K content. On the other hand, there was no significant effect of other treatments. There was no significant difference between organic and conventional crop protection on N content of tubers. Similar results of organic and conventional crop protection were obtained for the total N and K contents while different results of same treatments were obtained for total P and S contents after two years of analysis (Table 37).

No significant interactions could be detected between the 4 factors for total N, P and S contents. In contrast, significant interactions between crop rotation, fertilisation and variety were detected for total K content of potato tubers (Table 37). The results also showed that there were no significant main effects of crop rotation for any of the individual N, P, K and S contents of tubers.

3.5.1.2 Mg, Na and Ca

A significant effect of variety was only detected for total Ca contents, with concentrations increasing in Sarpo Mira variety and decreasing in Sante. Also similar to the variety a significant main effect of fertilisation was only detected for total Ca content of tubers. When NPK fertilisation regimes were used Ca concentrations were higher compared to compost where the concentrations were lower (Table 38). There was also a trend towards crop protection regimes affecting Ca content of potato tubers. For total Mg, Na and Ca concentrations there were no significant differences between beans and barley crop rotation. No significant interactions could be detected for total Mg concentrations. However, significant 2-way interactions were detected between crop rotation and crop protection for total Na concentrations. Tubers of conventional crop protection had higher levels of Na after beans than organic tubers. Tubers of organic crop protection had higher levels of Na after barley cultivation as compared to conventional tubers (Table 39). A 3-way interaction was only detected for total Ca concentrations (Table 38).

Table 37 Main effect means ± SE and ANOVA P-values for the effects of variety, rotation, fertility management, and crop protection on concentrations of total macronutrient contents N, P, K and **S** of potato tubers 2011

Factor	**N(**g/100g DW)	***P*-value**	**P** (g/100g DW)	***P*-value**	**K** (g/100g DW)	***P*-value**	**S (g/100g DW)**	***P*-value**
Variety		0.246		0.001		0.003		0.004
Sante	0.70 ±0.03a		0.16± 0.00b		1.17 ±0.01b		0.11±0.00a	
Sarpo Mira	0.64 ±0.03a		0.17±0.00a		1.25± 0.01a		0.10 ±0.00b	
Fertilisation		0.263		0.359		0.604		0.676
Compost	0.64 ±0.03a		0.17± 0.00a		1.22± 0.01a		0.10± 0.00a	
NPK	0.70 ±0.03a		0.16± 0.00a		1.20 ±0.01a		0.10 ± 0.00a	
Crop Protection		0.124		0.953		0.907		0.021
Organic	0.63± 0.03a		0.17±0.00a		1.21± 0.01a		0.10 ±0.00b	
Conventional	0.71± 0.03a		0.17±0.00a		1.21 ±0.01a		0.11 ±0.00a	
Pre-crop		0.076		0.938		0.166		0.364
Beans	0.62 ±0.03a		0.17±0.00a		1.23 ±0.01a		0.10 ±0.00a	
Barley	0.72± 0.04a		0.17±0.00a		1.19± 0.01a		0.10 ±0.00a	

Interactions				ANOVA p-values			
N	**p-value**	**P**	**p-value**	**K**	**p-value**	**S**	**p-value**
PC ×FE	0.423	PC ×FE	0.769	PC ×FE	0.972	PC× FE	0.645
PC ×CP	0.975	PC× CP	0.516	PC ×CP	0.622	PC× CP	0.914
PC× VAR	0.588	PC× VAR	0.698	PC× VAR	0.249	PC× VAR	0.433
FE ×CP	0.762	FE ×CP	0.516	FE ×CP	0.933	FE ×CP	0.763
FE× VAR	0.795	FE× VAR	0.201	FE ×VAR	0.723	FE ×VAR	0.599
CP ×VAR	0.739	CP× VAR	0.379	CP× VAR	0.862	CP× VAR	0.783
PC ×FE ×CP	0.731	PC× FE CP	0.762	PC× FE× ×CP	0.927	PC ×FE ×CP	0.481
PC× FE ×VAR	0.715	PC ×FE× VAR	0.175	PC× FE× VAR	0.035	PC× FE× VAR	0.605
PC ×CP ×VAR	0.703	PC ×CP ×VAR	0.942	PC ×CP ×VAR	0.464	PC× CP ×VAR	0.347
FE× CP ×VAR	0.996	FE ×CP× VAR	0.459	FE× CP ×VAR	0.897	FE× CP ×VAR	0.876
PC×FE×CP×VAR	0.502	PC×FE ×CP ×VAR	0.445	PC× FE ×CP ×VAR	0.924	PC ×FE ×CP ×VAR	0.726

VAR: *Variety, FE: Fertilisation, CP: Crop protection, PC: Pre-crop*

Means with same letter are not significantly different at P < 0.05)

Table 38 Main effect means ± SE and ANOVA P-values for the effects of variety, pre-crop, fertility management, and crop protection on concentrations of total macronutrient contents Mg, Na and Ca of potato tubers (2011)

Factor	**Mg (g/100 DW)**	***p*-value**	**Na (g/100g DW)**	***p*-value**	**Ca (g/100g DW**	***p*-value**
Variety		0.211		0.087		<0.000
Sante	0.70± 0.03a		66.58 ± 4.44a		0.02± 0.00b	
Sarpo Mira	0.64 ± 0.03a		55.98 ± 4.11a		0.03 ± 0.00a	
Fertilisation		0.692		0.241		0.029
Compost	0.64± 0.03a		57.67± 4.32a		0.02 ± 0.00a	
NPK	0.70± 0.03a		64.89 ± 4.35a		0.03± 0.00b	
Crop protection		0.136		0.275		0.050
Organic	0.07 ± 0.00a		57.93 ± 3.98a		0.02± 0.00a	
Conventional	0.07 ± 0.00a		64.63 ± 4.68a		0.02 ± 0.00a	
Pre-crop		0.865		0.447		0.535
Beans	0.62± 0.02a		63.61 ± 4.88a		0.02± 0.00a	
Barley	0.72 ± 0.03a		58.95 ± 3.77a		0.02 ± ×0.00a	

Interactions

Mg	***P*-value**	**Na**	***P*-value**	**Ca**	***P*-value**
PC× FE	0.826	PC× FE	0.964	PC ×FE	0.068
PC× CP	0.585	PC ×CP	0.028	PC× CP	0.836
PC× VAR	0.351	PC× VAR	0.589	PC× VAR	0.519
FE× CP	0.478	FE ×CP	0.608	FE ×CP	0.626
FE× VAR	0.928	FE ×VAR	0.422	FE× VAR	0.560
CP× VAR	0.364	CP× VAR	0.452	CP× VAR	0.328
PC× FE ×CP	0.258	PC× FE ×CP	0.641	PC ×FE ×CP	0.013
PC× FE ×VAR	0.099	PC× FE×VAR	0.493	PC× FE	0.393
PC× CP ×VAR	0.832	PC×CP ×VAR	0.131	PC×CP×	0.351

				VAR	
FE ×CP×VAR	0.707	FE× CP×VAR	0.822	FE ×CP	0.759
PC× FE ×CP× VAR	0.693	PC× FE× CP ×VAR	0.546	PC ×FE ×CP ×VAR	0.952

Means with same letter are not significantly different at P < 0.05)

VAR: Variety, FE: Fertilisation, CP: Crop protection, PC: Pre-crop

Table 39 Interaction effect between pre-crop and crop protection on Na content of tubers (g/100 DW) mean ±SE

	Organic	**Conventional**	**Mean**
Beans	53.4± 4.83	73.8± 7.83	63.6
Barley	62.5 ±6.27	55.4 ±4.22	58.9
Mean	57.9	64.6	

3.5.2 Effect of variety, fertility, pre-crop and crop protection on micronutrient contents of potato tubers

3.5.2.1 Fe, Mn, Zn, Cu and B

There was significant difference (*P* <0.05) in the levels of Fe and B in tubers between varieties. The levels of Fe were observed to be higher in Sarpo Mira than Sante. The same was also found for the levels of B. The levels of B were noted to be significantly higher in Sarpo Mira than Sante. No significant differences were however observed in Mn, Zn and Cu levels between varieties (Table 40). There was no significant difference between fertilisation treatments for concentrations of Fe, Mn, Z, Cu and B.

