Optimisation of nitrogen and potassium nutrition for selected new potato (*Solanum tuberosum* L.) cultivars

by

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DECLARATION

I declare that this dissertation, for the degree of MSc (Agric.) Agronomy at the University of Pretoria is my work, except where duly acknowledged and that it has never been submitted before by myself for any degree at any university.

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Tlotlisang Nkhase Date

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ABSTRACT

There are many older potato cultivars in South Africa such as BP1, Up-to-date and Avalanche. These older varieties of potatoes have been studied intensively under South African conditions such that nutrient requirements for such cultivars are well known. However, new cultivars are developed in order to improve yield, increase pest resistance and improve tuber quality, and as well as to meet the industrial market for processing. These newer cultivars are either developed locally or imported into South Africa. Nutrient requirements for these new cultivars have to be known under South African conditions, since nutrient requirements may vary among cultivars and even across regions. Knowledge of the nutritional requirements of such cultivars, especially nitrogen and potassium, which are taken up in largest quantities, are essential to fine-tune production management and improve yield and quality of tubers. Literature suggests that study attempts should not only focus on levels of N and K, but to also investigate N-K interaction (N:K ratios), since yield response to K is related to N status in the soil.

For the aforementioned reasons, the study was conducted to evaluate the response of two newer potato cultivars to nitrogen (N) and potassium (K) levels in the South African environment. The studied cultivars were two foreign cultivars, namely Innovator and Lanorma. Two trials were conducted, first, a pot trial and then a field trial as a follow up. The pot trial was conducted between October 2015 to March 2016, while the field trial was conducted from September 2016 to February 2017. The two cultivars were evaluated at four levels of N and four levels of K for the pot trial, which then gave 16 N x K treatment combinations and 16 N:K ratios. The levels of N were 180, 230, 280 and 330 kg.ha^{-1} and K levels 160, 230, 300 and 370 kg.ha^{-1}. For the field trial, treatments were reduced to three levels of N and K each, i.e. 160, 230 and 300 kg.ha^{-1} for both N and K, giving seven different N:K ratios.

Destructive growth analyses were performed once during the growing season for the pot trial, while for the field trial destructive growth analyses were done four times during the growing season. During each harvest, plant height, dry leaf mass, dry stem mass, stolon length, dry tuber mass and tuber number were recorded. At final harvest, yield, specific gravity, chip colour score and dry matter content were recorded for statistical analysis. SAS was employed in order to perform an analysis of variance and means were separated using the LSD test at 95% probability level. Growth analyses results for both trials showed that Lanorma outweighed Innovator in terms of dry leaf and stem mass. Lanorma was also taller than Innovator and had longer stolons than Innovator. On the other hand, Innovator had a higher total dry tuber mass than that of Lanorma, although Lanorma had more tubers per plant.

At final harvest for the pot trial, yield for Innovator was significantly higher than that of Lanorma. Yield for both cultivars were significantly influenced by N:K levels and ratios. N:K ratios ranging between 0.62 to 1.22 showed a tendency of better yield than yields outside that ratio range, provided none of the two nutrients were insufficient. Field trial yield was also influenced by the N:K ratio, similarly to the pot trial. In contrary to the pot trial, Lanorma had a significantly higher yield than Innovator in the field trial. Tuber specific gravity (SG) was also influenced by N:K ratio for both cultivars. For both pot and field trials, N:K ratios around 1.1 or less proved to have better SGs for both cultivars in most cases. Innovator, a processing cultivar, had higher SG values as compared to Lanorma. Yield and tuber size generally increased with increase in N. Yield also increased with increase in K up to 230 kg.ha^{-1} in most cases, whereafter it then remained constant with further K increase. For the specific conditions, it is recommended that N and K levels be kept at around 230 kg.ha^{-1} for both cultivars for optimal yield. However, if the priority is to improve tuber quality for processing, then a fertilizer treatment combination of 160 kg.ha^{-1} N and 300 kg.ha^{-1} K would be the best option due to lighter chip colour and higher specific gravity associated with that treatment combination.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Potato (*Solanum tuberosum* L.) is the most important vegetable crop in South Africa and the world at large. Potato is acknowledged worldwide as one of the most important crops, and ranks fourth amongst the top contributors to the world food basket (Khan et al. 2012). When it comes to matters of future food security, Ahmadi et al. (2010) predicts that potato production globally is likely to continue increasing significantly, which will largely benefit the nations of the world in terms of food provisioning, nutrition and better economic returns. Potato is nutritionally rich, not only in carbohydrates, but it also has protein of high biological value (Eppendorfer and Eggum 1994), vitamins B and C and minerals (Khan et al. 2012).

In the context of South Africa, potato production occurs throughout the year, but the production season differs across different regions in the country (DAFF 2013). Potatoes make up about 4% of the total agricultural production of the country, contributing about 43% of the main vegetables and 15% of horticultural products (DAFF 2013). From an economic standpoint, the annual potato production gives returns that is worth approximately R 1.6 billion (DAFF 2013). It is with regard to the importance, value and economic potential of potatoes that efficient production of potatoes becomes a great interest and concern to South Africa.

The complex nature of the potato crop poses a number of threats to its production. For instance, Ruža et al. (2013) established that the nutrient-use efficiency of crops increases with an increase in number of root hairs per given root length, greater root depth, high root density and increased root growth longevity. However, potato has a poorly developed, shallow and sparse root system (Ahmadi et al. 2010), with roots normally occupying mostly the top 60 cm soil layer and about 90% of roots reside in the top 25 cm layer (Tanner et al. 1982). It follows, therefore, that nutrient uptake of potatoes is mostly from the top 25 cm. Furthermore, potatoes have relatively few root hairs (about 21% of root mass) as compared to crops such as cereals (30-60% of root mass) (Yamaguchi 2002). Unlike cereals, potatoes consume high amounts of nutrients within a short period of time, because of high accumulation of dry matter within that period (Moinnudin et al. 2004). Furthermore, the shallow and poorly developed root system of potatoes makes it highly susceptible to drought (Ahmadi et al. 2010), which makes irrigation necessary. Potatoes are normally grown in light-textured soils, and the type of soil, coupled with the shallow and poorly developed root system, as well as frequent irrigation, make nutrients, particularly nitrogen (N) in the form of nitrate (NO_3^-), more susceptible to leaching in potatoes, compared to many other crops (Pehrson et al. 2011). Such leaching of NO_3^+ from potato fields has been documented as the main pollutant associated with potato production (Ruža et al. 2013).

Alva (2010) advises that there has been major advancements in agricultural production systems, which include establishment of new cultivars in order to increase yield, pest and disease resistance, and improve quality, marketable yield and resilience to abiotic stresses such as drought. According to Hijmans (2003) potato production is at risk and is likely to decrease in some parts of the world by 9 to 18% owning to climate change. It is with regard to this consideration that new potato cultivars are being investigated to develop cultivars that can better resist the negative effects of climate change, and result in more stable yield, even in less favourable conditions (Abelenda et al. 2011). The complexity though is that while improved new cultivars may be able to better withstand biotic and abiotic stress conditions, their nutritional requirements may differ significantly from that of the older cultivars, posing yet another uncertainty to the successful production of such new potato cultivars (Westermann 2005). Alva et al. (2010) indeed confirmed that cultivars differ in their response to important inputs such as N and water, and therefore each cultivar's requirements for nutrients must be known in order to increase yield while at the same time minimising any negative impact on the environment.

As N application rates differ, depending on cultivar choice and end use of the tubers (Ruža et al. 2013), Westermann (2005) argues that the actual plant demand for N must be known in order to improve its efficiency. One of the legitimately acknowledged solutions is the application of appropriate nitrogen to potassium (N:K) ratios, as they can improve yield and optimise N uptake, which could reduce N losses to the environment (Lal et al. 2007). It has been established that best plant growth and development is associated with optimal N:K ratios, while N and K imbalances lead to sub-optimal plant growth (Xie et al. 2000; Wells and Wood 2007). For optimal yield of potatoes, appropriate N, P and K fertilisation levels and ratios are therefore required (Zhang et al. 2010).

In this regard, it is important that producers do apply sufficient N and K to achieve optimal economic returns and acceptable tuber quality for end use, with minimal negative impact on the environment (Kavvadias et al. 2012). This study, therefore, examined the effects of N and K ratios (with constant amount of P) on two relatively newly introduced potato cultivars (Lanorma and Innovator) in South Africa. The study further aimed to determine the optimal ratio of N to K necessary to achieve optimum tuber yield and appropriate size and quality for the two new potato cultivars.

1.2 Problem statement

Potato is one of the most important vegetable crops in South Africa, and its physiology often tends to complicate production. The potato’s shallow root system affects its effectiveness in exploiting nutrients from the deeper soil horizons, resulting in higher amounts of nutrients being required for the supply to the root zone. The predicament is that nutrients (especially N and K) have to be supplied in appropriate amounts and at optimal ratios to maximise yield and quality, while at the same time ensuring cost effectiveness in production of potatoes. Cultivars can respond differently to different ratios of N and K, and the interaction effect between N and K is often not known for newer cultivars. It is, therefore, important that the optimal ratios which will give optimum tuber yield, size and quality are determined, and that consideration is taken to ensure that the determined ratios do not result in wastage of fertilizer and pollution of ground water resources due to leaching (Ruža et al. 2013). In addition, there is a need to investigate and optimise the interaction between N and K. For building a sustainable and economically viable production system for new potato cultivars, the interaction between nutrients in the soil has to be known and guidelines for optimal ratios have to be developed, as has been done for the older cultivars (Alva et al. 2011).

Furthermore, while many authors have stated the relationship between potato cultivars and fertiliser requirements, climatic factors such as temperature and soil moisture content are often not taken into consideration in the related studies, and yet potatoes are sensitive to temperature and water stress. A cultivar with known growth response to a specific fertiliser application in the country of its origin, may behave differently under new climatic conditions with the same fertiliser application. Fertiliser requirements for a specific cultivar under prevailing climatic conditions should therefore be specified to limit nutrient losses and optimize crop performance.

1.3 Hypotheses

The main hypothesis statement of this study is:

There is a defined optimal level of nitrogen and potassium that will result in optimal tuber yield and quality.

In addition, the following hypotheses were investigated:

- There is a specific nutrient combination that will result in best tuber quality
- Cultivars vary in responsiveness to K

1.4 Aim and objectives

The main aim of this study was to investigate the interaction effects of progressive levels of N and K (with constant amount of P) on two selected newly introduced potato cultivars (Lanorma and Innovator) and determine the optimal ratio of N to K needed for optimum tuber yield, appropriate size and better quality of these new potato cultivars. The two cultivars under observation were Lanorma and Innovator. Figures 1.1 and 1.2 show the pedigrees of Lanorma (http//variaties.ahdb.org.uk) and Innovator (http//www.europotato.org), respectively.

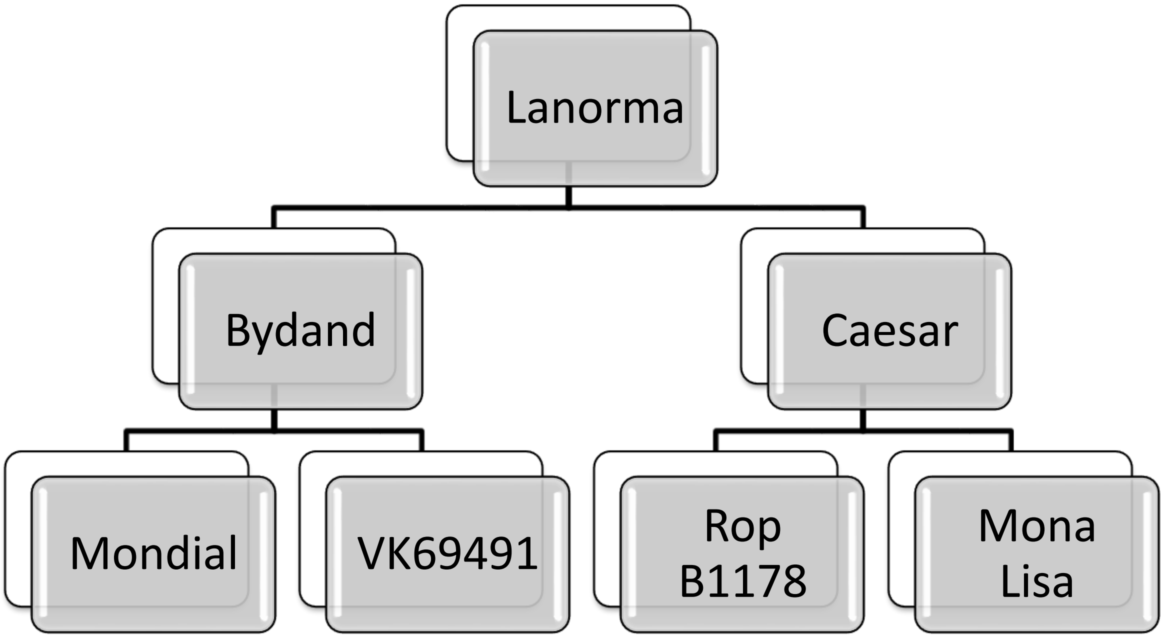


Figure 1.1: Pedigree of the table cultivar Lanorma (http//variaties.ahdb.org.uk)

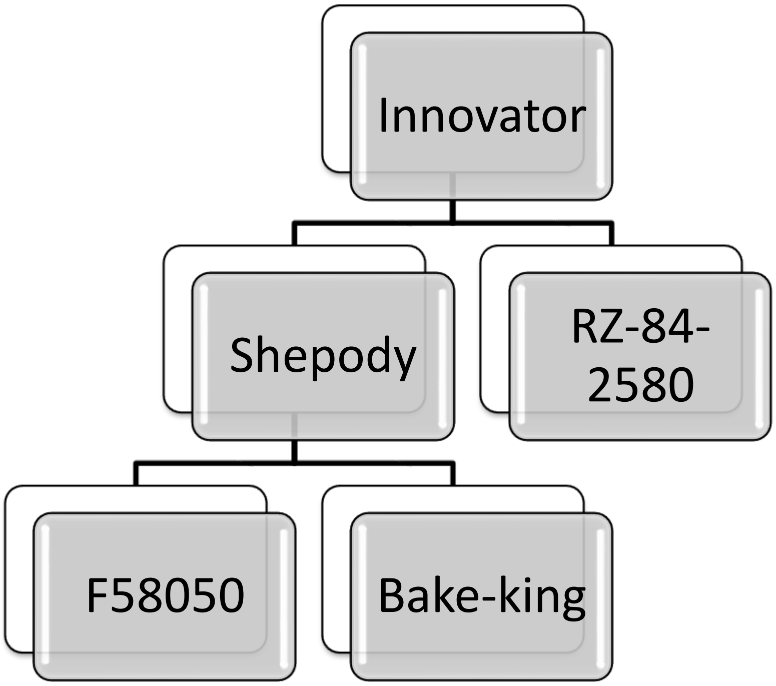


Figure 1.2: Pedigree of the processing cultivar Innovator (http//www.europotato.org)

The specific objectives of the study were:

- To investigate the interaction effects of four progressive ratios of N and K (with constant P level) on the growth, yield and quality of two selected new potato cultivars.
- To develop optimal N-to-K fertiliser ratios to achieve the best tuber yield, size distribution and quality for the two cultivars.
- To evaluate nitrogen and potassium use efficiencies of the two cultivars.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For optimal yield of potatoes, appropriate N, P and K fertilisation levels and ratios are required (Zhang et al. 2010). Fertiliser requirements of older South African potato cultivars such as BP1 have been studied intensively. However, little local research on potato nutrition has been conducted in the past decade and there is a need to optimise fertiliser guidelines for some newer cultivars. Nutrient requirements vary across cultivars. Furthermore, the yield and quality attributes of a specific cultivar may vary, depending on the climatic conditions in which it is grown. For example, Steyn et al. (2009) compared two foreign cultivars with two locally developed cultivars under South African conditions. These foreign cultivars were known to be adequate for processing in countries of their origin; however, they produced tubers of lower quality under South African conditions. Appropriate fertiliser application programmes should result in increased yield, less environmental pollution and better quality (Alva et al. 2011).

The shallow and poorly developed root system of the potato crop tends to make the production of potatoes quite demanding in terms of nutrient requirements. In this regard, nutrient management programmes need to be carefully designed and implemented to ensure that production conditions will meet agricultural requirements to effectively support sustainable potato production (Pehrson et al. 2011). According to Alva (2010), the phrase ‘sustainable agricultural practice’ can be understood to refer to a practice that is both economically and technically viable, while at the same time it also has less negative impacts on the environment.

One of the best ways of ensuring sustainable production of potatoes is to ensure proper management of nitrogen (N), phosphorus (P) and potassium (K) in a way that will give better results in terms of high yield and good quality potatoes (Khan et al. 2012). While sustainable production of potatoes is one of the most important considerations from an agricultural perspective, the main challenge is that potatoes are known to have very high production costs due to the high input levels required, including nutrients (Hopkins et al. 2010), which are the focus of this study. The potatoe's high nutrient demand is due to the crop's shallow and poorly developed root system, accompanied by its tendency of high dry matter accumulation over a short time, which results in a rapid utilisation of more nutrients within a short period, as compared to other crops such as cereals. As Ruža et al. (2013) points out, the additional challenge is that potato yield and quality are greatly influenced by nutrient availability in the soil, and therefore farmers normally apply fertilisers in high amounts to improve yield. Without careful consideration of the relevant nutrient programmes, the application of fertilisers can create nutrient imbalances, which can even reduce yield and compromise the quality of potatoes. For this reason, scientific research globally has given much attention to proper fertiliser management (Šreka et al. 2010).

Although nitrogen management practises have been well studied due to rising environmental concerns of leaching and pollution of groundwater resources, potassium (K) management has received less attention in developing countries. This resulted in a decline in native K reserves and deterioration in crop yield (Zhang et al. 2010). Potassium plays an important role in growth and yield, but its role in the tuber is particularly related to the quality of potatoes. For a progressive life cycle of potatoes and sustainable development, best management practises (BMP) for both N and K have to be developed for each new cultivar (Alva et al. 2011). In support of the argument that the study of N-K interaction is presently of high interest, Zhang et al. (2010) argues that it is important for study attempts not to only focus on levels of N and K, but to also investigate N-K interaction, since yield response to K is related to N status in the soil. An example of this proposed approach is the study of Ruža et al. (2013), which showed that an application of K without N had no significant effect on potato yield. For the full exploration of a cultivar's potential, it is therefore necessary to provide efficient crop management practices and a balanced nutrient programme (Moinuddin and Umar 2004, Moinuddin et al. 2005). This includes optimal amounts and ratios of N to K to ensure high yield and the best quality potatoes (Zhang et al. 2010).

Many factors, including a cultivar's genetic makeup, biophysical properties and as well as climate, should be taken into consideration if high quality yield of potatoes has to be achieved (Brown 1993). According to David et al. (1983), potatoes destined for processing should be firm, consistent in size and well-shaped. Shape differs among the end use purpose, such that oblong tubers more than 50 mm long are more suitable for French fries, while round tubers of about 40-60 mm diameter are suitable for crisp processing (Burton 1989, Beukema and Van Der Zaag 1990, NIVA 2002).

David et al. (1983) further stated that tubers should also be free from physical damage, greening, adhering soil and diseases. Other attributes that render potato tubers fit for processing are high specific gravity (or dry matter content) and low reducing sugars (fructose and glucose) (Hayes & Thill 2002). Factors that affect specific gravity of potatoes include climate, fertiliser use, location, cultivar, soil chemical and physical properties (Khan et al. 2012).

2.2 Effect of potassium on the potato crop

Nitrogen (N), P and K are the main macronutrients needed for growth and development of potatoes (Öztürk et al. 2010). Insufficiency of any or inappropriate combinations of these nutrients can result in stagnant growth and reduced yield (Crozier et al. 2004). Examining the N, P and K dynamics, Kavvadias et al. (2012) reported that potatoes consume more K than N and P, and the consumed K was observed to correlate better with good quality, compared to the yield of potatoes. K plays an important role in the manufacturing of starch and sugars, and in the translocation of carbohydrates to storage organs (Khan et al. 2012). K is efficient in stimulating enzymes catalysing the conversion of glucose into complex molecules of starch (Mengel and Kirkby 1987). This accumulation of starch resulting from the process is associated with the growth of potato tubers (Singh and Singh, 1996). K application below optimal amounts results in the exhaustion of K in the native soil reserves, a situation that can eventually lead to land degradation (Khan et al. 2012). The uptake of N and P is associated with optimal K content in the soil, which results in better shoot growth (Moinuddin et al. 2005). Excessive potassium application, however, has been reported to reduce specific gravity of potatoes (Hopkins et al. 2010).

Kang et al. (2014) observed an increase in yield at varying levels of K application and constant N application in a pot trial. They reported an increment in yield as K application was increased from 5 g to 8 g per pot. However, as K was increased to 16 g per pot, there was no further yield increment, but rather only an increase in K concentration in the tubers. This uptake of K without further yield uptake is referred to as luxury absorption of K (Hommels 1989). Some other researchers also reported no yield increase with K application (Locascio et al. 1992; Yan et al. 2005; Xia and Guo 2008; Jiang 2009). This could be due to high K content already present in the soil (Jiang 2009).

Many authors, including Chapman et al. (1992) and Westermann et al (1994), have observed a positive response of yield to K application. Westermann et al. (1994) advises that optimum application levels of K can be determined by knowing the specific K effects and its interaction with N. High levels of both N and K fertilizer are also known to increase the number of tubers in the medium (25 - 75 mm) and large (>75 mm) size grades, while reducing the number of small grade size tubers (<25 mm) (O'Brien et al. 1998). Al-Moshileh and Errebi (2004) observed an increase in SG, carbohydrates and K tuber content with an increase in K fertiliser application. Their recordings are presented in Table 2.1.

Grewal and Trehan (1993), Trehan and Claassen (1998) and Trehan and Claassen (2000) noted that potato cultivars grown in the same soil had different K requirements, and they attributed the requirement differences to the variation in K influx (K uptake rate per unit root length), in relative growth rate, and in root-shoot dry matter ratio amongst the cultivars. Trehan and Sharman (2002) observed that the potato cultivar that had high influx rate had higher K uptake, compared to the one with high root to shoot ratio. It could be concluded, therefore, that influx was the most important parameter of K uptake efficiency in their study.

Table 2.1: Effect of different levels of potassium sulphate on tuber specific gravity, carbohydrates, potassium concentration and marketable yield (Al-Moshileh and Errebi 2004)

Treatment K_2SO_4 (kg.ha^{-1})	Specific gravity	Carbohydrates	K (%)	Yield (t.ha^{-1})
0	1.067	36.66	1.08	17.91
150	1.069	39.66	1.17	21.53
300	1.069	42.66	1.71	28.66
450	1.084	50.66	2.09	31.90
600	1.086	51.33	2.12	31.96
LSD (0.05)	0.003	1.65	0.21	2.43

2.3 Effect of nitrogen on the potato crop

Although potatoes consume a lot of nutrients, proper management of those nutrients is necessary for sustainable potato production. A bulky once off N application is not sustainable, because the plant's N requirement for growth and development is continuous (Sun et al. 2012). Timing of nutrient application can play a vital role in the performance of a crop. Sun et al. (2012) compared split N application with once off application and they observed a significant increase in yield when N was split. High yield in split N application could be due to improved synchrony between N crop demand and N supply. Shoji et al. (2001) found the same yield of potato with controlled N release fertilizer at 134 kg ha^{-1}, compared to traditional practice of 269 kg ha^{-1}.

Suboptimal to low N supply leads to reduction in leaf area and early defoliation, which result in low yield and reduced tuber size (Goffart et al. 2008; Ruza at al. 2013). Excessive N application, on the other hand, results in high dry matter partitioning to the shoot and stolon at the expense of tubers (Sun et al. 2012; Ruza et al. 2013). Excessive

N application also delays tuber differentiation, tuber growth with about 7 to 10 days and leaf maturation, while the length of tuber bulking period is reduced (Kleinkopf and Westermann 1981; Westermann 2005; Ruža et al. 2013). When Ruža et al. (2013) investigated the effect of N at seven levels (30, 60, 90, 120, 150, 180, and 210 kg ha^{-1}) on the yield of two cultivars, namely, ‘Borodjanskiy Rozoviy’ and ‘Brasla’, they noticed an increase in yield with an increase in N level for both cultivars. The increase was observed to occur until the optimal N level was reached, whereafter there was no further yield increase beyond the optimal level. The optimal N levels of the two cultivars were, however, different, with the optimal N level for ‘Brasla’ and ‘Borodjanskiy Rozoviy’ being 90 and 150 N kg.ha^{-1} respectively, showing that cultivars do vary in nutrient requirements.

A study by Wang et al. (2016) showed the effect of deficient, sufficient and excessive amounts of N on tuber yield at different water supply levels (Figure 2.1). It can be seen that yield declined with both deficient and excessive N under appropriate water level.

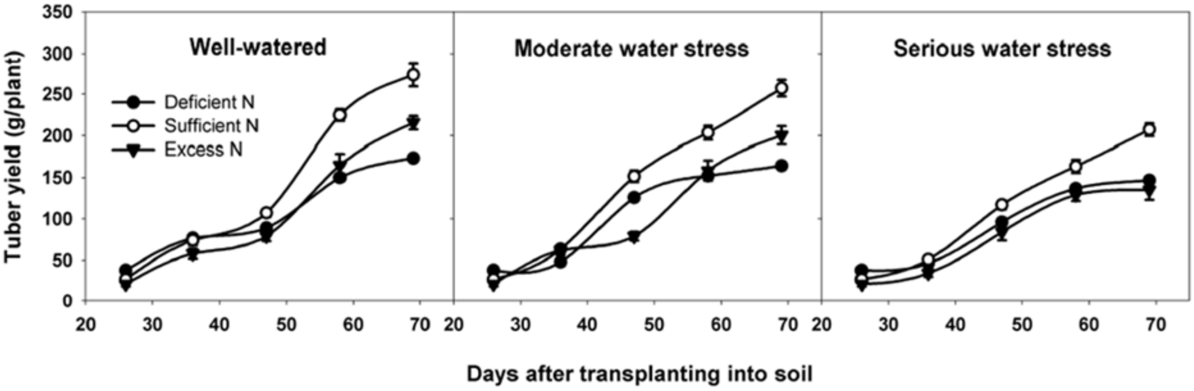


Figure 2.1: Potato yield response to different N and water supply levels (Wang et al. 2016)

Some studies have shown that an application of N late in the season delays maturity and decreases specific gravity, and according to MacLean (1984) the effect is more pronounced if N application is above 34 kg ha^{-1} with vine kill within 4 to 5 weeks. Contrary to the findings of MacLean (1984), a study conducted by Sun et al. (2012) showed no decrease in specific gravity when some N application was done late in the season, compared to once off N application at the time of planting. Indiscriminate and over application of N fertiliser, on the other hand, could result in pollution of ground water aquifers, reduction in yield potential, poor quality yield, delayed maturity and high fertiliser input cost, which will result in high production costs (Šreka et al. 2010, Alva et al. 2011).

2.4 Optimal nitrogen and potassium levels in potato plant tissues during different crop growth stages

According to Lang et al. (1999), potato has four distinctive developmental stages, namely, (1) planting until tuber initiation (period from emergence of seedlings to initiation of tubers); (2) tuberization (stolon enlargement); (3) tuber bulking (rapid increase in tuber size) and (4) tuber maturation (characterised by yellowing of vines, followed by rapid defoliation). In carefully considering the developmental processes of the potato crop, for production of carbohydrates during tuber bulking stage, plants should be kept green, but towards harvest, senescence is important for carbohydrate translocation to the tubers (Sun et al. 2012). Across these growth stages, nutrient contents in plant tissue should thus differ. Table 2.2 illustrates the four growth stages and optimal concentration of NO_3-N and K in the petioles, and N content in the soil.

Table 2.2: Recommended optimal soil nitrogen and petiole nitrate and potassium concentrations across different plant growth stages

Development stage	Description of growth stages	Soil (NO_3- N + NH_4-N) Conc. (45 cm depth) (ppm)	Petiole NO_3-N Concentration ($\times 10^3$ ppm)	Petiole K Concentration ($\times 10^4$ ppm)
Stage I	Planting until tuber initiation	15	N/A	N/A
Stage III	Tuberization	>10 to 15	15 to 26	8 to 11
Stage III	Tuber Bulking	10	12 to 20	6 to 9
Stage IV	Tuber Maturity	< 10	6 to 10	4 to 6

*N/A = Not applicable. Petiole sampling not done during this growth stage (Lang et al. 1999).

2.5 Effect of nitrogen and potassium on potato tuber quality attributes

In the processing industry, potato quality is normally assessed by specific gravity (SG), since it is closely related to starch concentration, mealiness and total solids (Marwaha and Kumar 1987). According to Steyn et al. (2009), there is a positive relationship between tuber SG and dry matter content (DM). In fact, Hassanpanah et al. (2011) used Equations 2.1 and 2.2 to correlate SG, DM and starch percentage, showing a relationship between DM and SG and a relationship between starch content and SG.

$$DM\% = 24.182 + 211.4 \times (SG - 1.0988) \qquad Equation\ 2.1$$

$$Starch\% = 17.546 + 119.07 \times (SG - 1.0988) \qquad Equation\ 2.2$$

According to Khan et al. (2012), high specific gravity and low oil consumption is indicative of good quality chips. Potatoes with SG of 1.075 or above are considered suitable for processing (Somsen et al. 2004), and high quality chips should not have more than 36% oil content (Khan et al. 2012). K fertilization of potato crops is known to reduce oil consumption during processing (Khan et al. 2012). Zebarth et al. (2004) observed a decrease in specific gravity with an increase in N application. K and N oppositely affect specific gravity, with N reducing it, while K positively influences SG (Kunkel and Holstad 1972, Khan et al. 2012). Since both nutrients are needed for the growth and development of potatoes, the appropriate N:K fertilizer ratio which would result in high SG has to be known.

High dry matter and starch contents are necessary for industrial purposes such as alcohol production (Khan et al. 2012). Potatoes with high DM content (or SG) have lower water content (Steyn et al. 2009), while potatoes with low DM content will have high water content and consume more oil when processed into fries or crisps. Mosley and Chase (1993) explain that about two thirds of water are removed and replaced by oil during the processing of potatoes with high water content, resulting in the processed potatoes being oily and soggy. According to Steyn et al. (2009) processed fries should ideally be low in oil content, mealy in the inside and crisp on the outside. In examining the N and dry matter content relationship, Zelalem et al. (2009) and Zewide et al. (2016)

suggested that an increase in N application results in reduced dry matter content, while Jenkins and Nelson (1992) and Allison et al. (2001) discovered a negative response in DM% with an increase of both N and K.

With a focus on the chip colour factor, Melito et al. (2017) established that dark chips are unacceptable and not marketable. The Maillard reaction, a reaction between reducing sugars and amino acid groups during frying at high temperature, is known to be the main reason for the dark colouration of chips. It is always important to consider that any fertilizer combination that will result in high levels of reducing sugars and higher amino acid content will result in darker chips. Considering that reducing sugar content negatively affects chip quality by depicting brown or black colouring, either reducing sugar or amino acid content should be reduced in order to obtain lighter chips (Hayes and Thill 2002; Khan et al. 2012).

There are conflicting reports whereby some authors claimed that increasing N results in the darkening of chips and other authors suggested that chip darkening occurs only when N is applied above the optimum level (Feibert et al. 1998). A study conducted by Zebarth et al. (2004), on the other hand, did not indicate any significant change in chip colour across different levels of N ranging from 0 to 300 kg ha^{-1}.

2.6 Interaction effect of N and K on potato yield

When Singh and Lal (2012) studied the N and K interaction effect on the yield of potato, they observed an increase in yield with an increase in N until an optimal level was reached, whereafter yield was observed to remain constant (or level off) as N was applied beyond the optimal level. Singh and Lal (2012) also observed yield increase with an increase in K at each level of N (Figure 2.2). In addition, they noticed that as N level increased, the proportion of medium and large tubers also increased. Ruža et al. (2013) explored the performance of K in the presence/absence of N and stated that K does not have any significant effect on potato yield in the absence of N. Zhang et al. (2010) concurred and concluded that potato yield responded positively to K only when sufficient N is applied. Conversely, studies by Roberts and Beacon (1988), Westermann et al. (1994), Panique et al. (1997) and Singh and Lal (2012) have shown an increase in yield with K application even in the absence of N application. Singh and Lal (2012) reported an increment of 35% yield when K and N were applied at 100 $kg.ha^{-1}$ each, compared with 100 $kg.ha^{-1}$ N and 0 $kg.ha^{-1}$ K.

Kavvadias et al. (2012) investigated the interaction effect of N and K on potatoes at three levels of N (330, 495, and 660 kg N ha^{-1}) and four levels of K (112, 225, 450, and 675 kg ha^{-1} K_2O). They observed an increase in yield at the two lower levels of N with an increase in K up to 225 $kg.ha^{-1}$ K_2O, while the application of K_2O at 450 $kg.ha^{-1}$ only increased tuber numbers significantly, compared to lower levels of K. The application of K_2O at 675 $kg.ha^{-1}$ significantly decreased tuber numbers. O'Brien et al. (1998) noted that K application positively affects tuber numbers on very low K level soils and therefore this suggests that the soil on which Kavvadias et al (2012) had conducted their research had a low K level.

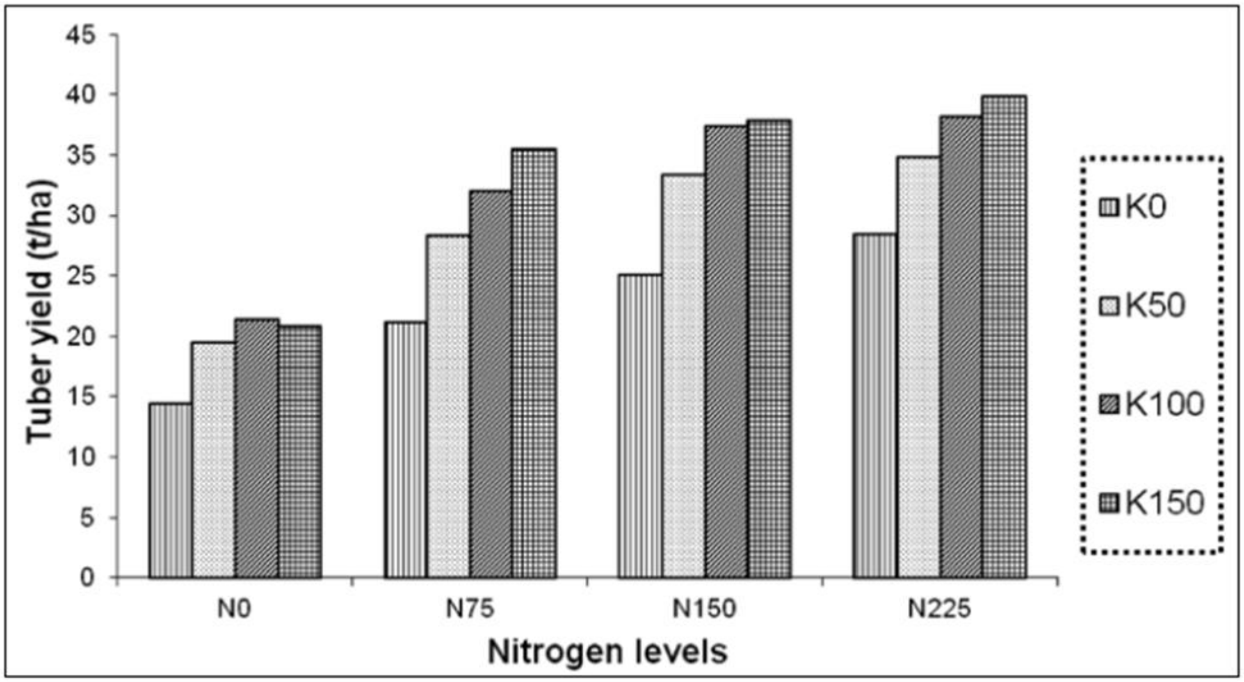


Figure 2.2: Effect of potassium fertilisation on potato total tuber yield at different nitrogen levels (Singh and Lal 2012).

Khan et al. (2012) investigated the effect of K on marketable tuber yield using two sources of K, muriate of potash (MOP) and sulphate of potash (SOP); and they observed a significant increase in marketable tubers with K application from 0 to 150 kg ha^{-1}. However, the K sources varied in performance, such that MOP increased yield by 44%, while SOP increased yield by 34%. There was a slight marketable tuber yield increase of 6 and 4% for MOP and SOP respectively, when K was increased from 150 to 225 kg.ha^{-1}. Panique et al. (1997) contradicted the findings of Khan et al. (2012) and reported that no significant difference in yield was observed with an increase in K.

2.7 Temperature effects on dry matter partitioning in potato crops

According to Geremew et al. (2007), dry matter (DM) production and partitioning vary greatly among cultivars, depending on a number of factors that deserve attention to ensure high efficiency of potato production. Looking closely at partitioning, Pashiardis (1987) indicated that temperature has a great influence on the potato crop's partitioning of assimilates. Haverkort and Harris (1987) and Jenkins and Mahmood (2003) explain that the sensitivity to climate varies among cultivars, as some cultivars already compromise yield to shoot at temperatures above 23^{0}C. According to Spitters (1987) tuber yield is the proportion of total biomass yield portioned to tubers, while total biomass is a function of photosynthetically active radiation (PAR), which in turn is dependent on plant canopy size (Spitters 1987; Vos & Groenwold 1989; Van Delden 2001).

Kooman and Rabbinge (1996) and Kooman et al. (1996) reported research findings on the effect of temperature on potato crop development and growth, and they found that temperatures above 30^{o}C and below 7^{o}C had a serious negative impact on potato development and growth. The authors reiterated that potato is a cool weather crop, with optimal production conditions being cool seasons that are frost-free. For tuberization, optimal temperatures should range from 15 to 20^{o}C, while for rapid haulm growth the optimal temperature range is 20-25^{o}C (Rykaczewska 1993; Van Dam et al. 1996). Higher temperatures promote shoot growth at the expense of tubers (Rykaczewska 2013), although the sensitivity to high temperatures varies among cultivars, as stated earlier. A study was conducted by Aien et al. (2017) comparing two cultivars, namely Kufri Surya and Kufri Chipsona-3 for their tolerance to high temperatures and they observed that cultivar Kufri Chipsona-3 was more tolerant to higher temperatures than Kufri Surya. Aien et al. (2017) suggested that this was due to its high efficiency of dry matter partitioning to the tubers during tuber bulking.

2.8 Potassium availability in the soil

According to Wang et al. (2010b), K in the soil can be classified into four main forms, namely, (1) immediately available, (2) readily available, (3) slowly available, and (4) relatively unavailable K, which is the K that is adsorbed and integrated into the structure of the primary soil minerals and is non-exchangeable. The non-exchangeable mineral K is the most abundant form in most soils, attributing to 90 - 99% of the total K. K on the edges and surface of clay minerals is in a dynamic equilibrium with the K in soil solution. It is of paramount importance to understand K dynamics and its availability, as K is involved not only in soil fertility, but also in ecological processes such as inter-specific competition or plant-micro-organism symbiotic interactions (Barre et al. 2007).

Another important consideration in K dynamics is the clay mineralogy, as it plays a major role in K adsorption and release (Barre et al. 2008). For instance, some 2:1 clays are known to release K, while some are known to fix it in the interlayer spaces (Barre et al. 2008). Soil clay mineral layers containing mainly anhydrous K are known as illite. In illite clays, K is tightly fixed in the interlayer spaces and this renders it unavailable for plant uptake while in smectite, it is exchangeable and available for plant uptake. Application of Ca containing products, such as calcite or gypsum in soil dominated by illite, can result in considerable release of K (Schneider et al. 2013). This release of K is associated with exchange of K with Ca, an ion with bigger hydration shells, which opens the interlayer from 1 nm to about 1.4 nm and allows K to diffuse out of the layer. The change in interlayer space changes the mineralogy from illite to vermiculite. However, the exchange of K by ions or cations of a similar hydration radius such as NH_4^+ does not change the interlayer but rather fixes NH_4^+ (Zhang et al. 2013). The locality of negative charge and its magnitude in 2:1 minerals plays a major role in K fixation. K fixation is promoted more by the locality of negative charge in the tetrahedral sheet, compared to the locality of the octahedral negative ones (Simonsson et al. 2009). The formation of hydroxyl interlayers and redox processes do affect K fixation according to Simonsson et al. (2009).

K fixation and release does not only depend on the interlayer spaces but also on the competing cations in the solution, especially calcium (Ca) and magnesium (Mg) (Schneider et al. 2013). In agricultural soils, K fixation is by far seen as a positive factor, limiting its leaching rather than restricting fertilizer efficiency, and is influenced by the parent material, degree of weathering and nutrient balances (Schneider et al. 2013). In sandy soils or other clay minerals such as kaolinite, which have low cation exchange capacity, K is susceptible to leaching and the soil is at risk of losing considerable amounts of K (Ma et al. 2013). In such cases, K depletion in the soil could rapidly occur unless it is sustained by fertilizer or organic amendments (Ma et al. 2013).

2.9 Nitrogen availability in the soil

Nitrogen is the most abundant gas in the atmosphere, however it has to be readily available for plants in order for them to use it. Most plants take up N in the form of nitrate and ammonium. Nitrogen availability can be summarised by its cycle, as illustrated in Figure 2.3 (Brady and Weil 2008). Briefly, nitrogen can be added to the soil in an organic form from plant or animal remains or animal excreta. N can also be fixed by nitrogen fixing bacteria in certain plants. Organic forms are then mineralised into inorganic forms, first as ammonium, whereafter nitrification occurs, which leads to nitrate formation.

The main source of inorganic forms of nitrogen is synthetic N fertilizers. N can undergo transformation processes, which in the end could lead to either leaching or volatilisation. Volatilised nitrogen could be brought back into the soil, either by plants fixing it or synthetic fertilizers. The inorganic N forms can be leached out of the root zone and pollute groundwater aquifers in the form of nitrate. The maximum safe limit of nitrate in drinking water is 10 mg L^{-1} (WHO 1985). The process of denitrification leads to release of nitrite and nitrous oxide into the atmosphere. Ammonia can be synthesised and then applied as fertiliser and part of it can volatilize back into the atmosphere.

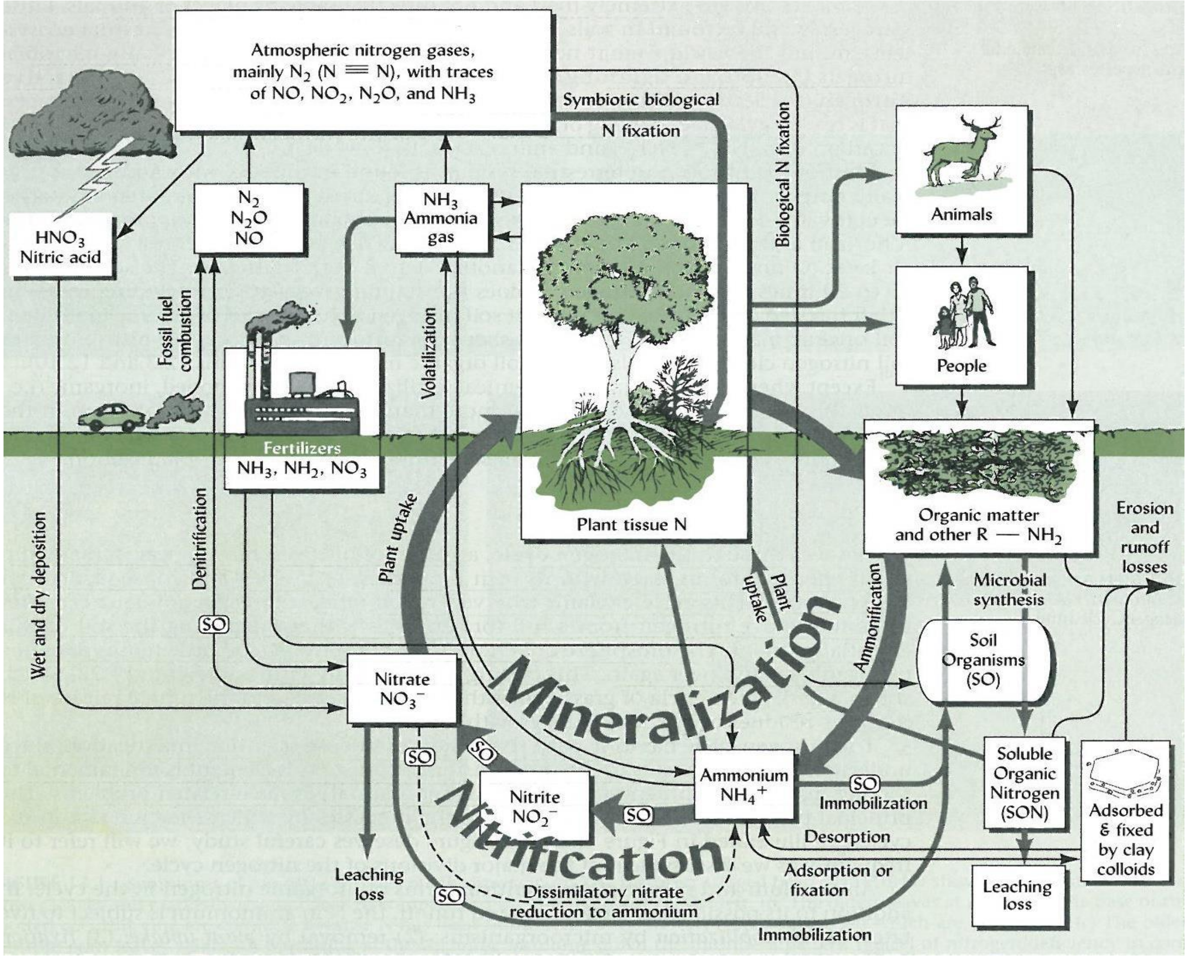


Figure 2.3: Nitrogen cycle in order to describe the interrelationship of the various forms and processes of N in the soil (Brady & Weil, 2008).