For crop protection the results showed that there was significant difference between organic and conventional crop protection regimes for total Fe and Zn concentrations. Conventional crop protection resulted in significantly higher Fe and Zn concentration than organic crop protection. Additionally, there was no significant difference between crop rotation for mineral Fe, Mn, Zn, Cu and B contents. Also, no significant interactions could be detected between the 4 factors (Table 40).

3.5.3 Effect of variety, fertility, pre-crop and crop protection treatments on Cd content of potato 2011

Analysis of variance of potato minerals showed that Cd content was affected significantly by variety and crop protection treatments, while there was no significant influenced of other treatments or their interactions (Figure 26). The results also showed that Cd levels in tubers were significantly higher in Sante than Sarpo Mira and significantly higher under conventional treated plots than under organic plots.

Table 40 Main effect means ± SE and ANOVA P-values for the effects of variety, pre-crop, fertility management, and crop protection on concentrations of total micronutrient contents Fe, Mn, Zn, *Cu* and B of potato tubers (2011)

Factor	**Fe**	***p*-value**	**Mn**	***p*-value**	**Zn**	**p-value**	**Cu**	***p*-value**	**B**	***p*-value**
Variety		0.033		0.978		0.910		0.074		<0.000
Sante	34.2±0.74b		4.6±0.06a		10.1±0.18a		3.6±0.06a		5.9±0.05b	
Sarpo Mira	36.3±0.69a		4.6± 0.11a		10.0±0.46a		3.8±0.12a		6.4± 0.06a	
Fertilisation		0.076		0.312		0.685		0.703		0.137
Compost	34.3±0.72a		4.6±0.11a		9.9±0.38a		3.7±0.11a		6.2±0.08a	
NPK	36.1±0.73a		4.7±0.07a		10. ±0.31a		3.7±0.08a		6.1±0.05a	
Crop protection		0.009		0.065		0.016		0.243		0.327
Organic	33.9±0.53b		4.5± 0.08a		9.4±0.26b		3.6 ±0.08a		6.1±0.06a	
Conventional	36.6±0.84a		4.8± 0.09a		10.6 0.39a		3.8±0.11a		6.2 ±0.08a	
Pre-crop		0.504		0.724		0.749		0.701		0.836
Beans	35.6±0.82a		4.6 ±0.08a		9.9± 0.34a		3.7±0.08a		6.1±0.06a	
Barley	34.9±0.66a		4.7±0.09a		10.1±0.35a		3.7±0.11a		6.1±0.08a	

Interactions

F	*p*-value	Mn	*P*-value	Zn	*p*-value	Cu	*p*-value	B	*p*-value
PC× FE	0.277	PC × FE	0.253	PC× FE	0.063	PC × FE	0.973	PC× FE	0.413
PC× CP	0.299	PC× CP	0.941	PC× CP	0.701	PC × CP	0.957	PC × CP	0.994
PC × VAR	0.658	PC× VAR	0.678	PC× VAR	0.446	PC ×VAR	0.598	PC × VAR	0.735
FE ×CP	0.325	FE ×CP	0.997	FE × CP	0.888	FE × CP	0.843	FE ×CP	0.998
FE ×VAR	0.823	FE ×VAR	0.601	FE× VAR	0.958	FE ×VAR	0.650	FE× VAR	0.085
CP× VAR	0.424	CP ×VAR	0.724	CP× VAR	0.072	CP ×VAR	0.927	CP× VAR	0.129
PC× FE ×CP	0.188	PC ×FE ×CP	0.549	PC× FE ×CP	0.804	PC× FE ×CP	0.510	PC ×FE× CP	0.934
PC ×FE ×VAR	0.661	PC× FE× VAR	0.944	PC× FE ×VAR	0.253	PC× FE ×VAR	0.614	PC× FE× VAR	0.155
PC ×CP× VAR	0.833	PC ×CP× VAR	0.455	PC× CP× VAR	0.169	PC× CP ×VAR	0.610	PC× CP ×VAR	0.676
FE ×CP ×VAR	0.711	FE ×CP× VAR	0.976	FE ×CP× VAR	0.433	FE× CP ×VAR	0.898	FE × CP × VAR	0.336
PC× FE ×CP VAR	0.322	PC× FE ×CP VAR	0.921	PC× FE ×CP VAR	0.544	PC× FE ×CP VAR	0.778	PC× FE ×CP VAR	0.463

VAR: Variety, FE: Fertilisation, CP: Crop protection, PC: Pre-crop.

Means with same letter are not significantly different at $P < 0.05$).

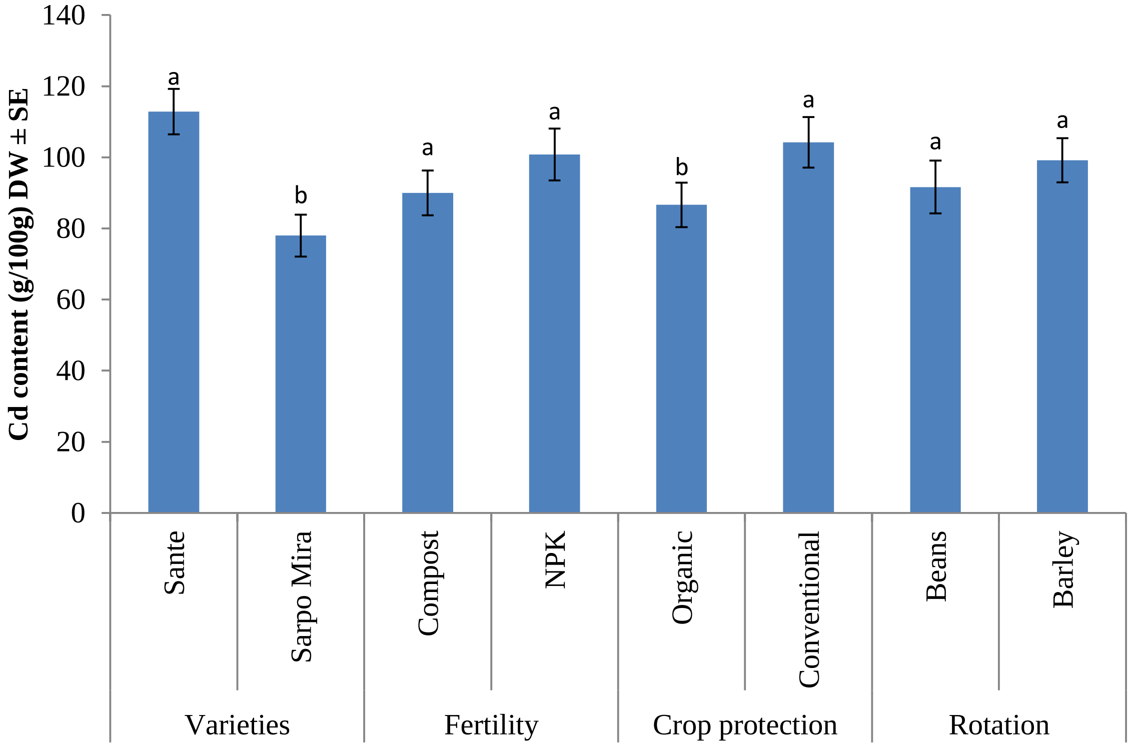


Figure 26 Effect of variety, fertility, crop protection and rotation on Cd content of potato. Mean ± SE. Bars with same letter are not significantly different.

3.6 Mineral results of NUE potato trial 2011

3.6.1 **Effect of variety, fertility and crop protection on macronutrient content of potato**

3.6.1.1 N, P, K and S

Apart from agronomic parameters the variety, fertilisation and crop protection managements may also affect nutritional quality (mineral contents) of potato. When concentrations of total N, P, K and S were compared, there was a significant mean effect of variety and fertilisation (Table 41). P, K and S were significantly affected by variety while a significant mean effect of fertilisation was only detected for total N content. There was also a trend (*P*= 0.058**)** towards fertilisation rate affecting S content of potato tubers. No significant difference in potato N, P, K and S concentrations could be detected between organic and conventional treatments. In addition, Tukey's honestly significant difference test did not detect significant differences between interaction means (Table 41).

P content of potato was also affected significantly by variety. P content of Cara was significantly higher than all other varieties. Sarpo Mira and Nicola were similar in P content. In contrast, K concentrations were higher in Sarpo Mira as compared with other varieties. In terms of fertilisation effect, high NPK resulted in significantly higher N content than high, low compost, low NPK and control plots.

3.6.1.2 Mg, Na and Ca

Ca and Mg content were affected significantly by variety. Crop protection had no effect on Mg, Na and Ca contents (Table 42). In addition, there were no interactions between the 3 factors.

Data also showed that Mg content of Agria was significantly lower than Nicola and Sante. Other varieties were similar. However, although there was no effect of fertilisation treatments on total Ca, high NPK resulted in higher Ca content compared with high and low compost treatments (Table 42).

Table 41 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total macronutrient contents N, P, K and S of NUE potato tubers (2011)

Factor	N (g/100g DW)	*p*-value	P (g/100g DW)	*p*-value	K (g/100g DW)	*p*-value	S (g/100g DW)	*p*-value
Variety		0.700		<0.001		<0.001		0.005
Agria	0.8 ±0.04a		0.14 ±0.00cd		1.3± 0.01b		0.09 ±0.00ab	
Cara	0.8± 0.04a		0.18 ±0.00a		1.4 ±0.02a		0.09 ±0.00b	
Sarpo Mira	0.7 ±0.03a		0.16 ±0.00b		1.4 ±0.02a		0.10± 0.00ab	
Fontane	0.7± 0.03a		0.14 ±0.00cd		1.3 ±0.01b		0.10± 0.00a	
Nicola	0.8 ±0.03a		0.15 ±0.00bc		1.3± 0.01ab		0.10 ±0.00a	
Sante	0.8 ±0.04a		0.14 ±0.00d		1.2± 0.01b		0.10± 0.00ab	
Fertility treatment		<0.001		0.339		0.141		0.058
High compost	0.7± 0.03d		0.16± 0.00a		1.3 ±0.02a		0.1 ±0.00a	
Low compost	0.7± 0.03cd		0.15 ±0.00a		1.3± 0.01a		0.1± 0.00a	
High NPK	0.9 ±0.03a		0.15 ±0.00a		1.3± 0.02a		0.1 ±0.00a	
Low NPK	0.8 ±0.02bc		0.15 ±0.00a		1.3 ±0.01a		0.1 ±0.00a	
Control	0.8± 0.02ab		0.15 ±0.00a		1.3 ±0.01a		0.1 ±0.00a	
Crop protection		0.453		0.500		0.772		0.266
Organic	0.8± 0.02a		0.1± 0.00a		0.15 ±0.00a		0.10± 0.00a	
Conventional	0.8 ±0.02a		0.15± 0.00a		0.15± 0.00a		0.10± 0.00a	

Interactions				**ANOVA results**			
N	***p*-value**	**P**	***p*-value**	**K**	***p*-value**	**S**	***p*-value**
CP ×FE	0.970	CP× FE	0.691	CP× FE	0.467	CP× FE	0.715
CP× VAR	0.933	CP× VAR	0.389	CP× VAR	0.825	CP ×VAR	0.646
FE ×VAR	0.729	FE ×VAR	0.473	FE ×VAR	0.853	FE ×VAR	0.181
CP ×FE ×VAR	0.587	CP ×FE× VAR	0.766	CP ×FE ×VAR	0.995	CP ×FE ×VAR	0.725

VAR: Variety, FE: Fertilisation, CP: Crop protection

Means with same letter are not significantly different at P < 0.05)

Table 42 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total macronutrients Mg, Na and Ca of NUE potato tubers (2011)

Factor	**Mg (g/100g DW)**	***p*-value**	**Na (g/100g DW)**	***p*-value**	**Ca (g/100g DW)**	***p*-value**
Variety		<0.001		0.127		<0.001
Agria	0.08 ± 0.00c		66.1 ±4.72a		0.04± 0.00ab	
Cara	0.09± 0.00abc		70.0 ±11.8a		0.05 ±0.00a	
Sarpo Mira	0.09 ±0.00bc		54.5 ±3.50a		0.03± 0.00c	
Fontane	0.09± 0.00abc		52.4 ±2.49a		0.04 ±0.00bc	
Nicola	0.09 ±0.00ab		52.8 ±2.80a		0.03± 0.00bc	
Sante	0.09± 0.00a		53.1± 2.92a		0.03 ±0.00c	
Fertility treatments		0.100		0.692		0.069
High compost	0.09 ±0.00a		54.8± 2.30a		0.03± 0.00a	
Low compost	0.09 ±0.00a		54.3 ±3.31a		0.03 ±0.00a	
High NPK	0.09 ±0.00a		63.7± 9.89a		0.04 ±0.00a	
Low NPK	0.09 ±0.00a		60.9 ±3.16a		0.03 ±0.00a	
Control	0.09 ±0.00a		57.1± 4.05a		0.03 ±0.00a	
Crop protection		0.260		0.971		0.064
Organic	0.09± 0.00a		58.2 ±4.18a		0.04 ±0.00a	
Conventional	0.09 ±0.00a		58.1 ± 2.23a		0.04 ±0.00a	

Interactions **ANOVA results**

Mg	***p*-value**	**Na**	***p*-value**	**Ca**	***p*-value**
CP ×FE	0.915	CP× FE	0.739	CP× FE	0.787
CP ×VAR	0.127	CP× VAR	0.306	CP ×VAR	0.914
FE ×VAR	0.279	FE ×VAR	0.621	FE ×VAR	0.496
CP ×FE× VAR	0.880	CP ×FE ×VAR	0.932	CP ×FE ×VAR	0.794

VAR: Variety, FE: Fertilisation, CP: Crop protection.

Means with same letter are not significantly different at P < 0.05).

3.6.2 **Effect of variety, fertility, and crop protection on micronutrient contents**

3.6.2.1 Fe, Mn, Z, Cu and B

Significant effects of variety, fertilisation and crop protection were detected for micronutrient contents of potato tubers. Significant main effects of variety were detected for total Fe, Mn, Zn, Cu and Cara was observed to be higher in Fe, Zn, Cu and B contents, while Sarpo Mira was observed to be higher in Mn content as compared with other varieties.

For fertilisation, higher concentrations of Zn were obtained after application of high NPK whereas higher concentrations of B was obtained after application of high compost as compared to low NPK which resulted in significantly decrease B content (Table 43).

B concentrations were highest in tubers receiving the high compost treatment and decreased in the following order: high compost > non-fertilised> low compost≥ high NPK ≥low NPK.

Crop protection had no effect on potato Fe, Mn, Zn and B levels, but concentrations of Cu were significantly higher when organic crop protection was applied compared with conventionally treated plots (Table 43). There were significant 3-way interactions between crop protection, fertilisation and variety for total Mn content. There was also a significant 2-way interaction between fertilisation rate and variety for total Cu content (Table 43).