CHAPTER 3

POT TRIAL TO STUDY THE EFFECTS OF NITROGEN AND POTASSIUM LEVELS ON POTATO CROP GROWTH, TUBER YIELD AND QUALITY

3.1 Materials and methods

3.1.1 Experimental site

A pot trial was conducted at the University of Pretoria's experimental farm inside a glasshouse in Pretoria, South Africa.

3.1.2 Soil preparation, experimental design and data collection

The pot trial was conducted from 28 October 2015 to 10 March 2016. Topsoil was collected from the University's experimental farm, air dried, and sieved through a 2 mm sieve. Pots were then provided with 10 kg (7 litres) of air-dried soil each. The height of pots used was 25 cm and they had a cylindrical shape, with bottom diameter of 20 cm and top diameter of 24 cm. The trial was conducted using soil having a CEC of 3.104 $cmol.kg^{-1}$ and K percentage of the cation exchange capacity (CEC) was 5.4%. Sand, silt and clay contents were 75, 10 and 15% respectively. Organic matter content was 0.45% and soil pH (H_2O) was 5.9. Nutrient status and CEC of the soil used are shown in Table 3.1. Each plastic pot was provided with one sprouted minituber of about 20 g per pot (certified minitubers were used), which were planted at 10 cm depth.

The factorial experiment was laid out in a completely randomized design. Two cultivars, Innovator and Lanorma, were evaluated at sixteen N x K treatment combinations (per cultivar) of four N levels (180, 230, 280 and 330 $kg.ha^{-1}$) and four K levels (160, 230, 300 and 370 $kg.ha^{-1}$) at constant P dose (70 $kg.ha^{-1}$). These nutrient rates relate to 1, 1.44, 1.88 and 2.3 g $K.pot^{-1}$ and 1.13, 1.44, 1.75 and 2.06 g $N.pot^{-1}$, (working on a 10 cm soil layer depth) (Table 3.2) and assuming a soil bulk density of 1500 kg m^{-3}. Each treatment was replicated eight times, and therefore, there were a total of 128 plants per cultivar, which gave a total of 256 experimental units (pots). The sources for N were ammonium nitrate (NH_4NO_3,) potassium nitrate (KNO_3), calcium nitrate ($Ca(NO_3)_2$), sodium nitrate (NaNO3) and magnesium nitrate ($Mg(NO_3)_2.6H_2O$), while the K sources were potassium nitrate (KNO_3,) potassium sulphate (K_2SO_4) and monopotassium phosphate (KH_2PO_4). Monopotassium phosphate and calcium dihydrogen phosphate ($Ca(H_2PO_4)_2$) were used as P sources. Magnesium sulphate and calcium sulphate were used to balance the elements. Table A.1 in Appendix A shows the exact amount of chemicals applied per pot. The mentioned N and K levels gave N:K ratios ranging from 0.6:1 to 2.06:1 (Table 3.2).. These ratios were expressed as the amount of N ($kg.ha^{-1}$) divided by the amount of K ($kg.ha^{-1}$). Pots were placed on rotating tables (Figure 3.1) and all nutrients were applied in solution at once after planting. Thereafter, plants were watered manually every other day. Final emergence percentage for Larnoma was 83% and for Innovator it was 100%.

Table 3.1: Nutrient status of soil from the Hatfield Experimental farm used for the pot trial.

Nutrients	$mg.kg^{-1}$	$cmol.kg^{-1}$	% of CEC
NO_3^-	4.33	-	-
NH_4^+	2.80	-	-
P	28.4	-	-
K	65.2	0.1672	5.4
Ca	405.5	2.0273	65.3
Na	1	0.0043	0.1
Mg	108.7	0.9059	29.2
Total CEC		3.1048	

Table 3.2: Fertiliser treatment combinations and N:K ratios for each treatment

Treatment	N (kg ha^{-1})	N (g pot^{-1})	K (kg ha^{-1})	K (g pot^{-1})	N:K ratio
T1	180	1.13	160	1	1.125
T2	230	1.44	160	1	1.44
T3	280	1.75	160	1	1.75
T4	330	2.06	160	1	2.06
T5	180	1.13	230	1.44	0.78
T6	230	1.44	230	1.44	1
T7	280	1.75	230	1.44	1.22
T8	330	2.06	230	1.44	1.43
T9	180	1.13	300	1.88	0.6
T10	230	1.44	300	1.88	0.77
T11	280	1.75	300	1.88	0.93
T12	330	2.06	300	1.88	1.1
T13	180	1.13	370	2.3	0.49
T14	230	1.44	370	2.3	0.62
T15	280	1.75	370	2.3	0.76
T16	330	2.06	370	2.3	0.89

At 30 days after emergence (DAE), three plants were harvested from each treatment. The average plant height, stem mass, leaf mass, and total tuber mass, as well as tuber number per pot, were measured. Leaf nutrient analyses were also conducted, and the procedure was as follows: the 4th and 5th leaves from the top of the plant were collected, washed and rinsed three times with distilled water. The leaves were then placed inside paper bags and oven dried at 70^{o}C for 48 hours. The dried leaves were ground and a sub-sample of 0.3 g was taken from each sample. Then 10 ml of nitric acid (100%) was added to each 0.3 g sample for digestion inside a digestion chamber. After digestion, the solution was placed in test tubes and filtered before analysis. An ICP system was used to read the concentrations of K, Mg, Ca, P and S. At final harvest, yield, SG and tuber number data were collected. SG was done according to the underwater weighing method as illustrated in Equation 3.1 (USDA, 1997). All data were subjected to analysis of variance, followed by the least significant difference (LSD ≤ 0.05) test to separate means for significance, using SAS for Windows (2002).

$$\text{Specific gravity} = \frac{mass\ on\ air}{mass\ on\ air - mass\ in\ water} \qquad \text{Equation 3.1}$$

3.1.3 Cultural practices and general observations during the growing period

Infestation of aphids and red spider mites were detected early and treated with Ripcord (active ingredient cypermethrin). Biweekly alternating spraying of Virikop (copper oxychloride as active ingredient) and Dithane 750 WG Neotec (mancozeb as active ingredient) was applied to plants throughout the season to control blight. It was observed that Innovator started senescence two weeks before Lanorma. There were a few incidences of Innovator tubers appearing above the soil surface, which did not occur for Lanorma. During harvest, Innovator tubers were generally located near the soil surface, while Lanorma tubers were found deeper in the pots.

Figure 3.1: Potted plants on rotating tables in the glasshouse

3.2 Results

3.2.1 Mid-season growth results

At 30 DAE, across treatments, Lanorma plants were taller than Innovator plants. However, Innovator had more stems, ranging from 1 to 4 per pot, while Lanorma had 1 to 3 stems per pot. K seemed to have an influence on plant height, since plant height increased as K was increased from 160 kg ha^{-1} to 230 kg ha^{-1}, irrespective of N level (Figure 3.2a). There was no clear trend in dry leaf and stem mass among fertilizer treatments. However, Lanorma had greater dry leaf and stem masses than Innovator (Figure 3.2b). On the other hand, Innovator had greater total dry tuber mass yield than Lanorma (Figure 3.2c). Within a specific K treatment, yields tended to increase with increase in N, but the trend was not consistent, although significant differences occurred. Surprisingly, Lanorma did not initiate any tubers at the highest level of K (370 kg ha^{-1}) across the three highest levels of N (230 – 330 kg ha^{-1} N). Furthermore, these particular treatments exhibited quite long stolons, compared to the other treatments (Figure 3.3).

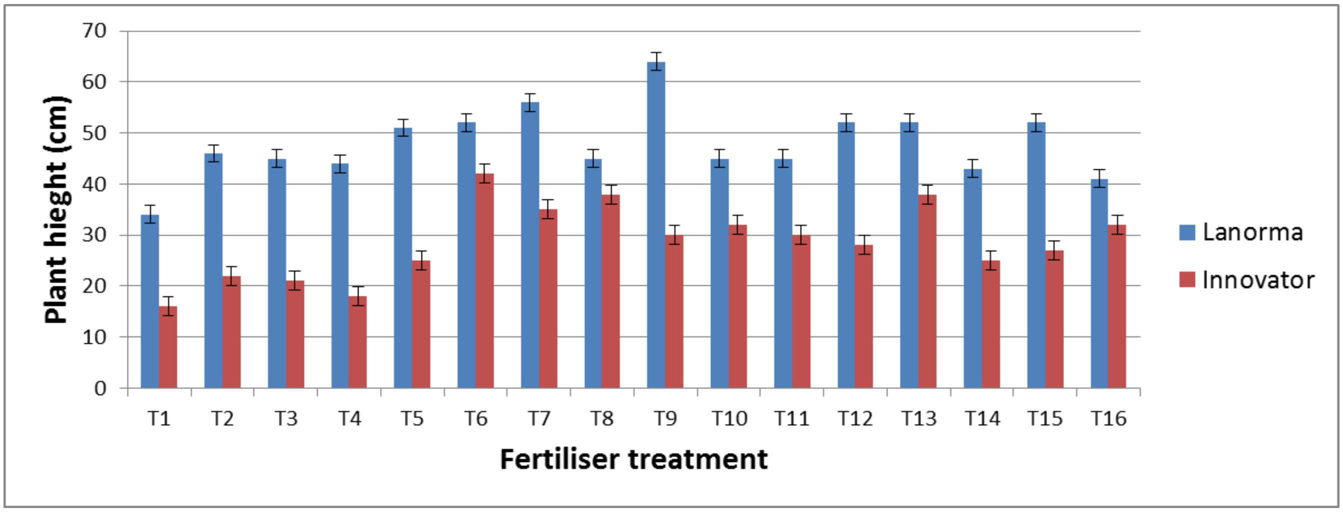


Figure 3.2a: Plant height per cultivar per fertiliser treatment. Vertical bars represent maximum and minimum standard errors

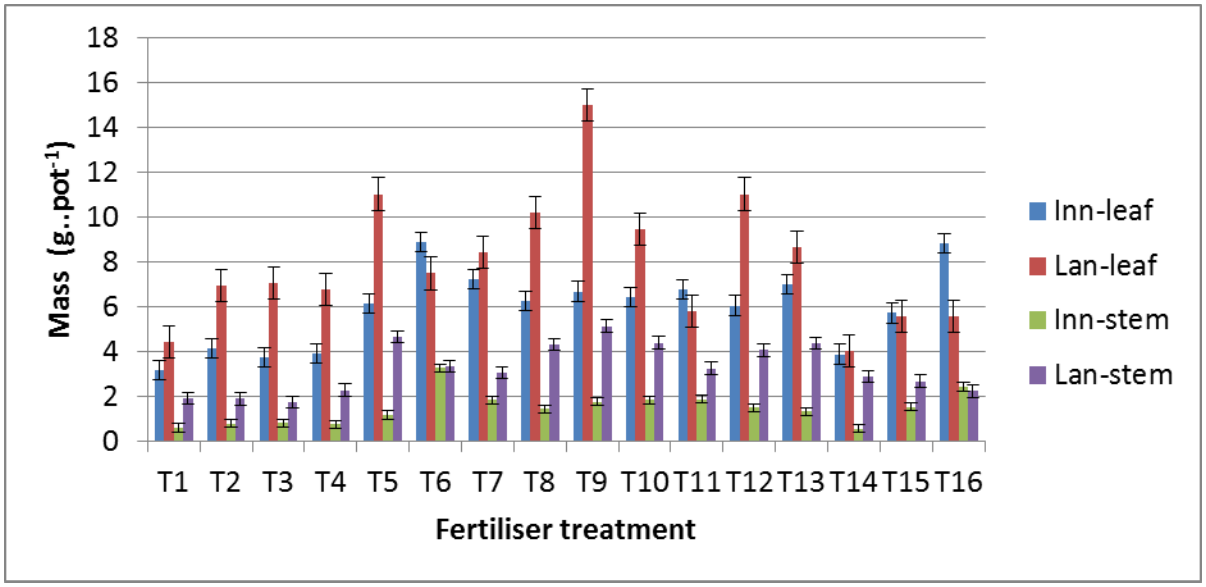


Figure 3.2b: Dry stem and leaf mass per cultivar per fertiliser treatment. Vertical bars represent maximum and minimum standard errors

**Inn-leaf = Innovator leaf, Lan-leaf = Lanorma leaf, Inn-stem = Innovator stem, Lan-stem = Lanorma stem*

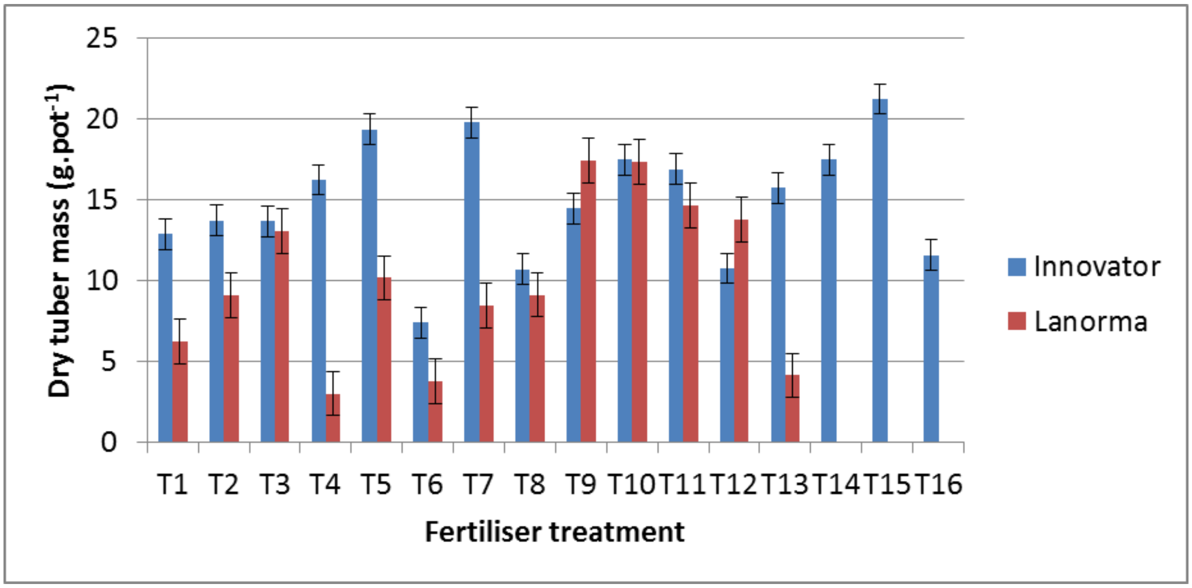


Figure 3.2c: Dry tuber mass for Innovator and Lanorma per fertilizer treatment. Vertical bars represent maximum and minimum standard errors

Figure 3.3: Lanorma had long stolons at highest K level (left) and shorter stolons at optimal K level (right)

3.2.2 Leaf analysis results

The leaf K content data for Lanorma and Innovator are illustrated in Figure 3.4a. Generally, Lanorma leaves had higher K content than Innovator. However, these values were exceptionally lower than optimal K levels of 50000 mg kg^{-1} (5%) at 30 DAE, as suggested by Sharma and Arora (1989). The content of other nutrients (Ca, Mg, P and S) in the leaves of Lanorma and Innovator are illustrated in Figures 3.4b and 3.4c, respectively. Calcium content was higher than other elements, followed by magnesium. However, these elements did not show a clear trend across fertilizer treatments. The S content was almost similar across treatments for both cultivars. On the other hand, P content was lower at lowest K level, while other treatments had higher P contents.

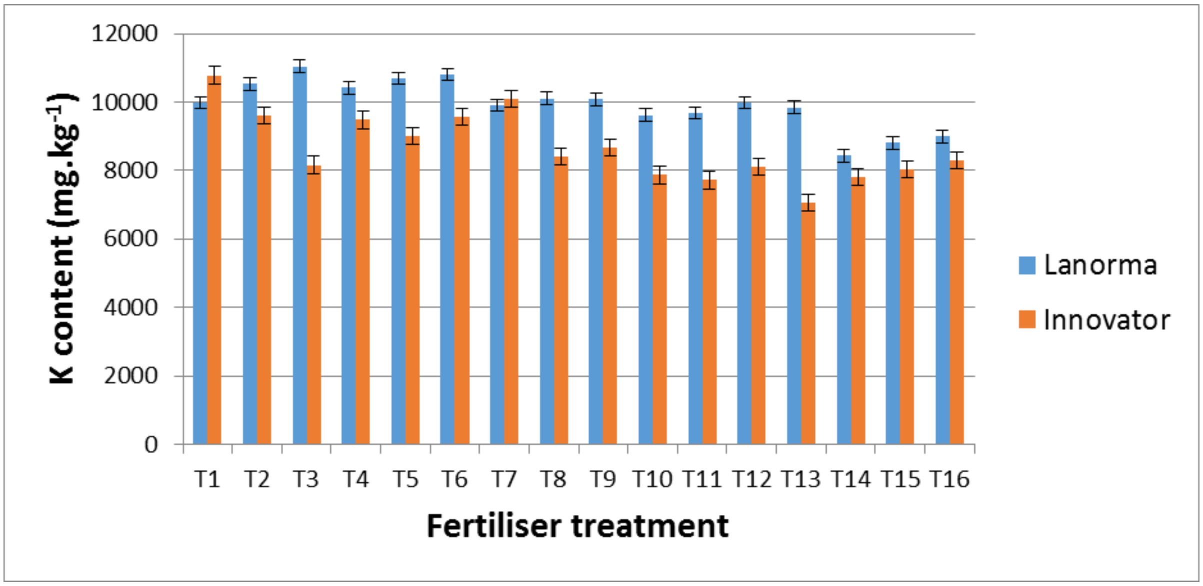


Figure 3.4a: K content in the leaves of Innovator and Lanorma. Vertical bars represent maximum and minimum standard error

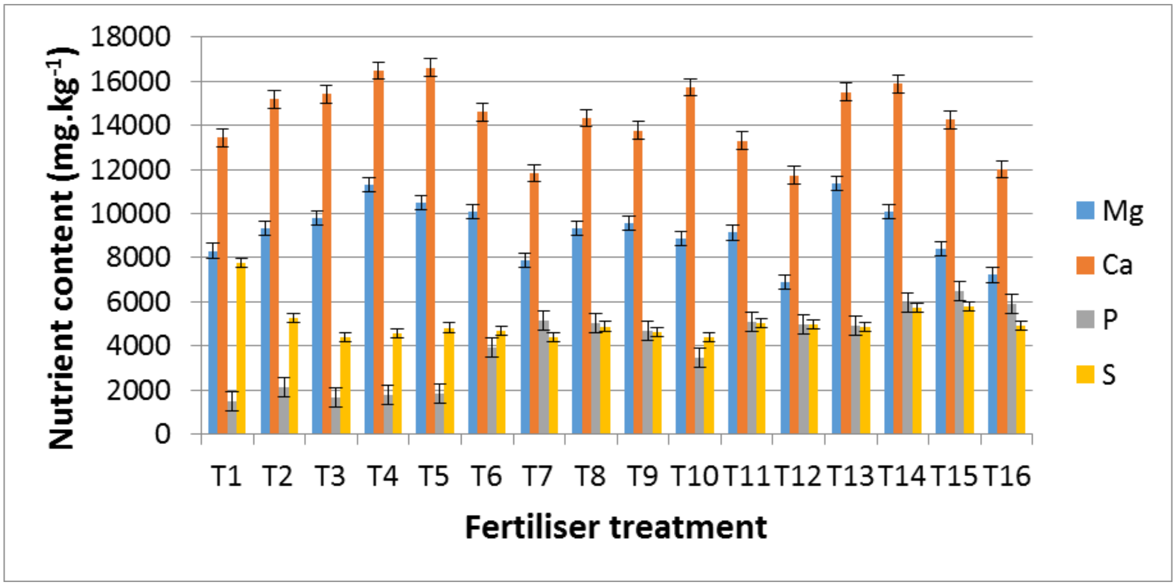


Figure 3.4b: Nutrient contents in the leaves of Lanorma. Vertical bars represent maximum and minimum standard errors

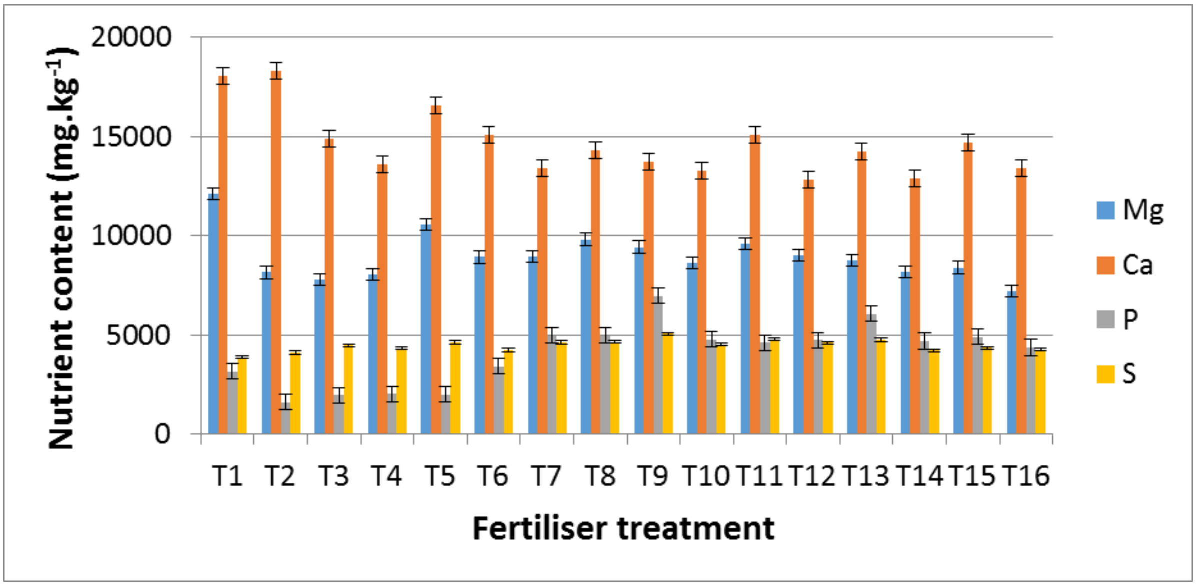


Figure 3.4c: Nutrient contents in the leaves of Innovator. Vertical bars represent maximum and minimum standard errors

3.2.3 Final harvest results

At final harvest, treatments varied in yield and SG per cultivar (Table 3.3). The summary of ANOVA tables for yield and SG are documented in Appendix A, Tables A.2 and A.3 for cultivars Innovator and Lanorma respectively. Tuber yields ranged between 300 and 450 g.pot^{-1}. (average of 356.8 g.pot^{-1}), which compare well with yields of around 300 g.pot $^{-1}$ reported by Wang et al. (2016) for a similar pot trial under sufficient N level. Lower yield was observed at the lowest K level (T1, T2, T3 and T4) across all four levels of N.

Table 3.3: Final tuber yield (g pot^{-1}) and SG per fertiliser treatment per cultivar

			Innovator		Lanorma	
Treatment	N:K level (kg.ha^{-1})	N:K ratio	Yield	SG	Yield	SG
T1	180N:160K	1.125	216.6h	1.078ba	262.3egf	1.067bdc
T2	230N:160K	1.44	173.7i	1.078ba	216.7hg	1.062gfe
T3	280N:160K	1.75	242.3h	1.077ba	154.7h	1.060g
T4	330N:160K	2.06	231.7h	1.082a	311.7edf	1.061gf
T5	180N:230K	0.78	368.7f	1.079ba	328.3ed	1.062gfe
T6	230N:230K	1	441.0bdc	1.077ba	252.0gf	1.063gfed
T7	280N:230K	1.22	466.7ba	1.069c	451.3a	1.061gf
T8	330N:230K	1.43	387.7ef	1.076b	371.7bdc	1.060g
T9	180N:300K	0.6	306.3g	1.080ba	358.3dc	1.065fedc
T10	230N:300K	0.77	451.1bac	1.079ba	420.3bac	1.072a
T11	280N:300K	0.93	473.7ba	1.079ba	472a	1.068bac
T12	330N:300K	1.1	477.0a	1.079ba	425.0bac	1.067bedc
T13	180N:370K	0.49	384.7ef	1.080ba	223.0hg	1.064gfedc
T14	230N:370K	0.62	415.7ed	1.082a	414.3bac	1.068bac
T15	280N:370K	0.76	419.0edc	1.081a	440.7ba	1.071ba
T16	330N:370K	0.89	398.0ef	1.081a	461.3a	1.07ba
LSD			35.34	0.0055	76.28	0.0047
CV			5.81	0.31	13.19	0.27

** Values followed by the same letter in their respective columns are not significantly different from each other at $p \leq 0.05$*

Lower yield was also associated with lowest level of N (180 kg.ha^{-1}) and yields tended to respond to specific N:K ratios, with ratios between 0.6 and 1.22 generally giving better yields. Average tuber mass across treatments ranged between 90 – 100 g.

Table 3.4 shows average values for yield, SG and tuber number per cultivar across fertilizer treatments (ANOVA summary in Appendix A). Cultivar Innovator significantly surpassed Lanorma in yield and SG, while Lanorma outcompeted Innovator in tuber numbers. The average SG for Innovator was 1.079 and that of Lanorma was 1.065. According to Somsen et al. (2004), SG values of 1.075 and above are suitable for processing chips and therefore the tubers of Innovator, which is a recognised French fry processing cultivar, were suitable for processing, while Lanorma tubers were more suitable for table consumption. Tuber mass loss over time was similar across fertilizer treatments for both cultivars (Figure 3.5).

Table 3.4: Average yield, SG and tuber number per cultivar (means across treatments)

Cultivar	Yield	SG	Tuber number
Innovator	365.9a	1.079a	7.6b
Lanorma	347.7b	1.065b	9.8a
LSD	14.6	0.0013	0.35
CV	10.2	0.287	9.9

** Values followed by the same letter in the respective columns are not significantly different from each other at $p \leq 0.05$*

These results contradict what had been documented by Camire (2009), who stated that cultivars which senesce earlier would have lower yield, compared to the ones which senesce later. This higher yield for cultivar Innovator, although it senesced quite earlier than Lanorma, may suggest that Innovator had a rapid uptake of nutrients early in the season, which benefitted growth and tuber yield. Maltas et al. (2018) observed a substantial variation in N uptake earlier in the season between two cultivars. Growers have reported that Lanorma respond less to N fertilizer applications than other cultivars, which may have resulted in delayed response to higher N levels (personal communication Mr G Bester, 2019). Lanorma yield also could have been thwarted by the fact that nutrients were applied all at once at planting. Later maturing cultivars are known to benefit more when N application is split (Tiemens-Hulscher et al. 2014). This suggests that Lanorma may have performed better if N application was split over the growing season.

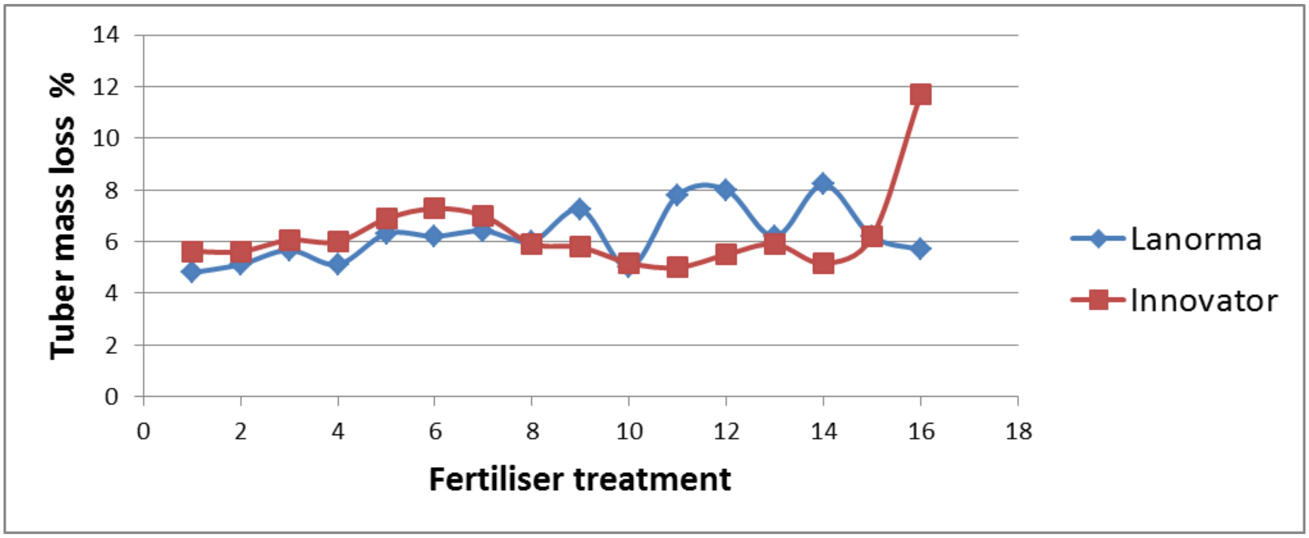


Figure 3.5: Tuber mass loss (percentage) after 8 weeks of storage at a room temperature of 18^{0}C

3.2.4 Interaction effect of N and K on tuber yield and SG

In order to assess if there was any interaction effect of nutrient combination on yield and SG, data was presented graphically (Figures 3.6 and 3.7) to facilitate better visual comparison. There seems to be a tendency of better yield associated with N:K ratios ranging from 0.62 to 1.22, provided that none of the two nutrients are insufficient. In most cases, treatments with such N:K ratios had significantly higher yields than treatments with ratios outside of that range. According to Table 3.3, highest yield for cultivar Innovator was at levels of 330 kg.ha^{-1} N and 300 kg.ha^{-1} K, which had a N:K ratio of 1.1. The second highest yield for Innovator was at 280 kg.ha^{-1} N and 300 kg.ha^{-1} K, with a corresponding N:K ratio of 0.93. Lower yields for cultivar Innovator were obtained at N:K ratios lower than 0.62 and higher than 1.22, except when one of the two elements were critically limiting (180 kg.ha^{-1} N or 160 kg.ha^{-1} K). Cultivar Lanorma yields followed a similar pattern, such that the treatment combination of 280 kg.ha^{-1} N and 300 kg.ha^{-1} K (0.93 N:K ratio) gave the highest yield, while ratios below 0.6 and above 1.2 generally gave lower yields.

The interaction effect between N and K on yield and SG were generally significant for both cultivars. For convenience sake, Figures 3.6a and 3.6b graphically display the yield results for Innovator and Lanorma, respectively. The interaction seemed to be mainly influenced by the N:K ratio, as observed earlier. Best yields for Innovator were obtained with moderate amounts of both N and K (230 - 280 kg.ha^{-1}; N:K ratio around 1). Lanorma gave best yields at 230 kg.ha^{-1} N and 300 kg.ha^{-1} K (N:K ratio 0.77). This yield was not significantly lower than the highest yield obtained. The treatment combination of 230 kg.ha^{-1} of both N and K did not result in better yield for Lanorma; probably lower yield for this treatment was due to poor emergence encountered with this specific treatment. Apart from the interactions, yields of both cultivars proved to be significantly influenced by both N and K level. Highest K level seemed to have substantially suppressed yields, as compared to the second and third highest K levels.

There was a statistically significant interaction effect of N and K level on SG for both cultivars. There seemed to be a tendency of higher SG values for both cultivars in relation to specific N:K ratios. With the exception of Innovator at 330 kg.ha^{-1} N and 160 kg.ha^{-1} (N:K ratio of 2.06), N:K ratios ranging from 0.49 to 0.93 gave substantially higher, and in some cases significantly higher SG values. Figures 3.7a and 3.7b graphically illustrate the SG values per treatment combination for cultivars Innovator and Lanorma, respectively. According to Table 3.3, N:K ratios of 1 or higher resulted in lower SG values for Innovator. This trend tended to be more conspicuous for Lanorma, although the range seemed to be narrower. N:K ratios ranging between 0.62 to 0.93 proved to give substantially (mostly significantly) higher SG values than N:K ratios ranging between 1 to 1.22. All treatments with N:K ratios ranging from 1.43 to 2.06 thus proved to have significantly lower SGs than treatments with N:K ratios between 0.62 to 0.93.

With respect to Innovator, the findings for this study are different from those of Zebarth et al. (2004), who observed a consistent decrease in specific gravity with an increase in N application. However, this proved to be true for Lanorma in some cases. The results of this study are partially in agreement with the observations of Al-Moshileh and Errebi (2004), who reported that SG generally increases with an increase in K fertiliser application. However, it contradicts the findings of Westermann et al. (1994), who reported a decrease in SG with increase in K application. The main factor that influenced SG in the study proved to be the N:K ratio.

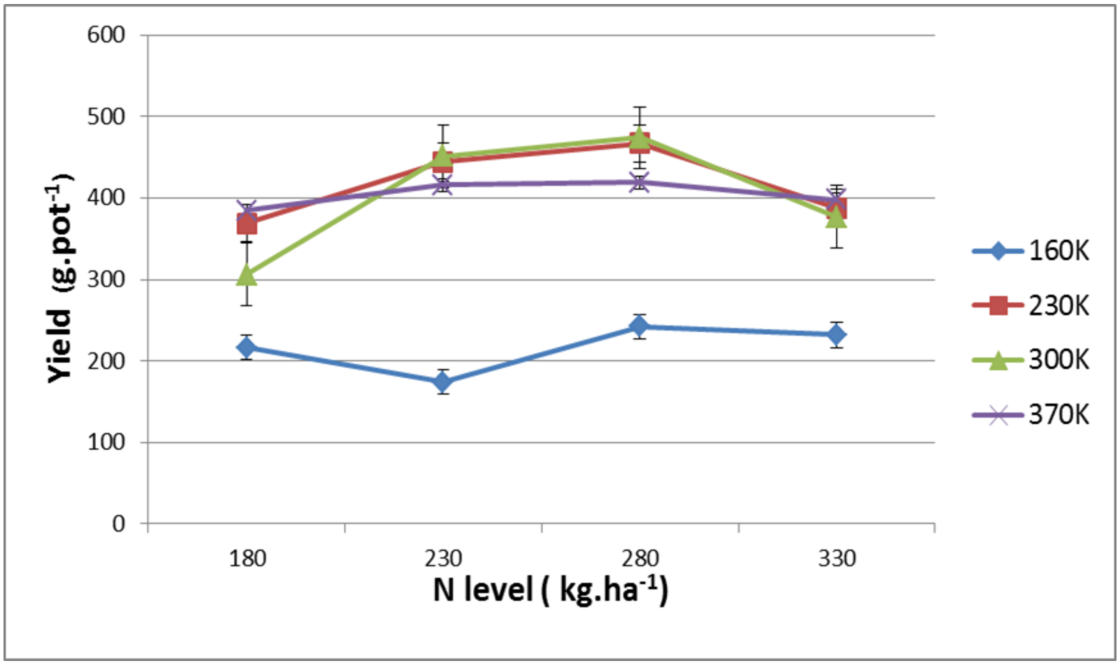


Figure 3.6a: Interaction effect of N and K on tuber yield for cultivar Innovator. Vertical bars represent maximum and minimum standard errors

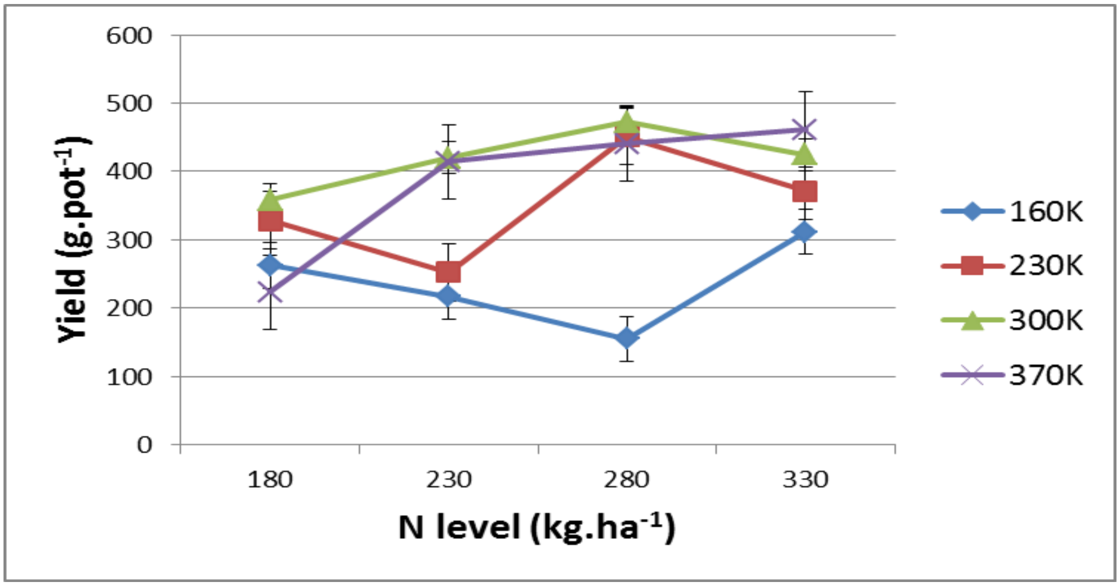


Figure 3.6b: Interaction effect of N and K on tuber yield for cultivar Lanorma. Vertical bars represent maximum and minimum standard errors

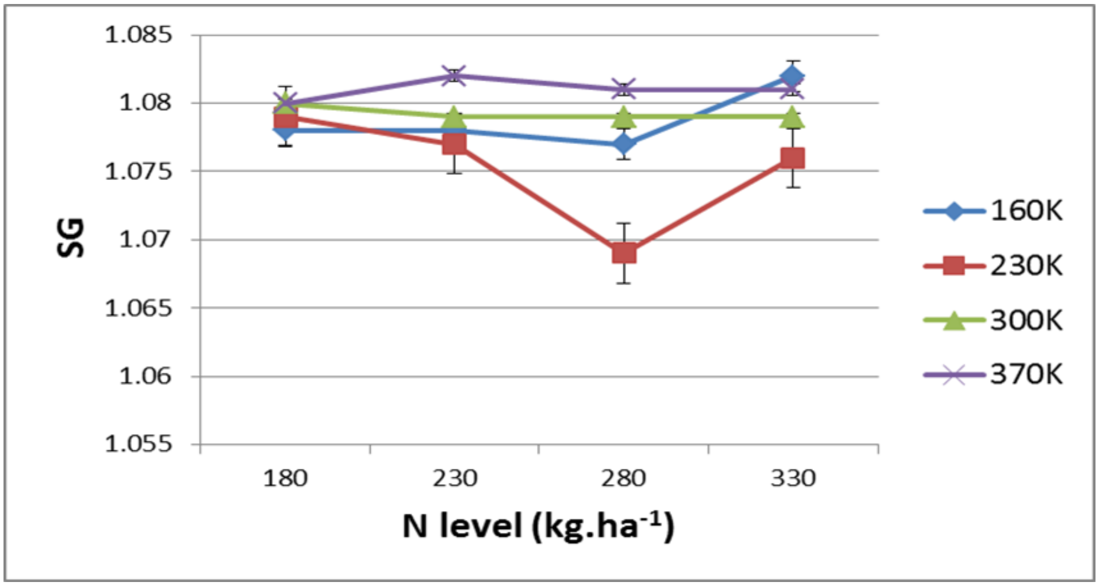


Figure 3.7a: Interaction effect of N and K on tuber SG for cultivar Innovator. Vertical bars represent maximum and minimum standard errors

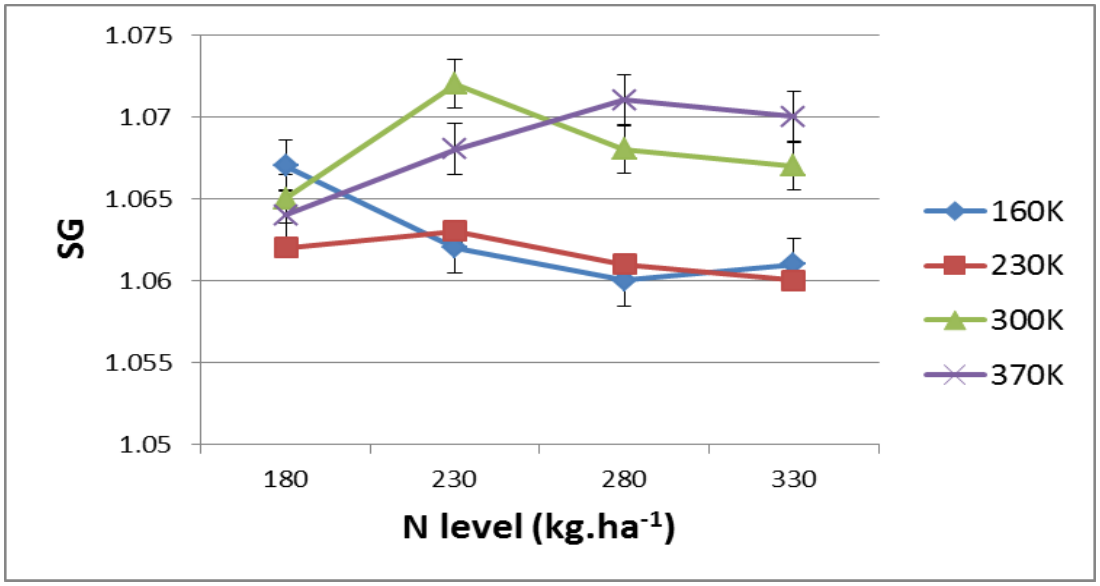


Figure 3.7b: Interaction effect of N and K on tuber SG for cultivar Lanorma. Vertical bars represent maximum and minimum standard errors

3.3 Summary and conclusions

Low levels of K (160 kg.ha^{-1}) for this particular soil resulted in retarded growth and lower tuber yields and therefore higher levels of K are needed to increase yield. The N:K fertilizer ratio proved to play a major role for both cultivars in terms of both yield and SG, provided none of the two nutrients were insufficient (<180 kg.ha^{-1}). If yield is prioritised over SG, a treatment combination of 230 kg.ha^{-1} N and K (N:K ratio of 1) were the best for cultivar Innovator. At this ratio, better yields were achieved with lower levels of both nutrients. For cultivar Lanorma, better yields were attained at 280 kg.ha^{-1} N and 300 kg.ha^{-1} K (N:K ratio 0.93), which confirms the observation by growers that this cultivar tend to be less responsive to N fertilizer applications.

If higher values of SG are desired for both cultivars, then N:K ratios should be slightly lower than one. A combination of 230 kg.ha^{-1} N and 300 kg.ha^{-1} K (N:K ratio 0.93) for both cultivars resulted in better SG and yield, with lower level of N. This combination should be better if not only N fertiliser costs are taken in to consideration, but also limiting potential N leaching into groundwater. It can be concluded that N:K ratios ranging from 0.66 to 1.22 give better yields compared to other ratios, while N:K ratios ranging from 0.76 to 0.93 give higher SG values than other ratios. The results of the present study confirm what has been reported by Zhang et al. (2010), namely that optimal potato yield and best tuber quality are attainable with appropriate N and K levels. When N:K ratio is not optimal, N and K imbalances often occur, which leads to competition for uptake, sub-optimal growth and yield (Xie et al. 2000; Wells and Wood 2007). These results also support the findings of Zhang et al. (2010), who reported that tuber quality is influenced by ratio of N:K .

CHAPTER 4

FIELD TRIAL: POTATO GROWTH RESPONSE TO NITROGEN AND POTASSIUM FERTILIZER LEVELS

4.1 Introduction

Although a pot trial is a convenient way of conducting a multiple of treatments, it also has some shortfalls due to limited soil and confinement of the roots associated with it. It is important to confirm the results obtained from a pot trial with a field trial where root growth is not confined. In this regard, a field trial was conducted with the aim of confirming the pot trial results. Parameters such as light interception, which could not be efficiently measured in a pot trial, were also measured in the field trial to compare the two cultivars (Innovator and Lanorma).

According to Geremew et al. (2007) dry matter partitioning between plant organs varies among potato cultivars and across different growth stages. Based on growth, development and dry matter (DM) partitioning, potato cultivars can be categorized into three groups according to Spitters (1987). For the first category, tuber filling commences only later in the growing season and there is a gradual increase in harvest index (HI) during that time. There is also a continuous partitioning of assimilates to new leaves and stem growth during the growing season. The second category is characterized by rapid tuber filling and hence an exponential increase in HI caused by mass exodus of assimilates to the tubers. In the third category, tuber filling starts early but DM partitioning to tubers and haulms occurs concurrently and therefore the rate of increase in HI is slower.

Knowledge of the growth pattern of cultivars can help in management decision making, such as fertilizer application. For example, N will not be effectively utilized when it is applied later in the season for an early maturing cultivar, since the crop would senesce quickly and leave more N in the soil for leaching. On the other hand, a late maturing cultivar would still utilize N that is applied later in the season due to a longer growing season. N management can also influence the harvest index (HI). High levels of N may result in lower harvest index (HI) in some cultivars, that is, more dry matter is partitioned to shoots at the expense of tubers (Millard and Marshall 1986; HU et al. 2014).

Like other crops, potato growth is related to the proportion of photosynthetically active radiation (IPAR) intercepted by the canopy, which is dependent upon the total leaf area, leaf area duration and the efficiency with which IPAR is converted into dry matter (Nyende et al. 2005). It then follows that potato yield is related to IPAR (Tarkalson et al. 2012) and across different environments, many research studies have documented that total potato tuber dry matter production is directly proportional to cumulative IPAR (Haverkort and Harris1986; Fahem and Haverkort 1988; Jefferies and MacKerron 1989; Boyd et al. 2002). IPAR could be measured using leaf area and canopy cover measurements (Singh et al. 1993). Since ground cover does not consider canopy density, it cannot be used to calculate IPAR as accurately as LAI (Firman and Allen 1989). At 100% canopy cover LAI varies with IPAR, depending on canopy density and therefore LAI is considered to be more accurate to calculate IPAR (Boyd et al. 2002).

Cultivars vary in maximum IPAR, as shown by the study conducted by Nyende et al. (2005) on two cultivars, namely Désirée and Tomensa. In their study, it was observed that the two cultivars varied such that maximum IPAR for Désirée was lower than that of Tomensa. Maximum IPAR for Désirée was 92.5% and for Tomensa it was 96.5% (Nyende et al. 2005). Of all nutrients, N is the most influential nutrient on IPAR. In the potato plant, leaf expansion rate and leaf number per plant are affected by nitrogen supply (Vos and Van der Putten 1998), and these two factors in turn affect radiation interception and production of a crop (Vos 1995). It follows, therefore, that N deficiency leads to a reduction in leaf expansion rate and leaf size, which in turn leads to the reduction in carbon accumulation (Hu et al. 2014). According to Vos and Van der Putten (1998), nitrogen deficiency will also lead to a shortfall of potential number of leaves per plant, restricted potential leaf area, as well as reduced levels of nitrogen in plant organs, which ultimately will limit plant growth. N deficiency therefore leads to inefficient use of intercepted radiation to produce dry matter or a reduction in intercepted radiation, or both, and this leads to reduction in biomass production (Muchow & Davis 1988) and tuber yield. Therefore, it is important to assess canopy cover under different N levels in order to determine the rate and the amount of IPAR which can then be used to estimate final yield or help in adjusting crop N requirement.

Intercepted photosynthetically active radiation is thus a major determinant of total dry matter production and biomass accumulation, and increases with an increase in canopy cover (Spitters 1987; Vos & Groenwold 1989; Van Delden 2001). Cultivars differ not only in maximum canopy cover, but also in rapidness of accumulating canopy cover; the earlier accumulation of canopy cover, the higher the IPAR earlier in the season. The area under the canopy cover progress curve (AUCCPC) can be used to predict yield, particularly where the growing season is long enough to allow natural senescence (Khan et al. 2013). A cultivar which would attain higher IPAR earlier than other cultivars could have early tuber growth and early tuber bulking than other cultivars, as this would be facilitated by early accumulation of foliage (Nyende et al. 2005). In this study, the growth and yield responses of two potato cultivars to different N and K treatment combinations were compared in a field trial to verify earlier findings obtained in the pot trial.

4.2 Material and Methods

4.2.1 Experimental design and layout

The number of treatments for the field trial was narrowed down to three levels of N and K each. Both N and K levels were set on 160, 230 and 300 kg ha^{-1} each, which was slightly different from the pot trial treatments. These treatments gave seven N:K level ratios. Ratios were expressed as the amount of N (kg.ha^{-1}) divided by the amount of K (kg.ha^{-1}). Table 4.1 illustrates the fertilizer treatments and the corresponding N:K ratios. A control treatment of 160 kg ha^{-1} N and 0 kg ha^{-1} K was added to evaluate the responsiveness of these cultivars to K application. The same two cultivars as in the pot trial, namely Innovator and Lanorma, were also used in this trial.

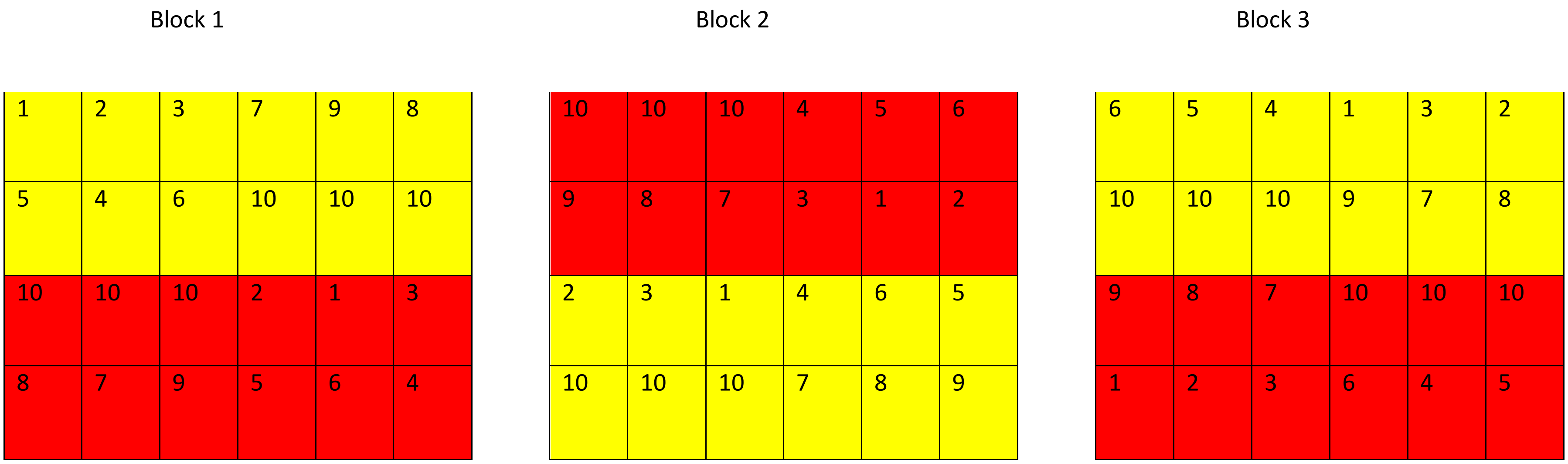
The experimental layout was a split-plot randomised complete block design (RCBD) with 20 treatment combinations and three blocks (replications). Cultivars were allocated to the main plots, while N x K treatment combinations were allocated to the sub-plots. Two available extra plots per replicate block were allocated to the additional control

(160N 0K; treatment 10) plots (Figure 4.1a). Each subplot consisted of four rows of 5 m length and the spacing between rows as well as between sub-plots was 1 m. Well-sprouted tubers were planted with a two-row Grimme^{TM} planter at a depth of 0.20 m and tubers were spaced 0.25 m apart within the row.

Single superphosphate (14%) was broadcasted at a rate of 70 kg.ha^{-1} and incorporated into the soil with a harrow disk prior to planting. N and K fertilizer dressings were split into two, with the first half applied at planting (on the rows), and the remainder at 14 days after emergence (DAE). The N source was limestone ammonium nitrate (LAN 28%) and the K source was potassium sulphate (K_2SO_4).

Table 4.1: Fertilizer treatment combinations and their corresponding N:K ratios

Treatment Number	N (kg.ha^{-1})	K (kg.ha^{-1})	N:K ratio
1	160	160	1
2	160	230	0.70
3	160	300	0.53
4	230	160	1.44
5	230	230	1
6	230	300	0.77
7	300	160	1.88
8	300	230	1.30
9	300	300	1
10	160	0	-



Block 1

🟨 1	🟨 2	🟨 3	🟨 7	🟨 9	🟨 8
🟨 5	🟨 4	🟨 6	🟨 10	🟨 10	🟨 10
🟥 10	🟥 10	🟥 10	🟥 2	🟥 1	🟥 3
🟥 8	🟥 7	🟥 9	🟥 5	🟥 6	🟥 4

Block 2

🟥 10	🟥 10	🟥 10	🟥 4	🟥 5	🟥 6
🟥 9	🟥 8	🟥 7	🟥 3	🟥 1	🟥 2
🟨 2	🟨 3	🟨 1	🟨 4	🟨 6	🟨 5
🟨 10	🟨 10	🟨 10	🟨 7	🟨 8	🟨 9

Block 3

🟨 6	🟨 5	🟨 4	🟨 1	🟨 3	🟨 2
🟨 10	🟨 10	🟨 10	🟨 9	🟨 7	🟨 8
🟥 9	🟥 8	🟥 7	🟥 10	🟥 10	🟥 10
🟥 1	🟥 2	🟥 3	🟥 6	🟥 4	🟥 5

Figure 4.1a: Field trial layout in a RCBD split-plot design for two cultivars. Yellow colour represents Lanorma and the red colour represents Innovator. Numbers represent the different fertilizer combinations (treatment number).

4.2.2 Growth analysis procedures

Destructive growth analyses were performed four times during the growing season. The following parameters were recorded: plant height, fresh and dry leaf mass, fresh and stem dry mass, as well as fresh and dry tuber mass. Four plants per replicate plot were sampled per harvest. Analysis of variance was performed and means were separated for these parameters. The destructive growth harvests were done on the following dates: 31 October 2016 (41 days after planting, DAP), 21 November 2016 (62 DAP), 12 December 2016 (83 DAP) and 2 January 2017(104 DAP). These harvest dates were also denoted as harvest 1, harvest 2, harvest 3 and harvest 4, respectively. Leaf nutrient content was determined during the third harvest (62 DAP), following the same procedure as explained in Chapter 3 (for the pot trial). Figure 4.1b shows the trial at the University of Pretoria experimental farm.

Figure 4.1b: View of one replication of the field trial at the University of Pretoria experimental farm, with cultivars Innovator (left) and Lanorma (right)

4.2.3 General observations and cultural practices

Both cultivars showed more than 50% emergence at 21 days after planting (DAP). During this time, Innovator had fully emerged (99%), while Lanorma showed 70%

emergence. Lanorma had fully emerged by 28 DAP (97%). From two weeks after plant emergence, a fungicide spray programme to control blight was applied, alternating products every two weeks until early January 2017. These fungicides were Virikop (copper oxychloride as active ingredient) and Dithane 750 WG Neotec (mancozeb a.i.). Irrigation was provided through sprinklers during the growing season and the total amount of irrigation plus rain for the entire growing season was 740 mm. The maximum and minimum temperature readings were recorded from the weather station at the farm throughout the growing season from the first day to 130 days after planting (DAP) (Figure 4.2). During the growing season, it was observed that Innovator flowered before Lanorma, and it also produced berries, which were more conspicuous with N increment. On the other hand, Lanorma had no berries across all treatments. At 8 weeks after emergence, Innovator started senescing, and this was more conspicuous at the two lower levels (160 and 230 kg ha^{-1}) of nitrogen. Treatments which received 300 N kg ha^{-1} started to senesce a week later.

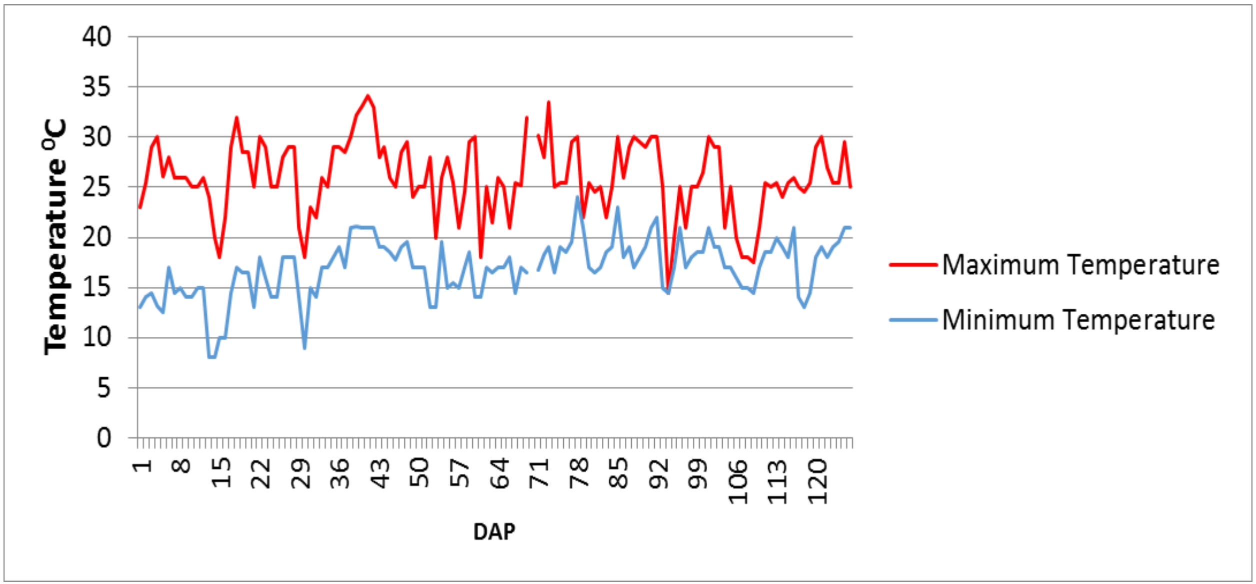


Figure 4.2: Maximum and minimum temperatures recorded throughout the growing season of the field trial.

4.2.4 Canopy cover measurement procedure

An AccuPAR LP-80 ceptometer was used to measure intercepted photosynthetically active radiation (IPAR), which served as an estimate for canopy cover. One reading per subplot was taken above the crop canopy, while six more readings were taken below the canopy at ground level. The IPAR measurements were conducted on a weekly basis on Mondays when the weather conditions were favourable, or measurements were taken the following day if that particular Monday was cloudy. IPAR was calculated as the difference between the incident radiation and the radiation transmitted through the canopy, expressed as a percentage of the incident radiation (Equation 4.1).

$$\mathrm{IPAR} = 100 - \left(\frac{\mathrm{PARbelow\ canopy}}{\mathrm{PARabove\ canopy}}\right)100 \qquad 4.1$$

4.3 Results and discussion

4.3.1 Plant height

At the first destructive harvest, plant height was not significantly different between the two cultivars across fertilizer treatments, although cultivar Lanorma plants tended to be slightly taller than cultivar Innovator. On average, cultivar Lanorma height was 49.4 cm, while cultivar Innovator was 46.2 cm. It was observed that as from the second harvest to the fourth harvest, cultivar Lanorma plants were significantly taller than those of cultivar Innovator (Table 4.2a). The summary of ANOVA for all destructive growth analyses are shown in Appendix C. The height for Innovator plants at harvest 4 was slightly shorter than on the two preceding harvest dates, which could be due to the fact that most cultivar Innovator treatments had senesced by then and some stems were broken due to that.

Graphical presentations of plant height per harvest per treatment are illustrated in Figures 4.3a - d. At first harvest, there was no clear trend in plant height with respect to N:K ratio or fertiliser combination (Figure 4.3a). As from the second harvest onwards, plant height tended to increase with increase in both nutrients. It can be clearly seen that cultivar Lanorma plants were consistently taller than cultivar Innovator plants. It is conspicuous from the graphs that at each level of N, plant height increased with an increase in K level for most treatments. It is also noteworthy that plant height increased with an increase in N level. It has been documented in literature that K increases plant height in potato crops (Pervez et al. 2013). Increase potato crop height with increase N, or with both N and K has been widely documented, including by authors like Shunka et al. (2017).

Table 4.2a: Plant height per cultivar at each harvest interval (means across fertilizer treatments)

Cultivar	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Lanorma	49.4a	78.8a	83.4a	87.2a
Innovator	46.2a	64.9b	65.5b	59.5b
LSD	Ns	2.4	2.9	4.0
CV	14.63	6.34	7.63	10.51

**Values followed by the same letter in their respective columns are not significantly different from each other at p ≤ 0.05*

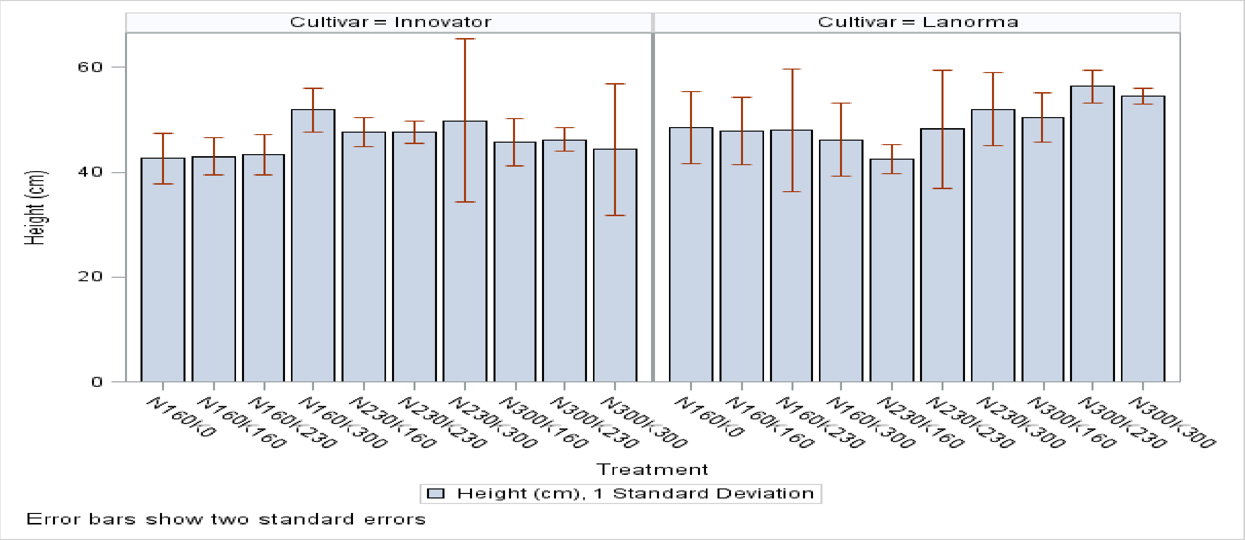


Figure 4.3a: Plant height per treatment and per cultivar at the first destructive harvest.

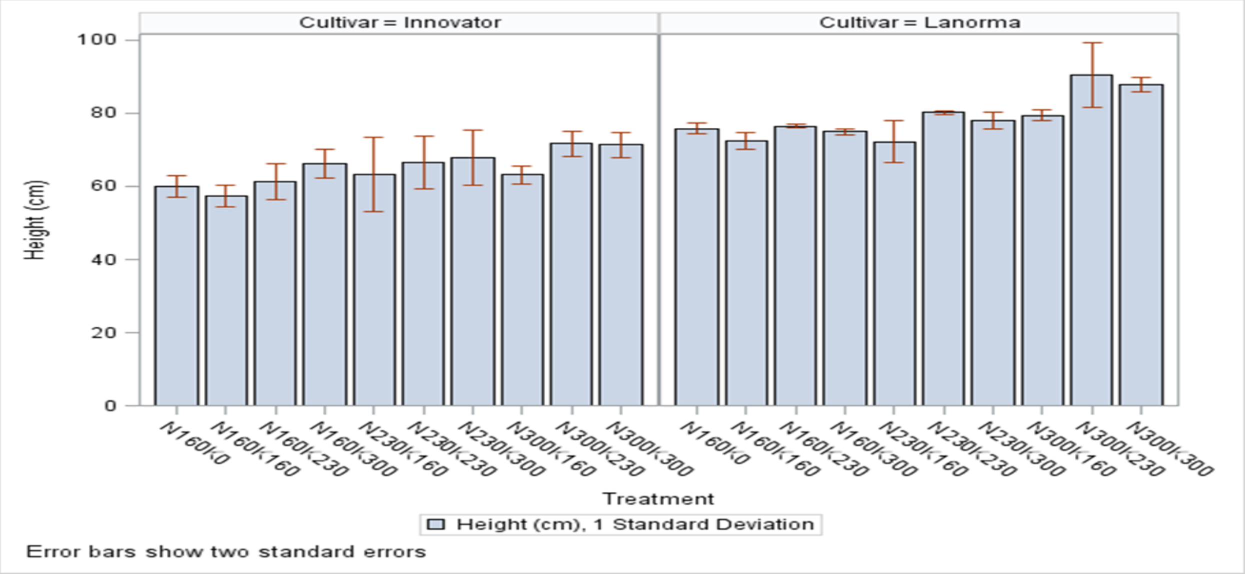


Figure 4.3b: Plant height per treatment and per cultivar at the second destructive harvest.

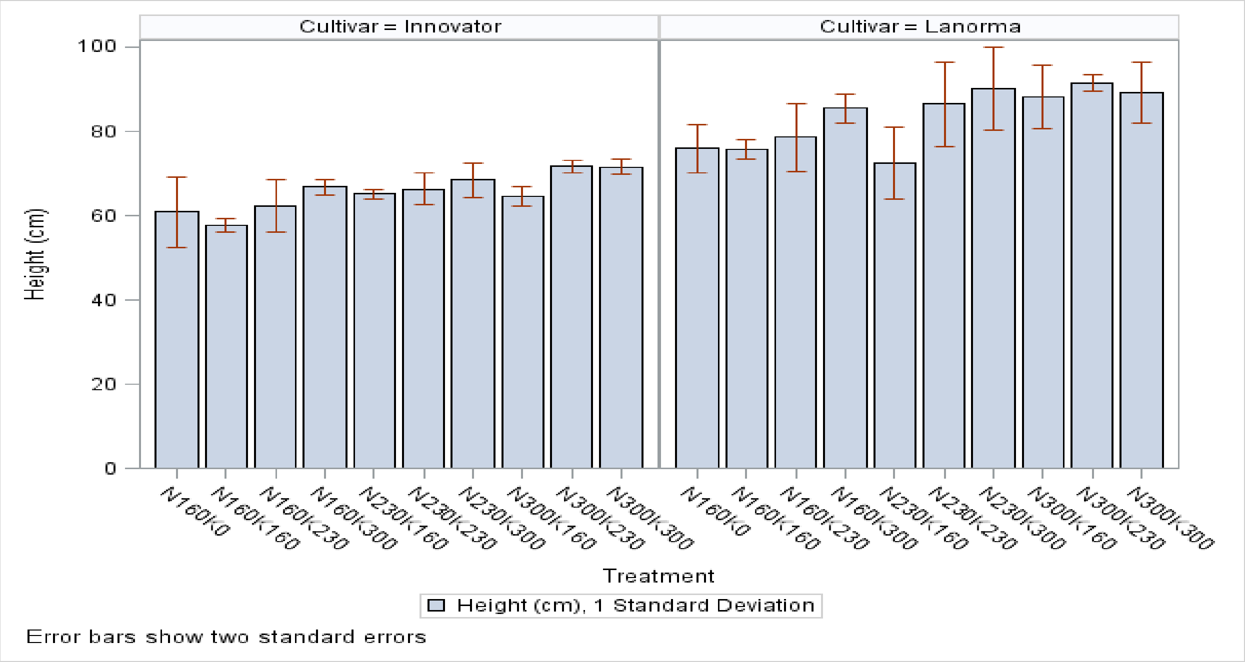


Figure 4.3c: Plant height per treatment and per cultivar at the third destructive harvest.

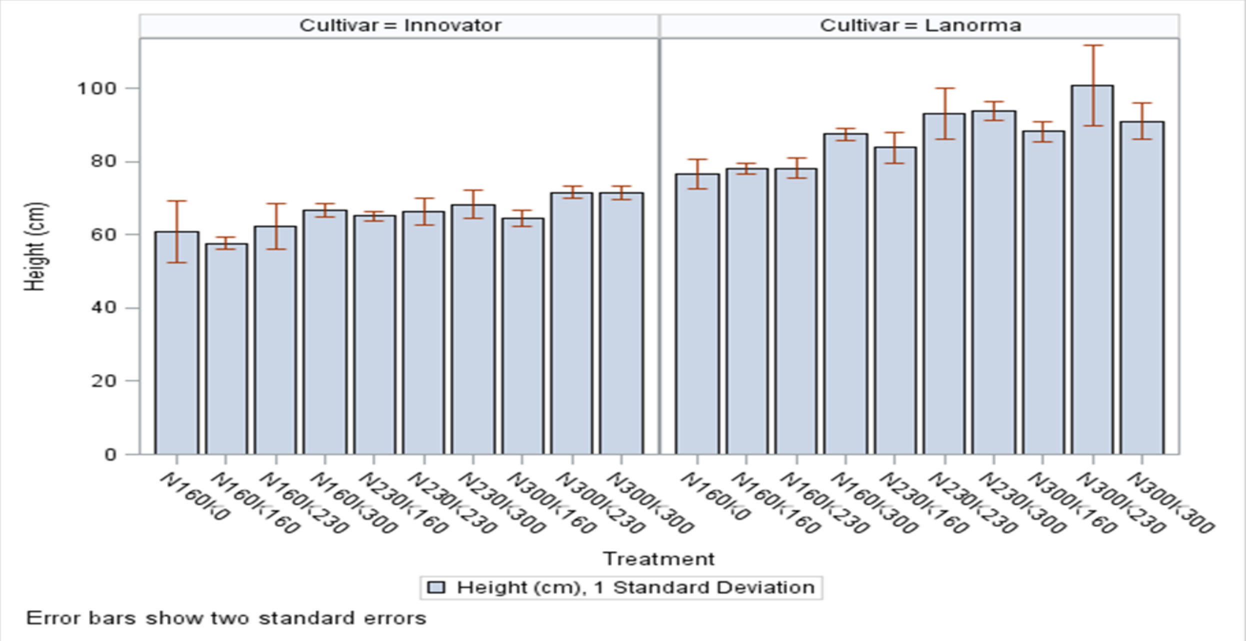


Figure 4.3d: Plant height per treatment and per cultivar at the fourth destructive harvest.

Plant height was also compared across destructive harvest dates per fertiliser treatment. Plant height increased significantly from the first to the second harvest across all treatments for both cultivars. For most treatments, there was also a slight increase from the second to the third harvest, and from the third to the fourth harvest. Table 4.2b shows cultivar Lanorma plant heights per fertilizer treatment from the first to the fourth harvest. It can be seen that rapid growth occurred between the period of the first and the second harvests. For cultivar Innovator, plant height increment over time was similar to that of cultivar Lanorma (Table 4.2c).

Table 4.2b: Cultivar Lanorma plant height (cm) across four harvests per fertilizer treatment

Harvest	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1	47.8b	48.0b	46.2c	42.5c	48.2b	52.0c	50.3b	56.3b	54.43b	48.5b
2	72.3a	76.4a	75.0b	72.3b	80.2a	77.8b	79.5a	90.6a	87.7a	75.9a
3	75.7a	78.6a	85.4a	72.5b	86.5a	90.1a	88.3a	91.6a	89.3a	75.9a
4	78.1a	78.2a	87.53a	83.8a	93.1a	93.9a	88.3a	100.9a	91.1b	76.6a
LSD	7.0	13.6	7.5	10.7	15.6	11.9	8.9	13.72	8.5	9.3
CV	5.4	10.3	5.4	8.4	10.7	8.1	6.2	8.6	5.6	7.2

** Values followed by the same letter in their respective columns are not significantly different from each other at p ≤ 0.05*

Table 4.2c: Cultivar Innovator plant height across four harvests per fertilizer treatment

Harvest	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1	43.0b	43.3b	51.8b	53.3b	47.7b	49.8b	45.7b	46.2b	44.3b	42.7b
2	57.3a	61.4a	66.3a	63.3a	66.5a	68.0a	63.1a	71.7a	71.4a	60.0a
3	57.7a	62.2a	66.8a	63.1a	66.4a	68.4a	64.5a	71.7a	71.5a	60.8a
4	53.2a	56.9a	58.0b	56.6a	58.3a	57.8a	62.8a	64.0a	72.9a	54.5a
LSD	7.4	11.5	7	22.79	11.16	17.2	12.7	10.3	12.7	9.7
CV	7.4	10.9	6.1	20.3	9.9	15.0	11.4	8.7	10.4	9.5

** Values followed by the same letter in their respective columns are not significantly different from each other at p ≤ 0.05*

4.3.2 Intercepted photosynthetically active radiation (IPAR)

PAR measurements showed that IPAR was more responsive to N levels and slightly so with respect to K. Rapid increase in IPAR was associated with higher level of N, and it decreased with a decrease in N application. Figures 4.4 a - c illustrate IPAR at 160, 230 and 300 kg.ha^{-1} N respectively for both cultivars (means across the three K levels) for the entire growth season. From these figures, it can be seen that IPAR for cultivar Innovator increased more rapidly early in the season, but it was also quicker to senesce, even if N was applied at a high level. On the other hand, IPAR for cultivar Lanorma initially increased at a slower rate and dropped later as the canopy senesced slower as N level was increased. As the season progressed, cultivar Lanorma overtook cultivar Innovator in IPAR (at 56-70 DAP); probably cultivar Lanorma was advantaged by its taller stems, which intercepted some of the PAR. Nyende et al. (2005) stated that cultivars with a more rapid exponential growth are likely to have earlier tuber bulking and tuber growth due to enough green foliage to intercept PAR. This was confirmed by the fact that cultivar Innovator started tuber growth and bulking earlier than cultivar Lanorma.

While cultivar Innovator did not achieve IPAR of more than 80% at the lowest level of N across all levels of K, cultivar Lanorma was able to reach close to 90% IPAR at the lowest N level. The intermediate level of N (230 kg.ha^{-1}) resulted in more rapid canopy development and higher maximum IPAR for both cultivars (cultivar Innovator 93% and cultivar Lanorma 96%) than that of the lowest level of N (160 kg.ha^{-1}). At 300 kg.ha^{-1} N, a maximum IPAR value of 96% was achieved for both cultivars. Increasing N from 230 to 300 kg.ha^{-1} did not increase peak value for IPAR for cultivar Lanorma, but there was a slight increase for cultivar Innovator. The peak IPAR value for cultivar Lanorma was rapidly achieved at highest level of N and senescence was delayed.

Generally, the results from this study are similar to that of Tiemens-Hulscher et al. (2014), who observed an increase in area under the canopy cover progress curve (AUCCPC) with an increase in N, since an increase in AUCCPC implies prolonged higher IPAR values, as observed in this study. The highest level of IPAR was at 77 DAP for both cultivars at the low and intermediate levels of N. Highest N level resulted in earlier (70 DAP) maximum IPAR for both cultivars. cultivar Innovator started senescing rapidly from 84 DAP, which led to a decline in IPAR. In Figure 4.4d it is evident that at 91 DAP cultivar Innovator had already started senescing across all treatments, while cultivar Lanorma was still actively growing and green. At 123 DAP, cultivar Innovator had completely senesced, while cultivar Lanorma, on the other hand, had only started senescing and the intensity of senescence varied with N level, such that treatments which received highest N level were still actively growing and green (Figure 4.4e).

The main limiting factor for yield in early maturing cultivars is the duration of leaf growth (Lahlou et al. 2003). Leaf growth duration directly affects IPAR. AUCCPC varies between early maturing cultivars and late maturing cultivars due to extended growth of shoots in late maturing cultivars. This implies that IPAR values will also differ between early and late maturing cultivars. It also implies that for late maturing cultivars, prolonged higher IPAR values will be obtained as observed in this research. Tiemens-Hulscher et al. (2014) observed highly significant differences between maturity type and AUCCPC, confirming that late maturing cultivars had higher AUCCPC.

The extended duration of photosynthetically active leaves plays a positive role in partitioning of assimilates to tubers (Lahlou et al. 2003). It was, therefore, expected that cultivar Lanorma would have higher yield than cultivar Innovator due to its prolonged higher IPAR. Potato cultivars are normally classified based on the number of days from planting to maturity. Cultivars which reach maturity at 65 to 70 (DAP) are classified as very early maturing; those that reach maturity at 70-90 (DAP) as early maturing; 90 -100 (DAP) as mid-season, 110-130 (DAP) as late, and more than 130 (DAP) as very late maturing cultivars (CFIA 2008). Based on this criterion, cultivar Innovator can be classified as an early maturing cultivar. Cultivar Lanorma can be regarded as a mid-season maturing cultivar, however, higher levels of N can effectively delay its maturity, propelling this cultivar to become a late maturing cultivar. Senescence of cultivar Lanorma at higher N level was quite slow, compared to cultivar Innovator and its growing season can substantially be prolonged with higher N levels.

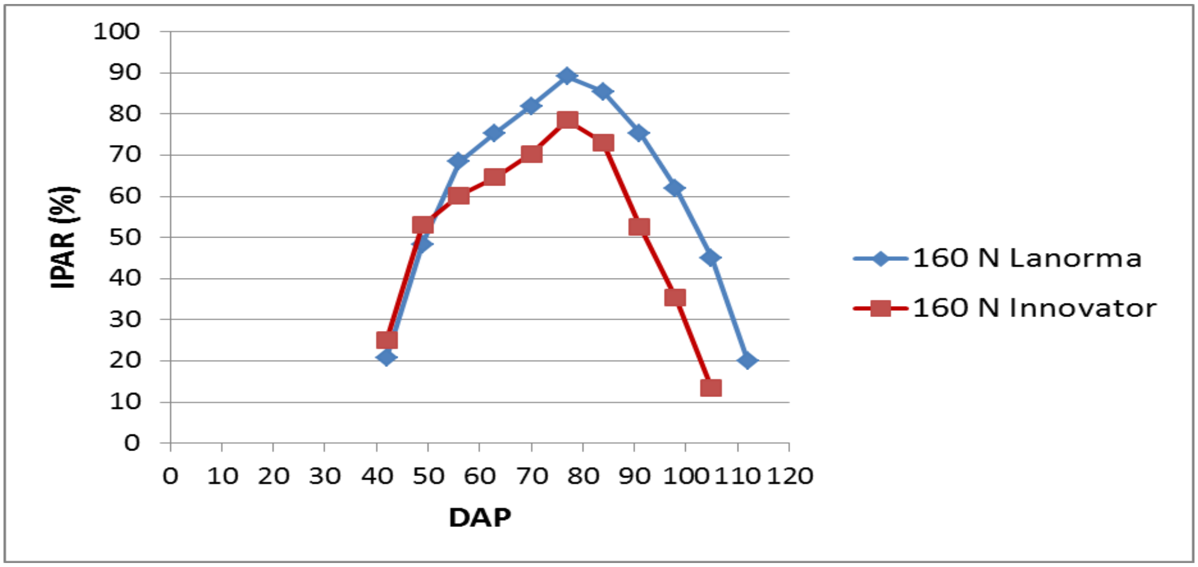


Figure 4.4a: Cultivars Innovator and Lanorma canopy development at 160 kg.ha^{-1} N (means across K levels)

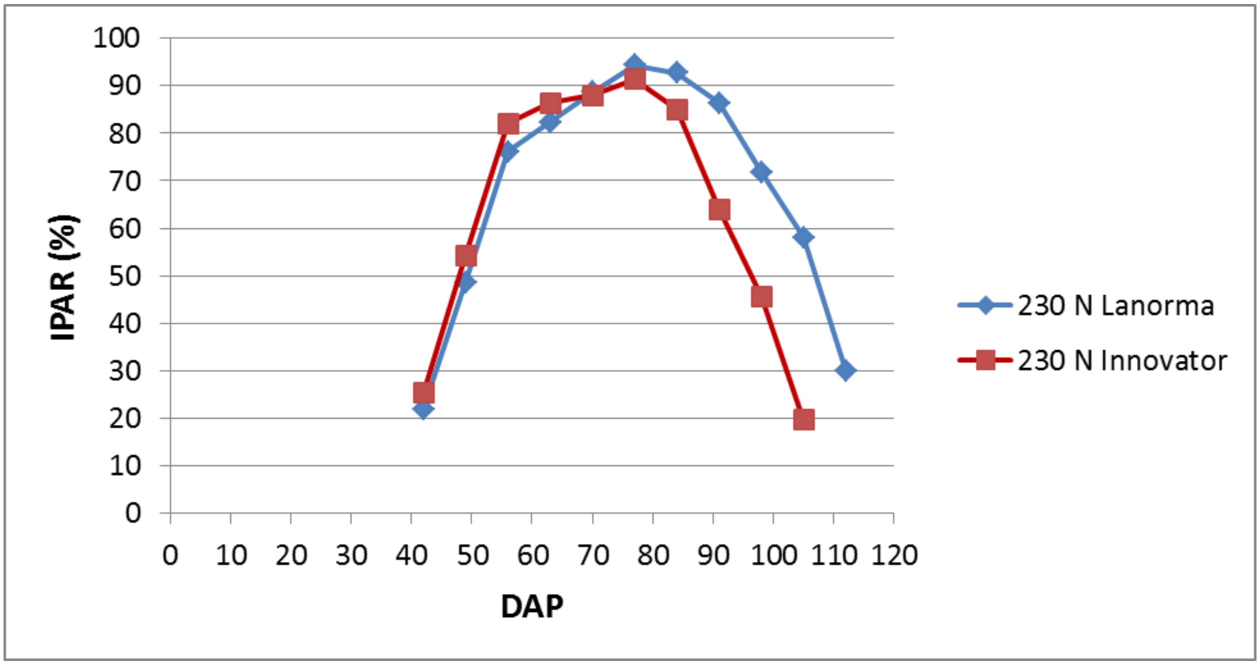


Figure 4.4b: Cultivars Innovator and Lanorma canopy development at 230 kg.ha^{-1} N (means across K levels)

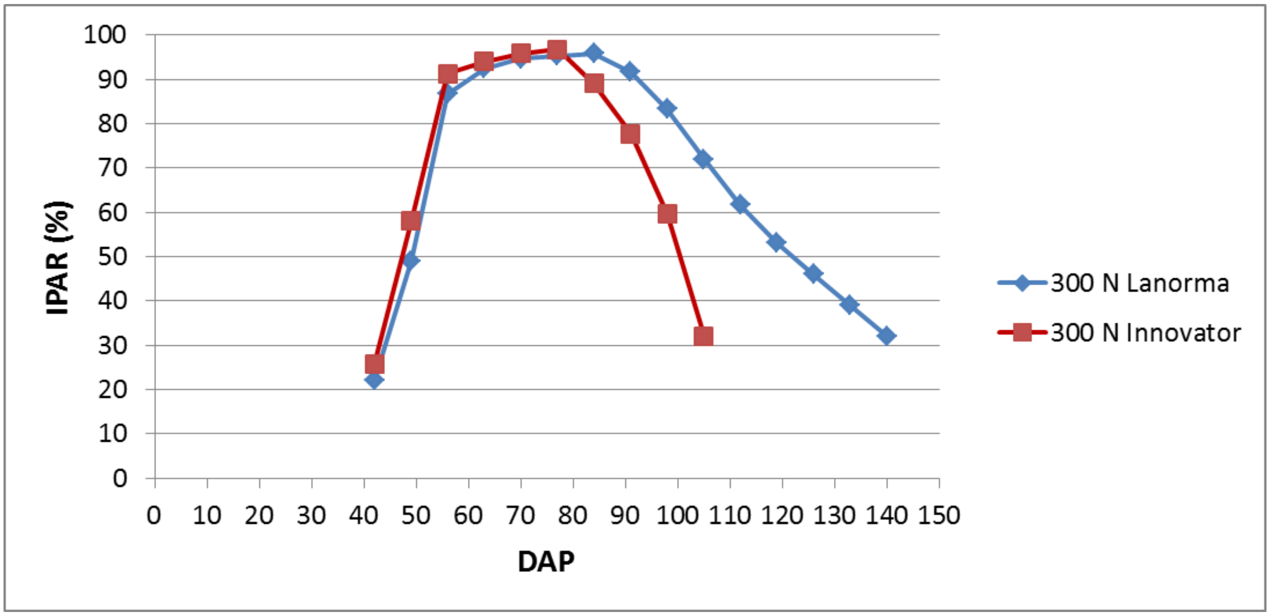


Figure 4.4c: Cultivars Innovator and Lanorma canopy development at 300 kg.ha^{-1} N (means across K levels)

Figure 4.4d: Cultivars Lanorma (left) and Innovator (right) at 91 DAP

Figure 4.4e: Cultivars Innovator (left) and Lanorma (right) at 123 DAP (during Cultivar Innovator harvest)

4.3.3 Dry leaf mass

Initial leaf growth for cultivar Innovator was more rapid at the first harvest and it had a significantly greater (27.8 g plant^{-1}) dry leaf mass per plant than cultivar Lanorma (22.1g plant^{-1}) (Table 4.3a). The trend continued to the second harvest, thereafter cultivar Lanorma overtook cultivar Innovator from the third harvest onwards. These results are analogous to the findings of other authors who observed that cultivars do differ in DM partitioning over time during a growing season (Spitters 1987, Geremew et al. 2007). To facilitate visual comparison, Figures 4.5a - d show dry leaf mass per cultivar per treatment at each destructive harvest. It is quite clear that from the first havest (Figure 4.5a) to the third harvest dry leaf mass for both cultivars increased with an increase in N level. N is responsible for leaf growth and leaf number (Vos 1995) and hence greater N levels resulted in higher dry leaf mass. Both cultivars had started senescence at the fourth harvest, as maximum dry leaf mass dropped below 25 g.plant^{-1} (Figure 4.5d) which was lower than the average dry leaf mass for the third harvest. Lowest level of N resulted in dry leaf mass of less than 10 g.plant^{-1} for Cultivar Innovator. This suggests that senescence for those treatments commenced earlier than at higher N level treatments. The control for Cultivar Lanorma had the highest dry leaf mass, followed by the treatment with 160 kg.ha^{-1} of both N and K. This could mean that K was not sufficient to translocate assimilates to tubers at those low levels. A statistical difference was observed among treatments from the first harvest to the fourth harvest for Cultivar Innovator dry leaf mass. Cultivar Innovator dry leaf mass proved to increase with increase in N application. This is presented in Tables 4.5a to 4.5d. in section 4.3.8 under harvest index. The same pattern was observed for cultivar Lanorma dry leaf mass as presented in Tables 4.5e to 4.5h. This, therefore, attests to what has been documented in literature, namely that higher levels of N result in rapid leaf growth (Vos and Van der Putten 1998).

The control treatment had a significantly greater leaf mass compared to all other treatments and it also had lowest tuber yield. This could indicate that assimilates failed to be sufficiently translocated from the leaves to the tubers. This treatment did not receive any K application, hence assimilates could not be efficiently translocated to the tubers since K is known to be involved in the translocation of assimilates from leaves to storage sites (tubers).

Table 4.3a: Dry leaf mass per cultivar per harvest (means across fertilizer treatments)

Cultivar	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Lanorma	22.1b	30.2b	64.1a	15.1a
Innovator	27.8a	37a	39.5b	11.4b
LSD	2.0	3.0	4.8	1.8
CV	15.3	17.0	17.9	20.1

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

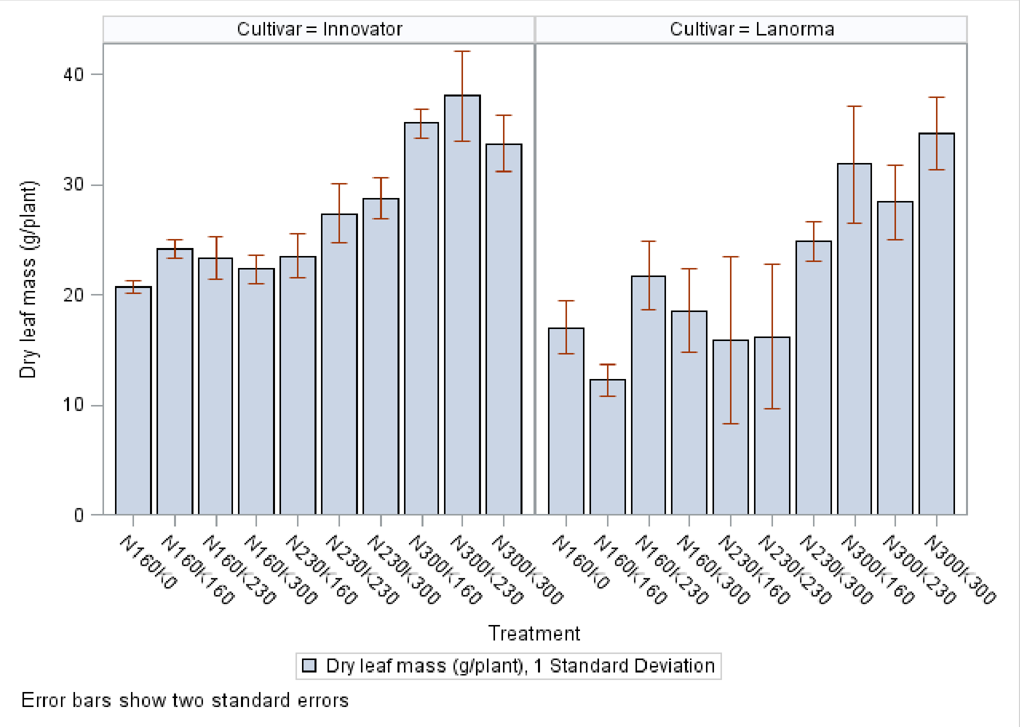


Figure 4.5a: Dry leaf mass per fertiliser treatment and per cultivar at the first destructive harvest.