Table 43 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total micronutrients Fe, Mn, Zn, Cu and B of NUE potato tubers (2011)

Factor	**Fe (g/100g DW)**	***p*-value**	**Mn (g/100g DW)**	***p*-value**	**Zn (g/100g DW)**	***p*-value**	**Cu (g/100g DW)**	***p*-value**	**B (g/100g DW)**	***p*-value**
Variety		<0.001		0.003		0.013		<0.001		<0.001
Agria	54.6 ±1.85b		4.6 ±0.19ab		8.4± 0.17b		3.8 ±0.11bc		6.1 ±0.09c	
Cara	67.7 ±1.71a		4.9 ±0.15a		9.3 ±0.25a		4.4 ±0.11a		**7.**1 ±0.08a	
Sarpo Mira	45.7 ±1.34c		5.1± 0.13a		8.8 ±0.17ab		4.1 ± 0.07ab		6.6± 0.06b	
Fontane	51.5 ±1.24bc		4.4 ±0.12b		8.6 ±0.15ab		3.7 ±0.08c		6.1± 0.08c	
Nicola	55.2± 1.95b		4.7 ±0.09ab		8.7 ±0.17ab		3.6 ±0.08c		6.1 ±0.06c	
Sante	50.1 ±1.76bc		4.8 ±0.09ab		8.5± 0.17b		3.6 ±0.10c		6.3 ±0.08c	
Fertility treatments		0.573		0.173		0.017		0.460		0.017
High compost	54. 5± 1.80a		4.6 ±0.11a		8.6± 0.17ab		3.8± 0.11a		6.5 ±0.09a	
Low compost	54.6± 2.19a		4.8 ±0.19a		8.6 ±0.16b		3.8 ±0.08a		6.4 ±0.09ab	
High NPK	55.8 ±1,87a		5.0 ±0.12a		9.30 ±0.21a		4.0 ± 0.10a		6.3 ±0.07ab	
Low NPK	52.8 ±1.37a		4.8± 0.09a		8.7 ±0.14ab		3.8 ±0.09a		6.2 ±0.08b	
Control	52.9 ±1.69a		4.6± 0.08a		8.6 ±0.143ab		3.9 ±0.09a		6.4 ±0.08ab	
Crop protection		0.871		0.132		0.658		0.001		0.723
Organic	54.0 ±1.12a		4.7 ± 0.06a		8.7± 0.09a		4.0 ± 0.05a		6.4 ±0.05a	
Conventional	54.3± 1.16a		4.8± 0.09a		8.8 ±0.12a		3.7±0.06b		6.4 ±0.05a	

Interactions					**ANOVA results**				
F (g/100g DW)	***p*-value**	**Mn (g/100g DW)**	***p*-value**	**Zn (g/100g DW)**	***p*-value**	**Cu (g/100g DW)**	***p*-value**	**B (g/100g DW)**	***p*-value**
CP× FE	0.440	CP ×FE	0.753	CP× FE	0.783	CP× FE	0.644	CP ×FE	0.568
CP× VAR	0.341	CP ×VAR	0.106	CP× VAR	0.192	CP× VAR	0.259	CP× VAR	0.244
FE ×VAR	0.578	FE ×VAR	0.219	FE ×VAR	0.322	FE× VAR	**0.048**	FE ×VAR	0.064
CP× FE ×VAR	0.092	CP× FE ×VAR	0.026	CP ×FE ×VAR	0.309	CP ×FE ×VAR	0.302	CP ×FE ×VAR	0.800

Means with different letter are significantly different. Tukey's honestly significant difference test, at P < 0.05

***V**ariety: VAR, Fertilisation: FE, Crop protection: CP.*

3.6.3 **Effect of variety, fertility and crop protection on Cd content of potato**

Similar to the N a significant mean effect of fertilisation was detected for total Cd contents of potato tubers, with high NPK fertilisation regimes resulting in higher concentrations as compared with other treatments. Significant mean effects of variety were also detected for total content of Cd. The interaction effect of potato variety, rate of fertilisers and crop protection on mineral content of Cd was statistically not significant (Table 44).

Table 44 Main effect means ± SE and ANOVA P-values for the effects of variety, fertility management, and crop protection on concentrations of total Cd content of potato tubers

Factor	**Cd (g/100g DW)**	***P*-value**	**Interactions**	***P*-value**
Variety		<0.001	CP ×FE	0.324
Agria	59.6 ±3.46a		CP ×VAR	0.972
Cara	40.6± 2.27b		FE ×VAR	0.781
Sarpo Mira	44.7 ±1.84b		CP ×FE ×VAR	0.080
Fontane	61.4 ±3.50a			
Nicola	48.0± 2.37b			
Sante	61.4 ±3.60a			
Fertilisation		0.009		
High compost	49.2 ±2.90ab			
Low compost	50.8 ±2.77ab			
High NPK	59.3± 3.38a			
Low NPK	56.1± 3.00ab			
Control	47.9 ±2.16b			
Crop protection		0.285		
Organic	51.4± 1.74a			
Conventional	53.9 ±1.94a			

Means with different letter are significantly different. Tukey's honestly significant difference test, at P < 0.05

***V**ariety: VAR, Fertilisation: FE, Crop protection: CP.*

CHAPTER 4 Discussion

4.1 Yield

4.1.1 **Effect of treatments on tuber yield**

4.1.1.1 Variety choice

The results of the present study indicated that no significant difference between varieties was detected on tuber yield of potato. Similar results were observed by other workers Eggert and Kahrmann (1984) who found no significant differences in yield between the varieties investigated. The results are also in agreement with those obtained by Foulkes *et al.* (1998). In contrast, different significant effect of variety on tuber yield was observed by Nitithamyong *et al.* (1999). Chen *et al.* (2012) also reported a significant influence of variety on maize yield.

4.1.1.2 Fertilisation

The findings that total tuber yields were higher on NPK fertilized plots was most likely due to higher N-availability from NPK fertiliser when compared to compost. The lower yields were also probably due to lower and less predictable N supply in compost fertilized crops. This conclusion is supported by previous studies showing that fertilisation regimes used in organic farming result in lower N-supply to crop compared with mineral fertiliser based regimes used in conventional farming (Berry *et al.*, 2003, Ryan *et al.*, 2004). Similar results were found by Vogtmann (1993) who reported that compost application lowered vegetable yield more than NPK application.

This also confirms a previous study by Herencia *et al.* (2007) who reported that organic crop management (which involved regular composted manure inputs over a 4 years period) decreased potato yields, as compared to conventional previous soil management (involving regular mineral fertiliser inputs). They suggested that mineral fertilisation resulted in higher residual soil nutrient concentration and that this had a greater effect on crop yields and nutrient supply, more so than possible effects of regular organic fertiliser inputs on mineralization capacity and soil biological activity.

These findings also confirm previous studies showing how mineral fertilisers in comparison with the organic fertiliser (cattle manure) increased both protein content and potato yield

(Jarvan, 2009). Similar results reported that the highest mean value of potato tubers yield was recorded with mineral fertilisers compared to all other treatments Ayman (2011) Černý *et al.* (2010) Sharma (1998) Warman and Fairchild, 1983) Hachicha *et al.* (2008) (Wang *et al.*, 2008 Doltra *et al.* (2011)

Higher yields can also be attributed to increased vegetative growth, proper maturity of the crop and better tuberization and bulking (Tremblay, 2001).

In contrast, other authors have shown that yields of crops grown either with mineral or organic fertiliser can be equivalent to one another (Reider *et al.*, 2000). Equivalent yields were obtained regardless of the kind of fertiliser (Polat *et al.*, 2010).

Furthermore, the results of this study showed that no clear differences in yield between the two growing seasons.

4.1.1.3 Crop protection regimes

The findings that crop protection (organic, conventional), significantly affected the total tuber yield of potato confirms previous studies which reported that conventional crop protection resulted in 35% higher yields and that this was mainly caused by the differences in the crop protection regimes (Cooper *et al.*, 2011). These results also confirm those reported by Warman and Havard (1998). Difference in nutrient availability appeared to be the main reason for yield differences between the organic and conventional crop protection systems (Eltun, 1996).

Palmer *et al.* (2013) indicated that marketable yield differences among crop protection regimes were attributed both to fewer discarded tubers and large tuber size in crops under conventional crop protection. They also revealed that limitation in N availability was the main reason for the lower yield in organically fertilized crops which can considerably affect the tuber yield and the growth of potato plant. Similar observation were also obtained by Hornick (1992) who shown that yields in organic crop protection systems were decreased due to higher weed pressure and lower nutrient availability.

Seufert *et al.* (2012) and Vogtmann (1993) reported that organic yields under these conditions are typically lower than conventional. Morris and Petermann (1985) on their article on “crop rotation and wheat nutrient content: Glenlea” indicating that yield in organic systems were decreased due to higher weed pressure and lower soil nutrient availability.

On the other hand, the results by Eggert and Kahrmann (1984) indicated no differences in yield and β carotene content of conventionally and organically fertilized carrots. Variable results were also obtained by Drinkwater *et al.* (1995) showed that yields of tomato were not significantly different in organic and conventional fields.

4.1.1.4 Pre-crop/ rotational position

Similar to fertilisation and crop protection, pre-crop treatments had a significant effect on tuber yield. This was mainly due to contrasting N -supply to crops as it is not surprising since beans are known to significantly increase N-availability to subsequent crops. This confirms results from previous studies by Morris and Petermann (1985) Russo (1997) and Cooper *et al.* (2011).

4.1.1.5 Effect of growing season on tuber yield of potato

The findings that the tuber yield was not affected by growing seasons of over two years confirms previous studies which reported no significant difference of growing seasons on the tuber yield of potatoes (De Temmerman *et al.*, 2002). On the other hand, opposite results observed by Chen *et al.* (2012) who reported that the yield of summer maize is affected significantly by a number of factors including growing seasons, variety and cultivation measures.

4.2 Effect of treatments on vitamin C content of potato

4.2.1 **Vitamin C (Titration method) 2010, 2011**

4.2.1.1 Variety choice

Variety had a significant and consistent effect on the vitamin C content of potato tubers in 2010 and 2011. This observation was similar to previous studies that have reported that variety has a major effect on the vitamin C concentration in potato tubers (Morris and Lee, 1984).

In the second year of the current experimental study the results of using colorimetric titration method of NUE potato showed significant difference in vitamin C content between varieties and the experimental years. Genetic factors also could play the most important role in the difference between varieties in vitamin C content. These results agree with other experimental studies (Hyde, 1962) (Ayman, 2011). This is consistent with previous studies which reported that vitamin C concentrations are affected significantly by variety (Warman and Havard, 1998).

4.2.1.2 Fertilisation

The finding that vitamin C concentrations did not differ between fertilisation regimes confirms previous studies which show no significant effects of compost on vitamin C content (Tavarini *et al.*, 2011). The results of the effects of mineral fertiliser on vitamin C content are also in accordance with previously reported findings (Bushway *et al.*, 1983). Results also support previous studies, which showed that no significant differences were observed between various rates of fertiliser treatments and years on concentrations of vitamin C in kidney bean (Liu *et al.*, 2008).

In contrast, variable results were obtained by Mitova *et al.* (2008) who found that organic fertiliser had a significant effect on vitamin C content compared with NPK fertiliser. The difference in vitamin C results may have been due to different fertiliser combinations, crops and a difference in location of the experiments.

4.2.1.3 Crop protection regimes

The results of this study indicated that there were no significant differences between the effects of organic and conventional treatments on vitamin C content. This is probably because these treatments did not have as strong an effect on vitamin C as variety does.

These findings were akin to a report published by Growers Association and Organic Retailers of Australia (GAAOR) which showed no significant differences in β-carotene and vitamin C of vegetables produced conventionally or organically (Ismail and Cheah, 2003) and as reported by Lairon D (1984), (Zhang *et al.*, 1997) and Asami *et al.* (2003), Mondy and Gosselin (2006). However, these observations are at variance with results published by Lester and Saftner (2011) and Worthington (2001) who indicated that organic crops contained more vitamin C than conventional crops.

4.2.1.4 Pre-crop rotational position

There was no significant difference in the total vitamin C contents between crop rotation treatments (pre-crops of barley or beans). Differences have been found in different crops however. For example, (Wu and Wang, 2007) reported that crop rotation affected vitamin C contents: the vitamin C content of cucumber was higher in crops grown in a rotation than those grown continuously as a monocrop.

4.2.2 **Vitamin C (HPLC method) 2010, 2011**

4.2.2.1 Variety choice

A large difference between varieties in the vitamin C content of potato tubers from year 2010 to 2011 was found, varying from 46.23, 36.57 mg/100g DW 2010 and 44.22, 36.51 mg/100g DW 2011. Other researches have also found that variety and fertility type, metrological conditions, post- harvest handling and soil types influence the vitamin C concentration of potato crop (Warman and Havard, 1998).

Significant varietal differences in tuber vitamin C content have also been observed by others (Mullin *et al.*, 1991) (Hamouz *et al.*, 1999) (Burgos *et al.*, 2009). On the other hand, Kumar *et al.* (2007) reported no significant differences between varieties for vitamin C content of potatoes.

4.2.2.2 Fertilisation

There was no significant difference between compost and mineral NPK fertiliser on vitamin C content. These results are similar to those reported by Mullin *et al.* (1991) and Termine *et al.* (1987) who demonstrated that the vitamin C content of turinps and leeks were not strongly affected by fertlisation regimes. On the other hand, there are two studies where slightly lower vitamin C content in organic compared with mineral fertilisation was reported (Stark and Porter, 2005), (Friedman and Dao, 1992).

4.2.2.3 Crop protection regimes

No significant differences between the two crop protection systems on vitamin C were detectable. These results agreed with the results published by Mondy and Gosselin (2006) who found out that the vitamin C concentration of cabbage and carrots was not affected by organic and conventional treatments.

4.2.2.4 Effect of growing seasons on vitamin C content

The findings that vitamin C content was not influenced by growing seasons confirms previous studies which reported no significant effect of growing seasons on vitamin C content of potato tubers (Seung, 2000).

Kolbe *et al.* (1995) demonstrated that potato quality response to fertilisation is negligible when compared to the response to growing seasons and other factors.

4.3 Effect of treatments on the vitamin C content of NUE potato HPLC (2011)

4.3.1 **Variety choice**

The differences in vitamin C content were due to the varietal differences. There are clear findings confirming significant influence of variety on vitamin C content of potato tubers by previously referenced above in contrast to reports by Kumar *et al.* (2007) who reported no significant effect of variety on vitamin C contents to potato tubers and reports by Anac and Martin-Prével (1998) and Westermann (2005) who concluded that soil or local condition were more important with respect to vitamin C production than either variety or fertilisation.

4.3.2 **Fertilisation**

The findings that fertilisation did not influence vitamin C concentrations, confirms the results from the previous studies of Termine *et al.* (1987) who indicated that vitamin C of turnips and leeks was not influenced by different fertilisation regimes.

4.3.3 **Crop protection regimes**

The results are similar to those obtained by Fjelkner-Modig *et al.* (2000) who found no significant differences in vitamin C content between organic and conventional crop protection systems. The results are also in agreement with the results obtained by Masamba and Nguyen (2008) who shown that no significant difference was observed in vitamin C concentration in organically and conventionally grown cabbage.

4.4 Glycoalkaloids

4.4.1 Effect of treatments on alpha solanine content of potato (2010, 2011)

4.4.1.1 Fertilisation and variety choice

Solanine glycoalkaloid concentrations were not affected by all imposed management factors. Results observed for each individual year showed that there were no significant differences between fertility, rotation and crop protection practices. Also there was no significant interaction among all the treatments on alpha solanine content.

Sante showed slightly higher alpha solanine content in comparison with Sarpo Mira in 2010, while in 2011 Sarpo Mira exhibited significantly higher alpha solanine content than Sante. Apart from varietal differences this observation could additionally be other external factors such as stress weather conditions that stimulated an increase in alpha solanine content.

Friedman and Dao (1992) showed that glycoalkaloids content in potato varieties can change both within the range of varieties and between them. Other researches Russo (1997) showed that varieties with high total glycoalkaloid contents are more likely to produce excessive glycoalkaloid contents when subject to less than ideal improper handling or environmental conditions.

The findings that glycoalkaloid concentrations did not differ significantly between varieties confirms by Zrůst (1997) which reported that the year has a greater effect on content of glycoalkaloid than the variety.

Magkos *et al.* (2003) found significant differences in tuber glycoalkaloids content between five commercial varieties at different locations. This may be because of differences in variety, climatic and soil variations. Significant differences on alpha solanine content between varieties have also been observed by Maga (1980), Love *et al.* (1994) and Nitithamyong *et al.* (1999) who demonstrated that the choice of variety for any study of total glycoalkaloid (alpha solanine) will obviously affect the results.

In contrast to finding is this study, Asami *et al.* (2003) reported that glycoalkaloids level tended to be higher in organic potato treatments compared with conventional.

Zolnowski (2010) demonstrated that NPK fertiliser had a significant effect on the total glycoalkaloids in potato tubers. Ankumah *et al.* (2003) demonstrated a significant increase of total glycoalkaloid (alpha solanine) caused by the application of NPK+ Mg fertilisation before flowering and at harvest.