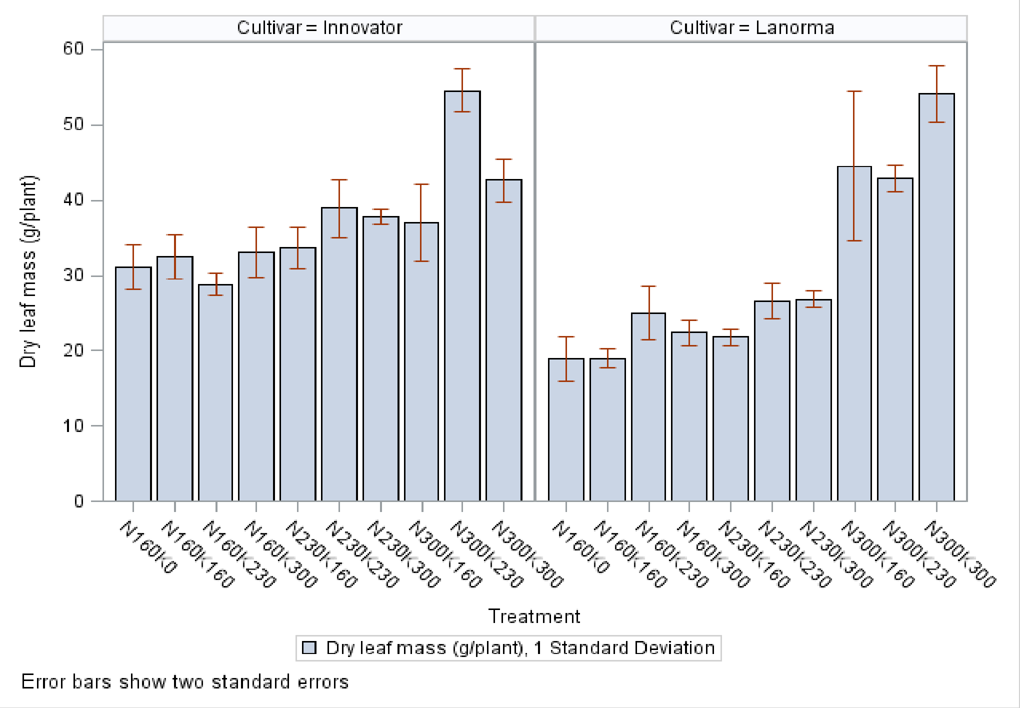


Figure 4.5b: Dry leaf mass per fertiliser treatment and per cultivar at the second destructive harvest

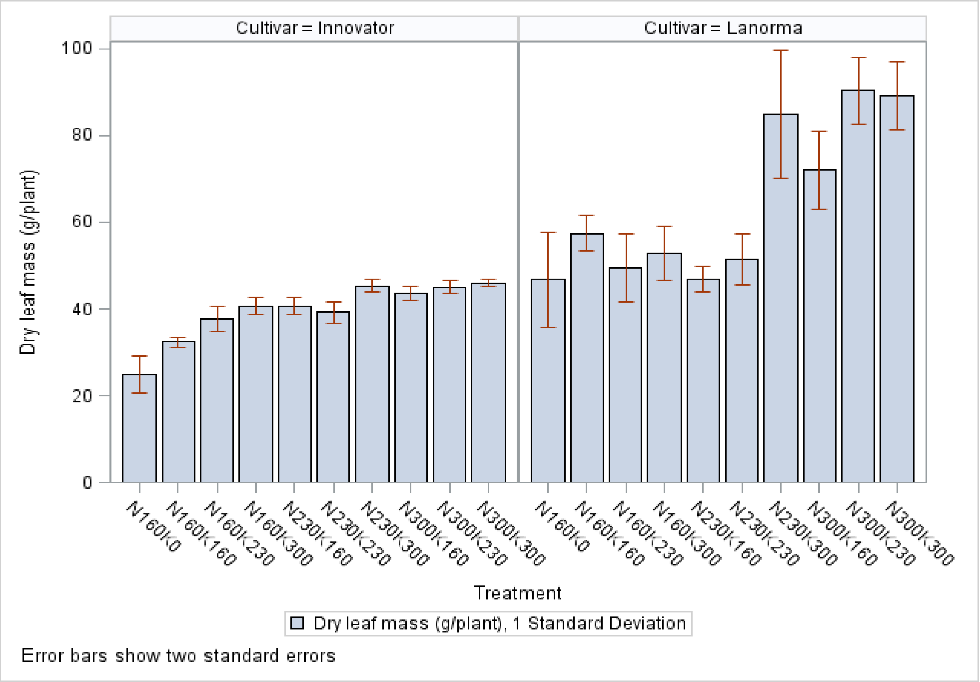


Figure 4.2c: Dry leaf mass per fertiliser treatment and per cultivar at the third destructive harvest

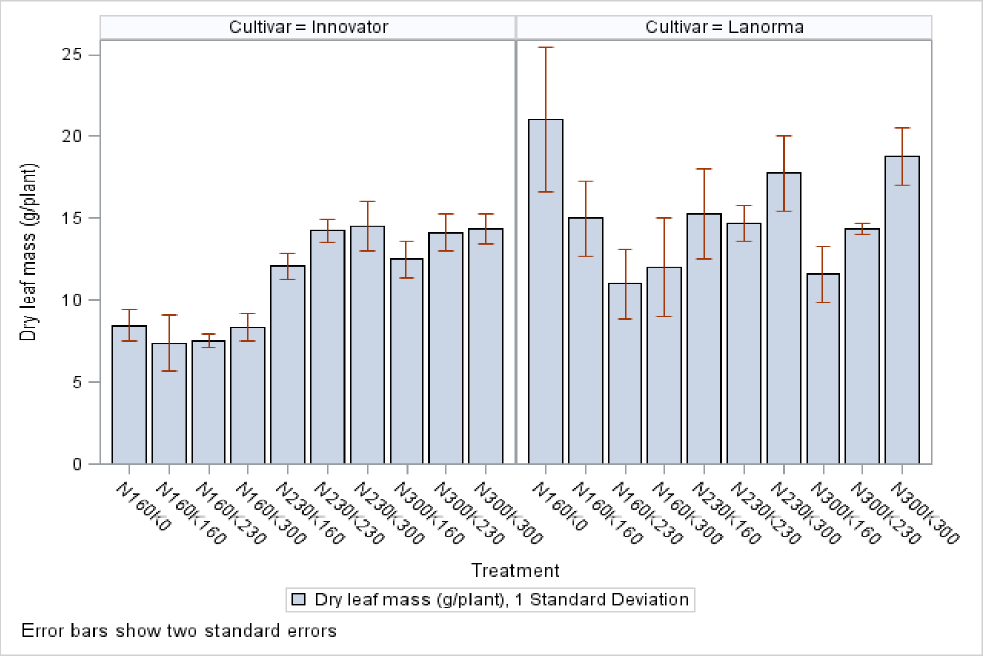


Figure 4.5d: Dry leaf mass per fertiliser treatment and per cultivar at the fourth destructive harvest

4.3.4 Dry stem mass

Dry stem mass did not show any significant differences in the first two harvests for cultivar Innovator (see tabulated dry stem masses per treatment per harvest for both cultivars in Section 4.3.8). At the third and fourth harvests, dry stem masses for cultivar Innovator showed a tendency of greater dry mass at the high level of N, compared to lower N levels. This greater dry stem mass could be attributed to growth stimulation associated with higher N levels or it could be due to better translocation of assimilates from the leaves down to the tubers. As seen earlier under the dry leaf mass discussion, higher dry leaf mass values were obtained from treatments that received high N, which means more assimilates were manufactured by these leaves and hence more assimilates will be translocated from them. For cultivar Lanorma, most treatments from the first to the third harvest did not show any clear trend with respect to dry stem mass, such that most treatments were not significantly different from each other. At the fourth harvest, the dry stem mass of cultivar Lanorma was significantly lower at lowest level of N than most treatments which received higher levels of N. This may suggest that N deficiency limited stem mass, such that treatments which received low levels of N had lower stem mass.

4.3.5 Tuber number

Tuber number was noted at each harvest, however, only the data for the fourth harvest is presented here since tuber number remained almost the same across harvest intervals. This shows that both cultivars had finished initiating tubers by the first harvest and, therefore, only results of the fourth harvest were analysed for significant differences. Table 4.3b shows tuber number per treatment per cultivar. Cultivars differed significantly in tuber numbers across fertilizer treatments, with average tuber numbers of 9.5 for cultivar Lanorma and 6.8 for cultivar Innovator. As for tuber number per fertilizer treatment, there seemed to be no clear trend and only a few significant differences were observed for cultivar Lanorma. This is quite different from results in the pot trial, where higher levels of N and K resulted in higher tuber numbers. The differences in response could be attributed to the difference in application procedures between the field and pot trials. In the pot trial, all fertilizer was applied once at planting, while in the field trial N and K were split into two dressings (half at planting and the remainder two weeks after emergence). The conditions are quite different between a pot and field trial, as roots are confined in a pot and nutrients such as K can be depleted easily. On the other hand, in the field roots can explore a larger soil volume to take up needed nutrients. It, therefore, follows that crops would be more responsive to available nutrients in a pot than in the field.

Table 4.3b: Tuber number (per plant) per treatment and cultivar at the fourth harvest

Treatment	N:K ratio	Lanorma	Innovator
N 160 K 160	1	11.1ba	6a
N 160 K 230	0.70	10.8ba	6.9a
N 160 K 300	0.53	8.4ba	6.9a
N 230 K 160	1.44	7.5b	6.8a
N 230 K 230	1	9.3ba	6.1a
N 230 K 300	0.77	10.2ba	7.3 a
N 300 K 160	1.88	11.5a	6.6a
N 300 K 230	1.30	8.0ba	7.9a
N 300 K 300	1	10.2ba	6.6a
N 160 only	-	9.0ba	6.9a
LSD		3.8	3.1
CV		23.5	26.6

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

4.3.6 Stolon length

Across fertilizer treatments, cultivar Lanorma had longer stolons on average (8.0 cm) than cultivar Innovator (4.5 cm). Table 4.3c shows stolon lengths for both cultivars per fertilser treatment. The stolon length measurements documented were from the fourth harvest since they were almost similar in length to those of earlier harvests. cultivar Innovator seemed to initiate tubers just above and close to the mother tuber. For cultivar Lanorma, careful heaping should be done due to its long stolons. Long stolons imply that tubers may appear on the surface if ridges are not well constructed. Therefore, it is recommended that special care be taken that ridges be maintained well, as failure to that would lead to poor quality tubers if tubers appear on the soil surface.

Table 4.3c: Stolon length for the two cultivars per fertilizer treatment

Treatment	Cultivar Lanorma	Cultivar Innovator
N 160 K 160	6.3d	3.5cd
N 160 K 230	8.2bdac	4.9bc
N 160 K 300	7.3dc	4.7bc
N 230 K 160	6.7dc	4.2bcd
N 230 K 230	7.7bdc	3.2cd
N 230 K 300	7.6dc	5.5ba
N 300 K 160	10.5a	4.7bc
N 300 K 230	9.3bac	4.5bc
N 300 K 300	10.2ba	7.3a
N 160 only	6.7dc	2.2d
LSD	2.8	2
CV	20.6	26.1

*Values with the same letters within a column are not significantly different *at $p \leq 0.05$*

4.3.7 Dry tuber mass yield

Cultivar Lanorma had a significantly lower dry tuber mass yield than cultivar Innovator from the first harvest to the fourth harvest (Table 4.4a). The fact that cultivar Innovator outweighed cultivar Lanorma from the first harvest onwards suggests that cultivar Innovator matures earlier than cultivar Lanorma. Similarly, many studies have reported variation among cultivars in the date of maturity (Spitters 1987, Geremew et al. 2007). Dry tuber yield per harvest per fertiliser treatment are presented graphically in Figures

4.6a – d. It can be seen in Figure 4.6a that cultivar Innovator dry tuber mass was higher than that of cultivar Lanorma. There was, however, no clear trend in tuber yield with respect to N and K fertilizer treatments at the time of the first destructive harvest. However, treatment combination 230 kg.ha^{-1} N and 300 kg.ha^{-1} K (N:K ratio 0.77) gave highest dry tuber mass for both cultivars.

Dry tuber yield at the second harvest showed a similar trend, such that there was no clear pattern of yield with respect to N and K fertilisation, except that dry tuber yields for cultivar Innovator were higher than that of cultivar Lanorma (Figure 4.6b). Similarly, at the third harvest, the trend was still not clear (Figure 4.6c). At the time of the fourth harvest, however, the results showed a tendency of an increase in yield with an increase in K at the two lower levels of N (Figure 4.6d). This pattern of growth was also observed by Singh and Lal (2012), who reported an increase in yield as both nutrients were increased. However, at the highest N level of 300 kg.ha^{-1}, dry tuber yield seemed to increase with increase in K level up to 230 kg.ha^{-1}, thereafter tuber yields levelled off for both cultivars.

Table 4.4a: Dry tuber mass yield (g/plant) per cultivar per harvest date (means across fertilizer treatments)

Cultivar	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Lanorma	5.1a	67.1b	177.9a	204.0a
Innovator	7.7b	106.1a	184.9a	218.0b
LSD	1.4	12.2	Ns	9.9
CV	43.8	27.1	17.4	9.0

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

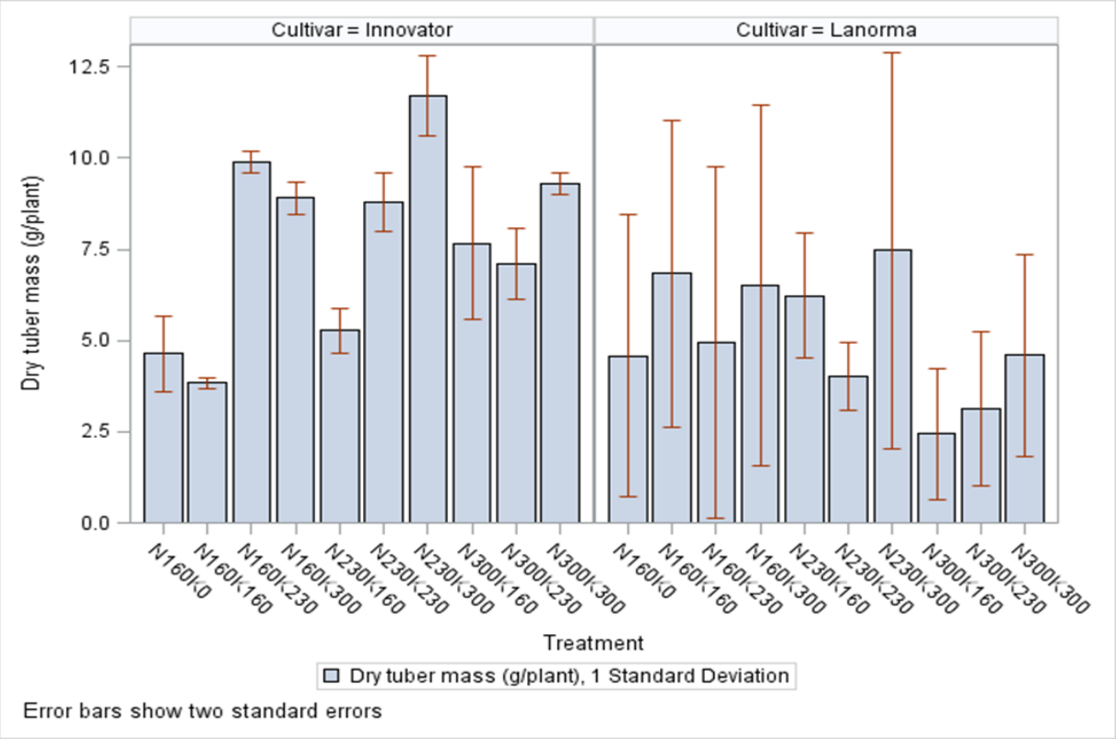


Figure 4.6a: Dry tuber mass per fertiliser treatment and per cultivar at the first destructive harvest.

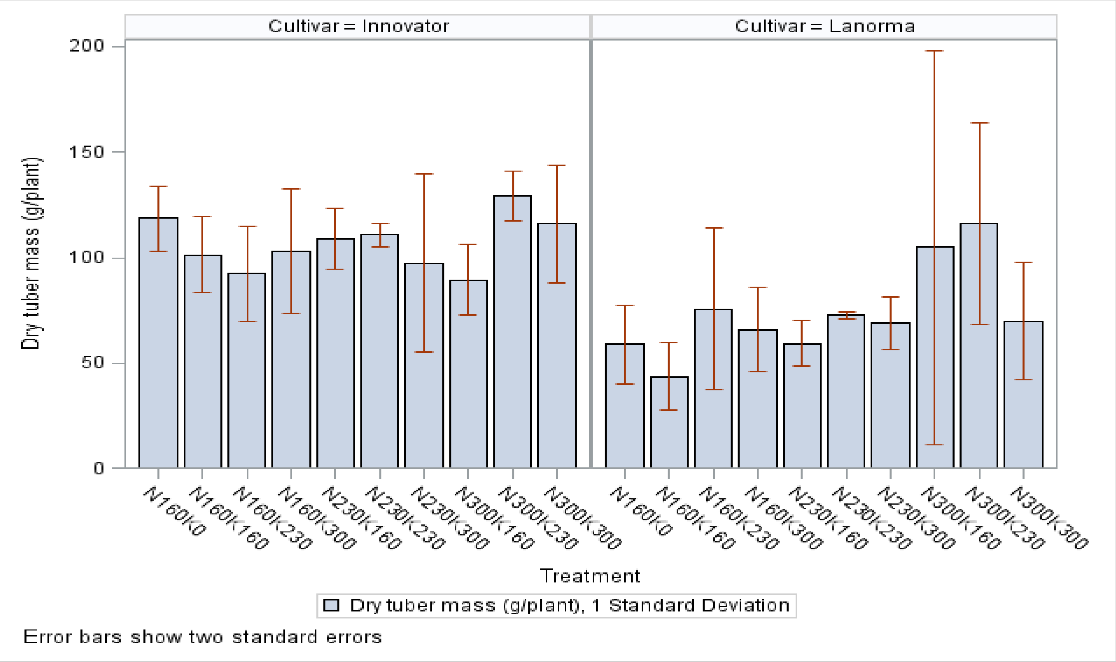


Figure 4.6b: Dry tuber mass per fertiliser treatment and per cultivar at the second destructive harvest.

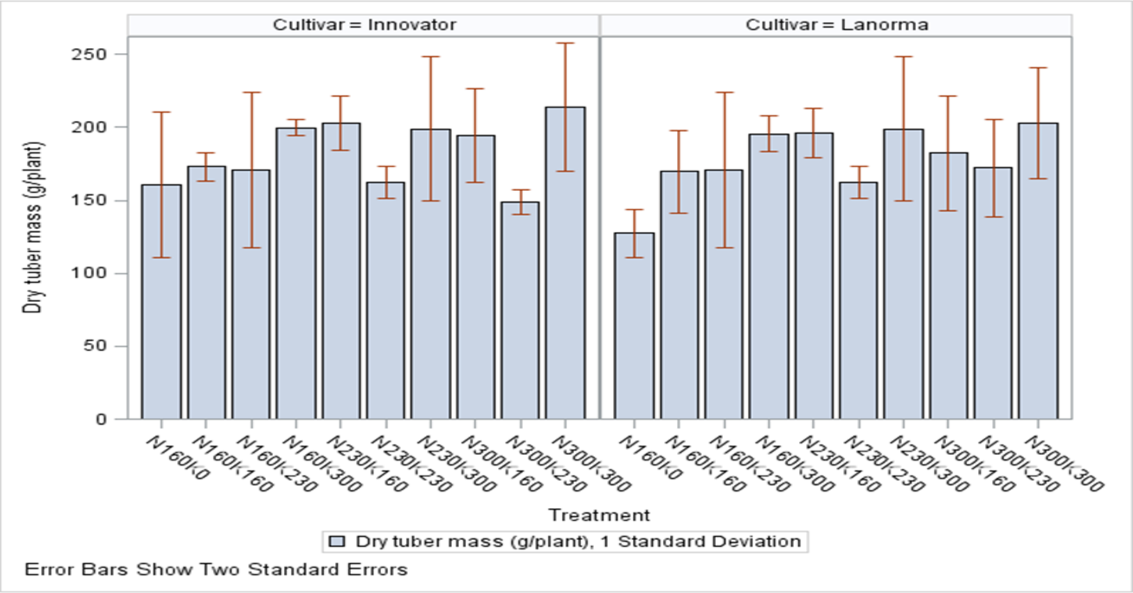


Figure 4.6c: Dry tuber mass per fertiliser treatment and per cultivar at the third destructive harvest.

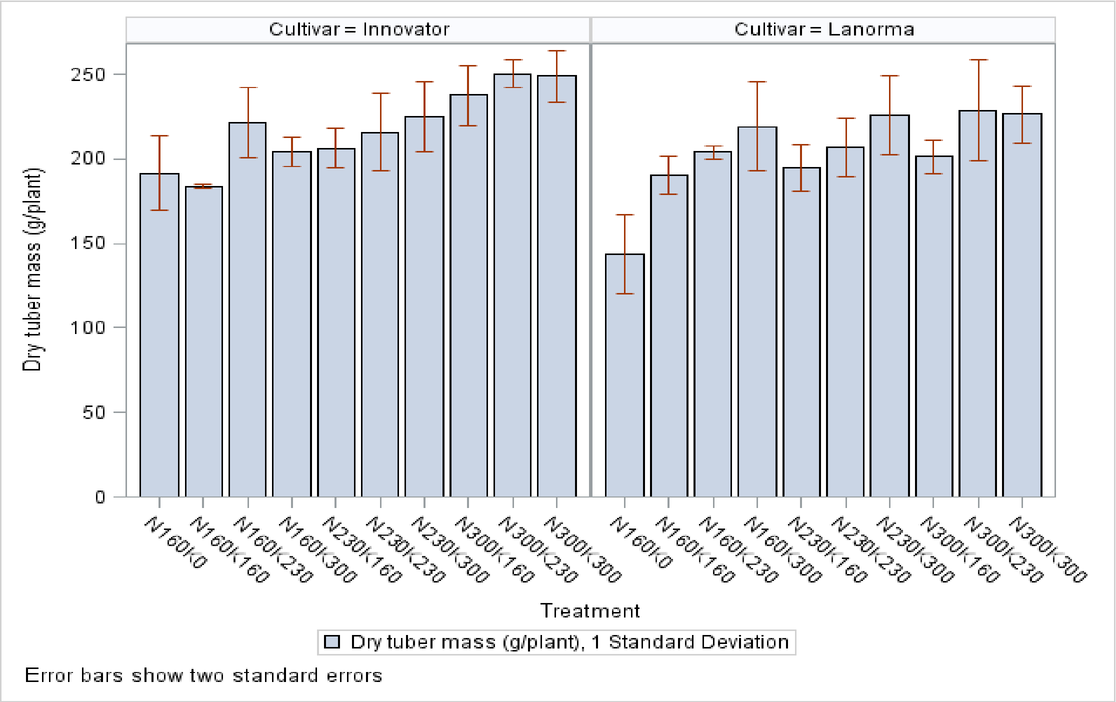


Figure 4.6d: Dry tuber mass per fertiliser treatment and per cultivar at the fourth destructive harvest.

Dry tuber mass was also tabulated per harvest and per fertiliser treatment across the four destructive harvests. These results are illustrated in Tables 4.4b and 4.4c for cultivar Lanorma and cultivar Innovator, respectively. It can be seen that for both cultivars, dry tuber mass increased significantly from the first to the second harvest, and from the second to the third harvest. Dry tuber mass for cultivar Lanorma then increased substantially, but not significantly from the third to the fourth harvest. For cultivar Innovator, at higher levels of N, there was a tendency of significant increase in dry tuber mass from the third to the fourth harvest. This suggests that for cultivar Innovator, an early maturing cultivar, assimilates were rapidly translocated to the tubers early in the growing season and by the third harvest, most tuber filling had already occurred, while cultivar Lanorma continued tuber filling until the fourth harvest.

Dry tuber mass per treatment per harvest is tabulated in section 4.3.8 under the harvest index discussion. Cultivar Innovator dry tuber mass is presented in Tables 4.5a to 4.5d (section 4.3.8). Dry tuber mass for cultivar Innovator did not show a clear trend at first harvest and at the second and third harvests dry tuber mass also did not show any significant differences across treatments. It therefore suggests that N:K ratios resulted in no clear trends at those two harvest dates. At the fourth harvest, cultivar Innovator dry tuber mass showed substantially higher yield at N:K ratios of 0.77 to 1.3 at intermediate and highest levels of N. Lowest N level did not show a clear trend with respect to dry tuber mass. This may suggest that N:K ratio is more influential when none of the two nutrients is insufficient.

Tables 4.5e to 4.5h (Section 4.3.8) show cultivar Lanorma dry tuber mass per treatment per harvest. cultivar Lanorma dry tuber mass did not show any significant differences at first harvest. At both the second and third harvests dry tuber yield for cultivar Lanorma did not show any clear trends. At fourth harvest, just like in the case of cultivar Innovator, dry tuber mass was substantially higher at N:K ratios ranging from 0.77 to 1.3. The fact that N:K ratio showed an influence on dry tuber yield, mainly at the fourth harvest, may suggest that at earlier harvests effective translocation of assimilates from the shoots to tubers had not started yet. For both cultivars at the fourth harvest, there seemed to be a tendency of substantial increase in yield with an increase K for a specific N level, at the intermediate and highest levels of N. This contradicts findings by Yan et al. 2005, who reported no increase in yield with increment in K. On the other hand, these results are similar to those of Kang et al. (2014), who noted an increase in yield with increase in K at a specific N level. Based on N:K ratio, a tendency of statistically higher yield was obtained at ratios ranging from 0.7 to 1.3, except at the lowest level of N and K.

Table 4. 4b: Dry tubermass yield (g/plant) for cultivar Lanorma across four harvests per fertilizer treatment

Harvest	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1	6.8c	4.9c	6.5c	6.2c	4.0d	7.53c	2.43d	3.8d	4.6c	4.3c
2	43.5b	75.6b	65.8b	59.1b	72.5c	68.7b	41.1b	115.9b	69.70b	58.9b
3	169.7a	170.8a	195.6a	196.2a	162.4b	199.1a	182.3a	172.1ba	203.03a	127.3a
4	190.3a	203.8a	219.3a	194.5a	206.8a	225.7a	201.2a	228.7a	226.6a	143.4a
LSD	32.5	62.4	33.5	22.9	19.4	52.86	42.2	61.7	47.2	32.2
CV	16.9	29.1	14.6	10.7	9.3	22.5	20.9	25.1	19.9	20.5

** Values followed by the same letter in their respective columns are not significantly different from each other at p ≤ 0.05*

Table 4.4c: Dry tuber mass yield (g/plant) for cultivar Innovator across four harvests per fertilizer treatment

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Harvest1	3.8c	9.9c	8.9c	5.3c	8.8d	11.7c	7.7d	7.1d	9.30c	4.6c
Harvest2	101.3b	92.2b	103.3b	108.7b	110.5c	97.3b	89.4c	124.0c	115.8b	118.4b
Harvest3	173.1a	170.8a	199.6a	202.8a	162.4b	199.1a	194.3b	172.1b	213.7a	160.7ba
Harvest4	183.8a	222.0a	204.5a	206.3a	215.9a	225.0a	237.8a	244.7a	248.8a	191.6a
LSD	19.2	58.1	29.4	24.6	24.5	64.4	38.04	37.5	51.2	53.2
CV	8.8	25.0	12.1	10.0	10.5	25.7	15.3	14.5	18.5	23.8

** Values followed by the same letter in their respective columns are not significantly different from each other at p ≤ 0.05*

4.3.8: Harvest index

Harvest index (HI) was significantly different between treatments from the first harvest for cultivar Innovator. There was a tendency of significantly higher HI at lower and intermediate levels of N. Lower HI at highest level of N could be attributed to higher leaf mass production associated with these treatments. The second and third harvests showed a tendency of substantially higher HI at lower N levels, as compared to the ones with higher N levels. At the fourth harvest, lowest N level treatments still maintained higher HI although not always significant.

Table 4.5a: Dry mass of leaves, stems and tubers, and corresponding harvest index for cultivar Innovator at the first harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	24.1de	8.0a	3.8e	10.7f
N 160 K 230	0.70	23.4e	7.1a	9.9b	24.6a
N 160 K 300	0.53	22.3e	8.2a	8.9cb	22.7ba
N 230 K 160	1.44	23.5e	7.7a	5.3e	14.2def
N 230 K 230	1	27.4dc	7.1a	8.8cb	20.5bc
N 230 K 300	0.77	28.8c	6.6a	11.7a	24.9a
N 300 K 160	1.88	35.6ba	7.1a	7.7cd	15.2de
N 300 K 230	1.30	38.1a	8.5a	7.1d	13.3ef
N 300 K 300	1	33.7b	9.1a	9.3b	17.9dc
N 160 only	-	22.7e	7.4a	4.6e	14.1def
LSD		3.64	Ns	1.6	3.9
CV		7.7	27.9	12.4	12.8

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 4.5b: Cultivar Innovator dry mass for leaves, stems and tubers and corresponding harvest index at the second harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	32.5 ed	9.8a	101.3a	70.2ba
N 160 K 230	0.70	28.8 e	12.2a	92.2a	68.7ba
N 160 K 300	0.53	33.0 ed	10.7 a	103.3a	69.5ba
N 230 K 160	1.44	33.7 ced	12.6a	108.4a	69.9ba
N 230 K 230	1	38.9 cb	11.6a	110.5a	68.6ba
N 230 K 300	0.77	37.8cbd	12.5a	97.3a	63.6b
N 300 K 160	1.88	37.0 cd	9.4a	89.4a	65.7ba
N 300 K 230	1.30	54.5a	13.2a	124.0a	64.5ba
N 300 K 300	1	42.6b	12.4a	115.8a	67.2ba
N 160 only	-	31.1e	11.7a	118.4a	73.4a
LSD		5.29	Ns	Ns	9.6
CV		8.39	19.7	21.9	8.3

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 4.5c: Cultivar Innovator dry mass for leaves, stems and tubers and corresponding harvest index at third harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	24.1de	9.7dc	173.1a	87.7ba
N 160 K 230	0.70	23.4 e	12.3bac	170.8a	86.1ba
N 160 K 300	0.53	22.3 e	10.3dc	199.6a	88.6a
N 230 K 160	1.44	23.5 e	11.7 bc	202.8a	87.6ba
N 230 K 230	1	27.4 dc	11.0bdc	162.4a	86.0ba
N 230 K 300	0.77	28.8 c	13.2a	199.1a	86.3ba
N 300 K 160	1.88	35.6 ba	12.3bac	194.3a	86.7ba
N 300 K 230	1.30	38.1a	14.7a	172.1a	84.0b
N 300 K 300	1	33.7 b	14.8a	213.7a	86.5ba
N 160 only	-	20.7 e	8.3d	160.7a	87.2ba
LSD		3.64	2.7	Ns	3.9
CV		10.88	13.7	19.1	2.7

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 4.5d: Cultivar Innovator dry mass for leaves, stems and tubers and corresponding harvest index at the fourth harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	7.367d	6.00f	183.77e	93.37a
N 160 K 230	0.70	7.53d	8.23ef	221.97bac	93.23a
N 160 K 300	0.53	8.33d	10.97bdc	204.50edc	91.40bac
N 230 K 160	1.44	12.10c	11.63bac	206.50edc	89.67dc
N 230 K 230	1	14.27ba	10.93bdc	215.93bdc	89.47dc
N 230 K 300	0.77	14.53a	13.03ba	225.03bac	89.00d
N 300 K 160	1.88	12.5bc	14.27a	237.80ba	89.83dc
N 300 K 230	1.30	14.13ba	9.60edc	244.67a	91.17 bc
N 300 K 300	1	14.33a	14.03a	248.83a	89.73 dc
N 160 only	-	8.47d	7.8ef	191.57 ed	92.10ba
LSD		1.82	2.74	28.08	2.03
CV		9.42	15.12	7.56	1.31

**Values with the same letter within a column are not significantly different at p ≤ 0.05*

Harvest index for cultivar Lanorma did not show a clear trend at the first and second harvests. However, as from the third to the fourth harvest, HI for cultivar Lanorma proved to have a tendency of significantly higher HI at lowest N level compared to highest N level, as it was in the case of cultivar Innovator. This could imply that most of the assimilates were still present in the leaves at higher levels of N, while at lower N levels more assimilates were translocated to tubers. High harvest index at low rates of N could also be due to low dry mass of leaves associated with these treatments, while low HI at high level of N could be due to high dry mass of leaves. Yield showed a tendency to increase at each N level as K was increased, as in the case of cultivar Innovator. The N:K ratio also seemed to play a role since ratios greater than 1.3 tended to suppress yield. The fact that N:K ratio for cultivar Lanorma had more influence on yield at the fourth harvest than earlier harvests, could be due to the fact that cultivar Lanorma matured later than cultivar Innovator and therefore assimilate translocation to tubers only began later as compared to cultivar Innovator. Greater translocation of assimilates to tubers could have led to higher HI and tuber yield.

Table 4.3e: Cultivar Lanorma dry mass for leaves, stems and tubers and corresponding harvest index at first harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	12.3 f	7.0a	6.8a	25.3a
N 160 K 230	0.70	21.7 edc	6.5ba	4.9a	13.2ba
N 160 K 300	0.53	18.6edf	7.9a	6.5a	18.1ba
N 230 K 160	1.44	15.6ef	7.9a	6.2a	21.5ba
N 230 K 230	1	16.2ef	7.4a	4.0a	15.5ba
N 230 K 300	0.77	24.9bdc	7.4a	7.5a	18.1ba
N 300 K 160	1.88	31.8ba	5.6b	2.4a	6.2b
N 300 K 230	1.30	28.4bac	7.5a	3.8a	9.5ba
N 300 K 300	1	34.6a	6.5ba	4.6a	9.6ba
N 160 only	-	17.0ef	6.7a	4.3a	14.0ba
LSD		7.4	1.8	Ns	16.2
CV		19.5	15.3	69.3	62.9

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 4.5f: Cultivar Lanorma dry mass for leaves, stems and tubers and corresponding harvest index at the second harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	19.0d	14.5a	43.51b	55.1ba
N 160 K 230	0.70	25.0dc	10.2bac	75.6b	66.3a
N 160 K 300	0.53	22.4dc	13.5ba	65.8b	63.7a
N 230 K 160	1.44	21.8dc	10.8bac	59.1b	64.1a
N 230 K 230	1	26.6c	10.6bac	72.7b	66.1a
N 230 K 300	0.77	26.8c	10.8bac	68.7b	64.5a
N 300 K 160	1.88	44.5b	10.0bac	41.0b	42.4b
N 300 K 230	1.30	42.8b	10.6bac	115.9a	66.5a
N 300 K 300	1	54.1a	8.5c	69.7b	51.4ba
N 160 only	-	18.9d	11.5bac	58.8b	64.8a
LSD		6.6	4.52	42.2	16.2
CV		12.8	23.9	36.9	15.8

Values with the same letter within a column are not significantly different at $p \leq 0.05$

Table 4.5g: Cultivar Lanorma dry mass for leaves, stems and tubers and corresponding harvest index at the third harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	57.5c	26.3ba	169.7ba	66.7bc
N 160 K 230	0.70	49.6c	17.8b	170.8ba	70.9ba
N 160 K 300	0.53	52.7c	26.7ba	195.6a	71.1ba
N 230 K 160	1.44	47.0c	16.4b	196.2a	75.5a
N 230 K 230	1	51.6c	24.3ba	162.37ba	68.3bac
N 230 K 300	0.77	84.9ba	34.0a	199.1a	62.0dc
N 300 K 160	1.88	71.7b	24.8ba	182.3ba	65.1bdc
N 300 K 230	1.30	90.4a	33.8a	172.1ba	57.8d
N 300 K 300	1	89.1a	26.3ba	203.3a	63.5dbc
N 160 only	-	46.8c	17.3b	127.3b	66.8bc
LSD		14.2	10.9	56	8.5
CV		13.0	28.8	18.7	7.5

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 4.5h: Cultivar Lanorma dry mass for leaves, stems and tubers and corresponding harvest index at the fourth harvest

Treatment	N:K ratio	Leaves	Stems	Tuber	HI
N 160 K 160	1	15.00bedc	12.58 cd	190.27 c	87.37ba
N 160 K 230	0.70	11.00e	11.87d	203.80bac	89.90a
N 160 K 300	0.53	12.00ed	18.27b	219.33bac	87.8ba
N 230 K 160	1.44	15.30 bdc	25.53a	194.47bc	82.63dc
N 230 K 230	1	14.67bedc	25.83a	206.8 bac	83.60dc
N 230 K 300	0.77	17.77bac	22.37a	225.73ba	84.83bc
N 300 K 160	1.88	11.57ed	15.90cb	201.23bac	87.93ba
N 300 K 230	1.30	14.37edc	22.37a	228.73a	86.03 bc
N 300 K 300	1	18.77ba	25.17a	226.57ba	83.73dc
N 160 only	-	21.03a	13.43cd	143.34 d	80.30d
LSD		4.12	3.9062	32.713	3.6037
CV		15.96	11.86	9.4135	2.477

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

The pattern of growth, development and DM partitioning between these two cultivars varied, similar to reports by Spitter (1987) that cultivars differ in terms of growth and DM partitioning. Cultivar Innovator's rapid early shoot growth and its associated early assimilate translocation from shoot to tubers, is indicative that this cultivar can be classified as an early tuber filling cultivar, with early high HI, as reported by Spitters (1987). On the other hand, for cultivar Lanorma tuber filling was more gradual during the season and therefore lower HI was obtained early during the growing season. Table 4.5 shows the harvest index for both cultivars across four harvest intervals and it is evident that cultivar Innovator had a significantly higher HI than cultivar Lanorma from the second harvest to the fourth harvest. This indicates that cultivar Innovator matures earlier than cultivar Lanorma. Figure 4.7 illustrates dry mass for tubers, stems and leaves of both cultivars. It can be seen from the graph that cultivar Innovator is an early maturing cultivar as its senescence occurred before 83 DAP, while cultivar Lanorma was still accumulating assimilates in the leaves by then. It therefore follows that cultivar

Innovator will have higher HI early in the season than cultivar Lanorma. cultivar Innovator was bred from Shepody and RZ-84-2580 as illustrated earlier in Chapter One, and it was observed that Shepody accumulated its highest leaf dry matter yield at 72 DAP and then it dropped rapidly (Geremew et al. 2007), similar to what is observed here for cultivar Innovator.

Table 4.6: Harvest index at each harvest interval per cultivar (means across treatments)

Cultivar	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Lanorma	15.1a	60.5b	66.8b	85.4b
Innovator	17.8a	68.1a	86.6a	90.9a
LSD	4.0	4.5	2.5	1.4
CV	47.4	13.7	6.3	3.04

**Values with the same letter within a column are not significantly different at p ≤ 0.05*

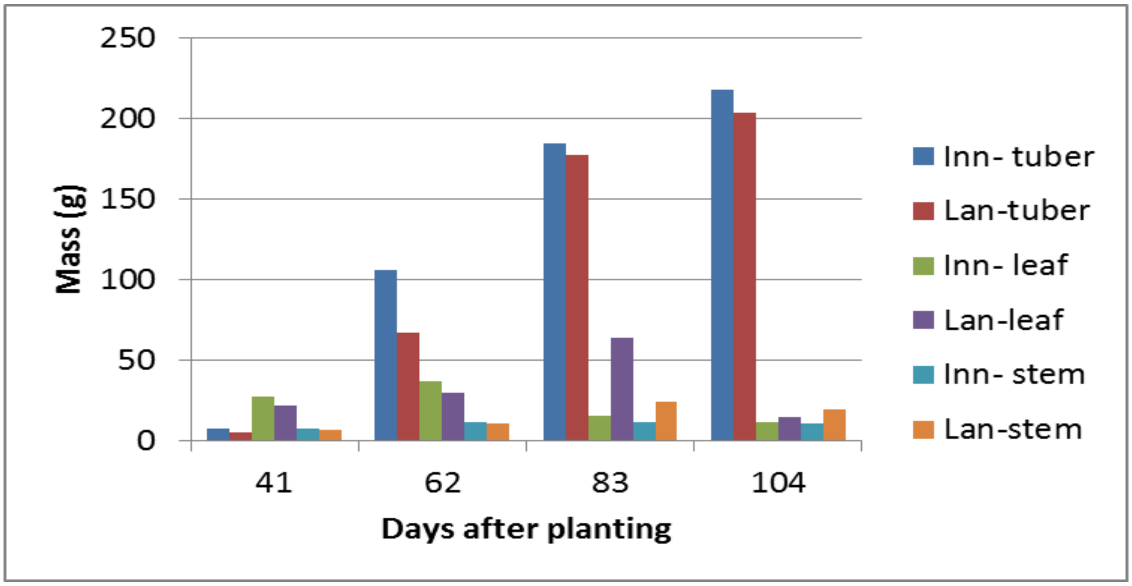


Figure 4.7: Tuber, leaf and stem dry masses per plant for two cultivars across four harvest intervals (means across treatments)

**Inn-tuber = Innovator dry tuber mass, Lan-tuber = Lanorma dry tuber mass, Inn-leaf = Innovator dry leaf mass, Lan-leaf = Lanorma dry leaf mass, Inn-stem = Innovator dry stem mass, Lan-stem = Lanorma dry stem mass*

4.3.9 Leaf analysis results

Figure 4.8 illustrates the results of leaf K content per cultivar and fertilizer treatment. Generally, leaf K concentration seemed to increase with increase in K level across all levels of N for both cultivars. At the lowest N level, cultivar Lanorma surpassed cultivar Innovator in terms of K content in the leaves. As N was increased to 230 and 300 kg.ha^{-1}, leaf K contents for both cultivars were almost equal. Control treatments (0 K) for both cultivars showed lowest leaf K content, however K content for cultivar Innovator was higher than that of cultivar Lanorma at this treatment, which may indicate that cultivar Innovator has higher K uptake efficiency than cultivar Lanorma. Tables 4.8 and 4.9 show the leaf K, Mg, Ca, S and P contents for cultivar Innovator and cultivar Lanorma, respectively. For both cultivars, Ca and Mg showed a tendency to decline with increase in K application, suggesting that higher K level may have an antagonistic effect on Ca and Mg uptake. S content increased with an increase in K (due to K_2SO_4 being used as K source), while P remained almost constant across treatments.

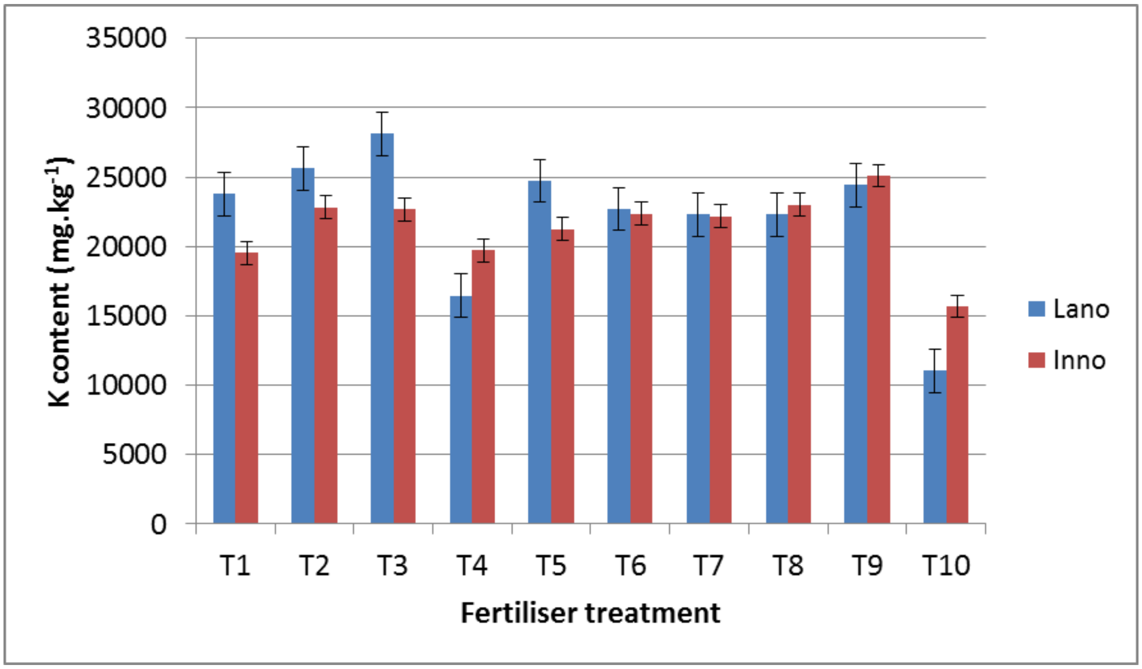


Figure 4.8: Leaf potassium content for Cultivar Lanorma (Lan) and Cultivar Innovator (Inn). Error bars represent standard errors.

Table 4.7: Cultivar Innovator leaf nutrient contents

Treatment	N:K Ratio	K	Mg	Ca	S	P
		…………………………..mg.kg^1………………………………				
N 160 K 160	1	19512d	13926bac	35008a	6670ba	3745.7a
N 160 K 230	0.70	22806ba	12960bc	27145ba	7048a	2958.7a
N 160 K 300	0.53	22674ba	11216c	23190b	6976ba	2600.3a
N 230 K 160	1.44	19710dc	18371a	27262ba	5164bac	3317.3a
N 230 K 230	1	21254bcd	16812ba	27413ba	5482bac	3067.7a
N 230 K 300	0.77	22363b	13403bc	27363ba	6019bac	3258.0a
N 300 K 160	1.88	22184bc	14367bac	25185b	4903bc	3071.0a
N 300 K 230	1.30	23016ba	12497bc	24108b	5281bac	3100.0a
N 300 K 300	1	25096a	14367bac	24127b	5535bac	3487.0a
N 160 only	-	15681e	18254a	29237ba	4512c	3291.0a
LSD		2606.4	4793.3	8044.3	2137.2	1148.1
CV		7.14	19.29	21.13	21.79	17.49

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 4.8: Cultivar Lanorma leaf nutrient contents

Treatment	N:K Ratio	K	Mg	Ca	S	P
		……………………..……..mg.kg^{-1}……………………………				
N 160 K 160	1	23778ba	14182bcd	28592a	5834.7cb	4249.0ba
N 160 K 230	0.70	25633ba	10290d	21534b	7739.0a	3908.3ba
N 160 K 300	0.53	28099a	13430cd	25504ba	8360.3a	4146.7ba
N 230 K 160	1.44	16436c	18356ba	26383ba	4211.3ed	3243.7b
N 230 K 230	1	24719ba	12044cd	21860b	5717.0cb	4384.7a
N 230 K 300	0.77	23362ba	12248cd	23750ba	4999.3cbd	4493.a
N 300 K 160	1.88	22697b	13070cd	21514b	5495.7cb	3853.0ba
N 300 K 230	1.30	22312b	15299bc	22692ba	4671.3ced	3944.7ba
N 300 K 300	1	23362ba	11358cd	23202ba	6015.0b	4375.0a
N 160 only	-	11036d	20300a	25356ba	3537.7e	3670.3ba
LSD		5285.8	4750.6	6710.1	1259.3	1105.9
CV		13.94	19.84	16.38	13.07	16.12

**Values with the same letter within a column are not significantly different at p ≤ 0.05*

4.4 Conclusions

The two cultivars proved to differ in plant height, such that cultivar Lanorma surpassed cultivar Innovator in height. Tuber dry mass yield for cultivar Innovator increased more rapidly over harvest intervals, compared to cultivar Lanorma, which suggests that cultivar Innovator is earlier maturing than cultivar Lanorma. On the other hand, cultivar Lanorma surpassed cultivar Innovator in terms of dry leaf mass, tuber number and stolon length. This higher dry mass of tubers for cultivar Innovator and lower leaf and stem dry mass, as compared to cultivar Lanorma, made cultivar Innovator to have a significantly higher HI than cultivar Lanorma. The two cultivars were almost similar in terms of nutrient contents, particularly with respect to K. Tuber yield had a tendency of increasing at each N level as K was increased for both cultivars. This was analogous with the findings of Singh and Lal (2012). This increase in tuber yield was also associated with N:K ratios for both cultivars, such that N:K ratios greater than 1.3 seemed to supress yield.

The two cultivars varied in IPAR measurements and patterns of canopy growth. cultivar Innovator slightly surpassed cultivar Lanorma in IPAR percentage early in the season. On the other hand, cultivar Lanorma reached higher maximum IPAR than cultivar Innovator at lower and intermediate levels of N. The earlier senescence of cultivar Innovator than cultivar Lanorma further illustrates that cultivar Innovator is an early-maturing cultivar. In order to achieve maximum yield, canopy cover must reach its maximum early and natural senescence should occur unimpaired. Cultivars such as Innovator, which rapidly reach maximum IPAR and rapidly senesce, can as well be planted later in summer or early autumn, since they would still be able to complete their growth and development cycle before winter commences. As for cultivar Lanorma, late plantation could be caught by winter, which will force premature senescence and decrease yield. It is advised that cultivar Lanorma be planted earlier in the season so that it can reach senescence without being affected by winter.

CHAPTER 5

FIELD TRIAL: SOIL NUTRIENT STATUS PRIOR TO PLANTING AND AFTER HARVEST

5.1 Introduction

Determining soil nutrient status prior to planting is of great importance as it assists in informing about nutrients needed and how much of those nutrients have to be applied. Application of N and K without prior knowledge of their contents in the soil could lead to nutrient imbalances, as well as the under or over-application of those nutrients. Some soils are sufficient with respect to some nutrients and therefore application of those nutrients would be a waste of fertilizer resources. It has been documented that for a reasonable potato yield, P and K soil contents of more than 30 and 200 mg.kg^{-1} respectively are adequate and application of these nutrients would be a waste since there would not be any yield response (Doll et al. 1971; Greenwood et al. 1974; Šreka et al. 2010). Perhaps the reason why AbdelGadir et al. (2003) failed to get any yield response after K application at five levels (0, 25, 50, 75 and 100 kg.ha^{-1} K) was the high available K content of 215 mg.kg^{-1} in that soil, which was above the limit for K response. Therefore, nutrient status in the soil has to be known in order to fine tune fertilizer application.

It is also important to conduct a nutrient analysis post-harvest in order to assess nutrient uptake by the crop. Application of one nutrient may have an antagonistic or synergistic effect on another nutrient. For example, Singh and Lal (2012) applied N at four levels, (0, 75, 150 and 225 kg.ha^{-1}) and observed a significant increase in K uptake as N was increased from 0 to 75 and 75 to 150 kg.ha^{-1}. However, they observed no further K uptake increase as N was increased from 150 to 225 kg.ha^{-1}. Šreka et al. (2010) observed that N, P and K concentrations in the tuber did not predetermine tuber yield but rather, uptake was the main factor that determined tuber yield, such that higher uptake resulted in higher yield.

5.2 Materials and methods

The field trial was performed on the same field from which soil for the pot trial was collected. Prior to planting, composite samples were taken from the 5 to 15 cm and 35 to 45 cm depths and the samples were then analysed for nutrient contents. Due to limited available budget, N analysis was done only on topsoil layer (5 – 15 cm). Other nutrients were analysed on two layers (5 – 15 cm and 35 – 45 cm). Information on the N and K treatment combinations and cultivars used in the trial is presented in Chapter 4, section 4.2.1.

Table 5.1 shows the soil nutrient contents and percentage of cation exchangeable capacity thereof prior to planting. Topsoil sand, silt and clay contents were 75, 10 and 15% respectively. The subsoil had 68.1% sand, 10% silt and 21.9% clay. After harvest, the topsoil was analysed for N, K, Ca, Mg and S and subsoil was analysed for K, Ca, Mg and S. These nutrients were subjected to analysis of variance, followed by the least significant difference test (LSD ≤ 0.05) to separate means for significance using SAS for Windows (2002).

Table 5.1: Soil nutrient status before planting

	…………Topsoil (5-15 cm)…………			………Subsoil (35-45 cm)……...		
Nutrients	$mg.kg^{-1}$	$cmol.kg^{-1}$	CEC%	$mg.kg^{-1}$	$cmol.kg^{-1}$	CEC%
NO_3^-	4.24	-	-	4.37	-	-
NH_4^+	2.32	-	-	2.36	-	-
P	23.5	-	-	23.1	-	-
K	62.3	0.160	6.6	51.2	0.131	4.8
Ca	299	1.450	60.1	358.9	1.795	65.4
Na	2.88	0.013	0.5	0.3	0.001	0.04
Mg	94.55	0.788	32.7	98.2	0.819	29.8
Total CEC		2.411			2.746	

5.3 Results and discussion

Post-harvest N (NO_3^- and NH_4^+), K, Ca, Mg and S contents for the topsoil on which cultivar Lanorma was grown are shown in Table 5.2. The summary ANOVA for soil nutrient contents for both cultivars are documented in Appendix D. Ammonium level was not significantly different across treatments and was equivalent to the amount prior to planting. On the other hand, nitrate content was significantly higher at the highest level of N applied, compared to other levels of N at harvest. This supports earlier suggestions that cultivar Lanorma may have a lower N demand than most other cultivars, as it responds less (uptake and growth) to high N levels. K in the soil increased with an increase in K application level, such that treatments which received highest level of K had significantly higher K content than treatments which received lower levels of K. For cultivar Innovator, both nitrate and ammonium levels in the topsoil did not to differ across fertilizer treatments, contrary to the observation for cultivar Lanorma. N content across the three N level treatments remained in the same order at the end of the trial as compared to prior to planting. The pattern for other nutrients was almost similar to that of cultivar Lanorma (Table 5.3).

The K, Ca, Mg and S contents in subsoils for cultivars Lanorma and Innovator are shown in Tables 5.4 and 5.5 respectively. The K content in the subsoil increased with increase in applied K level (less prominent for cultivar Lanorma), especially at the lowest N level. This can probably be attributed to the fact that low application of N led to early crop senescence, which resulted in less K uptake from the soil due to a shortened life cycle. Furthermore, the higher K residues in the subsoil at higher K rates indicate that excess K was not taken up by plants, which then leached lower down into the profile.

For the control plot (no K applied), the amount of K left in the soil was less than the initial amount of K prior to planting. The same pattern was observed by Šreka et al. (2010), who reported negative surplus in N and K content at harvest when 0 $kg.ha^{-1}$ of both N and K were applied at planting. In this study, the application of K at 160 $kg.ha^{-1}$ resulted in surplus K in the topsoil for cultivar Lanorma only. Cultivar Innovator showed consistent K surplus from levels of 230 $kg.ha^{-1}$ K upwards. This could mean that K requirement for cultivar Lanorma is lower as compared to cultivar Innovator. In the sub-soil, both cultivars showed a surplus at highest K level. Lower and intermediate levels of K applied results in almost similar residual soil K level than before planting, although in some cases it was lower.

For convenient comparison, K contents in the topsoil for both cultivars at harvest are also presented graphically in Figure 5.1. Topsoil ammonium and nitrate contents for both cultivars are illustrated in Figures 5.2 and 5.3, respectively. Šreka et al. (2010) observed N surplus at harvest when as little as 140 kg.ha^{-1} N was applied, while in the current study surplus was observed at 300 N kg.ha^{-1} and with respect to cultivar Lanorma only. The deviation between the study of Šreka et al. (2010) and the current study in terms of N surplus, could be due to the differences in amount of precipitation received. Šreka et al.(2010) conducted their study under dryland farming conditions and the annual precipitation for that region was around 422 mm, while in the current study the amount of precipitation plus irrigation was 740 mm during the growing season. It follows that more N leaching would be expected in the current study and hence N surplus would be achieved only at higher N applications.

Calcium content seemed to be substantially higher at lower levels of N in the topsoil for cultivar Lanorma. This implies that calcium uptake was influenced by the rate of senescence, that is, the earlier senescence occurred, the less uptake of calcium occurred. Magnesium seemed to follow the same trend, except for the lowest level of N at the highest level of K. This implies that high levels of K may suppress magnesium uptake. Sulphur content in the topsoil did not show a clear trend with respect to treatments for cultivar Lanorma. For cultivar Innovator, topsoil calcium did not show a clear trend. Calcium content was highest at the treatment with 230 kg.ha^{-1} of both N and K, and lowest at 160 kg.ha^{-1} N and 300 kg.ha^{-1} K. Magnesium content in the topsoil was not significantly different across treatments for cultivar Innovator. Sulphur tended to be significantly higher at lowest N level, although it was not consistent. Higher S content at lower level of N could be attributed to early senescence which led to a shorter period of nutrient uptake from soil.

In the subsoil, calcium content was not significantly different for most treatments for cultivar Lanorma. Soil calcium content was highest at the treatment of 160 kg.ha^{-1} N in combination with 230 or 300 kg.ha^{-1} of N. This suggests that application of high K level may have suppressed Ca uptake due to competition. However, in cases where N application was higher, higher Ca uptake occurred due to the prolonged growing season and leaching of K within that period. Soil magnesium tended to be higher at lower levels of N in most cases for cultivar Lanorma. This implies that Mg uptake was influenced by the length of the growing period, that is, the earlier the senescence, the less uptake of Mg. Sulphur did not show any clear trend in the subsoil. For cultivar Innovator, subsoil Ca and Mg levels were not significantly different and similar to their levels prior to planting. This suggests that cultivar Innovator roots were not deep enough to take up nutrients from the subsoil layer. Sulphur was also influenced by N level, such that treatments with lower level of N had a tendency of higher sulphur content. This implies that early senescence also had an impact on sulphur uptake.

Table 5.2: Topsoil (5-15 cm) nutrient status after harvest for cultivar Lanorma

	Nutrient (mg.kg^{-1})					
Treatment	N-NO_3^-	N-NH_4^+	K	Ca	Mg	S
N160K160	4.12d	2.48a	84.70b	289.37ba	97.37ba	1.334bc
N160K230	5.38 bdc	2.62a	85.401b	291.73a	102.43a	0.733c
N160K300	4.12d	3.55a	131.17a	281.87ba	87.57bac	3.763ba
N230K160	4.67dc	2.64a	82.47b	271.43ba	80.82c	1.940bac
N230K230	5.17bdc	2.29a	86.75 b	277.57ba	94.48bac	2.977bac
N230K300	4.09d	2.06a	120.27a	248.57b	84.71bc	2.609bac
N300K160	8.7a	2.53a	84.98b	280.27ba	90.16bac	4.493a
N300K230	8.07ba	3.27a	91.13b	271.00ba	93.96bac	1.967bac
N300K300	7.38bac	2.78a	120.17a	275.30ba	93.91bac	2.089bac
N160 only	4.30dc	2.14a	53.93c	292.40a	100.89a	2.846bac
LSD	3.21	Ns	16.21	51.25	16.52	2.95
CV	33.59	34.86	10.11	10.61	10.34	63.08

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 5.3: Topsoil (5-15 cm) nutrient status after harvest for cultivar Innovator

	Nutrient (mg.kg^{-1})					
Treatment	N-NO$_3^-$	N-NH$_4^+$	K	Ca	Mg	S
N160K160	4.49a	2.67ba	61.87 dc	255.43 ba	84.37 a	4.53 d
N160K230	4.23a	2.57ba	82.67 bdc	243.73 ba	82.97 a	18.97ba
N160K300	3.98a	2.82ba	114.50 ba	232.97 b	70.47 a	24.47a
N230K160	4.68a	3.10ba	60.13 dc	268.63 ba	93.10 a	14.30 bc
N230K230	4.28a	2.62ba	79.57 bdc	318.87 a	93.07 a	6.633 dc
N230K300	3.82a	2.51ba	96.97 bac	257.03 ba	79.67 a	4.733 d
N300K160	4.70a	3.41a	76.00 bdc	261.87 ba	82.40 a	4.133 d
N300K230	4.72a	2.32b	84.00 bc	237.33 b	77.37 a	5.30 d
N300K300	4.28a	2.82ba	130.53a	257.13ba	79.73a	3.83 d
N160 only	3.86a	2.55ba	40.07 d	299.73 ba	89.27 a	3.73 d
LSD	1.89	1.08	43.3	76.66	Ns	8.29
CV	25.55	23.01	30.77	17.10	16.06	53.72

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 5.4: Subsoil (35-45 cm) nutrient status after harvest for cultivar Cultivar Lanorma

	Nutrient mg.kg^{-1}			
Treatment	K	Ca	Mg	S
N 160 K 160	41.77b	299.37ba	96.50ba	8.5ba
N 160 K 230	48.03b	308.13ba	93.90ba	7.5b
N 160 K 300	78.2a	358.8a	103.93a	15.77a
N 230 K 160	52.37b	332.93ba	105.27a	8.10ba
N 230 K 230	44.5b	256.63b	84.93ba	7.27b
N 230 K 300	57.47b	249.0b	78.67b	12.90ba
N 300 K 160	50.60b	299.50ba	85.87ba	11.30ba
N 300 K 230	54.18b	301.67ba	93.20ba	11.80ba
N 300 K 300	57.93b	291.37ba	82.97b	11.87ba
N 160 only	43.07b	292.60ba	85.37ba	8.57ba
LSD	18.52	91.81	20.5	7.83
CV	20.59	18.03	13.22	44.41

**Values with the same letter within a column are not significantly different*

Table 5.5: Subsoil (35-45 cm) nutrient status after harvest for cultivar Cultivar Innovator

	Nutrient (mg.kg $^{-1}$)			
Treatment	K	Ca	Mg	S
N 160 K 160	47.37c	358.33a	102.77a	16.23ba
N 160 K 230	53.87bc	369.63a	106.53a	20.70ba
N 160 K 300	95.20a	363.43a	117.10a	23.07a
N 230 K 160	39.83c	412.50a	129.70a	17.40ba
N 230 K 230	46.57c	352.70a	101.73a	13.47ba
N 230 K 300	75.90ba	403.90a	117.43a	10.53b
N 300 K 160	53.37bc	363.27a	105.23a	12.10b
N 300 K 230	51.10bc	369.27a	104.63a	12.07b
N 300 K 300	91.67a	323.80a	94.33a	15.87ba
N 160 only	52.23bc	391.17a	107.67a	10.53b
LSD	24.63	Ns	Ns	10.35
CV	23.82	21.04	22.62	39.53

**Values with the same letter within a column are not significantly differe*nt *at p ≤ 0.05*

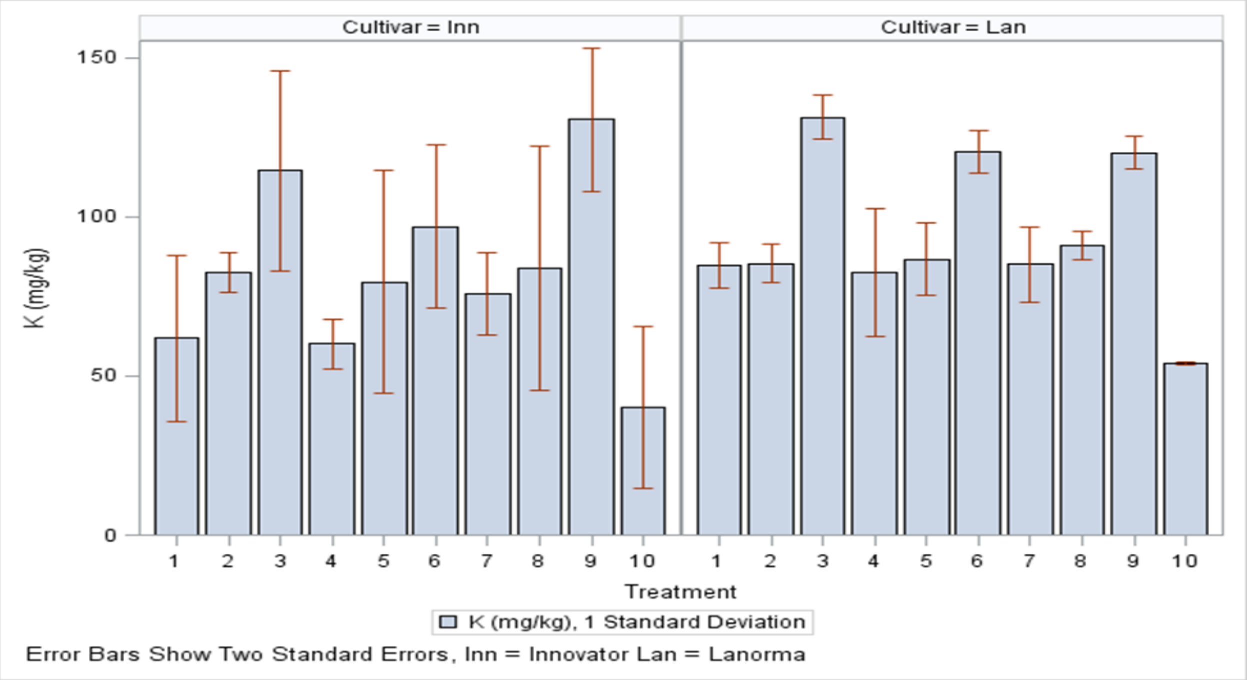


Figure 5.1: Potassium content in the topsoil after final harvest

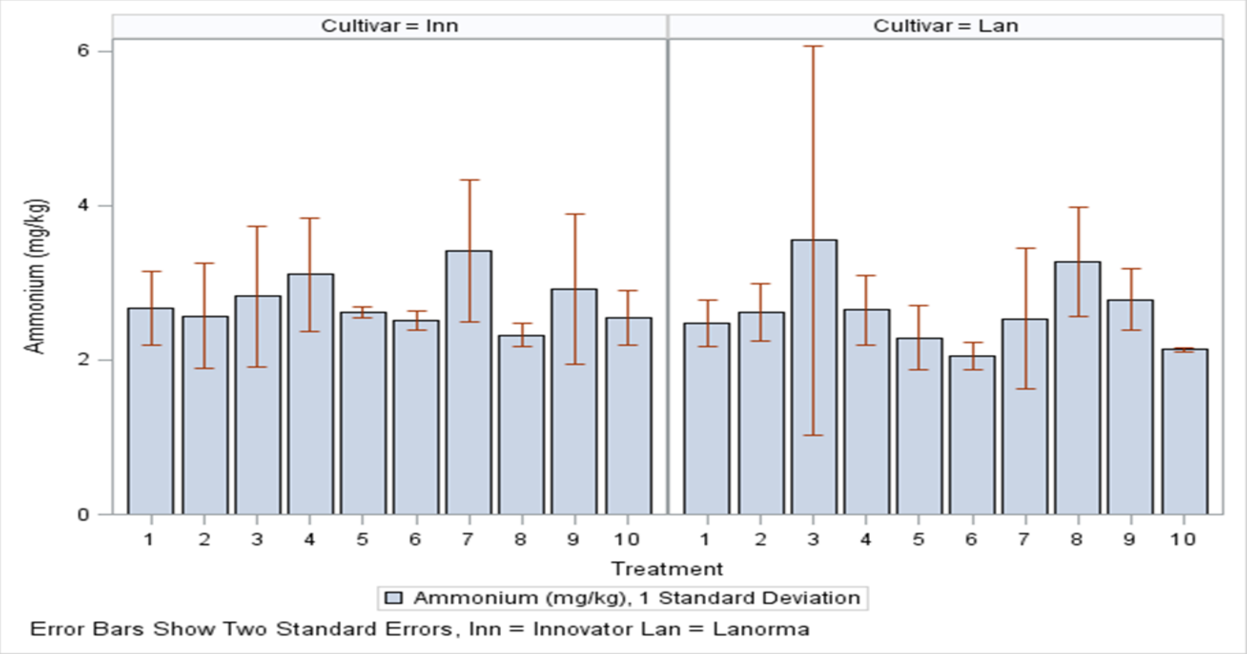


Figure 5.2: Ammonium content in the topsoil after final harvest

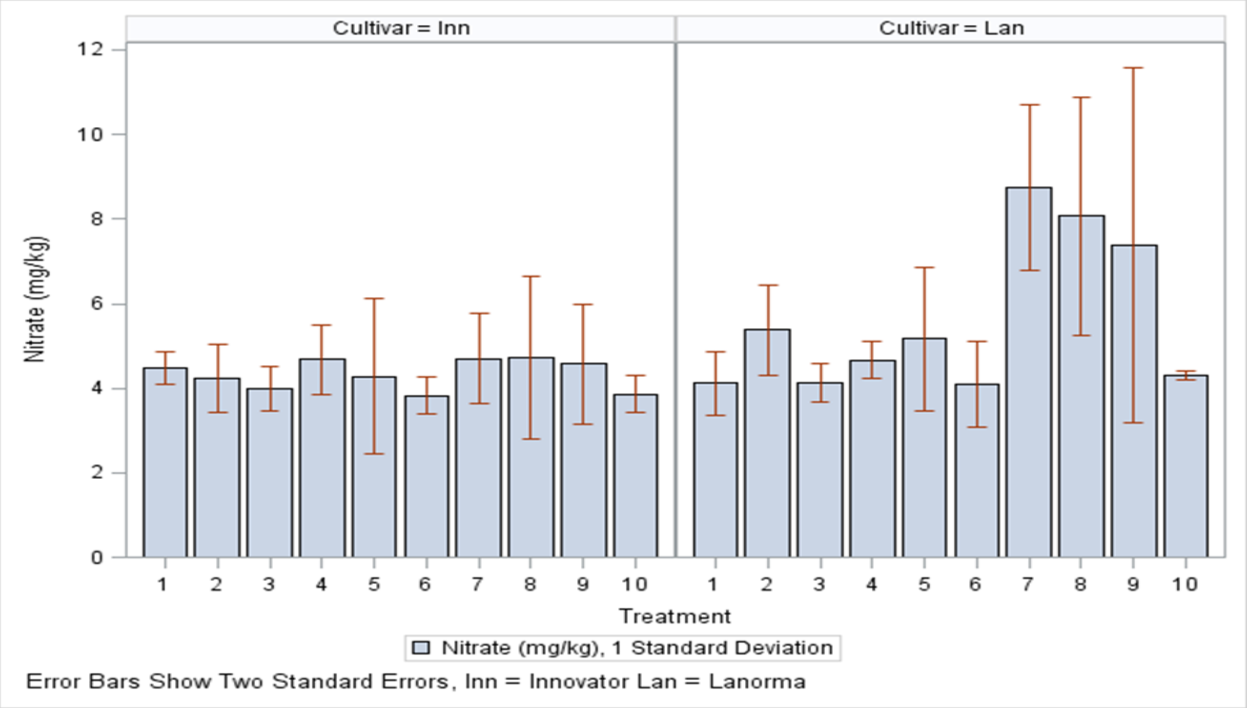


Figure 5.3: Nitrate content in the topsoil after final harvest

5.4 Conclusions

Potassium (K) application at 160 kg.ha^{-1} level resulted in a surplus of K for cultivar Lanorma in the topsoil post-harvest, while for cultivar Innovator there was no K surplus at this level. This implies that K requirement for these two cultivars do differ. K at highest level also resulted in higher residual K in the subsoil as compared prior to planting. It is therefore important to apply K not only to improve yield, but also to preserve K from being depleted in the soil. Careful consideration should be taken so that K is not over applied, since this would lead to nutrient imbalances, which may eventually lead to a decline in yield or quality. Excess K will also move down the profile, as was seen in this study, and can consequently lead to groundwater pollution.

Nitrogen in the form of ammonium after harvest was at par with soil ammonium content prior to planting. This could be due to the fact that in most soils ammonium rapidly transform into nitrate (nitrification) after application to the soil. Residual soil nitrate level was only higher with respect to Cultivar Lanorma at highest N application level. This implies that N application at this level for this cultivar in this particular soil was above optimal level. It is important to keep N at optimal level in order to minimize the risk of N leaching, which would lead to groundwater pollution.

CHAPTER 6

FIELD TRIAL: TUBER NUTRIENT CONTENTS IN RESPONSE TO NITROGEN AND POTASSIUM FERTILIZER LEVELS

6.1 Introduction

Many factors can influence potato response to fertilizer application. Such factors include genetic makeup, climatic conditions, availability of nutrients in the soil and fertilizer treatments during cultivation (Kavvadias et al. 2008). For instance, Ngobese et al. (2017) observed a significant variation in nutrient contents of different potato cultivars grown under the same agronomic conditions in South Africa. Cieslik and Sikora (1998) compared cultivars in terms of K content in tubers and observed a variation in K content between cultivars. Related studies led to the conclusion that K content in potato tubers is largely dependent on soil K content, cultivar, climate and level and kind of K applied (Cieslik and Sikora 1998). With respect to N content in potato tubers, there are conflicting reports. For example, Kavvadias et al. (2008) applied N at three levels (330, 495 and 660 kg.ha^{-1}) and K at four levels (112, 225, 450 and 675 K_2O kg.ha^{-1}) and could not find a significant change in tuber N content across treatments. On the contrary, Ruža et al. (2013) studied the effect of N application on tuber N content at seven levels of N (30, 60, 90, 120, 150, 180, and 210 kg.ha^{-1}), and they observed an increase in N tuber content with an increase in N level, until 120 kg.ha^{-1} N level, whereafter N content stabilized with further increase in N application.

Ngobese et al. (2017) stated that among other things, genetic makeup of the cultivar affects nutrient quality in potato tubers. Knowing nutrient contents of tubers can help in nutritional value and cooking decision making (Ngobese et al. 2017). Typical potato nutrient contents are well known, but most scientific study articles, including the one published in South Africa by Ngobese et al. (2017), show that potato nutrient contents based on a whole tuber, and yet different tuber tissue layers may have different nutrient compositions (Ortiz-medina et al. 2009). Potato tuber is composed of three tissue layers, namely, the skin, cortex and pith. Based on whole tuber nutritional content, Carter et al. (2008) investigated K, Ca, Mg, S and P, and noted amounts of around

18560, 259, 889, 1499 and 1990 mg.kg^{-1} respectively (dry mass basis). Almost similar values were obtained by other authors such as Warman and Havard (1998), Alvarez et al. (2006), Haase et al. (2007) and Tamasi et al. (2015).

The problem associated with this approach of analyzing nutrients based on the whole tuber is that some potato processing industries do not process the whole tuber but they only use certain tissue layers and these layers do not contribute equally in tuber mass. Across twenty cultivars evaluated, it was observed that the pith constitutes 54 – 73% of the tuber mass, with an average value of 64.3%. Cortex contributes 26 to 43%, with average of 33.8% and periderm contributes 0.8 to 3.4%, with mean value of 1.87% (Ortiz-Medina et al. 2009). When processing potatoes in the chip industry, the potato skin (periderm) is removed, while the cortex and pith are used as raw materials. This means that some nutrients would be lost when the skin is discarded. From an agronomy point of view, appropriate fertilization would result in adequate amounts of Ca in the skin, which facilitates good skin set. It is, therefore, important to know nutrient contents in each tissue layer, including the skin, since nutrients are unevenly distributed within the tuber.

6.2 Materials and methods

6.2.1 Sample preparation procedure

Eight medium size tubers (100 -170 g) per sample were washed and rinsed with distilled water. Each treatment had three samples. The tubers were peeled and then cut longitudinally into four pieces. Further, the tubers were sliced longitudinally in the pith to a depth of about 3 mm (Figure 6.1). Each slice was then reduced at each end by 1 cm in order to exclude the cortex region. The pith content and skin content of about 70 g were placed in separate glass beakers and oven dried at a temperature of 60 ^{o}C for 48 hours. Samples were then ground and analysed for N, K, Ca, Mg, S and P contents. The data was subjected to analysis of variance, followed by the least significant difference test (LSD ≤ 0.05) to separate means for significance using SAS for Windows (2002).

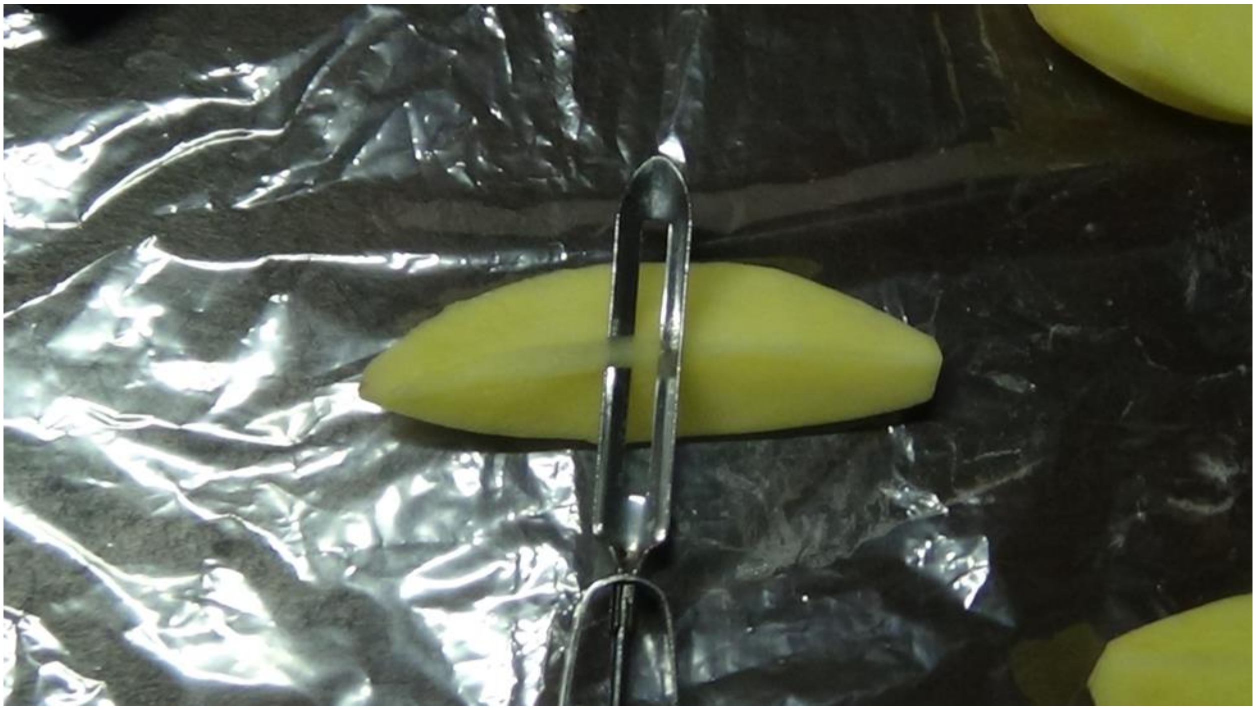


Figure 6.1: Extraction of samples from the pith

6.2.2 Tuber K, Ca, Mg, S and P analysis

For K, Ca, Mg, S and P analysis, 0.3 g of dried sample per replicate was used. A volume of 10 ml nitric acid was added to the sample and then digested using a digester. After digestion, the samples were placed in glass test tubes and distilled water was added to a volume of 35 ml. The samples were then filtrated and analysed using an ICP.

6.2.3 Tuber nitrogen analysis

Pulverised dry tuber samples of about 100 mg per replicate were weighed out with a high precision scale. Each sample was then wrapped with aluminium foil prior to placing them inside a combustion chamber. A combustion temperature of 950^{o}C ± 1°C and reduction temperature of 650°C in the reactor was used, with helium (He) as carrier gas. N analysis was then done using the Dumas method (Dumatherm$^{®}$ N Pro- Rapid Nitrogen / Protein Analyzer, C. Gerhardt GmbH & Co., Königswinter, Germany).

6.3 Results and discussions

6.3.1 Tuber pith and skin nutrient contents for cultivar Innovator

Cultivar Innovator pith nutrient contents are tabulated in Table 6.1. Pith K concentration for cultivar Innovator was substantially higher in other treatments compared to the control. The summary of ANOVA tables for tuber nutrient contents for both cultivars are documented in Appendix E. There was a tendency that at each level of N, K content increased with an increase in K level. Highest level of N application also seemed to increase K concentration in the pith. Singh and Lal (2012) applied N at four levels, 0 75, 150 and 225 $kg.ha^{-1}$ and observed a significant increase in K uptake as N was increased from 0 to 75 $kg.ha^{-1}$ and 75 to 150 $kg.ha^{-1}$, which is similar to the findings of the present study. However, in their case, K remained constant when N was increased from 150 to 225 $kg.ha^{-1}$. In the current study, nitrogen content was not significantly higher across most treatments, despite an increase in N application. This is similar to the observation by Kavvadias et al. (2008), who applied N at three levels (330, 495 and 660 $kg.ha^{-1}$) and four levels of K (112, 225, 450 and 675 K_2O $kg.ha^{-1}$), and they could also not find a significant change in N content across treatments.

In the current study, the lowest N content in the tuber pith was observed at 230 $kg.ha^{-1}$ of both N and K, while N content was highest for the control treatment (160 N and 0 K $kg.ha^{-1}$). Several reasons could explain why N concentration was higher in the absence of K. The reasons are, firstly, the antagonistic effect between K^+ and NH_4^+, and between NO_3^- and SO_4^{-2}. In the presence of K fertilizer (in this case K_2SO_4), K^+ ions would compete with NH_4^+ for uptake and this may result in less N being taken up. NO_3^- and SO_4^{-2} may also compete and less NO_3^- would be taken up by the tubers. It has also been reported that soils with insufficient K normally have higher NO_3^- in the tubers (Cieslik and Sikora 1998). Therefore, in the case of this study, the 0 $kg.ha^{-1}$ K treatment may have led to higher N uptake and translocation to the tubers.

The contents of Ca, Mg, S and P were not significantly different across most treatments. As compared to other macro nutrients, Ca content in the tubers was quite low, despite that fact that soil analysis results showed that Ca was abundant in the soil. It should be remembered that calcium content was higher in the leaves during in-season leaf analysis (Chapter 4). This proves that Ca is mainly transported to the foliage by “transpiration pull” and cannot be redistributed in the plant, hence the low Ca content of tubers (Busse and Palta 2006).

Table 6.1: Nutrient contents within the tuber pith for cultivar Innovator

	Nutrient element					
	(%)	………………………….. ($mg.kg^{-1}$)……………………..…				
Treatment	N	K	Ca	Mg	S	P
N160K160	2.14bdc	10351.0bc	354.4a	1130.8a	1849.7ba	2016.4ba
N160K230	2.20bdc	10692.0bc	179.6cb	1125.6a	1878.1ba	1988.0ba
N160K300	2.06dc	10765.0abc	241.1cb	1042.9a	1636.6b	1635.7b
N230K160	2.32bac	10292.7bc	183.0b	1111.5a	2005.3a	2126.5ba
N230K230	1.93d	10455.7bc	165.4c	1087.9a	1780.5ba	1777.2ba
N230K300	2.24bdc	11660.0ab	196.8cb	1163.8a	1959.8a	1870.5ba
N300K160	2.42ba	10610.0bc	249.6b	1108.5a	1859.4ba	2152.9a
N300K230	2.39ba	11380.7ab	220.0cb	1181.0a	1885.1ba	2215.1a
N300K300	2.45ba	12404.7a	216.5cb	1208.4a	1897.5ba	2288.6a
N160 only	2.62a	9708.4c	229.83	1086.3a	1959.8ba	2118.3ba
LSD	0.33	1679.0	84.2	204.8	295.9	512.0
CV	8.47	9.10	22.1	10.69	9.30	14.89

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 6.2 presents the K, N and other nutrient contents in the skin of cultivar Innovator. N level in the skin was highest in the absence of K application, like in the pith, followed by treatments with highest level of N. N content in the skin tended to decline significantly as N application level decreased to its lowest level. These results are consistent with the findings of Öztürk et al. (2010), who reported an increase in protein content in tubers with an increase in N application. In the current study, higher K concentration was associated with highest K application level across all levels of N and K concentration in the skin decreased with a decrease in K application. Similar to results for the pith, lowest K concentration was recorded for the control (treatment without K application), followed by the lowest K level at 230 kg.ha^{-1} of N. Ca, Mg, S and P contents seemed not to follow any trends and most treatment differences were not significant (Table 6.2).

Table 6.2: Nutrient contents in the tuber skin for cultivar Innovator

Treatment	N	K	Ca	Mg	S	P
	%	……………..………………..		mg.kg^{-1}……………………………		
N160K160	2.32dec	12906.3bac	774.6a	1379.4a	1885.1a	1766.4ba
N160K230	2.22e	12229.6bac	786.1a	1230.8b	1623.ba	1527.0ba
N160K300	2.31de	12357.9bac	802.7a	1222.3b	1687.9ba	1379.0b
N230K160	2.5bdac	11663.8dc	719.6a	1155.9cb	1829.1a	1795.5ba
N230K230	2.19e	12077.6bdca	725.8a	1237.4b	1741.6ba	1493.7ba
N230K300	2.55bac	13415.7ba	794.8a	1240.57b	1700.8ba	1498.8ba
N300K160	2.39bdec	11899.0bdc	678.0a	1126.9cb	1767.2ab	1851.9a
N300K230	2.57ba	12070.2bdca	849.9a	1162.6cb	1628.1ba	1734.0ba
N300K300	2.57ba	13617.9a	800.1a	1205.5b	1741.2ba	1770.2ba
N160 only	2.71a	10459.4d	708.6a	1042.5c	1538.2b	1523.7ba
LSD	0.24	1682.5	156.8	127.0	277.73	422.0
CV	5.76	8.05	11.71	6.21	9.50	15.14

**Values with the same letter within a column are not significantly different at p ≤ 0.05*

6.3.2 Tuber pith and skin nutrient contents for cultivar Lanorma

Nutrient contents for the tuber pith of Larnoma are shown in Table 6.3. Although there was a tendency of increasing K content with increase in K (within the same N level), differences were not significant, except for the control, for which tuber K content was significantly lower than the rest of the treatments. The N content in the pith of cultivar Lanorma tubers varied from 1.78 to 2.55%, with highest N content for the control treatment. Lowest N content was associated with combinations of high K application and lower N or intermediate N applications. Other nutrients were not significantly different for most treatments. For calcium, higher levels were obtained at highest levels of N and in most cases, Ca slightly decreased with an increase in K at each level of N. Ca levels ranged from 210 to 279 mg.kg^{-1}. It seems that a high level of K suppressed Ca uptake. Sulphur (S) content ranged from 160 to 186 mg.kg^{-1} and most treatments were not significantly different from each other. Lowest level of S was found in the control treatment, and this was due to the fact that control treatment did not receive S, since K_2SO_4 was not applied to it. P content was also not significantly different for most treatments, like Ca; however, higher contents of P were recorded at treatments with higher levels of N, but it decreased with an increase in K_2SO_4 application. Probably there was an antagonistic effect between sulphates and phosphates. Antagonistic effects between sulphates and phosphates on nutrient uptake have been reported by Aulakh and Pasricha (1977).

Table 6.3: Nutrient contents in the tuber pith for cultivar cultivar Lanorma

	N	K	Ca	Mg	S	P
Treatment	%	……………..…………………..mg.kg^{-1}………………………………				
N160K160	2.47ba	13462.4a	267.67bac	1289.9a	1668.9bc	2398.0bac
N160K230	2.02de	13579.1a	280.51bac	1372.4a	1698.0bac	2100.0c
N160K300	1.79e	13742.4a	266.43bac	1400.4a	1747.4bac	2455.4bac
N230K160	2.27bc	13477.9a	207.47c	1288.8a	1674.7bac	2322.5bac
N230K230	2.11bc	13730.7a	220.62bc	1294.2a	1617.2c	2223.3bc
N230K300	1.78e	1383.57a	251.42bc	1322.6a	1641.6bc	2242.7bc
N300K160	1.88de	14415.1a	265.45bac	1318.3a	1869.6a	2797.3a
N300K230	2.24bc	14559.0a	342.73a	1386.7a	1799.9bac	2707.0ba
N300K300	2.10dc	14104.0a	293.14ba	1421.0a	1839.2ba	2481.1bac
N160 only	2.55a	11864.1b	245.54bc	1132.2b	1603.6c	2377.0bac
LSD	0.27	1345.3	78.82	152.6	200.0	547.4
CV	8.16	5.78	17.52	6.77	6.84	13.33

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 6.4 shows nutrient contents in the skin of cultivar Lanorma. Most treatments that received K fertilizer were not significantly different in skin K content. However, K substantially increased with an increase in K application at each level of N. Tuber skin K content also tended to increase with N application. This is similar to the findings of Boydston et al. (2017), who observed an increase in K content in tubers with increase in N application. Higher levels of K were observed at 230 kg.ha^{-1} N and it increased with an increase in K level. Lowest K content was noted for the control, and this was for the obvious reason that the control did not receive any K. Second lowest K content was recorded for the treatment combination of 160 kg.ha^{-1} N and K. The highest K content was observed for the combination of 230 N and 300 K kg.ha^{-1}. For Ca, Mg, S and P, most treatments were not significantly different. Based on their observation with P content, ranging from 698 to 798 mg.kg^{-1} DM, which was substantially higher than the findings of this study, Šimkova et al. (2013) saw a significant difference in the P content among cultivars and stated that this difference was variety dependent.

Table 6.4: Nutrient contents in the tuber skin for cultivar cultivar Lanorma

Treatment	N	K	Ca	Mg	S	P
	%	………………..……………		mg.kg^{-1}……………	………………	
N160K160	2.12ed	17414bc	708.4b	1356.5ba	1549.1b	1539.6ba
N160K230	2.52ba	17480bc	837.9ba	1320.3b	1516.0b	1164.8b
N160K300	2.34bdc	19727bac	989.7ba	1622.1ba	1984.3a	1485.9ba
N230K160	2.44bac	18374bac	1079.4a	1696.7a	1976.1a	1702.6a
N230K230	2.19edc	20602ba	996.9ba	1543.1ba	1976.1a	1515.1ba
N230K300	2.52ba	21372a	806.7ba	1413.6ba	1623.8ba	1370.0ba
N300K160	2.29bedc	18884bac	910.9ba	1505.0ba	1854.4ba	1629.8ba
N300K230	2.03e	18572bac	795.1ba	1465.7ba	1717.1ba	1516.3ba
N300K300	2.24bedc	19077bac	892.5ba	1516.8ba	1725.7ba	1633.3a
N160 only	2.65a	15963c	877.0ba	1283.2b	1513.3b	1393.4ba
LSD	0.29	3871.1	296.7	365.7	397.6	384.8
CV	7.35	12.08	19.59	14.58	13.39	15.11

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 6.5 shows mean nutrient contents in the pith and skin across treatments. N, K, Mg and Ca contents were significantly higher in the skin than in the pith for both cultivars. Furthermore, K, Mg and Ca contents were significantly higher for cultivar Lanorma than cultivar Innovator. Cieslik and Sikora (1998) also reported varying potassium contents for different cultivars. According to Cieslik and Sikora (1998), K content in potatoes is largely dependent on soil K content, nature of the cultivar, climate and level and source of K applied.

Contrary to the nutrients discussed above, P content was significantly higher in the pith for both cultivars; S was not significantly different between the pith and skin for cultivar Lanorma, while for cultivar Innovator the pith had significantly higher S content than the skin.

Table 6.5: Tuber nutrient contents per cultivar (means across fertilizer treatments)

	Nutrient					
Cultivar	N	K	Mg	P	S	Ca
	%	………………..…….mg.kg^{-1}………………………………				
Lan-skin	2.33ba	18242.5a	1472.3a	1495.0c	1743.2b	889.5a
Lan-pith	2.04c	13677.0b	1322.7b	2411.a	1716.0b	264.1c
Inn-skin	2.44a	12269.7c	1200.4c	1636.0c	1714.2b	786.0b
Inn-pith	2.28b	10832.0d	1124.7d	2018.9b	1867.8a	223.6c
LSD	0.124	1118.8	73.8	149.2	98.5	58.1
CV	10.67	15.90	11.27	15.43	10.94	21.02

**Values with the same letter within a column are not significantly different at p ≤ 0.05;Lan-skin = Cultivar Lanorma skin, Inn-skin = Cultivar Innovator skin, Lan-pith = Cultivar Lanorma pith, Inn-pith = Cultivar Innovator pith.*

6.4 Conclusions

From the results of this study it can be concluded that cultivars vary in nutrient contents and nutrient contents also vary between different tuber tissues. Most nutrients seem to be more concentrated in the skin than in the pith, particularly N and K. Tuber N content tended to decrease with increase in K application. Tuber K content slightly increased with increase in K level. Tuber K content also increased with increase in N level, which can probably be attributed to longer growth duration associated with higher N rates.

CHAPTER 7

FIELD TRIAL: FINAL TUBER YIELD, SIZE DISTRIBUTION AND NUTRIENT USE EFFICIENCY RESPONSE TO NITROGEN AND POTASSIUM FERTILIZER LEVELS

7.1 Introduction

Potato yield has been observed in studies to respond positively to adequate application of both N and K. Nitrogen has been known to have more influence on yield than K, as was documented earlier in Chapter 2. Nitrogen promotes rapid canopy cover and a deficiency leads to early defoliation (as elaborated in Chapter 4), which eventually leads to reduction in yield. For K, yield responds positively until an optimal K level is achieved, but beyond the optimal level, K uptake increases while yield remains constant (Allison et al. 2001; AbdelGadir et al. 2003; Yan et al. 2005; Guo 2007; Karam et al. 2009; Kang et al. 2014). On the other hand, Kang et al. (2014) reported that potato yield does not respond to K application if K is abundant in the soil. Other authors such as Yan et al. (2005), Li et al. (2006), Xia and Guo (2008), and (Jiang 2009) have also observed the same trend on soils with high K content.