4.4.1.2 **Crop protection and pre-crop rotational position**

There was no effect of organic and conventional crop protection on total alpha solanine content. The results were not in agreement with the results obtained by Hajslova *et al.* (2005) who demonstrated that glycoalkaloid levels tended to be higher in organically grown potatoes than conventional. Wszelaki *et al.* (2005) also showed that glycoalkaloid contents tended to be higher in organically grown potatoes. However, Murphy (1946) showed that organically produced potato tubers contained significantly lower content of total glycoalkaloids (alpha chaconine and alpha solanine).

The findings that alpha solanine content did not differ between crop rotation treatments confirm previous study by Zhang *et al.* (1997).

4.4.2 **Effect of treatments on alpha chaconine content of potato (2010, 2011)**

4.4.2.1 Fertilisation and variety choice

There were significant interactions between variety, fertility and crop protection treatments in 2010. These results are not in accordance with findings by Ankumah *et al.* (2003) which concluded that glycoalkaloid concentrations were increased after application of NPK mineral fertiliser.

With respect to the effects of varieties and their interactions with fertilisation and crop protection factors the experiment carried out in 2010 and 2011 did not confirm the results from the experiments in previous study (Eltayeb *et al.*, 2003) (Zhang *et al.*, 1997). Zolnowski (2010) Musilova *et al.* (2009) where weather, variety, fertiliser regimes and weather had effects on glycoalkaloid concentrations.

4.4.2.2 Crop protection and pre-crop rotational position

There was no significant difference between organic and conventional crop protection systems for total tuber alpha solanine and alpha chaconine contents. Asami *et al.* (2003)

observed different effects of organic and conventional crop protection on alkaloid concentrations. The results obtained also showed that the effect of crop rotation was not significant for total alpha solanine and alpha chaconine. These results are in line with work published by Clark *et al.* (1999) which showed that in a six-year crop rotation trial no significant differences in total glycoalkaloids concentrations were observed.

4.4.3 Effect of growing seasons on glycoalkaloid (alpha solanine, alpha chaconine) content (2010, 2011)

A total alpha solanine concentration of potato tubers was significantly affected by growing seasons. The alpha solanine content was much higher in 2011 compared with 2010.

These variations could be due to weather conditions and environmental stress. In terms of alpha solanine content similar results were observed by (Sinden and Webb, 1974). The present findings for alpha solanine are also consistent with the results of previous studies but not compatible with alpha chaconine (Love *et al.*, 1994). This difference between growing seasons of years is due to uncontrolled factors and can be used as a measure of the influence of environment on total glycoalkaloid contents. Similar result was obtained by other scientists Bejarano *et al.* (2000) in most varieties, a significant increase in total glycoalkaloid content (alpha chaconine and alpha solanine) was observed under drought stress conditions.

4.5 Minerals 2010, 2011

4.5.1 **Effect of the treatment on macronutrient contents**

4.5.1.1 Variety choice

Difference in the N content of tubers was observed between varieties in 2010, while the effects of varieties were not significant on N content in 2011. These results are compatible with those reported by Jarvan (2009) and Talley *et al.* (1970) who found that, varieties had a significant effect on N content of potato.

P content in 2010, 2011 was also significantly affected by variety. This result confirms those obtained by Burrowes and Ramer (2008) and Ayman (2011) who showed that P concentrations vary significantly in different varieties of chilli. Previous studies have also indicated that variety had a significant effect on grain P concentration (Murphy *et al.*, 2008).

K and Mg contents in 2010 did not differ significantly between variety treatments confirmed the results from the experiment in previous studies Imoro Ziblim and Timothy (2012) which showed no significant differences between varieties in the levels of K and Mg. However, in 2011 variety had a significant effect on K content, confirms previous results by Ayman (2011) reported that K concentrations were significantly affected by different varieties of chilli.

Higher Ca concentration in Sarpo Mira potato than Sante for both years supported the results of the reviews by Ayman (2011). (Murphy *et al.*, 2008) also who indicated that effect of variety was significant for Ca grain concentrations. In 2010 and 2011 variety had a significant effect on S concentrations a result confirmed by other finding (Mondy and Gosselin, 2006).

The finding that Na contents also differ between varieties in 2010, confirms previous studies which reported significant effects of varieties on Na contents (Koudela and Petříková, 2008). In 2011 there was no significant difference between varieties for Na contents. These results did not support the results from previous studies which reported significant effect of varieties on Na contents (Koudela and Petříková, 2008).

4.5.1.2 Fertilisation

The N, P and K content of potato tubers were significantly affected by fertility treatments. Fertility treatment had no significant effect on N, P and K of QILF potato in 2011 compared to 2010. High N concentrations were observed with application of mineral NPK than compost ones, this is thought to be mainly due to insufficient supply of nitrogen from organic fertilisers, such as composted manure which contain very low concentration of water soluble content. These results are in agreement with Tremblay (2001) who reported that generally compost supplies less mineral nitrogen, proportionately, than green manures and crop residues.

Zolnowski (2010) and Song *et al.* (2011) found out that application of NPK fertiliser caused a significant increase in the content of total N in tubers of the test potato cultivars, miaze, wheat and soybean.

The use of composted cattle manure was shown to result in decreased levels of certain mineral nutrients especially N, K and leaf chlorophyll levels in plant tissues. Similar results were obtained by Herencia *et al.* (2007) Phillips *et al.* (2002) Clark *et al.* (1999).

However some studies show higher content of N in organic crops Roinila *et al.* (2003). Other studies show no difference between organic and mineral NPK fertilisation Warman and Havard (1998), Lairon *et al.* (1984).

In 2010 mineral NPK application increased P content of potato compared with compost application. The higher concentrations of P under NPK treatments could be attributed to the high levels of P made available by NPK fertiliser in the soil. The effect of the mineral NPK on P content of potato is in accordance with other studies (Heeb *et al.*, 2006). However the content of mineral substances in tubers over the two years average did not depend on the use of compost or mineral fertiliser. Other researches have shown too that mineral content of potato did not depend on the fact whether organic or mineral fertilisers were used (Mondy and Gosselin, 2006).

Luis *et al.* (2011) states, however, that in comparison with the organic fertiliser (cattle manure), the mineral fertilisers reduced the content of P, K and Mg in tubers. Other researches also observed higher content of P and K in organically fertilised samples compared with samples fertilised with mineral (Mullin *et al.*, 1991).

A significant effect of the compost application on K content of potato was only observed in year 2010 compared with NPK. Compost seems to be rich in K content as compared with mineral NPK. This also could be attributed to the high contents of K made available by compost fertiliser in the soil. These results agree with the results reported by Asami *et al.* (2003) who have shown that application of organic fertiliser (compost) increased content of K in potato tubers compared with mineral NPK fertiliser. Similar effects of compost application were obtained by Rosen and Allan (2007) Del Amor (2007) (Hyde, 1962).

Mg content of potato tuber was not affected by application of inorganic NPK fertiliser for both of years. These results are similar to those obtained by (Srikumar and öckerman, 1990). However, Warman and Cooper (2000) found that application of compost resulted in a significant decrease in concentrations of Mg compared with NPK fertiliser. In contrast, variable results were obtained by (Carpio *et al.*, 1997).

There was no significant difference between compost and NPK treatments on S concentrations for both years. These results are not in accordance with previously reported findings (Asami *et al.*, 2003) who showed that in tuber flesh and skin S concentrations were higher in organic treatments compared with the inorganic.

For Ca content there was also no significant difference between fertilisation treatments regimes, while in 2011 the difference between treatments was significant. These findings are in agreement with previously published work (Asami *et al.*, 2003) who indicated that Ca concentrations were not significantly different between fertilisation treatments.

4.5.1.3 Crop protection regimes

The results showed that in 2010 only P, and Na levels significantly affected by crop protection treatments, while in 2011 the effect of treatments were only detected for S content. In this study N content was shown to be slightly higher where conventional fertility management was used. This could be due to the use of different crop protection practises.

However, the finding of Palmer *et al.* (2013) observed that both crop protection and conventionally fertilisation practices resulted in significantly higher tuber N concentrations. Conventional fertilisation regimes resulted in (> 40%) higher tuber N concentrations than organic fertilisation, whereas, conventional crop protection resulted in a small (<10%)

increase in tuber N concentrations. The results showed that P levels were significantly affected by crop protection treatments. Concentrations of this element were found to be higher in organic treatments compared with the conventional potatoes. These results are comparable with other results by (Asami *et al.*, 2003).