Nutrient efficiency can be defined as the ability of a plant to achieve high yield under limiting conditions of a particular nutrient (Soratto 2015). According to Wang et al. (2010a), nutrient efficiency can be classified into two, namely, nutrient use efficiency and nutrient uptake efficiency. The latter is defined as the capability of a plant to take up the nutrient under observation from the soil, while the former is defined as the capability of a plant to produce biomass or a product of economic interest using that taken nutrient (Wang et al. 2010a).

Appropriate application levels of N and K would not only result in increasing yield and improving tuber quality, but it would also influence tuber size distribution. When it comes to marketability, tuber size distribution plays an important role. In this regard, medium and large size tubers are preferrable over small tubers. Some authors observed the influence of K on tuber size distribution. For example, Karam et al. (2009) examined two cultivars, Derby and Spunta, at four levels of potassium oxide (K_2O) (0, 96, 196 and 288 $kg.ha^{-1}$) and observed a significant increase in medium and large tuber size with an increase in K level up to 196 kg.ha^{-1} K_2O, at constant N and P. No further increase in tuber size above this level of K was observed. The results of Moinuddin et al. (2004) and Moinuddin et al. (2005) were analogous to those of Karam et al. (2009), while Singh (1997) observed conflicting results, and documented that medium and large tuber size decrease with an increase in K level. These conflicting reports could be attributed to different soil, environmental and climatic conditions under which these researches were conducted. It is therefore important to quantify yield and size distribution based on cultural practices such as fertilizer management and also taking into consideration the prevailing climatic conditions.

7.2 Materials and methods

Tuber yield observations were made on the same field trial for which growth, soil and tuber nutrient results are reported in Chapters 4 to 6. At final harvest, two inner rows (excluding borders) per replicate plot were harvested with a commercial harvester. Tuber mass obtained per plot was converted into mass per hectare. Data was subjected to analysis of variance, followed by the least significant difference ($LSD \leq 0.05$) test to separate yield means for significance using SAS for windows (2002). Yield attained was compared to potential yield based on local fertilizer guidelines.

For tuber size distribution, tubers were characterized as small (<100 g), medium (100 – 170 g) or large (>170 g). The mass per size class was recorded and expressed as percentage of the total mass per treatment per cultivar. Since control plot had 0 kg.ha^{-1} K and 160 kg.ha^{-1} N application, K responsiveness was conducted at 160 kg.ha^{-1} K at the same level of N (160 kg.ha^{-1}). The responsiveness was calculated using Equations 7.1. Yield at 0 kg.ha^{-1} K was compared with yield at 160 kg.ha^{-1} K at the same level of N (160 kg.ha^{-1}) in order to see if yield varied significantly. Nitrogen use efficiency (NUE) and potassium use efficiency (KUE), commonly known as partial factor productivity (PFP) were calculated to evaluate the efficiencies. Equation 7.2 was used to calculate PFP.

$$\text{Responsiveness (\%)} = \frac{Y-K}{Y+K} \times 100 \qquad \text{Equation 7.1}$$

where Y-K is the yield without K application, and Y+ K is the yield with K application.

$$\mathrm{PFP} = \frac{Y}{np} \qquad \text{Equation 7.2}$$

where Y represents yield in kg.ha^{-1} and np is the amount of the particular nutrient applied in kg.ha^{-1}.

7.3 Results and discussion

7.3.1 Tuber yield as affected by nitrogen and potassium

The ANOVA summaries for cultivars Innovator and Lanorma yields are documented in Appendix F (Tables F.1 and F.2 for cultivars Innovator and Lanorma respectively). Figure 7.1 shows yield per fertilizer treatment per cultivar. For both cultivars, the highest yield was attained at 300 kg.ha^{-1} N and 300 kg.ha^{-1} K and this highest yield was significantly higher than the yield of all other treatments. The corresponding N:K ratio for this particular treatment was one. For cultivar Innovator, the highest yield was 51.0 t.ha^{-1} and for cultivar Lanorma it was 64.2 t.ha^{-1}. The lowest yield for cultivar Innovator was recorded at N 160 and K 300 kg.ha^{-1} (N:K ratio 0.53), followed by the control. The yields of the latter two treatments were not significantly different from the yields at N 160 and K 160 kg.ha^{-1} and that of N160 and K230 kg.ha^{-1}. For cultivar Lanorma, the lowest yield was observed for the control, which was significantly lower than the rest, followed by N 160 and K 160 kg.ha^{-1} and then N 160 and K 300 kg.ha^{-1}. Based on N:K ratios, with exception of the lowest level of N, nutrient ratio proved to play a major role in yield. It can be clearly seen that at levels of 230 and 300 kg.ha^{-1} N, N:K ratios between 0.77 to 1 had significantly higher yield compared to ratios that ranged from 1.30 to 1.88. This shows that there is an interaction between N and K, provided that none of the two nutrients are limiting. These results are quite similar to the findings of Singh and Lal (2012). In their study, they observed no significant differences between two combinations of N and K, 225 kg.ha^{-1} N and 150 kg.ha^{-1} K (N:K ratio 1.5) and 150 kg.ha^{-1} of both N and K (N:K ratio 1). This means that without wasting much fertiliser resources, optimal yield can be obtained by increasing both nutrients in appropriate ratios in order to avoid nutrient imbalances.

It is conspicuous that yield increases as N is increased. For cultivar Innovator, yield increased slightly with an increase in K per N level. For cultivar Lanorma, at 160 and 230 N kg.ha^{-1}, the yield increases as K is increased from 160 to 230 kg.ha^{-1} per hectare and then slightly droped at 300 kg.ha^{-1} K. At 300 kg.ha^{-1} N the trend was different, such that a higher yield was achieved at 300 kg.ha^{-1} K. Generally, yield responded more to N than to K application. Table 7.1 shows yield response to N across the three levels of K and yield response to K across the three levels of N. It can be seen that for both cultivars, yield increases significantly with an increase in N (means across K levels). On the other hand, yield increased significantly with K application up to 230 kg.ha^{-1} and further increase in K did not lead to an increase in yield. The results of this study are similar to the findings of Tiemens-Hulscher et al. (2014), who reported that higher levels of N resulted in higher AUCCPC, which implies prolonged higher IPAR values, resulting in higher yield. High N level results in quicker canopy cover development and it also prolongs the growing season, which maximizes the time frame for light interception for synthesis of DM.

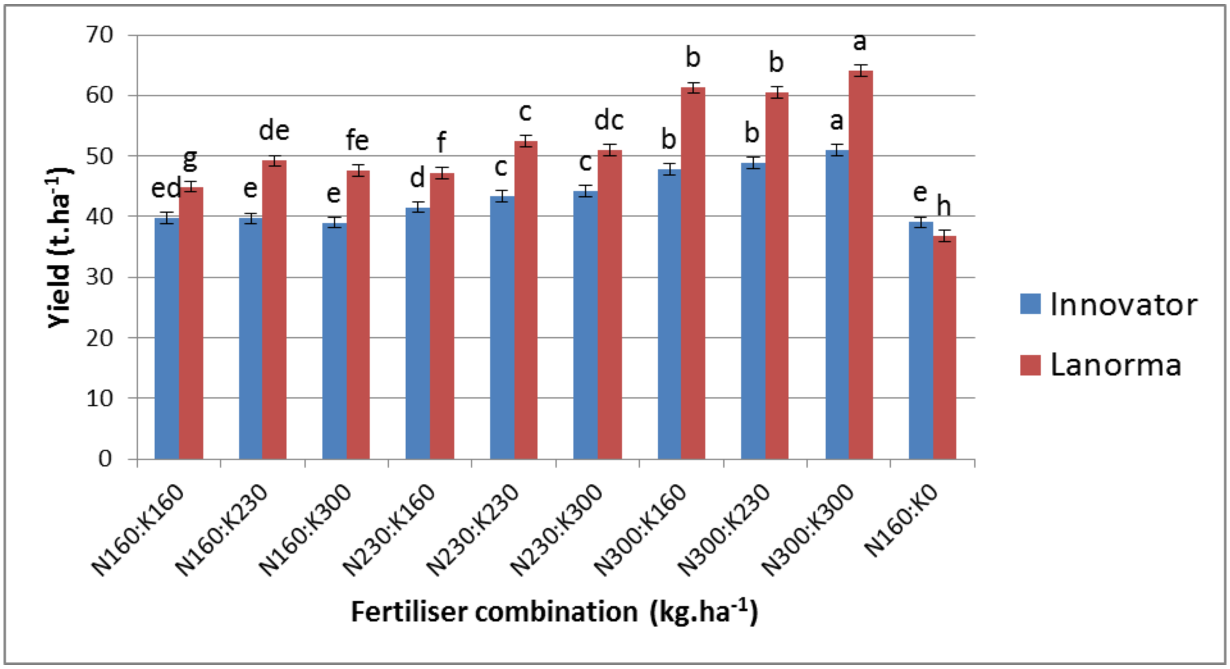


Figure 7.1: Tuber yield per cultivar at final harvest, N and K represents nitrogen and potassium the preceding values represent application level of these two nutrients. Yield with the same letter per cultivar are not significantly different at $p \leq 0.05$. Innovator LSD = 1.81, Lanorma LSD = 1.86.

Table 7.1: Effect of different levels of N and K on tuber yield of two potato cultivars.

Application	……Lanorma yield (kg.ha^{-1})…….		…..Innovator yield (kg.ha^{-1})……	
(kg.ha^{-1})	N	K	N	K
160	47.24c	51.14b	39.49c	43.06b
230	50.21b	54.06a	43.08b	43.98ba
300	61.99a	54.25a	49.23a	44.76a
LSD	2.1459	0.9146	1.2954	1.2452
CV	1.675	1.675	3.185	3.185

**means within N columns are across K levels, means within K columns are across N levels. Values with the same letter within a column are not significantly different at $p \leq 0.05$*

The lower yield observed for cultivar Innovator as compared to that of cultivar Lanorma could be due to the duration of growth for cultivar Innovator, which was quite short compared to cultivar Lanorma. A longer active leaf growth duration is one of the main factors that influence yield and this factor restricts yield of early maturing cultivars (Lahlou et al. 2003). It can be gathered, therefore, that lower yield for cultivar Innovator was due to limited active leaf growth duration and longevity, which was lower than that of cultivar Lanorma. The short growth duration of cultivar Innovator is a genetic characteristic, which this cultivar inherited from its one parent, Shepody, an early maturing cultivar. When Shepody was compared with three other cultivars in an earlier study in the same area (Pretoria), it accumulated DM more rapidly than other cultivars, but eventually had significantly lower yield than the rest (Gewemew et al. 2007).

Molahlehi et al. (2013) compared early maturing cultivars with late maturing cultivars at different locations in Lesotho (a country surrounded by South Africa) and observed that late-maturing cultivars out-competed early maturing cultivars in all locations. This is similar to the findings of the current study in that cultivar Innovator, which matured earlier than cultivar Lanorma, had a lower yield. This also confirms that higher yield is attained when days to maturity are longer, a claim that has been published (Camire 2009). On the other hand, results of this study conflict with those of Tiemens-Hulscher et al. (2014), who observed more intense increase in yield in early maturing cultivars at higher level of N than in late maturing cultivars. However, in their study, Tiemens-Hulscher et al. (2014) reported early infestation of late maturing cultivars with late blight, which resulted in a low response to N application, compared to early maturing cultivars.

7.3.2 Comparison of yield attained with current South African potato production fertiliser guidelines

In South Africa, potato fertilizer levels are recommended based on target yield (Steyn and du Plessis 2012). Table 7.2 is a compilation of some extracts from Steyn and du Plessis (2012), showing potential tuber yield based on N, P and K for soils similar to the one used in this study (soils with clay content of 10 - 20%). Based on the South African guidelines, cultivar Innovator and cultivar Lanorma performed well at lower levels of K and N. For example, 160 kg.ha^{-1} for both K and N would be expected to yield around 30 t.ha^{-1}, yet these cultivars yielded 39.77 and 44.95 t.ha^{-1} for cultivar Innovator and cultivar Lanorma, respectively. Intermediate levels of N and K (230 kg.ha^{-1}) would be expected to yield around 50 t.ha^{-1} according to the guidelines. However, Innovator gave a lower yield of 44.26 t.ha^{-1}, while cultivar Lanorma gave slightly higher yield of 52.44 t.ha^{-1}, compared to the guidelines. Since the applied P in the current study was 70 kg.ha^{-1}, the yield for cultivar Innovator could probably have been restricted by P, taking into consideration that the optimal P level for 50 t.ha^{-1} yield would be 90 kg.ha^{-1} for such a soil. At highest levels of N and K, the yield would be expected to be around 80 t.ha^{-1}, but both cultivars fell short of the potential yield. Limited P application would have thwarted the potential of these cultivars at these levels of N and K, since the corresponding P level needed would be 120 kg.ha^{-1}.

Table 7.2: Nitrogen, P and K fertilizer recommendations (kg.ha^{-1}) for different yield potentials under irrigation on soils with clay content of 10 - 20%

Soil nutrient contents (mg.kg^{-1})			……….……….Yield potential (ton.ha^{-1})…….……………….					
			30	**40**	**50**	**60**	**70**	**80**
			……………..…N fertilization (kg.ha^{-1})……………………					
……P content (mg.kg-^{1})…..			150	190	220	240	260	280
BRAY1	BRAY2	OLSEN	………………..P fertilization (kg.ha^{-1})……………….……					
20-25	25-32	12-15	70	80	90	100	110	120
K content (mg.kg^{-1})			……………..…K fertilization (kg.ha^{-1})..…………………					
50- 70			170	200	230	270	300	320

**Each column shows yield potential (in bold) and then recommended N, P and K.*

7.3.3 Responsiveness at 160 kg.ha^{-1} K, nitrogen use efficiency (NUE) and potassium use efficiency (KUE) per treatment combination

Table 7.3 shows the K responsiveness for the two cultivars at 0 and 160 kg.ha^{-1} K. Cultivar Innovator was more responsive to K than cultivar Lanorma at 0 kg.ha^{-1} K application. On the contrary, cultivar Lanorma was more responsive to K when K level was increased to 160 kg.ha^{-1}. Figure 7.2 shows K responsiveness for both cultivars. For cultivar Innovator, yield was not significantly affected as K was increased from 0 to 160 kg.ha^{-1}, hinting that cultivar Innovator is not that responsive to K application. Cultivar Innovator can, therefore, be regarded as more preferable than cultivar Lanorma in cases where K resources are limited.

Table 7.3: Yield response of two potato cultivars to K at constant L level of 160 kg.ha^{-1}

Cultivar	0 kg.ha^{-1} K	160 kg.ha^{-1} K	LSD	CV
Lanorma	36.84aA	44.95aB	2.08	2.24
Innovator	39.06bA	39.77bA	1.57	1.76
LSD	1.93	1.74		
CV	2.25	2.24		

**Values with the same capital letter within a row are not significantly different; values with the same small letter within a column are not significantly different at $p \leq 0.05$.*

Nitrogen use efficiency (NUE) and potassium use efficiency (KUE) values for cultivars Innovator and Lanorma are presented in Tables 7.4 and 7.5, respectively. NUE seemed to be higher at lower levels of N across all K levels, and it declined with increase in N level for both cultivars. Likewise, KUE declined with increase in K across N levels. A decline in a particular nutrient use efficiency with an increase in level of that nutrient applied has been documented in literature (Fontes et al. 2010, Zhang et al. 2017 & Wang et al. 2019). Both NUE and KUE were not clearly influenced by N:K ratios. NUE for cultivar Innovator increased at a specific level of N with increase in K, except at the lowest level of N. For cultivar Lanorma, at the lowest and intermediate levels of N, NUE increased with increase in K level. The trend was not so clear at the highest level of N. KUE tended to increase with increase in N for both cultivars. Cultivar Lanorma generally had higher NUE and KUE than cultivar Innovator due to the fact that it had higher yield than cultivar Innovator. Variation in NUE amongst potato cultivars have been observed before, such that some cultivars needed only one third the dose of N supplied to other cultivars to achieve the same yield (Dua et al. 2007). For cultivar Innovator, NUE varied from 159 to 248 kg.kg^{-1} and for cultivar Lanorma NUE ranged from 201.73 to 307.50 kg.kg^{-1}. Dua et al. (2007) observed NUE values ranging from 110 to 400 kg.kg^{-1} and therefore, the findings of this study fall within those limits.

Table 7.4: Nitrogen and potassium use efficiencies (kg potato kg^{-1} nutrient applied) per treatment for cultivar Innovator

Treatment	N:K ratio	NUE (kg.kg^{-1})	KUE (kg.kg^{-1})
N160K160	1	248.6	248.6
N160K230	0.70	248.1	172.6
N160K300	0.53	243.8	130.0
N230K160	1.44	180.7	259.7
N230K230	1	188.7	188.7
N230K300	0.77	192.4	147.5
N300K160	1.88	159.5	299.1
N300K230	1.30	162.7	212.3
N300K300	1	170.0	170.0
N160 only	-	244.1	

Table 7.5: Nitrogen and potassium use efficiencies (kg potato kg^{-1} nutrient applied) for cultivar Lanorma

Treatment	N:K ratio	NUE (kg.kg^{-1})	KUE (kg.kg^{-1})
N160K160	1	280.9	280.9
N160K230	0.70	307.5	213.9
N160K300	0.53	297.4	158.6
N230K160	1.44	205.2	295.0
N230K230	1	228.0	228.0
N230K300	0.77	221.7	170.0
N300K160	1.88	204.2	382.9
N300K230	1.30	201.7	263.1
N300K300	1	214.0	214
N160 only	-	230.3	

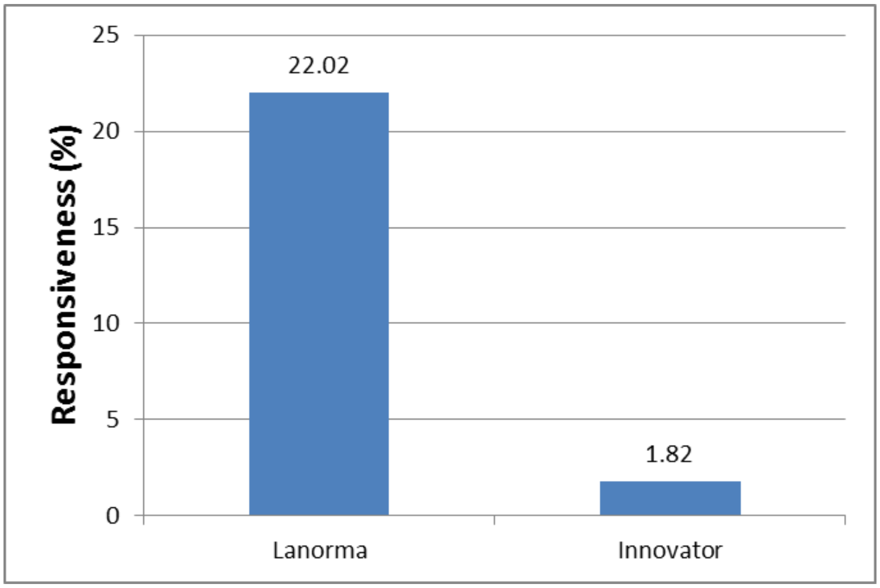


Figure 7.2: Responsiveness to K for two cultivars at 160 kg.ha^{-1}

7.3.4 Tuber size distribution

The results show that the two cultivars varied in tuber size distribution, which was greatly influenced by N level, more so than by K level. At 160 kg.ha^{-1} K across the three levels of N, the percentage of medium and large tubers tended to increase with N increase at the expense of smaller tubers for both cultivars, but more so for cultivar Innovator than for cultivar Lanorma (Figure 7.3). Generally, cultivar Innovator had a higher proportion of large tubers than cultivar Lanorma, but on the other hand, cultivar Lanorma had a higher proportion of medium tubers than cultivar Innovator. It should also be noted that large tubers for cultivar Lanorma at this level of K were weighing around 200 g per tuber, while for cultivar Innovator most of these large tubers weighed above 250 g per tuber. Both cultivars allocated smallest proportion of assimilates to small sized tubers, with cultivar Innovator yielding about 12% and cultivar Lanorma around 10% smalls. Figures 7.4 and 7.5 show cultivar Lanorma and cultivar Innovator tubers at 160 kg.ha^{-1} N and K during final harvest. From these figures, it can be seen that cultivar Innovator had larger tubers as compared to cultivar Lanorma. As K was increased to 230 kg.ha^{-1} across the three levels of N (Figure 7.6), the proportion of big tubers seemed to be constant, however smaller tubers seemed to decrease for both cultivars. At 300 kg.ha^{-1} K across three levels of N, percentage of large tubers for cultivar Innovator seemed to increase mainly at the expense of medium tubers as N was increased. On the other hand, the proportion of large tubers for cultivar Lanorma increased at the expense of both medium and small tubers (Figure 7.7). It should be noted that at lowest level of N, there were no incidences of malformed tubers for both cultivars, but as N was increased to 230 kg.ha^{-1}, the incidences of malformed tubers were observed for cultivar Innovator, and more so at the highest level of N. On the other hand, cultivar Lanorma did not have any incidences of malformed tubers across all treatments.

These results are similar to the results of Sun et al. (2017), who observed an increase in large tubers (>170 g) with increase in N application. At 300 kg.ha^{-1} N, the percentage of large tubers increased for both cultivars, with some observable differences between the two cultivars with regards to some attributes. From the observations of this study, tuber size distribution was mainly correlated with N level. This is in contrary to the findings of Sharma and Aroma (1987), who observed an increase in medium and large tubers at the expense of small tuber number with increase in both N and K, rather than with increase in N only. Since tuber size seemed to increase more with increase in N level, it then implies that N:K ratios equal or greater than one, particularly at higher N level would have higher proportion of large tubers. Higher proportion of medium and smaller tubers would be obtained mainly at lower levels of N irrespective of N:K ratios.

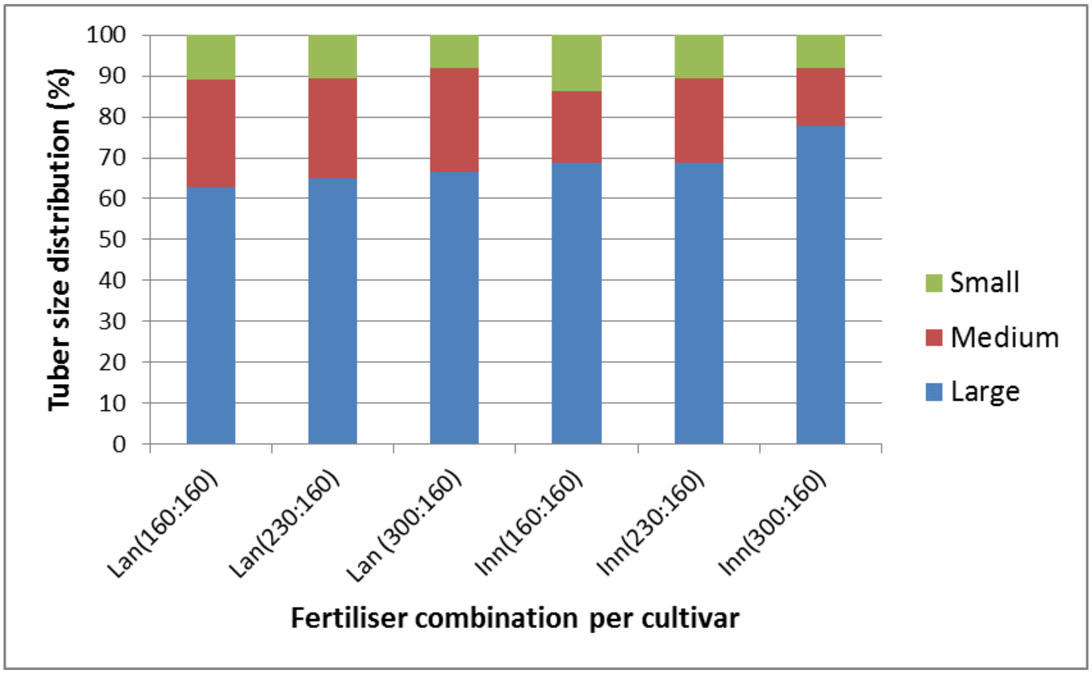


Figure 7.3: Tuber size distribution at 160 kg.ha^{-1} K across three levels of N

**Lan = cultivar Lanorma, Inn = cultivar Innovator, values in brackets are N and K levels respectively (kg.ha^{-1})*

Figure 7.4: Cultivar Lanorma tubers at 160 kg.ha^{-1} of N and K

Figure 7. 5: Cultivar Innovator tubers at 160 kg.ha^{-1} of N and K

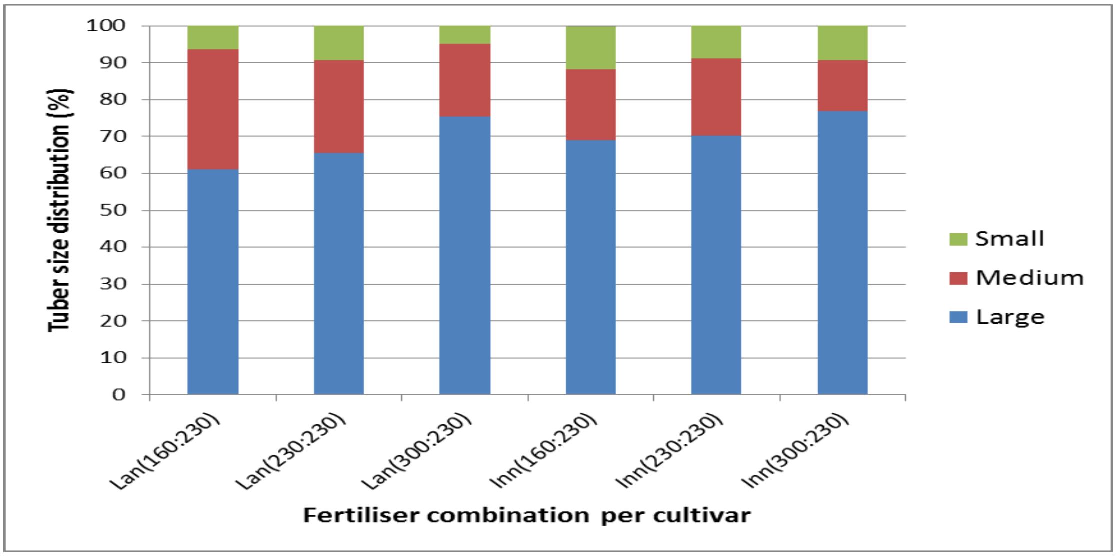


Figure 7.6: Tubers size distribution at 230 kg.ha^{-1} K across three levels of N

**Lan = cultivar Lanorma, Inn = cultivar Innovator, values in brackets are N and K level respectively*

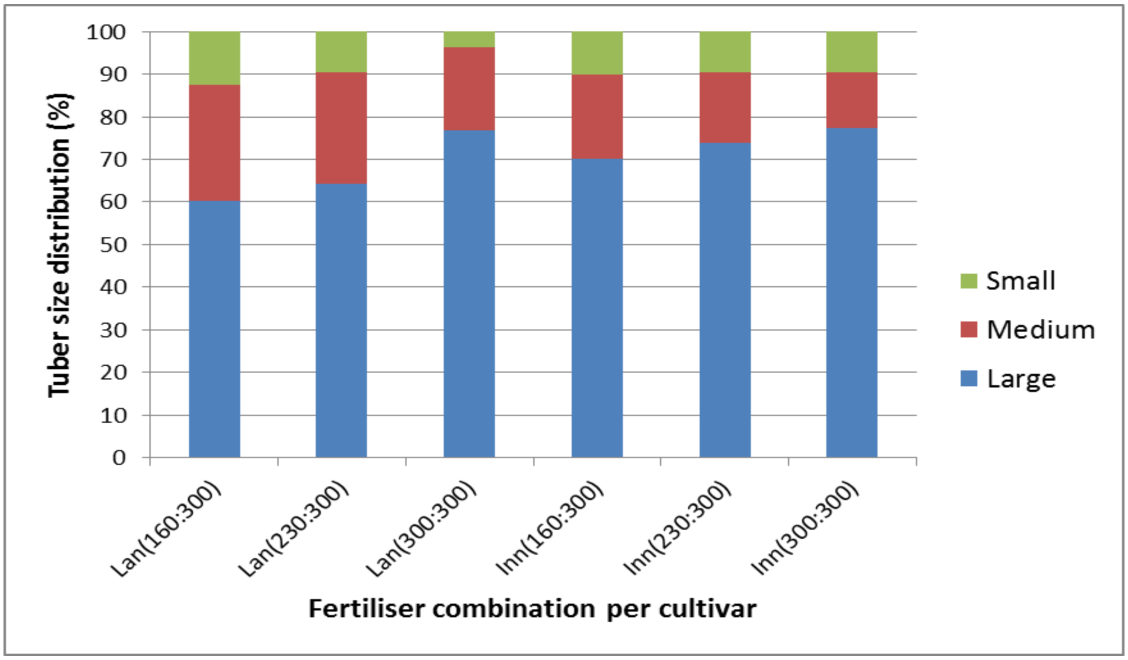


Figure 7.7: Tubers size distribution at 300 kg.ha^{-1} K across three levels of N*Lan = cultivar Lanorma, Inn = cultivar Innovator, values in brackets are N and K level respectively

7.4 Conclusions

Cultivar Lanorma generally gave significantly higher tuber yields than cultivar Innovator. On the other hand, cultivar Innovator had bigger tubers than cultivar Lanorma. For both cultivars yield increased as N was increased across the three K levels. Highest N application resulted not only in highest proportion of large tuber size, but also with more malformed tubers for cultivar Innovator, which rendered them unmarketable. Therefore, for the particular soil and conditions, the optimal N level would be 230 $kg.ha^{-1}$ for cultivar Innovator. For cultivar Innovator, more research may have to be conducted at lower N levels in order to find the optimum N level that will result in not too big tubers, in order to reduce incidences of malformed tubers. At a specific N level, yield increased slightly with increase in K level up to 230 $kg.ha^{-1}$ in most cases. Yield also proved to be sensitive to N:K ratios, such that ratios that ranged from 0.77 to 1 usually had statistically higher yields than higher ratios, except at the lowest level of N (160 $kg.ha^{-1}$). It is then concluded that indeed optimal N and K with appropriate N:K ratios result in better yield, as was observed by other authors such as Zhang et al. (2010). Therefore, it is not advisable to increment one of the two elements without considering the level of another nutrient. These results concur with literature reports that best plant growth and development is associated with optimal N:K ratios, while inappropriate N:K ratios result in nutrient imbalances, leading to sub-optimal plant growth and lower yields (Xie et al. 2000; Wells and Wood 2007). Tuber yield was more influenced by N level, such that higher N level resulted in higher proportion of large tubers. N:K ratio < 1 resulted in more small and medium size tubers than higher ratios. NUE decreased when N level increased, likewise KUE decreased when there was an increase in K level. Finally, NUE tended to increase when the K level increased, and likewise, KUE increased when the N level increased.

CHAPTER 8

FIELD TRIAL: TUBER QUALITY RESPONSE TO NITROGEN AND POTASSIUM FERTILIZER LEVELS

8.1 Introduction

In order for potato tubers to qualify for processing, they must have optimal specific gravity, higher dry matter content, acceptable chip colour and low reducing sugars (Solaiman et al. 2015). The quality attributes are largely affected by genetic make-up and fertilizer management. Some potato cultivars are not suitable for processing due to low dry matter content (Kabira and Berga 2003). On the other hand, some cultivars can be influenced by the amount and kind of fertilizer to have adequate dry matter content and SG for processing (Solaiman et al. 2015). Therefore, researchers should effectively inform farmers about varieties and appropriate fertilizer management which would result in better quality, as well as inform them in decision making about the most suitable end use (Elfnesh et al. 2011).

According to Steyn et al. (2009), SG is a major attribute that determines the suitability of tubers for processing and it is directly proportional to DM content. Tubers with higher DM content have lower water content (Steyn et al. 2009). Different authors stated different suitable SG values for processing in literature. According to Mosley and Chase (1993), potato tuber SG can be classified as low (1.060 to 1.069), medium (1.070 to 1.079) and high (1.080 to 1.089). On the other hand, Fitzpatrick et al. (1964) stated that SG values less than 1.077 are considered to be low, those between 1.077 and 1.086 are considered to be intermediate, and those more than 1.086 are considered to be high. Kabira and Berga (2003) suggested a minimum SG value of 1.080 as appropriate for processing, while Somsen et al. (2004) concluded that the SG value of 1.075 or higher is acceptable for processing. Solaiman et al. (2015) stated a much lower SG value of 1.070 as still appropriate for processing. Although higher SG values are necessary for processing, they should not exceed 1.089, as such values and above would render tubers unsuitable for processing due to hardness and brittleness of the chips (Mosley & Chase 1993).

Tuber dry matter percentage can also determine the suitability of tubers for processing (NIVA 2002). Cacace et al. (1994) suggested that dry matter content values can be assembled into three groups, namely, high dry matter content (higher than 20.0%), intermediate (dry matter content between 18.0 and 19.9%), and low (dry matter content lower than 18.0%). According to NIVA (2002), dry matter contents must range from 20 to 24% to be rendered suitable for French fries; while it should range from 22 to 24% for chips; and for the flakes industry it should be more than 21%.

Cultivars do vary in both chip colour and texture (Abong and Kariba 2011). Chip colour is a factor that is taken into consideration for processing. Tubers may have higher values of both SG and DM content but they may not be acceptable for processing if the colour is inappropriate. According to De Freitas et al. (2012), chip colour is most acceptable if it is golden yellow. Generally, lighter coloured chips are normally acceptable, while dark coloured chips are not. Dark coloured chips are a result of a reaction between reducing sugars (glucose and fructose) and the amino acid lysine and proteins (Feltran 2004). This reaction is known as the Maillard reaction and such chips are not only dark but they also have a bitter taste, which renders them unmarketable (Melito et al. 2017). Permissible limits for the content of reducing sugars range from 0.5% to 2%. Reducing sugar content above 2% is unacceptable for processing (Feltran 2004). However, Moreira et al. (1999) advocated for stricter reducing sugar content of below 0.25% and that chips are most suitable if reducing sugars contribute 0.1% or less. According to Solaiman et al. (2015), fried chips are major contributors of acrylamide, a suspected carcinogen. Acrylamide formation is mainly caused by the Maillard reaction (Pedreschi et al. 2005). Cultivars with low reducing sugars do not only positively affect chip colour, but also reduce the formation of acrylamide, which is formed during processing in the presence of abundant reducing sugars (Sun et al. 2017).

Tubers are susceptible to quality deterioration after storage, in particular, with respect to tuber mass loss. For example, tuber mass loss was observed by Golmohammadi and Afkari-Syyah (2013) after five weeks of storage. The rate of tuber mass loss can be controlled by nutrient management. For example, Singh and Lal (2012) stored tubers for

90 days and discovered tuber mass loss of 7.8% when K was applied at 83 kg.ha^{-1} compared to 10.62% mass loss at 0 kg.ha^{-1} K. This implies that K plays a positive role in enhancing tuber storage life. This improvement in tuber storage life is associated with the ability of K to retard senescence and also K is capable of inhibiting physiological disorders (Martin-Prevel, 1989). It is known that K does not only extend shelf life of tubers, but also improves the storage quality of tubers (Martin-Prevel 1989; Perrenoud 1993).

8.2 Materials and methods

Eight medium-sized (100 – 170 g) tubers free of defects were randomly sampled per treatment plot and specific gravity was determined according to the underwater weighing method as illustrated in Chapter 3 section 3.1.2 (USDA, 1997). In the use of this equation, the criterion for assessing the suitability for processing was adopted from Somsen et al. (2004), such that SG values below 1.075 were considered unsuitable for processing.

Another eight medium tubers free of defects were randomly sampled for determination of DM%. The tuber samples were weighed fresh, diced into small pieces, dried at 60^{o}C until constant mass and re-weighed. Dry matter content was then calculated according to Equation 8.1. The criterion for characterising the suitability of tubers based on dry matter content was adopted from NIVA (2002), as explained earlier.

$$\mathrm{DM}\ \% = \frac{dry\ mass}{fresh\ mass} \times 100 \qquad \text{Equation 8.1}$$

For chip colour analysis, 10 medium-sized tubers without defects were selected per replicate. These were taken to ARC-VOP for chip colour determination. The scoring was such that the lighter the chip colour, the higher the score and the more acceptable the chip. A chip colour score below 50 was considered unsuitable for processing.

For assessment of tuber mass loss, a sample of ±10 kg tubers was taken per replicate plot and packed in 10 kg commercial potato bags. Only tubers free from defects were used and the preference was to use medium-sized potatoes. For treatments which received highest N level, medium-sized tubers were few and most of the potatoes used for those treatments were large tubers. The bagged tubers were then weighed, stored for two months in a storage room at a temperature of 18ºC and re-weighed to assess mass loss.

SG, DM% and chip colour scores per fertilizer combination per cultivar were subjected to analysis of variance, followed by the least significant difference (LSD ≤ 0.05) test to separate means in order to find variation among treatments using SAS for Windows (2002). Treatments were also characterised for suitability for processing (control treatments included). The effect of N on SG, DM% and chip colour was also analysed (means across K levels) and as well as the effect of K on SG, DM% and chip colour (means across N levels). Tuber mass loss was expressed as percentage of original mass before storage.

8.3 Results and discussion

The ANOVA summary for SG, chip colour and DM% for cultivars Innovator and Lanorma are documented in Appendix F (Tables F.1 and F.2 for cultivars Innovator and Lanorma respectively). Across fertilizer treatments, cultivar Innovator had significantly higher SG values (1.078) than cultivar Lanorma (1.068). Tables 8.1 and 8.2 respectively show cultivar Innovator and cultivar Lanorma SG, DM% and chip colours. Highest SG for cultivar Innovator was recorded at the treatment combination of 160 kg.ha^{-1} of both N and K. This treatment had significantly higher SG than all other treatments. SG for cultivar Innovator seemed to drop as N was increased. On the other hand, no clear trend in SG was observed for changes in K level. A similar trend was observed for cultivar Lanorma, with the exception that the control for cultivar Lanorma had a significantly higher SG.

As illustrated in Figure 8.1, SG values for cultivar Innovator were above the minimum threshold of 1.075 for processing, while for cultivar Lanorma all SG values fell below the threshold, irrespective of treatment combination. With exception of the control treatment, highest SG values per cultivar in this study were 1.070 and 1.083 for cultivars Lanorma and Innovator, respectively. Based on the characterization of cultivars on SG by Mosley and Chase (1993), with the exception of the control and treatment combination of 160 N and and 300 kg.ha^{-1} K, it can be seen that cultivar Lanorma falls within the range of cultivars with low SG, while cultivar Innovator falls within the category of medium SG cultivars. However, by either keeping both N and K low (160 kg.ha^{-1}) or increasing K to 300 kg.ha-^{1} at low N level, cultivar Innovator SG can be propelled to a higher SG category cultivar.

Table 8.1: SG, DM% and chip colour per fertilizer treatment for cultivar Innovator

Treatment	N:K ratio	SG	DM%	Chip colour
N 160 K 160	1	1.083 a	21.03 ab	54.6 bcd
N 160 K 230	0.70	1.079 bcd	21.07 ab	52.4 e
N 160 K 300	0.53	1.081 bc	21.10 a	57.5 a
N 230 K 160	1.44	1.077 de	20.17 c	53.3 cde
N 230 K 230	1	1.078 cde	20.26 bc	55.9 ab
N 230 K 300	0.77	1.080 bc	20.30 abc	54.9 bc
N 300 K 160	1.88	1.079 bcd	20.20 c	54.8 bc
N 300 K 230	1.30	1.074 f	20.03 c	53.0 de
N 300 K 300	1	1.076 ef	20.13 c	55.0 cde
N 160 only	-	1.078 cde	20.01 c	53.3 cde
LSD		0.002	0.83	1.80
CV		0.109	2.38	1.95

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 8.2: SG, DM% and chip colour per fertilizer treatment for cultivar Lanorma

Treatment	N:K ratio	SG	DM%	Chip colour
N 160 K 160	1	1.069 b	17.53 b	54.5 bcd
N 160 K 230	0.70	1.068 cb	17.36 cb	55.6 bc
N 160 K 300	0.53	1.070 b	18.00 a	58.6 a
N 230 K 160	1.44	1.067cd	17.40cb	54.2 cd
N 230 K 230	1	1.067 cd	17.30cb	54.2 cd
N 230 K 300	0.77	1.065 e	17.00 c	53.4 de
N 300 K 160	1.88	1.066 de	17.20 cb	55.4 bcd
N 300 K 230	1.30	1.066 de	17.20 cb	54.2 cd
N 300 K 300	1	1.067 cd	17.43 cb	56.5 ab
N 160 only	-	1.072 a	18.11 a	52. e
LSD		0.0018	0.46	2.2
CV		0.098	1.55	2.36

**Values with the same letter within a column are not significantly different at $p \leq 0.05$*

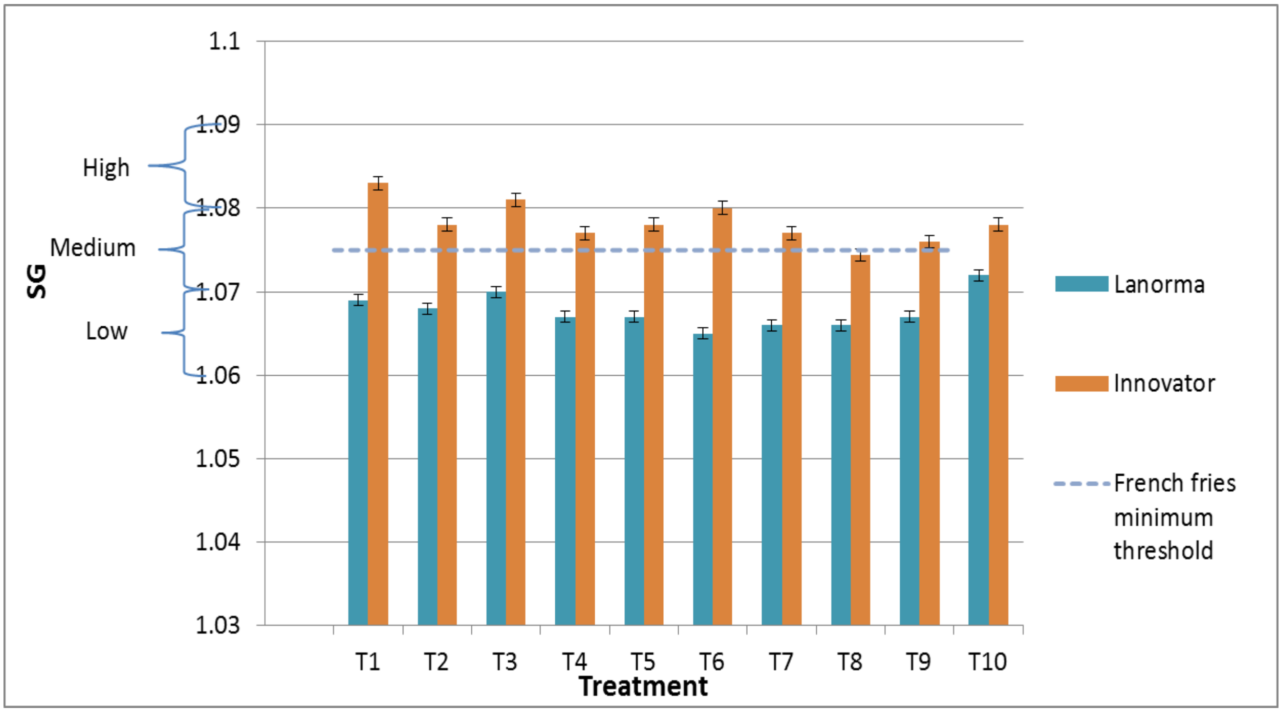


Figure 8.1: Characterization of tuber SG per treatment per cultivar according to Mosley and Chase (1993). Error bars represent maximum and minimum standard errors

With respect to dry matter content across fertilizer combinations (excluding control), dry matter content of cultivar Lanorma was significantly lower than that of cultivar Innovator. cultivar Innovator had an average DM content of 20.48% and cultivar Lanorma 17.38%. The pattern for DM% was almost similar to that of SG for both cultivars, such that DM% deteriorated with increase in N level. Higher DM% for both cultivars was observed at treatment combination of 160 kg.ha^{-1} and 300 kg.ha^{-1} N and K respectively (0.53 N:K ratio), (except for control). As per cultivar, DM percentage of final harvest was higher than the ones obtained during mid-season analysis, which confirms that DM% increases with the maturity of tubers. Similar findings were observed by other authors (Elfnesh et al. 2011; Mehta et al. 2011 and Solaiman et al. 2015). According to the classification of Cacace et al. (1994), dry matter content of cultivar Lanorma is considered to be low (< 18.0%), while cultivar Innovator can be classified as a high dry matter cultivar (> 20%). It is known that there is a positive correlation between SG and DM% and therefore it was not surprising to see that cultivar Innovator surpassed cultivar Lanorma, both with SG and DM%.

Figure 8.2 illustrates the suitability of both cultivars for processing per fertilizer treatment according to the guidelines of NIVA (2002). Based on this criterion, cultivar Innovator had a higher DM% (above 20%) across all fertilizer treatments and this rendered it suitable for French fries. Treatment combination of 160 and 300 kg.ha^{-1} for N and K respectively, resulted in highest DM content. cultivar Lanorma's peak value for DM content was 18% and for cultivar Innovator it was 21%. According to NIVA (2002), a minimum of 21% DM content is needed for the flake industry. It follows then that cultivar Innovator can also qualify for the flake industry for treatments with lowest N level across three levels of K, because of higher DM content (21%) in those treatments. The results of this study are contrary to the findings of Kavvadias et al. (2008), who reported an increase in DM content with an increase in N application. They reported highest DM content at highest application of N (660 kg.ha^{-1}) and a decrease in DM content with an increase in K application. On the other hand, the findings of this study are similar to what Zelalem et al. (2009) and Zewide et al. (2016) reported, since they observed a decrease in DM% with an increase in N. It is, therefore, important to keep N low (160 kg.ha^{-1}) for cultivar Innovator if the desired end use is the flake industry. It is surprising that the control treatment (T10), which also had 160 kg.ha^{-1} N, did not fit this criterion; this could suggest that K also plays a positive role in increasing dry matter content of the tubers.

It can also be clearly seen that both cultivars across all treatments were not suitable for chip (crisp) making, as their dry matter contents were below the minimum level required for chip processing, as their DM% was lower than 22%. Cultivar Lanorma is neither eligible for processing for chips nor French fries due to its low dry matter content, which makes it waxy rather than mealy. It has been documented that tubers which exhibit such a low dry matter content are more suitable for boiling (Ngobese et al. 2017). A study was conducted in South Africa, comparing dry matter content of 8 cultivars namely Electra, Fianna, cultivar Innovator, Mondial, Navigator, Panamera, Savanna and Sifra; and it was observed that cultivar Innovator had the second highest dry matter content after Fianna, and they got a DM of 21%, which is almost similar to the results of the present study. Nassar et al. (2012) also found results which were similar to the findings of this study when it comes to the DM% of cultivar Innovator.

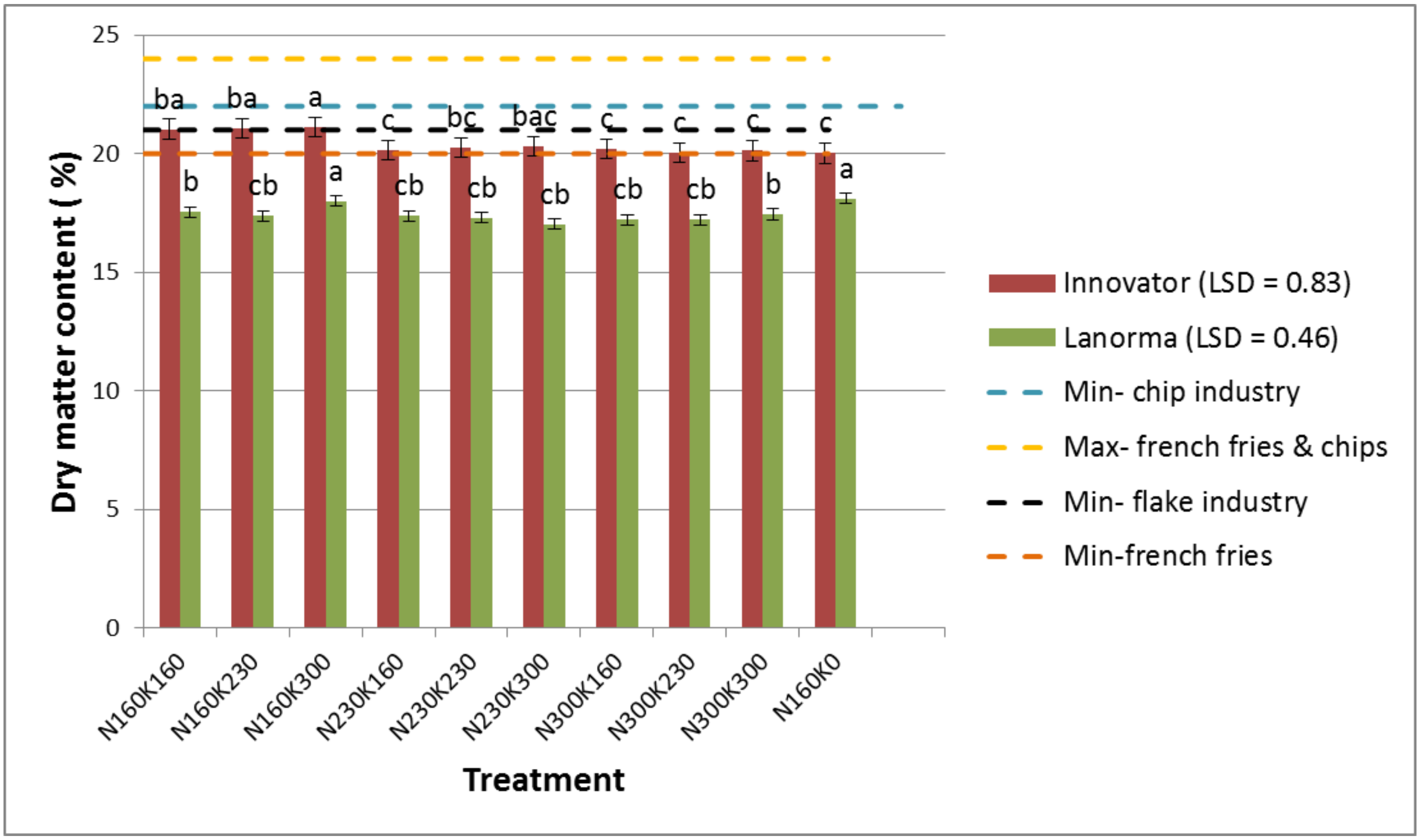


Figure 8.2: Characterization of tubers based on dry matter content for end use according to NIVA (2002). Error bars represent LSD

**Min- Minimum DM content suitable for chip industry, Min-french fries = minimum DM content acceptable for french fries, Max-french fries & chips = maximum DM content acceptable for french fries & chips, Min-flake industry = minimum DM content acceptable for flake industry.*

There was no significant difference between the two cultivars when it comes to chip colour. Across fertilizer treatments (control excluded), average chip score for cultivar Lanorma was 55.2 and for cultivar Innovator it was 54.5. Figure 8.3 shows chip colour scores for both cultivars per treatment. The highest chip score was 58.6 and 57.5 for cultivar Lanorma and cultivar Innovator, respectively, and these values were significantly higher than most values of other treatments (Tables 8.1 and 8.2). These peak values were observed at the treatment combination of 160 N kg.ha^{-1} and 300 K kg.ha^{-1} and this suggests that such N:K ratio (0.53) resulted in lowest reducing sugar content in the tuber, which retarded the Maillard reaction. It follows therefore that if the priority is to improve chip colour, then N level should be at 160 kg.ha^{-1} and K at 300 kg.ha^{-1}. In the current study, the treatment combination of N 160 and K 300 kg.ha^{-1} resulted in lower N content in the pith (Chapter 6), compared to other treatments and this could have suppressed the Maillard reaction.

According to Solaiman et al. (2015), a chip colour score of more than 50 is considered to be acceptable. It can be deduced from the chip colour scores that both cultivars have acceptable chip colour for processing. For both cultivars, chip colour score dropped in the absence of K (control treatment), implying that K plays a role in improving chip colour. Given the fact that reducing sugars are known to be associated with the dark colouring of the chips, it can be concluded that both cultivars, because of their acceptable chip colour, have low reducing sugars.

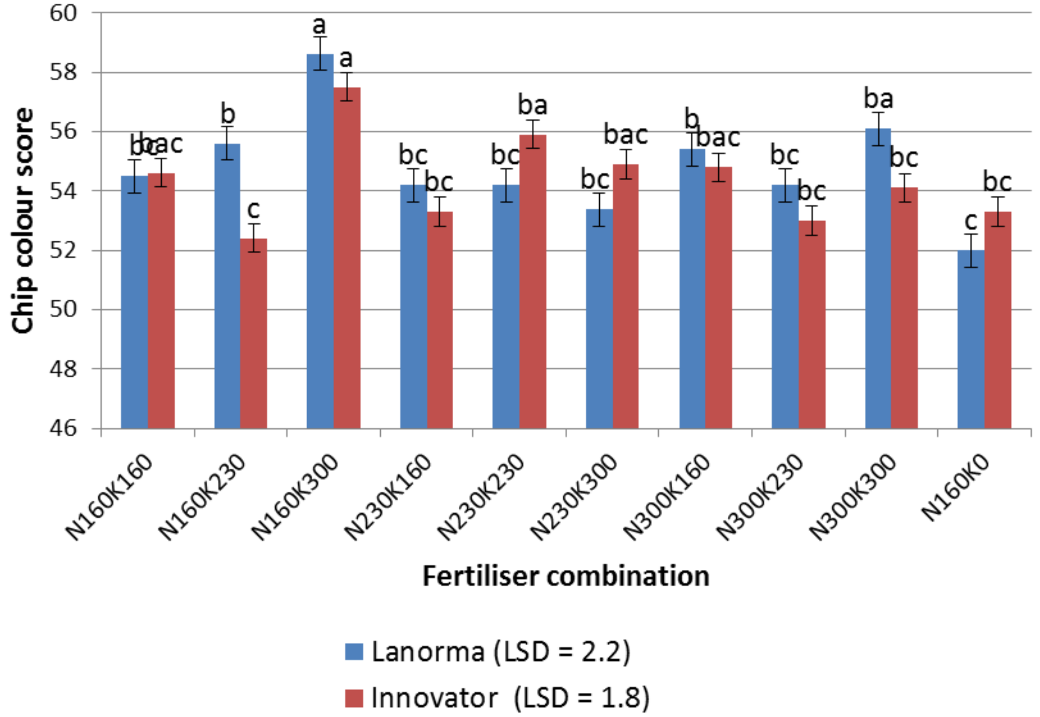


Figure 8.3: Chip colour score per treatment per cultivar (vertical bars represent LSD)

General influence of N and K on SG, DM% and chip colour was also documented across K levels per level of N and across levels of N per level of K. This is shown in Tables 8.3 and 8.4, respectively, for cultivars Innovator and Lanorma. For both cultivars, no significant variation in DM was recorded with an increase in K, while with respect to N, cultivar Innovator showed a significant decrease in DM content at 230 and 300 kg.ha^{-1} N when compared to 160 kg.ha^{-1}. Kavvadias et al. (2012) noted a significant decrease in DM content with an increase in K application and this was more pronounced at higher N level. Srikumar and Ockerman (1990) stated that an increase in DM content that is observed with an increase in N is due to an increase in amino acids. With respect to the results of the current study, Larnoma showed a slight decrease in DM content with an increase in N application. A significant chip colour improvement was observed when K was applied at 300 kg.ha^{-1} for both cultivars. No clear trend was observed between K and SG, while a significantly higher SG was achieved at the lowest N level, which is in contrary to the findings of Sun et al. (2017), who observed an increase in SG with increase in N application.

K seems to play a major role in improving chip colour, since its highest level resulted in lighter chip colours. The control experiment attests that K application improves chip colour since the lowest score for both cultivars was at the control treatment (treatment without K application). It seems that tuber K and N contents can determine the final outcome of a chip colour. As observed earlier in Chapter 6, control experiments proved to have higher N content in tubers than other treatments and at the same time, treatment N 160 and K 300 kg.ha^{-1} resulted in lower N content in the pith for both cultivars. The chip colour score corresponding to N 160 and K 300 kg.ha^{-1} was thus the highest of all the other treatments. It can be deduced from this that increasing K application could result in less N accumulated in the tubers; and therefore apart from K being known to improve chip colour by reducing the reducing sugar content (Moinuddin and Umar (2004), it seems that K could also improve chip colour by limiting N content in the tuber. The results of this study confirms what has been stated before by Hayes and Thill (2002) and Khan et al. (2012), that limiting at least reducing sugars or protein content in tubers could result in lighter chips.

Table 8.3: Tuber dry matter content (%), chip colour score and SG at each level of N for cultivar Innovator across three levels of K and at each level of K across three levels of N

Application	…………………..N…………………..			………………...K…………………….		
kg.ha^{-1}	DM	Colour	SG	DM	Colour	SG
160	21.07a	54.86a	1.081a	20.45a	54.86b	1.079a
230	20.24b	54.71ba	1.078b	20.46a	53.77b	1.076b
300	20.12b	53.96b	1.076c	20.51a	55.51a	1.079a
LSD	0.5561	0.7698	0.0007	0.5643	1.0701	0.0009
CV	2.69	1.91	0.079	2.69	1.91	0.079

**Means across K levels in columns under N; means across N levels in columns under K. values with the same letter within a column are not significantly different at $p \leq 0.05$*

Table 8.4: Tuber dry matter content (%), chip colour score and SG at each level of N for Cultivar Lanorma across three levels of K and at each level of K across three levels of N

Application	……….………..N……………………..			………..……….K……………………		
kg.ha^{-1}	DM	Colour	SG	DM	Colour	SG
160	17.63a	56.24a	1.069a	17.38a	54.70b	1.068a
230	17.28a	55.37a	1.066b	17.29a	54.68b	1.067a
300	17.20a	53.92a	1.066b	17.48a	56.16a	1.067a
LSD	0.4122	2.7142	0.001	0.2502	1.143	0.0012
CV	1.40	2.02	0.11	1.40	2.02	0.11

**Means across K levels in columns under N; means across N levels in columns under K. values with the same letter within a column are not significantly different at $p \leq 0.05$*

When it comes to tuber mass loss, treatments showed a decrease in tuber mass loss after 2 months storage, with no variation between the two cultivars. Mass loss percentage was around 6% at 160 and 230 kg.ha^{-1} N across all levels of K and increased to around 9% at 300 kg.ha^{-1} N across all levels of K. Tuber size could have had an influence on tuber mass loss, since treatments with high N content had large tubers compared to those with lower N content. Control treatment had a considerable number of rotten tubers and it therefore gave higher mass loss percentage of 15% for both cultivars. Shunka et al. (2017) observed higher weight loss and disease occurrence for tubers planted without K, as compared to tubers planted with K. This is also analogous to the observations of Moinuddin and Umar (2004), who reported an increase in tuber mass loss with a decrease in K level after 4 weeks of storage. However, increasing K above 160 kg.ha^{-1} did not have any further positive influence on tuber mass loss. These results therefore confirm that indeed K extend shelf life and also improves the storage quality of tubers (Martin-Prevel 1989; Perrenoud 1993).

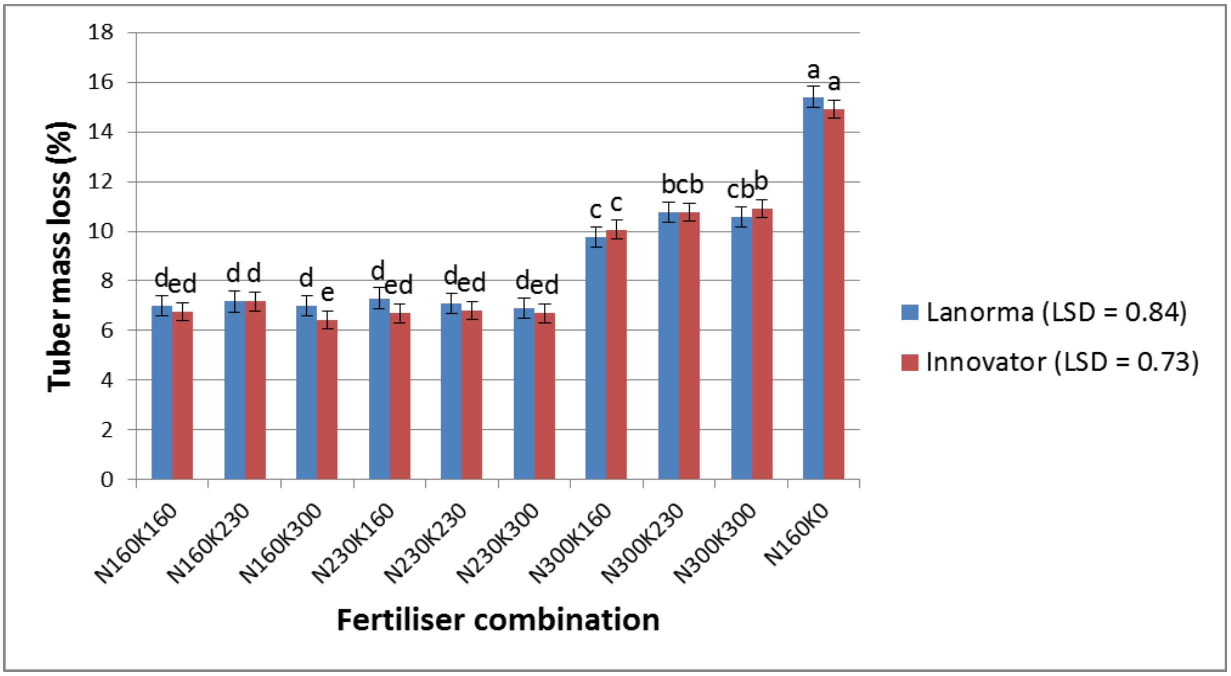


Figure 8.4: Tuber mass loss for cultivars Innovator and Lanorma 8 weeks after storage. Bars represent LSD.

During growth analyses and as well as when tubers were cut for nutrient analyses, tubers were examined for malformation (hallow heart and vascular discolouration). Both the cultivars did not exhibit internal disorders. Cultivar Lanorma also did not have external disorders. On the other hand, cultivar Innovator showed incidences of malformation in the large size tubers (Figure 8.5). Therefore, fertiliser combinations which resulted in higher proportions of large tubers also resulted in higher incidences of malformation of tubers for cultivar Innovator.

Figure 8.5: Cultivar Innovator with malformation of large tubers at high N levels.

8.4 Conclusions

Based on three tuber quality attributes, namely SG, DM content and chip colour, cultivar Innovator can be classified as suitable for processing due to its higher SG, DM content and acceptable chip colour. Cultivar Lanorma is suitable for table use due to its low SG and low DM content. However, by manipulating nutrient combinations, the SG of cultivar Lanorma can be increased to about 1.070, which can be considered suitable for processing, since other authors such as Solaiman et al. (2015) stated that a minimum SG value of 1.070 is suitable for processing. N:K ratios did not have a clear trend on tuber quality attributes, however an N:K ratio of 0.53 seemed to have a positive influence on SG, DM content and chip colour. Increase in N level generally tended to affect DM content, SG and chip colour negatively. K mainly had an influence on chip colour, such that highest K level resulted in significantly lighter chips. It is also concluded that tuber mass loss increased with increase in N application.

CHAPTER 9

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This study examined the effects of different levels of N and K and their corresponding ratios on the yield and tuber quality attributes of two newer potato cultivars (Innovator and Lanorma) under South African environment. The study also examined N and K use efficiency and responsiveness, growth patterns and days to maturity of the two cultivars. In conclusion, N:K ratios proved to play a leading role on yield, such that N:K ratios ranging between 0.62 to 1.0 had a tendency of higher yield compared to ratios above 1.0 for both the pot and field trials. However, this interaction effect mainly stands when none of the two nutrients are insufficient (at very low levels). The two cultivars varied in yield, with cultivar Lanorma having a significantly lower yield than cultivar Innovator in the pot trial, which was opposite for the field trial. Lower yield for cultivar Lanorma in the pot trial, although it matured later than cultivar Innovator, could be due to the timing of N application. Later maturing cultivars tend to benefit more when N application is split into more than one dressing. In this case all the N was applied once, which probably limited cultivar Lanorma yield. Tuber size for the pot trial was generally small, irrespective of treatment combinations.

In the field trial, the highest N level of 300 kg.ha^{-1} resulted in the highest yield and a larger proportion of large size tubers for both cultivars. However, the latter may not necessarily be desirable for cultivar Innovator, as the large size tubers had higher incidences of malformed tubers, which may not be marketable. Although 300 kg.ha^{-1} N did not result in any malformed tubers for cultivar Lanorma, this level of N resulted in surplus of N in the soil after harvest where cultivar Lanorma was planted and therefore N leaching may occur, which will lead to groundwater pollution. Therefore, 230 kg.ha^{-1} N is proposed as the optimum level for the production of cultivar Innovator and cultivar Lanorma on the specific soil type and region, since better yield and less incidences of malformed tubers were obtained for cultivar Innovator, in comparison to the N level of 300.kg.ha^{-1}. If less incidences of malformed tubers are desired for cultivar Innovator, N would have to be applied at lower levels than 230 kg.ha^{-1}, however this would have a negative impact on yield.

Potassium (K) proved to have an influence on the yield when it was increased from 160 up to 230 kg.ha^{-1} at 230 kg.ha^{-1} N, while a K application level beyond 230 kg.ha^{-1} did not have any influence on the yield at this level of N. In addition, a K level of 300 kg.ha^{-1} resulted in a substantially higher K content in the tubers than K at 230 kg.ha^{-1}. It follows, therefore, that the application of K above 230 kg.ha^{-1} would result in a phenomenon known as luxury absorption of K by these cultivars (Hommels et al. 1989). This luxury absorption phenomenon occurs when an element is applied above its optimal level, which does not result in further yield increase and yet its uptake keeps increasing. This behaviour observed in this study concurred with that of Karam et al. (2009), who observed the same pattern in potatoes with respect to K. For the specific conditions of this trial a K level of 230 kg.ha^{-1}, therefore, gave the optimal combination of best tuber yield and quality.

The intended end-use purpose of tubers is another important aspect that should be taken into consideration when applying fertilizer resources. This study indicated that fertilizer combinations influenced tuber quality for both cultivars. In both the pot and field trials, SG also proved to be influenced by N:K ratio. N:K ratios of not greater than one had better SG values than most higher N:K ratios. In the field trial, best chip colour, better SG and higher DM contents were obtained at the lowest N:K ratio. The high quality tubers were thus obtained at 160 kg.ha^{-1} N and 300 kg.ha^{-1} K (N:K ratio of 0.53) for both cultivars. Generally, the SG and DM content of the two cultivars varied substantially, such that average SG and DM content values for cultivar Innovator were above 1.075 and 20% respectively, which are the minimum threshold levels for processing. The SG and DM values for cultivar Lanorma were lower than the minimum threshold for processing. This cultivar can therefore be classified as a table potato cultivar. The optimal level of N (230 kg.ha^{-1}) recommended for optimal yield resulted in DM content of 20% for cultivar Innovator, which rendered it suitable for French fries. On the other hand, N for cultivar Innovator can be kept at 160 kg.ha^{-1} if the desired end use is the flake industry, since N at this level increased DM content to 21%, which is the minimum acceptable value for flake purposes.

In examining the relationship between the SG and DM content, the results of this study are contrary to the findings of Geremew et al. (2007) and Elfnesh et al. (2011), who documented that higher SG and higher tuber DM contents are associated with late-maturing cultivars. In this study, cultivar Innovator matured earlier than cultivar Lanorma and yet cultivar Innovator had higher SG and DM content. This means that genetic makeup also has a leading role in influencing SG and DM content of cultivars.

When it comes to chip colour, both cultivars had acceptable chip colour scores for processing. Fertilizer combination of N 160 and K 300 kg.ha^{-1} (N:K ratio 0.53) proved to give highest chip colour score of around 57 and 58 for cultivars Innovator and Lanorma, respectively. With regards to processing as the key end-use, this fertilizer combination can therefore be used for cultivar Innovator if the priority is to improve colour for processing. It is, therefore, imperative that the pros and cons are carefully weighed up before applying fertilizers on these two cultivars, taking into consideration the intended end use, production cost and the environmental impact associated with fertilizer application.

NUE decreased with increase in N level but it seemed to improve with increase in K level at a specific N level. KUE also showed a decrease with K increase, and it improved with increase in N level at a specific K level. The two cultivars responded differently under limited K resources. Cultivar Innovator significantly surpassed cultivar Lanorma in yield under limited K resources (0 kg.ha^{-1} K applied). This implies that cultivar Innovator can take precedence over cultivar Lanorma in cases where K resources are limited. Cultivar Lanorma, on the other hand, is more responsive to K application than cultivar Innovator and it surpassed cultivar Innovator in yield when K was applied at 160 kg.ha^{-1}. This implies that cultivar Lanorma would be preferred over cultivar Innovator in conditions where K is not limited.

In classification of these cultivars based on days to maturity, cultivar Innovator can be classified as an early maturing cultivar, while cultivar Lanorma can be regarded as a mid-season maturing cultivar. However, higher levels of N can effectively delay cultivar Lanorma’s maturity, propelling the cultivar to become a late-maturing cultivar. cultivar

Lanorma’s senescence at higher N level was quite slow, compared to cultivar Innovator, and its growing season can substantially be prolonged at higher N level. In regions like Pretoria, where winter can negatively affect natural senescence, it is not advisable to plant cultivar Lanorma in autumn, since it takes more days to mature and winter may negatively affect it. However, if the planting of cultivar Lanorma in autumn is unavoidable, then N should be kept low so that the growth cycle could occur unimpaired for the natural senesce to occur earlier before winter starts. For cultivar Innovator, autumn planting can be feasible since it is an early maturing cultivar. In planting cultivar Innovator, care must be taken to manage its tuber initiation, as the cultivar seemed to be initiating tubers above the mother tuber. This leads to propelling of tubers on the surface of the soil if heaping is not properly done. Cultivar Lanorma, on the other hand, initiate tubers deeper in the soil and hence no challenge of tubers appearing on the soil surface.

The low yields obtained and poor emergence in the pot trial could be due to confinement and lack of aeration of the roots in the pots, which lead to limited nutrient exploration. Nutrient application for the pot trial was all done at planting, while in the field trial N was split into two halves, one at planting and the remainder at two weeks after emergence. The pot trial could therefore be subjected to leaching of both nutrients, in particular N, because N in the form of nitrate is negatively charged and it would repel the predominant like-charged soil colloids. As was observed by Sun et al. (2012), the splitting of N application into portions that were applied at different periods of development proved to be more effective on yield than the application of N all at once. Different yield response between the pot trial and field trial have also been reported before by Kang et al. (2014), who observed an increase in tuber yield with an increase in K level in a pot trial, while they observed no yield response in the field trial.

APPENDICES

Appendix A

Table A.1: Nutrients supplied per treatment per pot ($g.pot^{-1}$)

Treatment Combination	KNO3	K2 SO4	K H2PO4	NH4NO3	Ca (NO3)2 . 2H2O^z	Mg SO4.7H2O	NaNO3	$Ca(H_2PO_4)_2.H_2O$	CaSO4	Mg(NO3)2 .6H2O
T1	0.00	2.23	0.00	1.06	2.10	3.08	2.84	1.79	1.00	0.00
T2	1.66	0.80	0.00	1.36	2.28	3.08	2.52	1.79	0.88	0.00
T3	2.22	0.31	0.00	1.65	3.58	3.08	2.21	1.79	0.00	0.00
T4	2.59	0.00	0.00	1.94	3.58	1.23	1.9	1.79	0	1.92
T5	0.00	3.88	1.93	1.06	3.8	2.41	1.39	0	0.08	0
T6	1.72	2.40	1.93	1.36	3.92	2.41	1.07	0	0	0
T7	3.60	0.78	1.93	1.65	3.92	2.41	0.77	0	0	0
T8	4.51	0.00	1.93	1.94	3.92	1.23	0.46	0	0	1.23
T9	1.19	4.42	1.93	1.06	2.92	1.8	1.14	0	0	0
T10	3.03	2.84	1.93	1.36	2.92	1.8	0.82	0	0	0
T11	4.91	1.22	1.93	1.65	2.92	1.8	0.51	0	0	0
T12	6.32	0.00	1.93	1.94	2.92	1.23	0.2	0	0	0.59
T13	2.46	4.87	1.93	1.06	1.9	1.16	0.94	0	0	0
T14	4.30	3.29	1.93	1.36	1.9	1.16	0.61	0	0	0
T15	6.18	1.67	1.93	1.65	1.9	1.16	0.31	0	0	0
T16	8.06	0.05	1.93	1.94	1.9	1.16	0	0	0	0

Table A.2: Summary of ANOVA for tuber number, SG and yield between two cultivars for a pot trial

Dependent Variable: Tuber number per pot

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	706.5000000	22.7903226	30.82	<.0001
Error	64	47.3333333	0.7395833		
Corrected Total	95	753.8333333			

R-Square	Coeff Var	Root MSE	Number Mean
0.937210	9.875487	0.859990	8.708333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	108.3750000	108.3750000	146.54	<.0001
N	3	40.2500000	13.4166667	18.14	<.0001
K	3	345.7500000	115.2500000	155.83	<.0001
Cultivar*N	3	6.5416667	2.1805556	2.95	0.0393
Cultivar*K	3	86.5416667	28.8472222	39.00	<.0001
Cultivar*N*K	18	119.0416667	6.6134259	8.94	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	1	108.3750000	108.3750000	146.54	<.0001
N	3	40.2500000	13.4166667	18.14	<.0001
K	3	345.7500000	115.2500000	155.83	<.0001
Cultivar*N	3	6.5416667	2.1805556	2.95	0.0393
Cultivar*K	3	86.5416667	28.8472222	39.00	<.0001
Cultivar*N*K	18	119.0416667	6.6134259	8.94	<.0001

Dependent Variable: SG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	0.00547374	0.00017657	18.65	<.0001
Error	64	0.00060600	0.00000947		
Corrected Total	95	0.00607974			

R-Square	Coeff Var	Root MSE	SG Mean
0.900325	0.287077	0.003077	1.071885

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	0.00430676	0.00430676	454.84	<.0001
N	3	0.00004511	0.00001504	1.59	0.2009
K	3	0.00057186	0.00019062	20.13	<.0001
Cultivar*N	3	0.00004395	0.00001465	1.55	0.2109
Cultivar*K	3	0.00008586	0.00002862	3.02	0.0360
Cultivar*N*K	18	0.00042019	0.00002334	2.47	0.0043

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	1	0.00430676	0.00430676	454.84	<.0001
N	3	0.00004511	0.00001504	1.59	0.2009
K	3	0.00057186	0.00019062	20.13	<.0001
Cultivar*N	3	0.00004395	0.00001465	1.55	0.2109
Cultivar*K	3	0.00008586	0.00002862	3.02	0.0360
Cultivar*N*K	18	0.00042019	0.00002334	2.47	0.0043

Dependent Variable: Yield in grams per pot

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	915387.2396	29528.6206	23.11	<.0001
Error	64	81770.0000	1277.6563		
Corrected Total	95	997157.2396			

R-Square	Coeff Var	Root MSE	Yield Mean
0.917997	10.01797	35.74432	356.8021

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	7902.5104	7902.5104	6.19	0.0155
N	3	106634.6979	35544.8993	27.82	<.0001
K	3	565743.6146	188581.2049	147.60	<.0001
Cultivar*N	3	12817.1146	4272.3715	3.34	0.0245
Cultivar*K	3	22719.6979	7573.2326	5.93	0.0012
Cultivar*N*K	18	199569.6042	11087.2002	8.68	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	1	7902.5104	7902.5104	6.19	0.0155
N	3	106634.6979	35544.8993	27.82	<.0001
K	3	565743.6146	188581.2049	147.60	<.0001
Cultivar*N	3	12817.1146	4272.3715	3.34	0.0245
Cultivar*K	3	22719.6979	7573.2326	5.93	0.0012
Cultivar*N*K	18	199569.6042	11087.2002	8.68	<.0001

Table A.3: ANOVA for Innovator pot trial

Dependent Variable: SG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	0.00042633	0.00002842	2.60	0.0113
Error	32	0.00034933	0.00001092		
Corrected Total	47	0.00077567			

R-Square	Coeff Var	Root MSE	SG Mean
0.549635	0.306331	0.003304	1.078583

Source	DF	Type I SS	Mean Square	F Value	Pr > F
N	3	0.00006033	0.00002011	1.84	0.1594
K	3	0.00021517	0.00007172	6.57	0.0014
N*K	9	0.00015083	0.00001676	1.54	0.1780

Source	DF	Type III SS	Mean Square	F Value	Pr > F
N	3	0.00006033	0.00002011	1.84	0.1594
K	3	0.00021517	0.00007172	6.57	0.0014
N*K	9	0.00015083	0.00001676	1.54	0.1780

Dependent Variable: Yield in grams per pot

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	450809.2500	30053.9500	66.56	<.0001

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Error	32	14450.0000	451.5625		
Corrected Total	47	465259.2500			

R-Square	Coeff Var	Root MSE	Yield Mean
0.968942	5.807995	21.25000	365.8750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
N	3	41551.5833	13850.5278	30.67	<.0001
K	3	362106.7500	120702.2500	267.30	<.0001
N*K	9	47150.9167	5238.9907	11.60	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
N	3	41551.5833	13850.5278	30.67	<.0001
K	3	362106.7500	120702.2500	267.30	<.0001
N*K	9	47150.9167	5238.9907	11.60	<.0001

Appendix B

Summary of ANOVA for Lanorma pot trial

Dependent Variable: SG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	0.00074065	0.00004938	6.16	<.0001
Error	32	0.00025667	0.00000802		
Corrected Total	47	0.00099731			

R-Square	Coeff Var	Root MSE	SG Mean
0.742642	0.265879	0.002832	1.065188

Source	DF	Type I SS	Mean Square	F Value	Pr > F
N	3	0.00002873	0.00000958	1.19	0.3277
K	3	0.00044256	0.00014752	18.39	<.0001
N*K	9	0.00026935	0.00002993	3.73	0.0027

Source	DF	Type III SS	Mean Square	F Value	Pr > F
N	3	0.00002873	0.00000958	1.19	0.3277
K	3	0.00044256	0.00014752	18.39	<.0001
N*K	9	0.00026935	0.00002993	3.73	0.0027

Dependent Variable: Yield in grams per pot

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	456675.4792	30445.0319	14.47	<.0001
Error	32	67320.0000	2103.7500		
Corrected Total	47	523995.4792			

R-Square	Coeff Var	Root MSE	Yield Mean

R-Square	Coeff Var	Root MSE	Yield Mean
0.871526	13.19034	45.86665	347.7292

Source	DF	Type I SS	Mean Square	F Value	Pr > F
N	3	77900.2292	25966.7431	12.34	<.0001
K	3	226356.5625	75452.1875	35.87	<.0001
N*K	9	152418.6875	16935.4097	8.05	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
N	3	77900.2292	25966.7431	12.34	<.0001
K	3	226356.5625	75452.1875	35.87	<.0001
N*K	9	152418.6875	16935.4097	8.05	<.0001

Appendix C

Table C.1: Summary of ANOVA for plant height per cultivar at each harvest interval

Dependent Variable: harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	443.385000	44.338500	0.91	0.5350
Error	49	2397.896833	48.936670		
Corrected Total	59	2841.281833			

R-Square	Coeff Var	Root MSE	harvest1 Mean
0.156051	14.62825	6.995475	47.82167

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	154.5615000	154.5615000	3.16	0.0817
Treatment	9	288.8235000	32.0915000	0.66	0.7439

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	154.5615000	154.5615000	3.16	0.0817
Treatment	9	288.8235000	32.0915000	0.66	0.7439

Dependent Variable: harvest2

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	10	4332.142667	433.214267	20.85	<.0001
Error	49	1017.916667	20.773810		
Corrected Total	59	5350.059333			

R-Square	**Coeff Var**	**Root MSE**	**harvest2 Mean**
0.809737	6.344712	4.557829	71.83667

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	2884.266667	2884.266667	138.84	<.0001
Treatment	9	1447.876000	160.875111	7.74	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	2884.266667	2884.266667	138.84	<.0001
Treatment	9	1447.876000	160.875111	7.74	<.0001

Dependent Variable: Harvest3

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	10	6384.285000	638.428500	19.82	<.0001
Error	49	1578.224833	32.208670		
Corrected Total	59	7962.509833			

R-Square	**Coeff Var**	**Root MSE**	**Harvest3 Mean**
0.801793	7.623096	5.675268	74.44833

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	4790.053500	4790.053500	148.72	<.0001
Treatment	9	1594.231500	177.136833	5.50	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	4790.053500	4790.053500	148.72	<.0001
Treatment	9	1594.231500	177.136833	5.50	<.0001

Dependent Variable: Harvest4

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	10	13521.12433	1352.11243	22.77	<.0001
Error	49	2909.78817	59.38343		
Corrected Total	59	16430.91250			

R-Square	**Coeff Var**	**Root MSE**	**Harvest4 Mean**
0.822908	10.50946	7.706065	73.32500

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	11484.43350	11484.43350	193.39	<.0001
Treatment	9	2036.69083	226.29898	3.81	0.0011

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	11484.43350	11484.43350	193.39	<.0001
Treatment	9	2036.69083	226.29898	3.81	0.0011

Table C.2: summary of ANOVA tables for Lanorma plant height across harvest dates

Dependent Variable: T1

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	1757.136667	585.712222	42.21	<.0001
Error	8	111.000000	13.875000		
Corrected Total	11	1868.136667			

R-Square	**Coeff Var**	**Root MSE**	**T1 Mean**
0.940583	5.439157	3.724916	68.48333

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	1757.136667	585.712222	42.21	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	1757.136667	585.712222	42.21	<.0001

Dependent Variable: T2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1997.046667	665.682222	12.74	0.0021
Error	8	418.153333	52.269167		
Corrected Total	11	2415.200000			

R-Square	Coeff Var	Root MSE	T2 Mean
0.826866	10.28413	7.229742	70.30000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	1997.046667	665.682222	12.74	0.0021

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	1997.046667	665.682222	12.74	0.0021

Dependent Variable: T3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3265.795833	1088.598611	69.46	<.0001
Error	8	125.386667	15.673333		
Corrected Total	11	3391.182500			

R-Square	Coeff Var	Root MSE	T3 Mean
0.963026	5.384503	3.958956	73.52500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	3265.795833	1088.598611	69.46	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	3265.795833	1088.598611	69.46	<.0001

Dependent Variable: T4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2816.646667	938.882222	28.88	0.0001
Error	8	260.060000	32.507500		
Corrected Total	11	3076.706667			

R-Square	Coeff Var	Root MSE	T4 Mean
0.915475	8.413480	5.701535	67.76667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	2816.646667	938.882222	28.88	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	2816.646667	938.882222	28.88	0.0001

Dependent Variable: T5

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3572.543333	1190.847778	17.36	0.0007
Error	8	548.793333	68.599167		
Corrected Total	11	4121.336667			

R-Square	Coeff Var	Root MSE	T5 Mean

R-Square	Coeff Var	Root MSE	T5 Mean
0.866841	10.75877	8.282461	76.98333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	3572.543333	1190.847778	17.36	0.0007

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	3572.543333	1190.847778	17.36	0.0007

Dependent Variable: T6

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3220.015833	1073.338611	26.87	0.0002
Error	8	319.613333	39.951667		
Corrected Total	11	3539.629167			

R-Square	Coeff Var	Root MSE	T6 Mean
0.909704	8.056165	6.320733	78.45833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	3220.015833	1073.338611	26.87	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	3220.015833	1073.338611	26.87	0.0002

Dependent Variable: T7

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2916.389167	972.129722	43.34	<.0001
Error	8	179.460000	22.432500		
Corrected Total	11	3095.849167			

R-Square	Coeff Var	Root MSE	T7 Mean
0.942032	6.182481	4.736296	76.60833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	2916.389167	972.129722	43.34	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	2916.389167	972.129722	43.34	<.0001

Dependent Variable: T8

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3451.493333	1150.497778	21.67	0.0003
Error	8	424.813333	53.101667		
Corrected Total	11	3876.306667			

R-Square	Coeff Var	Root MSE	T8 Mean
0.890408	8.586515	7.287089	84.86667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	3451.493333	1150.497778	21.67	0.0003

```
Source    DF    Type III SS     Mean Square   F Value   Pr > F

Harvest    3    3451.493333    1150.497778     21.67    0.0003
```

Dependent Variable: T9

```
Source            DF   Sum of Squares   Mean Square   F Value   Pr > F

Model              3      2764.229167    921.409722     44.99   <.0001

Error              8       163.840000     20.480000

Corrected Total   11      2928.069167


R-Square   Coeff Var   Root MSE   T9 Mean

0.944045    5.611843   4.525483   80.64167


Source    DF     Type I SS     Mean Square   F Value   Pr > F

Harvest    3    2764.229167    921.409722     44.99    <.0001


Source    DF    Type III SS    Mean Square   F Value   Pr > F

Harvest    3    2764.229167    921.409722     44.99    <.0001
```

Dependent Variable: T10

```
Source            DF   Sum of Squares   Mean Square   F Value   Pr > F

Model              3      1717.763333    572.587778     23.39   0.0003

Error              8       195.853333     24.481667

Corrected Total   11      1913.616667


R-Square   Coeff Var   Root MSE   T10 Mean
```

R-Square	Coeff Var	Root MSE	T10 Mean
0.897653	7.148416	4.947895	69.21667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	1717.763333	572.587778	23.39	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	1717.763333	572.587778	23.39	0.0003

Table C.3: Summary of ANOVA tables for Innovator plant height across four harvest dates

Dependent Variable: T1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	422.2066667	140.7355556	9.10	0.0059
Error	8	123.6933333	15.4616667		
Corrected Total	11	545.9000000			

R-Square	Coeff Var	Root MSE	T1 Mean
0.773414	7.447221	3.932133	52.80000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	422.2066667	140.7355556	9.10	0.0059

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	422.2066667	140.7355556	9.10	0.0059

Dependent Variable: T2

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	685.2691667	228.4230556	6.17	0.0178
Error	8	296.1800000	37.0225000		
Corrected Total	11	981.4491667			

R-Square	**Coeff Var**	**Root MSE**	**T2 Mean**
0.698222	10.87671	6.084612	55.94167

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	685.2691667	228.4230556	6.17	0.0178

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	685.2691667	228.4230556	6.17	0.0178

Dependent Variable: T3

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	462.9825000	154.3275000	11.29	0.0030
Error	8	109.3866667	13.6733333		
Corrected Total	11	572.3691667			

R-Square	**Coeff Var**	**Root MSE**	**T3 Mean**
0.808888	6.087662	3.697747	60.74167

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	462.9825000	154.3275000	11.29	0.0030

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	462.9825000	154.3275000	11.29	0.0030

Dependent Variable: T4

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	277.735833	92.578611	0.63	0.6149
Error	8	1172.493333	146.561667		
Corrected Total	11	1450.229167			

R-Square	**Coeff Var**	**Root MSE**	**T4 Mean**
0.191512	20.31537	12.10627	59.59167

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	277.7358333	92.5786111	0.63	0.6149

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	277.7358333	92.5786111	0.63	0.6149

Dependent Variable: T5

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	713.9825000	237.9941667	6.78	0.0138
Error	8	280.9466667	35.1183333		
Corrected Total	11	994.9291667			

R-Square	**Coeff Var**	**Root MSE**	**T5 Mean**
0.717621	9.925034	5.926072	59.70833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	713.9825000	237.9941667	6.78	0.0138

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	713.9825000	237.9941667	6.78	0.0138

Dependent Variable: T6

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	715.249167	238.416389	2.86	0.1045
Error	8	667.520000	83.440000		
Corrected Total	11	1382.769167			

R-Square	Coeff Var	Root MSE	T6 Mean
0.517259	14.97672	9.134550	60.99167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	715.2491667	238.4163889	2.86	0.1045

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	715.2491667	238.4163889	2.86	0.1045

Dependent Variable: T7

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	718.995833	239.665278	5.27	0.0267
Error	8	363.486667	45.435833		
Corrected Total	11	1082.482500			

R-Square	Coeff Var	Root MSE	T7 Mean
0.664210	11.41993	6.740611	59.02500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	718.9958333	239.6652778	5.27	0.0267

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	718.9958333	239.6652778	5.27	0.0267

Dependent Variable: T8

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1303.849167	434.616389	14.41	0.0014
Error	8	241.220000	30.152500		
Corrected Total	11	1545.069167			

R-Square	Coeff Var	Root MSE	T8 Mean
0.843878	8.662226	5.491129	63.39167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	1303.849167	434.616389	14.41	0.0014

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	1303.849167	434.616389	14.41	0.0014

Dependent Variable: T9

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1718.486667	572.828889	12.61	0.0021

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Error	8	363.320000	45.415000		
Corrected Total	11	2081.806667			

R-Square	Coeff Var	Root MSE	T9 Mean
0.825479	10.36248	6.739065	65.03333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	1718.486667	572.828889	12.61	0.0021

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	1718.486667	572.828889	12.61	0.0021

Dependent Variable: T10

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	632.2733333	210.7577778	7.89	0.0089
Error	8	213.6266667	26.7033333		
Corrected Total	11	845.9000000			

R-Square	Coeff Var	Root MSE	T10 Mean
0.747456	9.481701	5.167527	54.50000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	632.2733333	210.7577778	7.89	0.0089

Source	DF	Type III SS	Mean Square	F Value	Pr > F

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	632.2733333	210.7577778	7.89	0.0089

Table C.4: Summary of ANOVA tables for tuber mass between two cultivars across harvest dates

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	228.0370000	22.8037000	2.93	0.0058
Error	49	380.8848333	7.7731599		
Corrected Total	59	608.9218333			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.374493	43.48384	2.788039	6.411667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	101.1401667	101.1401667	13.01	0.0007
Treatment	9	126.8968333	14.0996481	1.81	0.0894

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	1	101.1401667	101.1401667	13.01	0.0007
Treatment	9	126.8968333	14.0996481	1.81	0.0894

Dependent Variable: Harvest2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	34038.92667	3403.89267	6.20	<.0001
Error	49	26915.54933	549.29693		
Corrected Total	59	60954.47600			

R-Square	Coeff Var	Root MSE	Harvest2 Mean
0.558432	27.06986	23.43708	86.58000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	22822.80067	22822.80067	41.55	<.0001
Treatment	9	11216.12600	1246.23622	2.27	0.0326

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	1	22822.80067	22822.80067	41.55	<.0001
Treatment	9	11216.12600	1246.23622	2.27	0.0326