The other question to be answered by this study was, is there a significant deference in mineral content of Mg of organic and conventional potatoes. Interestingly, results from the analysis of Mg also show that there were no significant differences among organic and conventional treatments. These data are similar to those obtained by Reider *et al.* (2000).

However, Worthington (2001) found that higher Mg in organic potatoes compared to conventional potatoes. More recent studies (Hajslova et al. 2005; Wszelaki et al. 2005) are consistent with that observation. The result obtained was not similar with those of experiments carried out in previous studies by Murphy *et al.* (2008) who showed that the organic wheat systems had significantly higher mineral concentrations of Mg compared to the conventional systems.

The finding that Ca concentration did not differ between organically and conventionally grown potato for both of years, supported previous studies which reported that Ca levels were not significantly different between organic and conventional treatments (Asami *et al.*, 2003). However, Zolnowski (2010) found higher Ca concentration in conventionally grown crops compared with organically grown crops. Similar observations for the effect of crop protection were obtained by (Vrček *et al.*, 2014).

K concentrations did not differ significantly between organic and conventional crop protection systems during two years and are not in agreement with the results obtained by Masamba and Nguyen (2008) who showed that K content tend to be higher in organically grown cabbage as compared to conventionally ones.

4.5.1.4 Pre-crop rotational position

In 2010, 2011 crop rotation had no significant effect on P, K, S, Mg, and Ca concentrations as compared to the year 2010 where the effect of rotation was significant on N, K and Na concentrations. N content was increased significantly after beans cultivation compared to a previous crop of barley. This is simply because of their symbiotic relationship with nitrogen fixing *Rhizobium* bacteria. Legumes release more mineral nitrogen than other crops when they decompose (Tremblay 2001).

Stark and Porter (2005) showed that rotation crops, particularly legumes, are known to increase soil N supply. Tremblay (2001) reported that green manures and crop residues can release significant amounts of nitrogen. The amount depends on the composition of the residue and the environmental factors that affect mineralisation rate. Similar observations for N content were also observed by Campbell *et al.* (2011). Differences between the treatments could be due to difference climatic conditions during the two years. Different results were obtained for P content by Campbell *et al.* (2011).

The result for Mg content is compatible with the results reported by Houx *et al.* (2011) who reported that Mg concentration was unaffected by tillage and crop rotation.

4.6 Effect of the treatments on micronutrient contents (2010, 2011)

4.6.1 **Variety choice**

In 2010 mineral content of Fe, Zn and B was affected significantly by variety treatments. However, in 2011 the effect of variety was only detected for F and B content. These results for Fe and Zn are in agreement with the results obtained by (Rivero *et al.*, 2003).

The result in 2011 for Zn content was similar to the results obtained by Murphy *et al.* (2008). However, the findings of Ayman (2011) showed that Zn content in dry fruits was found to be significantly differ in different varieties of chilli. Differences in mineral concentrations may also depend on environmental factors, genotypes and on potato sampling as indicated by Andre *et al.* (2007).

Similar to the first year 2010, the effect of variety was not significant on Cu and Mn content. These results were not in agreement with the results obtained by (Ayman, 2011), (Murphy *et al.*, 2008).

4.6.2 **Fertilisation**

As expected the various fertiliser and variety treatments differed in terms of their effects on minerals contents of potato tubers. In 2010 fertility treatments had a significant effect on mineral content of Zn, Fe only. Contrary, compared to 2011 where no significant effects between fertility treatments were detected for all micronutrient contents. Application of NPK led to increase in Zn content as compared to compost application. This response can be attributed to an increase in the availability of these elements in response to NPK fertiliser than compost.

The application of inorganic NPK fertiliser increased Fe content of potato tubers as compared with organic compost application. This could be as a result of the high level of N supplied by the NPK fertiliser facilitated the absorption of other nutrients including Fe.

These results are in agreement with the results reported by Herencia *et al.* (2007) who have indicated that NPK fertiliser did not improve Mg, Zn and Cu but increased the content of Fe in potato. Srikumar and öckerman (1990) support the finding in this study that there are no significant difference between organic and inorganice NPK fertlised potato samples in the content of Cu.

A study by White *et al.* (2009) reported that the application of fertilisers effects tuber elemental composition in a complex manner, probably as a consequence of interaction between mineral elements within the plant and soil chemistry. These findings agreed with those of Warman and Cooper (2000). On the other hand, Qiao and Ho (1997) reported that composting increased the availability of Zn content due to the release of organically bound metal by the decomposition process.

There was no significant difference between compost and mineral NPK on Mn content of potato for both of years. These results are in accordance findings by Lag and Dev (1964) who reported that a higher application of NPK fertiliser did not influence Mn content of potato.

On the other hand, the results obtained are not in agreement with the results reported by Srikumar and öckerman (1990) who showed that application of NPK fertiliser resulted in increasing significantly Mn content compared with compost fertiliser.

4.6.3 **Crop protection regimes**

In 2010 the results showed that there was a significant difference in Cu levels in tubers from application of organic and conventional crop protection systems. There was no significant difference between organic and conventional crop protection in Fe, Mn, Zn and B content. However, in 2011 the difference between organic and conventional was significant and recorded only for Fe and Zn content. This result for Fe supported by previous studies showing no difference between organically and conventionally systems for Fe concentration of wheat (Murphy *et al.*, 2008).

Obtained results for Fe content are in agreement with the results reported by Vrček *et al.* (2014) who found out that organic potato samples had significantly lower content of Fe compared to conventional samples. This likely is that tubers ability to take up minerals is different in the two crop protection systems regardless of availability. Similar observation have been shown by (Karlsson *et al.*, 2006) However, different results for Mn and Cu were reported by Hornick (1992) who reported that Cu and Mn contents in wheat were affected significantly by crop rotation but not by crop protection systems.

The results also showed no significant difference in Mn levels between organic and conventional crop protection systems in contrast to opposite findings by Murphy *et al.* (2008) who reported that the grain mineral concentration in organic wheat was higher for Mn than grain mineral concentration in conventional wheat.

The results from the present work showed no statistically significant difference between organic and conventional treatments on Zn content of potato tubers in 2010. These results were similar with those of Warman and Havard (1998) who found that Zn content did not differ significantly between organic and conventional potatoes. In contrast, Worthington (2001) found significantly less content of Zn in organic potatoes compared with conventional.

4.6.4 **Pre-crop rotational position**

Compared to varieties and fertilisation, contrasting crop rotation regimes were shown to have no effect on concentrations of Fe, Mn, Zn, Cu and B. similar results for Cu and B contents have been observed by Houx *et al.* (2011) who shown that Cu and B concentrations were unaffected by tillage and crop rotation treatments. However, the finding of Hornick (1992) revealed that Cu, Zn and Mn contents in wheat were affected by pre-crop but there was no effect by crop protection systems.

4.7 Effect of treatments on macronutrient contents of NUE potato 2011

4.7.1 **Variety choice**

There was significant difference ($P<0.05$) in the levels of P, K, S, Mg, Ca, in tubers between varieties. This could be as a result of the difference varieties and their difference ability to uptake the nutrient. This result for P element confirms the results obtained by (Burrowes and Ramer, 2008). However, compared to the first year, no clear differences were found between varieties for N content. These results supported the results obtained by (Navarre *et al.*, 2009).

The results that K and Mg content differ significantly between variety treatments confirmed the results from the experiment in previous studies Ayman (2011) who reported that Mg and K concentrations were affected significantly by different varieties of chilli.

The results which showed that S concentrations were affected significantly by variety, this possibly due to difference varieties used, which supported the results from (Yada *et al.*, 2011).

The finding that Ca concentrations differ between varieties treatments confirms the results reported by Murphy *et al.* (2008) who indicated that effect of variety was significant for Ca grain concentrations.

4.7.2 **Fertilisation**

The finding that N concentration was only affected by fertility treatments was expected since it is well known that NPK fertiliser resulted in increasing level of N. High significant level of

N under high NPK treatments than other fertility treatments could be as a result of high level of N supplied by the NPK fertiliser which facilitated the absorption of other nutrients including N. These results are similar to the results reported by (Zolnowski, 2010). The results obtained are also confirmed by other authors Song *et al.* (2011), showing that treatments with NPK fertiliser application incresed N content of miaze, wheat and soybean significantly.

There was however no significant difference (P> 0.05) between fertility treatments for Mg, P, K and Ca content. The results obtained for Mg and P content are in agreement with the report of Termine *et al.* (1987) who revealed that Mg and P contents were unaffected by the various of fertilisation regimes. On the other hand, the finding of Imoro Ziblim and Timothy (2012) revealed that Mg, P, K and Ca concentration was affected by NPK fertiliser. This could be ascribed to the fact that the amount of P supplied by NPK fertiliser to the soils could have been leached out through excessive watering or rain and therefore the tubers could not take up the P supplied and other minerals

4.7.3 **Crop protection regimes**

Organic and conventional crop protection did not affected N, P, K, S, Mg, Na, and Ca NUE tuber concentrations as compared to year 2010, which explains the lower effect of organic and conventional fungicide based- crop protection in the year 2011. These results for N are not similar to the results obtained by (Palmer *et al.*, 2013). The results for P are also not compatible with other results by (Asami *et al.*, 2003). However, the impact of organic and conventional treatments on the amount of Mg content in potato tubers was also shown in other studies (Reider *et al.*, 2000).

The results that S concentration did not differ between organic and conventional treatments are not confirming the results reported by (Asami *et al.*, 2003). As a consequence, no clear differences in total Ca content in tubers produced by the two crop protection systems could be identified. These results supported previous studies (Asami *et al.*, 2003). In contrast, different results for Ca contents were obtained by (Palmer *et al.*, 2013).

4.8 Effect of treatments on micronutrient contents of NUE potato (2011)

4.8.1 **Variety choice**

The variation in total micro minerals Fe, Mn, Zn, Cu and B content between tubers obtained from different varieties treatments, confirmed results for Zn and Fe content reported by (Ayman, 2011). Also these results for Mn and B contents are similar to the results obtained by Munshi *et al.* (1978) who indicated that mineral concentrations of Mn and B was influenced by varieties in the leaves of sweet orange. On the other hand, different trend for Cu and Mn content was reported in earlier studies (Murphy *et al.*, 2008).

4.8.2 **Fertilisation**

Other significant differences between fertility treatments observed in this investigation were a higher Zn content in the high NPK plots and B content in the high compost plots. This could be as a result of difference fertility treatments used and also due to different fertiliser combinations. These results are in agreement with the results obtained by (Cooper *et al.*, 2011). There was however no significant difference in the Mn, Fe, and Cu content. These results for Mn content are not in agreement with the results reported by Srikumar and öckerman (1990) who showed that application of NPK fertiliser resulted in increasing significantly Mn content compared with compost fertiliser.

4.8.3 **Crop protection regimes**

There were higher levels of Cu content under organic crop protection treatment than conventional. This could be attributed to the difference crop protection treatments. These results are in agreement with the results obtained by Cooper *et al.* (2011) who reported that organic crop protection resulted in significantly higher Cu concentrations in wheat compared to conventional crop protection. The result of the study also recorded no significant differences between organic and conventional treatments for the Fe, Zn, Mn and B. Obtained results for Fe content are not in agreement with the results reported by Vrček *et al.* (2014).

Also, the results obtained for Zn and Mn are not in agreement with what Murphy *et al.* (2008) who reported that mineral content in organic wheat was higher for Zn and Mn than the grain mineral content in conventional wheat.

4.8.4 Effect of growing seasons on macronutrient and micronutrient contents (2011)

Significant effects of growing seasons were detected for N, K, Mg and Na contents but no significant effect of growing seasons was detected for P and S contents. Obtained results for Mg, K and Na are in agreement with the results reported by Alvarado *et al.* (2012) but not in agreement for P result.

There was significant difference in the levels of Fe, Cu and Zn, while there was no difference in the levels of Mn. The results for Fe and Zn are in agreement with the results reported by Talley *et al.* (1970) indicated that micro- and macro-mineral contents were affected by growing seasons.

4.9 Effect of treatments on Cd content 2010, 2011

4.9.1 Variety choice

The results that Cd content was affected significantly by variety for both of years, confirmed previous results (Imoro Ziblim and Timothy, 2012). The results for the effect of variety on Cd content are also similar to the results reported by (Musilova *et al.*, 2009).

4.9.2 Fertilisation

There was a significant effect of fertility management on the concentration of Cd in 2010, with compost fertilisation resulting in lower Cd concentrations compared with mineral NPK fertiliser. This possibly due to the use of organic matter inputs (composted cattle manure) for vegetables under organic fertilisation in experimental plots regimes may have contributed to the difference in tuber metal contents between fertilisation regimes. Cd availability in soil and subsequent plant uptake may have been decreased by higher contents of organic compounds in soils under organic fertilisation regimes, which can lead to decreases in plant availability of metals and to raised chelation of metals in acidic soils.

Soil pH might be the additional factor that increased Cd availability in the conventional fertility plots. This result similar with the results obtained by (Cooper *et al.*, 2011).

4.9.3 **Crop protection regimes**

The findings that the effect of crop protection practise was not significant on Cd content of potato during 2010 and 2011, confirms previous studies (Eltun, 1996) which reported no significant differences were found between organic and conventional crop protection systems for Cd content in tuber of potato. This may explain the use of conventional fertiliser that affecting Cd uptake in potato tubers.

On the other hand, these results disagreed with the results obtained by Cooper *et al.* (2011) who found that Cd contents was higher on average when conventional crop protection practise was used.

4.9.4 **Pre-crop rotational position**

The findings that Cd content did not differ significantly between crop rotation treatments, these results were supported by the results from Cooper *et al.* (2011) who found out that pre-crop had no effect on wheat Cd concentrations.

4.9.5 **Growing seasons**

There was no significant difference between growing seasons of two years on Cd content. However, interaction was detected between growing seasons and fertilisation. These results are not similar to the results obtained by Addiscott (1974) who shown that metal content (Cd) was affected significantly by growing seasons and variety choice.

CHAPTER 5 Conclusion and Further Work Recommendation

5.1 Conclusion

The results of investigations carried out using the effects of low input and conventional pre-crop, crop protection, varieties examining and fertility management practices on the nutritional quality of potato crops were either in agreement or disagreement with published studies. It can be concluded that the influence of treatments on vitamin C content was more obvious with varieties, whereas there were no significant influences of other treatments (fertility, pre-crop and crop protection) on vitamin C or glycoalkaloid content.

The present study has shown that mineral content was affected by fertility, variety, crop protection and pre-crop. The growing season also appears to have a significant effect on alpha solanine, macro minerals and micro minerals but not on yield, vitamin C and alpha chaconine contents.

With regard to the effect of variety on yield, no significant difference between varieties was detected for both years 2010, 2011 of QILF potato experiments. On the other hand, significant difference between fertility, pre-crop and crop protection treatments were detected between the two years.

Results for NUE potato experiment 2011 indicated that yield was affected significantly by varieties, where the highest yield was recorded with Sante and the lowest recorded with Fontane potato. There were also significant differences between fertility and crop protection treatments on tuber yield.

The findings presented in this research provide a suitable guide to the choice of potato with high contents of vitamin C, low content of glycoalkaloids and information on other essential minerals nutrients that provides the most beneficial yield and nutritional quality. The improvement of the nutrient use efficiency is an important goal for both conventional and organic production systems with a potential impact enhanced and improved health of consumers.

5.2 Further Work Recommendations

Some practical recommendations can be reached as a result of this study. It would be useful to conduct and expand the study using different kinds of fertilisation and crop types such as other potato varieties or different types of vegetables and fruits, the findings of which would help to fill the gaps in our understanding of fertilisation and it is effects on nutrition.

Further research is also recommended in order to investigate the effects of different kinds of pre-crop and crop protection practices on nutritional quality of potato. Compared to variety, fertilisation and crop protection factors, not much research work has been done on the effects of growing seasons on the nutritional quality of fruits and vegetables including potato.

CHAPTER 6 References

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