Dependent Variable: Harvest3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	23175.86700	2317.58670	2.34	0.0242
Error	49	48614.30150	992.12860		
Corrected Total	59	71790.16850			

R-Square	Coeff Var	Root MSE	Harvest3 Mean
0.322828	17.36819	31.49807	181.3550

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	735.70017	735.70017	0.74	0.3934
Treatment	9	22440.16683	2493.35187	2.51	0.0188

Source	DF	Type III SS	Mean Square	F Value	Pr > F

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	735.70017	735.70017	0.74	0.3934
Treatment	9	22440.16683	2493.35187	2.51	0.0188

Dependent Variable: harvest4

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	10	28364.79600	2836.47960	7.85	<.0001
Error	49	17704.70333	361.32048		
Corrected Total	59	46069.49933			

R-Square	**Coeff Var**	**Root MSE**	**harvest4 Mean**
0.615696	9.007170	19.00843	211.0367

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	2940.00000	2940.00000	8.14	0.0063
Treatment	9	25424.79600	2824.97733	7.82	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	1	2940.00000	2940.00000	8.14	0.0063
Treatment	9	25424.79600	2824.97733	7.82	<.0001

Table C.5: Summary of ANOVA table for Lanorma tuber number

Dependent Variable: Lanorma tuber number

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	50.6736667	5.6304074	1.11	0.3996
Error	20	101.4333333	5.0716667		
Corrected Total	29	152.1070000			

R-Square	Coeff Var	Root MSE	Lanorma Mean
0.333145	23.48317	2.252036	9.590000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	50.67366667	5.63040741	1.11	0.3996

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	50.67366667	5.63040741	1.11	0.3996

Table C.6: Summary ANOVA table for Innovator tuber number

Dependent Variable: Innovator tuber number

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	7.96133333	0.88459259	0.27	0.9761
Error	20	65.79333333	3.28966667		
Corrected Total	29	73.75466667			

R-Square	Coeff Var	Root MSE	Innovator Mean
0.107943	26.62051	1.813744	6.813333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	7.96133333	0.88459259	0.27	0.9761

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	7.96133333	0.88459259	0.27	0.9761

Table C.7: Summary of ANOVA table for Lanorma stolon length

Dependent Variable: Lanorma stolon length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	61.1720000	6.7968889	2.48	0.0438
Error	20	54.8866667	2.7443333		
Corrected Total	29	116.0586667			

R-Square	Coeff Var	Root MSE	Lanorma Mean
0.527078	20.63874	1.656603	8.026667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	61.17200000	6.79688889	2.48	0.0438

Source	DF	Type III SS	Mean Square	F Value	Pr > F

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	61.17200000	6.79688889	2.48	0.0438

Dependent Variable: Innovator stolon length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	51.68533333	5.74281481	4.24	0.0034
Error	20	27.08666667	1.35433333		
Corrected Total	29	78.77200000			

R-Square	Coeff Var	Root MSE	Innovator Mean
0.656138	26.09323	1.163758	4.460000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	51.68533333	5.74281481	4.24	0.0034

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	51.68533333	5.74281481	4.24	0.0034

Table C.8: summary of ANOVA tables for Lanorma plant dry tuber mass across four harvest dates

Dependent Variable: T1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	74557.36250	24852.45417	83.09	<.0001
Error	8	2392.94667	299.11833		
Corrected Total	11	76950.30917			

R-Square	Coeff Var	Root MSE	T1 Mean
0.968903	16.85813	17.29504	102.5917

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	74557.36250	24852.45417	83.09	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	74557.36250	24852.45417	83.09	<.0001

Dependent Variable: T2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	73976.80667	24658.93556	22.48	0.0003
Error	8	8775.36000	1096.92000		
Corrected Total	11	82752.16667			

R-Square	Coeff Var	Root MSE	T2 Mean
0.893956	29.11203	33.11978	113.7667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	73976.80667	24658.93556	22.48	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	73976.80667	24658.93556	22.48	0.0003

Dependent Variable: T3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	94182.60333	31394.20111	98.99	<.0001
Error	8	2537.11333	317.13917		
Corrected Total	11	96719.71667			

R-Square	Coeff Var	Root MSE	T3 Mean
0.973768	14.61902	17.80840	121.8167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	94182.60333	31394.20111	98.99	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	94182.60333	31394.20111	98.99	<.0001

Dependent Variable: T4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	83550.75333	27850.25111	187.82	<.0001
Error	8	1186.26667	148.28333		
Corrected Total	11	84737.02000			

R-Square	Coeff Var	Root MSE	T4 Mean
0.986001	10.68172	12.17716	114.0000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	83550.75333	27850.25111	187.82	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	83550.75333	27850.25111	187.82	<.0001

Dependent Variable: T5

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	74218.70917	24739.56972	233.79	<.0001
Error	8	846.57333	105.82167		
Corrected Total	11	75065.28250			

R-Square	Coeff Var	Root MSE	T5 Mean
0.988722	9.232188	10.28697	111.4250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	74218.70917	24739.56972	233.79	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	74218.70917	24739.56972	233.79	<.0001

Dependent Variable: T6

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	97853.3092	32617.7697	41.02	<.0001
Error	8	6361.8800	795.2350		
Corrected Total	11	104215.1892			

R-Square	Coeff Var	Root MSE	T6 Mean
0.938954	22.51340	28.19991	125.2583

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	97853.30917	32617.76972	41.02	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	97853.30917	32617.76972	41.02	<.0001

Dependent Variable: T7

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	89493.50917	29831.16972	59.47	<.0001
Error	8	4012.66000	501.58250		
Corrected Total	11	93506.16917			

R-Square	Coeff Var	Root MSE	T7 Mean
0.957087	20.97826	22.39604	106.7583

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	89493.50917	29831.16972	59.47	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	89493.50917	29831.16972	59.47	<.0001

Dependent Variable: T8

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	82962.84917	27654.28306	25.76	0.0002
Error	8	8587.45333	1073.43167		
Corrected Total	11	91550.30250			

R-Square	Coeff Var	Root MSE	T8 Mean
0.906200	25.17830	32.76327	130.1250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	82962.84917	27654.28306	25.76	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	82962.84917	27654.28306	25.76	0.0002

Dependent Variable: T9

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	101866.3092	33955.4364	54.14	<.0001
Error	8	5017.3533	627.1692		
Corrected Total	11	106883.6625			

R-Square	Coeff Var	Root MSE	T9 Mean
0.953058	19.87962	25.04335	125.9750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	101866.3092	33955.4364	54.14	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	101866.3092	33955.4364	54.14	<.0001

Dependent Variable: T10

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	37167.51000	12389.17000	42.22	<.0001
Error	8	2347.46667	293.43333		
Corrected Total	11	39514.97667			

R-Square	Coeff Var	Root MSE	T10 Mean
0.940593	20.51894	17.12990	83.48333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	37167.51000	12389.17000	42.22	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	37167.51000	12389.17000	42.22	<.0001

Table C.9: Summary of ANNOVA for Innovator dry tuber tuber across harvest dates per treatment

Dependent Variable: T1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	59949.42000	19983.14000	183.87	<.0001
Error	8	869.42667	108.67833		

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Corrected Total	11	60818.84667			

R-Square	Coeff Var	Root MSE	T1 Mean
0.985705	8.968933	10.42489	116.2333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	59949.42000	19983.14000	183.87	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	59949.42000	19983.14000	183.87	<.0001

Dependent Variable: T2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	80889.88667	26963.29556	28.11	0.0001
Error	8	7673.00000	959.12500		
Corrected Total	11	88562.88667			

R-Square	Coeff Var	Root MSE	T2 Mean
0.913361	25.28830	30.96974	122.4667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	80889.88667	26963.29556	28.11	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	80889.88667	26963.29556	28.11	0.0001

Dependent Variable: T3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	79070.00917	26356.66972	105.17	<.0001
Error	8	2004.79333	250.59917		
Corrected Total	11	81074.80250			

R-Square	Coeff Var	Root MSE	T3 Mean
0.975272	12.32172	15.83032	128.4750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	79070.00917	26356.66972	105.17	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	79070.00917	26356.66972	105.17	<.0001

Dependent Variable: T4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	80682.38333	26894.12778	156.41	<.0001
Error	8	1375.61333	171.95167		
Corrected Total	11	82057.99667			

R-Square	Coeff Var	Root MSE	T4 Mean
0.983236	10.00868	13.11303	131.0167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	80682.38333	26894.12778	156.41	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	80682.38333	26894.12778	156.41	<.0001

Dependent Variable: T5

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	73486.44917	24495.48306	144.55	<.0001
Error	8	1355.64000	169.45500		
Corrected Total	11	74842.08917			

R-Square	Coeff Var	Root MSE	T5 Mean
0.981887	10.56543	13.01749	123.2083

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	73486.44917	24495.48306	144.55	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	73486.44917	24495.48306	144.55	<.0001

Dependent Variable: T6

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	89617.13667	29872.37889	25.38	0.0002
Error	8	9415.18000	1176.89750		
Corrected Total	11	99032.31667			

R-Square	Coeff Var	Root MSE	T6 Mean

```
R-Square   Coeff Var   Root MSE   T6 Mean

0.904928    25.94676    34.30594   132.2167


Source   DF     Type I SS    Mean Square   F Value   Pr > F

Harvest   3   89617.13667   29872.37889     25.38    0.0002


Source   DF   Type III SS    Mean Square   F Value   Pr > F

Harvest   3   89617.13667   29872.37889     25.38    0.0002
                  Dependent Variable: T7

Source            DF   Sum of Squares   Mean Square   F Value   Pr > F

Model              3     101031.8958     33677.2986     82.55   <.0001

Error              8       3263.6733       407.9592

Corrected Total   11     104295.5692


R-Square   Coeff Var   Root MSE   T7 Mean

0.968707    15.41930    20.19800   130.9917


Source   DF     Type I SS    Mean Square   F Value   Pr > F

Harvest   3   101031.8958    33677.2986     82.55    <.0001


Source   DF   Type III SS    Mean Square   F Value   Pr > F

Harvest   3   101031.8958    33677.2986     82.55    <.0001


                  Dependent Variable: T8

Source            DF   Sum of Squares   Mean Square   F Value   Pr > F
```

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	92221.28917	30740.42972	77.61	<.0001
Error	8	3168.78000	396.09750		
Corrected Total	11	95390.06917			

R-Square	Coeff Var	Root MSE	T8 Mean
0.966781	14.61874	19.90220	136.1417

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	92221.28917	30740.42972	77.61	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Harvest	3	92221.28917	30740.42972	77.61	<.0001

Dependent Variable: T9

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	108185.1158	36061.7053	48.65	<.0001
Error	8	5930.0533	741.2567		
Corrected Total	11	114115.1692			

R-Square	Coeff Var	Root MSE	T9 Mean
0.948034	18.68102	27.22603	145.7417

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Harvest	3	108185.1158	36061.7053	48.65	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	108185.1158	36061.7053	48.65	<.0001

Dependent Variable: T10

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	60451.78000	20150.59333	25.12	0.0002
Error	8	6417.60667	802.20083		
Corrected Total	11	66869.38667			

R-Square	**Coeff Var**	**Root MSE**	**T10 Mean**
0.904028	23.85442	28.32315	118.7333

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	60451.78000	20150.59333	25.12	0.0002

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Harvest	3	60451.78000	20150.59333	25.12	0.0002

Table C.10: Summary of ANOVA for Innovator dry leaf mass per harvest date across treatments.

Dependent Variable: Harvest1

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	1003.472000	111.496889	24.40	<.0001
Error	20	91.380000	4.569000		
Corrected Total	29	1094.852000			

R-Square	**Coeff Var**	**Root MSE**	**Harvest1 Mean**
0.916537	7.700007	2.137522	27.76000

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**

```
        Source      DF       Type I SS   Mean Square   F Value   Pr > F

        Treatment    9    1003.472000    111.496889     24.40   <.0001

        Source      DF     Type III SS   Mean Square   F Value   Pr > F

        Treatment    9    1003.472000    111.496889     24.40   <.0001
                          Dependent Variable: Harvest2
Source              DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                9      1475.247000    163.916333     17.02   <.0001

Error               20       192.660000      9.633000

Corrected Total     29      1667.907000

                R-Square   Coeff Var   Root MSE   Harvest2 Mean

                0.884490    8.390666   3.103707        36.99000

        Source      DF       Type I SS   Mean Square   F Value   Pr > F

        Treatment    9    1475.247000    163.916333     17.02   <.0001

        Source      DF     Type III SS   Mean Square   F Value   Pr > F

        Treatment    9    1475.247000    163.916333     17.02   <.0001
                          Dependent Variable: Harvest3
Source              DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                9       64.4670000     7.1630000      2.34   0.0547

Error               20       61.3000000     3.0650000

Corrected Total     29      125.7670000

                R-Square   Coeff Var   Root MSE   Harvest3 Mean

                0.512591    10.88076   1.750714        16.09000

        Source      DF       Type I SS   Mean Square   F Value   Pr > F

        Treatment    9    64.46700000    7.16300000      2.34   0.0547

        Source      DF     Type III SS   Mean Square   F Value   Pr > F

        Treatment    9    64.46700000    7.16300000      2.34   0.0547
                          Dependent Variable: Harvest4
Source              DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                9      255.0603333    28.3400370     24.76   <.0001

Error               20       22.8933333     1.1446667

Corrected Total     29      277.9536667

                R-Square   Coeff Var   Root MSE   Harvest4 Mean
```

R-Square	Coeff Var	Root MSE	Harvest4 Mean
0.917636	9.420819	1.069891	11.35667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	255.0603333	28.3400370	24.76	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	255.0603333	28.3400370	24.76	<.0001

Table C.11: Summary of ANOVA tables for Innovator dry stem per harvest date across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	16.2346667	1.8038519	0.39	0.9240
Error	20	91.6600000	4.5830000		
Corrected Total	29	107.8946667			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.150468	27.85075	2.140794	7.686667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	16.23466667	1.80385185	0.39	0.9240

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	16.23466667	1.80385185	0.39	0.9240

Dependent Variable: Harvest2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	42.8163333	4.7573704	0.91	0.5361
Error	20	104.6133333	5.2306667		
Corrected Total	29	147.4296667			

R-Square	Coeff Var	Root MSE	Harvest2 Mean
0.290419	19.72175	2.287065	11.59667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	42.81633333	4.75737037	0.91	0.5361

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	42.81633333	4.75737037	0.91	0.5361

Dependent Variable: Harvest3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	118.7150000	13.1905556	5.07	0.0012
Error	20	52.0466667	2.6023333		
Corrected Total	29	170.7616667			

R-Square	Coeff Var	Root MSE	Harvest3 Mean
0.695209	13.65169	1.613175	11.81667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	118.7150000	13.1905556	5.07	0.0012

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	118.7150000	13.1905556	5.07	0.0012

Dependent Variable: harvest4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	204.1283333	22.6809259	8.75	<.0001
Error	20	51.8466667	2.5923333		
Corrected Total	29	255.9750000			

R-Square	Coeff Var	Root MSE	harvest4 Mean
0.797454	15.11805	1.610072	10.65000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	204.1283333	22.6809259	8.75	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	204.1283333	22.6809259	8.75	<.0001

Table C.12: Summary of ANOVA table for Innovator dry tuber mass per harvest across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	68.2213333	7.5801481	0.60	0.7796
Error	20	251.2133333	12.5606667		
Corrected Total	29	319.4346667			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.213569	69.31101	3.544103	5.113333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	68.22133333	7.58014815	0.60	0.7796

```
         Source        DF     Type III SS   Mean Square   F Value    Pr > F

         Treatment      9   68.22133333      7.58014815      0.60    0.7796
                              Dependent Variable: Harvest2
Source               DF   Sum of Squares   Mean Square   F Value    Pr > F

Model                 9       3523.34167     391.48241      0.73    0.6800

Error                20      10773.26000     538.66300

Corrected Total      29      14296.60167

            R-Square   Coeff Var   Root MSE   Harvest2 Mean

            0.246446    21.87819   23.20911        106.0833

         Source        DF       Type I SS   Mean Square   F Value    Pr > F

         Treatment      9   3523.341667     391.482407      0.73    0.6800

         Source        DF     Type III SS   Mean Square   F Value    Pr > F

         Treatment      9   3523.341667     391.482407      0.73    0.6800
                              Dependent Variable: Harvest3
Source               DF   Sum of Squares   Mean Square   F Value    Pr > F

Model                 9       9772.04700    1085.78300      0.87    0.5674

Error                20      25012.66667    1250.63333

Corrected Total      29      34784.71367

            R-Square   Coeff Var   Root MSE   Harvest3 Mean

            0.280929    19.13066   35.36429        184.8567

         Source        DF       Type I SS   Mean Square   F Value    Pr > F

         Treatment      9   9772.047000    1085.783000      0.87    0.5674

         Source        DF     Type III SS   Mean Square   F Value    Pr > F

         Treatment      9   9772.047000    1085.783000      0.87    0.5674
                              Dependent Variable: harvest4
Source               DF   Sum of Squares   Mean Square   F Value    Pr > F

Model                 9      12939.26300    1437.69589      5.29    0.0009

Error                20       5436.62667     271.83133

Corrected Total      29      18375.88967

            R-Square   Coeff Var   Root MSE   harvest4 Mean

            0.704143    7.561714   16.48731        218.0367

         Source        DF       Type I SS   Mean Square   F Value    Pr > F
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	12939.26300	1437.69589	5.29	0.0009

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	12939.26300	1437.69589	5.29	0.0009

Table C.13: Summary of ANOVA to table for Innovator Harvest index per harvest across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	687.9763333	76.4418148	14.58	<.0001
Error	20	104.8933333	5.2446667		
Corrected Total	29	792.8696667			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.867704	12.83942	2.290124	17.83667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	687.9763333	76.4418148	14.58	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	687.9763333	76.4418148	14.58	<.0001

Dependent Variable: Harvest2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	234.7786667	26.0865185	0.82	0.6079
Error	20	639.1733333	31.9586667		
Corrected Total	29	873.9520000			

R-Square	Coeff Var	Root MSE	Harvest2 Mean
0.268640	8.296448	5.653200	68.14000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	234.7786667	26.0865185	0.82	0.6079

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	234.7786667	26.0865185	0.82	0.6079

Dependent Variable: Harvest3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	40.8546667	4.5394074	0.85	0.5779
Error	20	106.2400000	5.3120000		
Corrected Total	29	147.0946667			

R-Square	Coeff Var	Root MSE	Harvest3 Mean
0.277744	2.659973	2.304778	86.64667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	40.85466667	4.53940741	0.85	0.5779

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	40.85466667	4.53940741	0.85	0.5779

Dependent Variable: Harvest4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	68.92300000	7.65811111	5.37	0.0009
Error	20	28.52666667	1.42633333		
Corrected Total	29	97.44966667			

R-Square	Coeff Var	Root MSE	Harvest4 Mean
0.707268	1.313901	1.194292	90.89667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	68.92300000	7.65811111	5.37	0.0009

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	68.92300000	7.65811111	5.37	0.0009

Table C.14: Summary of ANOVA table for Lanorma dry stem mass per harvest date across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	14.53333333	1.61481481	1.40	0.2529
Error	20	23.07333333	1.15366667		
Corrected Total	29	37.60666667			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.386456	15.27140	1.074089	7.033333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	14.53333333	1.61481481	1.40	0.2529

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	14.53333333	1.61481481	1.40	0.2529

Dependent Variable: Harvest2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	81.4963333	9.0551481	1.29	0.3028
Error	20	140.6333333	7.0316667		
Corrected Total	29	222.1296667			

R-Square	Coeff Var	Root MSE	Harvest2 Mean
0.366886	23.88228	2.651729	11.10333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	81.49633333	9.05514815	1.29	0.3028

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	81.49633333	9.05514815	1.29	0.3028

Dependent Variable: Harvest3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1057.549667	117.505519	2.88	0.0234
Error	20	815.773333	40.788667		
Corrected Total	29	1873.323000			

R-Square	Coeff Var	Root MSE	Harvest3 Mean
0.564531	25.78361	6.386601	24.77000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	1057.549667	117.505519	2.88	0.0234

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	1057.549667	117.505519	2.88	0.0234

Dependent Variable: harvest4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	847.1830000	94.1314444	17.90	<.0001
Error	20	105.2000000	5.2600000		
Corrected Total	29	952.3830000			

R-Square	Coeff Var	Root MSE	harvest4 Mean
0.889540	11.86482	2.293469	19.33000

Source	DF	Type I SS	Mean Square	F Value	Pr > F

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	847.1830000	94.1314444	17.90	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	847.1830000	94.1314444	17.90	<.0001

Table C.15: Summary of ANOVA table for Lanorma dry leaf mass per harvest date across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1525.376333	169.486259	9.07	<.0001
Error	20	373.793333	18.689667		
Corrected Total	29	1899.169667			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.803181	19.52938	4.323155	22.13667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	1525.376333	169.486259	9.07	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	1525.376333	169.486259	9.07	<.0001

Dependent Variable: Harvest2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	4121.087000	457.898556	30.52	<.0001
Error	20	300.066667	15.003333		
Corrected Total	29	4421.153667			

R-Square	Coeff Var	Root MSE	Harvest2 Mean
0.932129	12.83579	3.873414	30.17667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	4121.087000	457.898556	30.52	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	4121.087000	457.898556	30.52	<.0001

Dependent Variable: harvest3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	8817.63333	979.73704	14.11	<.0001
Error	20	1388.41333	69.42067		
Corrected Total	29	10206.04667			

R-Square	Coeff Var	Root MSE	harvest3 Mean
0.863962	12.99154	8.331907	64.13333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	8817.633333	979.737037	14.11	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	8817.633333	979.737037	14.11	<.0001

Dependent Variable: harvest4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	286.2546667	31.8060741	5.44	0.0008
Error	20	116.9200000	5.8460000		
Corrected Total	29	403.1746667			

R-Square	Coeff Var	Root MSE	harvest4 Mean
0.710002	15.96292	2.417850	15.14667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	286.2546667	31.8060741	5.44	0.0008

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	286.2546667	31.8060741	5.44	0.0008

Table C.16: Summary of ANOVA table for Lanorma dry tuber per harvest date across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	170.0603333	18.8955926	20.67	<.0001
Error	20	18.2866667	0.9143333		
Corrected Total	29	188.3470000			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.902910	12.40218	0.956208	7.710000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	170.0603333	18.8955926	20.67	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	170.0603333	18.8955926	20.67	<.0001

Dependent Variable: Harvest2

```
Source           DF   Sum of Squares   Mean Square   F Value   Pr > F
Model             9      11574.97367    1286.10819      2.10   0.0804
Error            20      12260.10000     613.00500
Corrected Total  29      23835.07367

          R-Square   Coeff Var   Root MSE   Harvest2 Mean
          0.485628    36.91140   24.75894        67.07667

     Source       DF      Type I SS   Mean Square   F Value   Pr > F
     Treatment     9    11574.97367    1286.10819      2.10   0.0804

     Source       DF    Type III SS   Mean Square   F Value   Pr > F
     Treatment     9    11574.97367    1286.10819      2.10   0.0804
                         Dependent Variable: Harvest3
Source           DF   Sum of Squares   Mean Square   F Value   Pr > F
Model             9      14094.28800    1566.03200      1.41   0.2478
Error            20      22175.46667    1108.77333
Corrected Total  29      36269.75467

          R-Square   Coeff Var   Root MSE   Harvest3 Mean
          0.388596    18.72231   33.29825        177.8533

     Source       DF      Type I SS   Mean Square   F Value   Pr > F
     Treatment     9    14094.28800    1566.03200      1.41   0.2478

     Source       DF    Type III SS   Mean Square   F Value   Pr > F
     Treatment     9    14094.28800    1566.03200      1.41   0.2478
                         Dependent Variable: harvest4
Source           DF   Sum of Squares   Mean Square   F Value   Pr > F
Model             9      17375.31633    1930.59070      5.23   0.0010
Error            20       7378.29333     368.91467
Corrected Total  29      24753.60967

          R-Square   Coeff Var   Root MSE   harvest4 Mean
          0.701931    9.413578   19.20715        204.0367

     Source       DF      Type I SS   Mean Square   F Value   Pr > F
     Treatment     9    17375.31633    1930.59070      5.23   0.0010

     Source       DF    Type III SS   Mean Square   F Value   Pr > F
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	17375.31633	1930.59070	5.23	0.0010

Table C.17: Summary of ANOVA table for Lanorma harvest index per harvest date across treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	927.968333	103.107593	1.14	0.3797
Error	20	1803.393333	90.169667		
Corrected Total	29	2731.361667			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.339746	62.95539	9.495771	15.08333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	927.9683333	103.1075926	1.14	0.3797

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	927.9683333	103.1075926	1.14	0.3797

Dependent Variable: Harvest2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1790.408333	198.934259	2.19	0.0693
Error	20	1817.293333	90.864667		
Corrected Total	29	3607.701667			

R-Square	Coeff Var	Root MSE	Harvest2 Mean
0.496274	15.76020	9.532296	60.48333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	1790.408333	198.934259	2.19	0.0693

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	1790.408333	198.934259	2.19	0.0693

Dependent Variable: Harvest3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	696.716333	77.412926	3.12	0.0164
Error	20	496.693333	24.834667		
Corrected Total	29	1193.409667			

R-Square	Coeff Var	Root MSE	Harvest3 Mean

R-Square	Coeff Var	Root MSE	Harvest3 Mean
0.583803	7.464336	4.983439	66.76333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	696.7163333	77.4129259	3.12	0.0164

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	696.7163333	77.4129259	3.12	0.0164

Dependent Variable: Harvest4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	230.0946667	25.5660741	5.71	0.0006
Error	20	89.5400000	4.4770000		
Corrected Total	29	319.6346667			

R-Square	Coeff Var	Root MSE	Harvest4 Mean
0.719868	2.477239	2.115892	85.41333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	230.0946667	25.5660741	5.71	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	230.0946667	25.5660741	5.71	0.0006

Table C.18: Summary of ANOVA table for HI per cultivar per harvest across fertiliser treatments

Dependent Variable: Harvest1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	1819.067333	181.906733	4.41	0.0002
Error	49	2021.726000	41.259714		
Corrected Total	59	3840.793333			

R-Square	Coeff Var	Root MSE	Harvest1 Mean
0.473618	38.31037	6.423373	16.76667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	1	1085.450667	1085.450667	26.31	<.0001
Treatment	9	733.616667	81.512963	1.98	0.0627

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	1	1085.450667	1085.450667	26.31	<.0001
Treatment	9	733.616667	81.512963	1.98	0.0627

Table C.19: Summary of ANOVA table for Innovator leaf nutrient contents

```
                              The GLM Procedure

                           Dependent Variable: K
Source            DF  Sum of Squares  Mean Square  F Value   Pr > F
Model              9     181643671.3   20182630.1     8.62   <.0001
Error             20      46835964.0    2341798.2
Corrected Total   29     228479635.3

                 R-Square  Coeff Var  Root MSE    K Mean
                 0.795010   7.141030  1530.294  21429.59

       Source      DF      Type I SS  Mean Square  F Value   Pr > F
       Treatment    9  181643671.3     20182630.1     8.62   <.0001

       Source      DF    Type III SS  Mean Square  F Value   Pr > F
       Treatment    9  181643671.3     20182630.1     8.62   <.0001

                           Dependent Variable: Mg
Source            DF  Sum of Squares  Mean Square  F Value   Pr > F
Model              9     159692276.7   17743586.3     2.24   0.0639
Error             20     158408976.9    7920448.8
Corrected Total   29     318101253.5

                 R-Square  Coeff Var  Root MSE   Mg Mean
                 0.502017   19.28956  2814.329  14589.91

       Source      DF      Type I SS  Mean Square  F Value   Pr > F
       Treatment    9  159692276.7     17743586.3     2.24   0.0639

       Source      DF    Type III SS  Mean Square  F Value   Pr > F
       Treatment    9  159692276.7     17743586.3     2.24   0.0639
                           Dependent Variable: P
Source            DF  Sum of Squares  Mean Square  F Value   Pr > F
Model              9      2603411.98    289268.00     0.64   0.7532
Error             20      9087643.31    454382.17
Corrected Total   29     11691055.28

                 R-Square  Coeff Var  Root MSE    P Mean
                 0.222684   21.12854  674.0788  3190.370

       Source      DF      Type I SS  Mean Square  F Value   Pr > F
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	2603411.976	289267.997	0.64	0.7532

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	2603411.976	289267.997	0.64	0.7532

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	311874811.6	34652756.8	1.55	0.1968
Error	20	446160153.2	22308007.7		
Corrected Total	29	758034964.8			

R-Square	Coeff Var	Root MSE	Ca Mean
0.411425	17.49054	4723.135	27003.95

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	311874811.6	34652756.8	1.55	0.1968

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	311874811.6	34652756.8	1.55	0.1968

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	21102310.85	2344701.21	1.49	0.2187
Error	20	31492818.74	1574640.94		
Corrected Total	29	52595129.59			

R-Square	Coeff Var	Root MSE	S Mean
0.401222	21.79006	1254.847	5758.803

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	21102310.85	2344701.21	1.49	0.2187

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	21102310.85	2344701.21	1.49	0.2187

Table C.20: Summary of ANOVA table for Lanorma leaf nutrient content

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	659386350.5	73265150.1	7.61	<.0001

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Error	20	192633272.9	9631663.6		
Corrected Total	29	852019623.4			

R-Square	Coeff Var	Root MSE	K Mean
0.773910	13.94882	3103.492	22249.14

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	659386350.5	73265150.1	7.61	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	659386350.5	73265150.1	7.61	<.0001

The GLM Procedure

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	267538254.0	29726472.7	3.82	0.0060
Error	20	155600398.5	7780019.9		
Corrected Total	29	423138652.5			

R-Square	Coeff Var	Root MSE	Mg Mean
0.632271	19.84172	2789.269	14057.60

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	267538254.0	29726472.7	3.82	0.0060

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	267538254.0	29726472.7	3.82	0.0060

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3965366.37	440596.26	1.04	0.4410
Error	20	8434085.48	421704.27		
Corrected Total	29	12399451.85			

R-Square	Coeff Var	Root MSE	P Mean
0.319802	16.12607	649.3876	4026.943

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	3965366.374	440596.264	1.04	0.4410

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	3965366.374	440596.264	1.04	0.4410

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	59453255.83	6605917.31	12.08	<.0001
Error	20	10936650.45	546832.52		
Corrected Total	29	70389906.29			

R-Square	Coeff Var	Root MSE	S Mean
0.844628	13.06938	739.4813	5658.120

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	59453255.83	6605917.31	12.08	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	59453255.83	6605917.31	12.08	<.0001

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	150305471.5	16700607.9	1.08	0.4208
Error	20	310425522.3	15521276.1		
Corrected Total	29	460730993.8			

R-Square	Coeff Var	Root MSE	Ca Mean
0.326233	16.38902	3939.705	24038.68

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	150305471.5	16700607.9	1.08	0.4208

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	150305471.5	16700607.9	1.08	0.4208

Appendix D

Table D.1: Summary of ANOVA table for Lanorma top soil

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	14391.86380	1599.09598	17.66	<.0001

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Error	20	1811.01458	90.55073		
Corrected Total	29	16202.87838			

R-Square	**Coeff Var**	**Root MSE**	**K Mean**
0.888229	10.11286	9.515815	94.09617

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	14391.86380	1599.09598	17.66	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	14391.86380	1599.09598	17.66	<.0001

Dependent Variable: Ca

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	7143.61875	793.73542	0.88	0.5608
Error	20	18105.29167	905.26458		
Corrected Total	29	25248.91042			

R-Square	**Coeff Var**	**Root MSE**	**Ca Mean**
0.282928	10.61260	30.08762	283.5083

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	7143.618750	793.735417	0.88	0.5608

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	7143.618750	793.735417	0.88	0.5608

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	515.339721	57.259969	0.61	0.7755
Error	20	1881.476583	94.073829		
Corrected Total	29	2396.816304			

R-Square	Coeff Var	Root MSE	Mg Mean
0.215010	10.34261	9.699166	93.77867

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	515.3397208	57.2599690	0.61	0.7755

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	515.3397208	57.2599690	0.61	0.7755

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	38.32505234	4.25833915	1.42	0.2434
Error	20	59.83260050	2.99163003		
Corrected Total	29	98.15765284			

R-Square	Coeff Var	Root MSE	S Mean
0.390444	63.08193	1.729633	2.741883

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	38.32505234	4.25833915	1.42	0.2434

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	38.32505234	4.25833915	1.42	0.2434

Dependent Variable: NH4

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	5.99818667	0.66646519	0.79	0.6296
Error	20	16.89293333	0.84464667		
Corrected Total	29	22.89112000			

R-Square	**Coeff Var**	**Root MSE**	**NH4 Mean**
0.262031	34.86520	0.919047	2.636000

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	5.99818667	0.66646519	0.79	0.6296

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	5.99818667	0.66646519	0.79	0.6296

Dependent Variable: NO3

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	85.7793200	9.5310356	2.69	0.0314
Error	20	70.8858000	3.5442900		
Corrected Total	29	156.6651200			

R-Square	Coeff Var	Root MSE	NO3 Mean
0.547533	33.59437	1.882628	5.604000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	85.77932000	9.53103556	2.69	0.0314

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	85.77932000	9.53103556	2.69	0.0314

Table D.2: Summary of ANOVA table for Innovator top soil

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	18960.11633	2106.67959	3.26	0.0133
Error	20	12928.78667	646.43933		
Corrected Total	29	31888.90300			

R-Square	Coeff Var	Root MSE	K Mean
0.594568	30.76990	25.42517	82.63000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	18960.11633	2106.67959	3.26	0.0133

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	18960.11633	2106.67959	3.26	0.0133

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	19685.85200	2187.31689	1.08	0.4185
Error	20	40516.30667	2025.81533		
Corrected Total	29	60202.15867			

R-Square	Coeff Var	Root MSE	Ca Mean
0.326996	17.09594	45.00906	263.2733

Source	DF	Type I SS	Mean Square	F Value	Pr > F

```
      Source       DF      Type I SS   Mean Square   F Value   Pr > F

      Treatment     9   19685.85200    2187.31689       1.08   0.4185

      Source       DF    Type III SS   Mean Square   F Value   Pr > F

      Treatment     9   19685.85200    2187.31689       1.08   0.4185
                          Dependent Variable: Mg
Source               DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                 9      1364.618667    151.624296      0.85   0.5829

Error                20      3575.393333    178.769667

Corrected Total      29      4940.012000

                  R-Square   Coeff Var   Root MSE   Mg Mean

                  0.276238    16.06256   13.37048   83.24000

      Source       DF      Type I SS   Mean Square   F Value   Pr > F

      Treatment     9   1364.618667    151.624296       0.85   0.5829

      Source       DF    Type III SS   Mean Square   F Value   Pr > F

      Treatment     9   1364.618667    151.624296       0.85   0.5829
                          Dependent Variable: S
Source               DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                 9      1506.496333    167.388481      7.06   0.0001

Error                20       474.173333     23.708667

Corrected Total      29      1980.669667

                  R-Square   Coeff Var   Root MSE     S Mean

                  0.760599    53.72366   4.869155   9.063333

      Source       DF      Type I SS   Mean Square   F Value   Pr > F

      Treatment     9   1506.496333    167.388481       7.06   0.0001

      Source       DF    Type III SS   Mean Square   F Value   Pr > F

      Treatment     9   1506.496333    167.388481       7.06   0.0001
                          Dependent Variable: NH4
Source               DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                 9       2.80734667    0.31192741      0.78   0.6371

Error                20       8.00020000    0.40001000

Corrected Total      29      10.80754667

                 R-Square   Coeff Var   Root MSE   NH4 Mean
```

R-Square	Coeff Var	Root MSE	NH4 Mean
0.259758	23.00983	0.632463	2.748667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	2.80734667	0.31192741	0.78	0.6371

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	2.80734667	0.31192741	0.78	0.6371

Dependent Variable: NO3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3.32474667	0.36941630	0.30	0.9657
Error	20	24.52840000	1.22642000		
Corrected Total	29	27.85314667			

R-Square	Coeff Var	Root MSE	NO3 Mean
0.119367	25.54841	1.107438	4.334667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	3.32474667	0.36941630	0.30	0.9657

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	3.32474667	0.36941630	0.30	0.9657

Table D.3: Summary of ANOVA table for Lanorma subsoil

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3024.800333	336.088926	2.84	0.0248
Error	20	2364.466667	118.223333		
Corrected Total	29	5389.267000			

R-Square	Coeff Var	Root MSE	K Mean
0.561264	20.58901	10.87306	52.81000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	3024.800333	336.088926	2.84	0.0248

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	3024.800333	336.088926	2.84	0.0248

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	27637.76000	3070.86222	1.06	0.4332

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Error	20	58124.36000	2906.21800		
Corrected Total	29	85762.12000			

R-Square	Coeff Var	Root MSE	Ca Mean
0.322261	18.02988	53.90935	299.0000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	27637.76000	3070.86222	1.06	0.4332

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	27637.76000	3070.86222	1.06	0.4332

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	2177.425333	241.936148	1.67	0.1625
Error	20	2897.546667	144.877333		
Corrected Total	29	5074.972000			

R-Square	Coeff Var	Root MSE	Mg Mean
0.429052	13.21821	12.03650	91.06000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	2177.425333	241.936148	1.67	0.1625

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	2177.425333	241.936148	1.67	0.1625

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	211.3270000	23.4807778	1.11	0.3997
Error	20	423.0666667	21.1533333		
Corrected Total	29	634.3936667			

R-Square	Coeff Var	Root MSE	S Mean
0.333117	44.40884	4.599275	10.35667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	211.3270000	23.4807778	1.11	0.3997

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	211.3270000	23.4807778	1.11	0.3997

Table D.4: Summary of ANOVA table for Innovator subsoil

Dependent Variable: K

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	10372.46033	1152.49559	5.51	0.0007
Error	20	4183.82667	209.19133		
Corrected Total	29	14556.28700			

R-Square	**Coeff Var**	**Root MSE**	**K Mean**
0.712576	23.82383	14.46345	60.71000

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	10372.46033	1152.49559	5.51	0.0007

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	10372.46033	1152.49559	5.51	0.0007

Dependent Variable: Ca

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	18168.1800	2018.6867	0.33	0.9538
Error	20	121707.9800	6085.3990		
Corrected Total	29	139876.1600			

R-Square	**Coeff Var**	**Root MSE**	**Ca Mean**
0.129888	21.03802	78.00897	370.8000

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	18168.18000	2018.68667	0.33	0.9538

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	18168.18000	2018.68667	0.33	0.9538

Dependent Variable: Mg

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	2736.86133	304.09570	0.50	0.8551
Error	20	12091.07333	604.55367		
Corrected Total	29	14827.93467			

R-Square	**Coeff Var**	**Root MSE**	**Mg Mean**
0.184575	22.61698	24.58767	108.7133

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	2736.861333	304.095704	0.50	0.8551

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	2736.861333	304.095704	0.50	0.8551

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	453.660000	50.406667	1.37	0.2671
Error	20	738.106667	36.905333		
Corrected Total	29	1191.766667			

R-Square	Coeff Var	Root MSE	S Mean
0.380662	39.53347	6.074976	15.36667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	453.6600000	50.4066667	1.37	0.2671

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	453.6600000	50.4066667	1.37	0.2671

Appendix E

Table E.1: Summary of ANOVA table for Innovator pith nutrient content

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	16376909.28	1819656.59	1.87	0.1164
Error	20	19435335.58	971766.78		
Corrected Total	29	35812244.86			

R-Square	Coeff Var	Root MSE	K Mean
0.457299	9.100642	985.7823	10832.01

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	16376909.28	1819656.59	1.87	0.1164

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	16376909.28	1819656.59	1.87	0.1164

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	65086.1076	7231.7897	0.50	0.8571
Error	20	289156.8147	14457.8407		
Corrected Total	29	354242.9223			

```
                  R-Square   Coeff Var   Root MSE   Mg Mean

                  0.183733    10.69105   120.2408   1124.686

        Source       DF      Type I SS   Mean Square   F Value   Pr > F

        Treatment     9   65086.10760    7231.78973       0.50   0.8571

        Source       DF     Type III SS  Mean Square   F Value   Pr > F

        Treatment     9   65086.10760    7231.78973       0.50   0.8571
                         Dependent Variable: P
Source               DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                 9      1136648.503    126294.278      1.40   0.2538

Error                20      1807521.276     90376.064

Corrected Total      29      2944169.780

                  R-Square   Coeff Var   Root MSE    P Mean

                  0.386068    14.89047   300.6261   2018.917

        Source       DF      Type I SS   Mean Square   F Value   Pr > F

        Treatment     9   1136648.503    126294.278       1.40   0.2538

        Source       DF     Type III SS  Mean Square   F Value   Pr > F

        Treatment     9   1136648.503    126294.278       1.40   0.2538
                         Dependent Variable: S
Source               DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                 9      280626.6686    31180.7410      1.03   0.4487

Error                20      603592.9461    30179.6473

Corrected Total      29      884219.6147

                  R-Square   Coeff Var   Root MSE    S Mean

                  0.317372    9.300771   173.7229   1867.833

        Source       DF      Type I SS   Mean Square   F Value   Pr > F

        Treatment     9   280626.6686    31180.7410       1.03   0.4487

        Source       DF     Type III SS  Mean Square   F Value   Pr > F

        Treatment     9   280626.6686    31180.7410       1.03   0.4487
                         Dependent Variable: Ca
Source               DF   Sum of Squares   Mean Square   F Value   Pr > F

Model                 9       77636.3003     8626.2556      3.53   0.0090

Error                20       48836.0711     2441.8036
```

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Corrected Total	29	126472.3714			

R-Square	Coeff Var	Root MSE	Ca Mean
0.613860	22.09774	49.41461	223.6183

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	77636.30028	8626.25559	3.53	0.0090

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	77636.30028	8626.25559	3.53	0.0090

Dependent Variable: N

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1.12174667	0.12463852	3.35	0.0116
Error	20	0.74373333	0.03718667		
Corrected Total	29	1.86548000			

R-Square	Coeff Var	Root MSE	N Mean
0.601318	8.465252	0.192838	2.278000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	1.12174667	0.12463852	3.35	0.0116

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	1.12174667	0.12463852	3.35	0.0116

Table E.2: Summary of ANOVA table for Innovator skin content

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	22212702.84	2468078.09	2.53	0.0403
Error	20	19517105.14	975855.26		
Corrected Total	29	41729807.98			

R-Square	Coeff Var	Root MSE	K Mean
0.532298	8.051144	987.8539	12269.73

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	22212702.84	2468078.09	2.53	0.0403

```
          Source       DF     Type III SS   Mean Square   F Value    Pr > F

          Treatment     9   22212702.84      2468078.09      2.53   0.0403
                              Dependent Variable: Mg
Source                DF   Sum of Squares   Mean Square   F Value    Pr > F

Model                  9      210513.0411    23390.3379      4.21   0.0036

Error                 20      111119.4888     5555.9744

Corrected Total       29      321632.5299


                R-Square   Coeff Var   Root MSE   Mg Mean

                0.654514    6.209433   74.53841  1200.406


          Source       DF      Type I SS   Mean Square   F Value    Pr > F

          Treatment     9   210513.0411     23390.3379      4.21   0.0036


          Source       DF     Type III SS   Mean Square   F Value    Pr > F

          Treatment     9   210513.0411     23390.3379      4.21   0.0036
                              Dependent Variable: P
Source                DF   Sum of Squares   Mean Square   F Value    Pr > F

Model                  9       726979.151     80775.461      1.32   0.2894

Error                 20      1227501.370     61375.068

Corrected Total       29      1954480.520


                R-Square   Coeff Var   Root MSE    P Mean

                0.371955    15.14287   247.7399  1636.017


          Source       DF      Type I SS   Mean Square   F Value    Pr > F

          Treatment     9   726979.1507     80775.4612      1.32   0.2894


          Source       DF     Type III SS   Mean Square   F Value    Pr > F

          Treatment     9   726979.1507     80775.4612      1.32   0.2894
                              Dependent Variable: S
Source                DF   Sum of Squares   Mean Square   F Value    Pr > F

Model                  9      282869.6532    31429.9615      1.19   0.3555

Error                 20      530008.3861    26500.4193

Corrected Total       29      812878.0393


                R-Square   Coeff Var   Root MSE    S Mean

                0.347985    9.496407   162.7895  1714.222


          Source       DF      Type I SS   Mean Square   F Value    Pr > F
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	282869.6532	31429.9615	1.19	0.3555

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	282869.6532	31429.9615	1.19	0.3555

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	185942.7519	20660.3058	2.44	0.0467
Error	20	169602.5843	8480.1292		
Corrected Total	29	355545.3361			

R-Square	Coeff Var	Root MSE	Ca Mean
0.522979	11.71605	92.08762	785.9957

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	185942.7519	20660.3058	2.44	0.0467

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	185942.7519	20660.3058	2.44	0.0467

Dependent Variable: N

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.82568000	0.09174222	4.65	0.0020
Error	20	0.39466667	0.01973333		
Corrected Total	29	1.22034667			

R-Square	Coeff Var	Root MSE	N Mean
0.676595	5.760336	0.140475	2.438667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	0.82568000	0.09174222	4.65	0.0020

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	0.82568000	0.09174222	4.65	0.0020

Table E.3: Summary of ANOVA table for Lanorma pith nutrient content

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	14759009.29	1639889.92	2.63	0.0345
Error	20	12477849.84	623892.49		
Corrected Total	29	27236859.14			

R-Square	Coeff Var	Root MSE	K Mean
0.541876	5.775142	789.8687	13677.04

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	14759009.29	1639889.92	2.63	0.0345

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	14759009.29	1639889.92	2.63	0.0345

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	184886.8767	20542.9863	2.56	0.0383
Error	20	160460.2945	8023.0147		
Corrected Total	29	345347.1712			

R-Square	Coeff Var	Root MSE	Mg Mean
0.535365	6.772048	89.57128	1322.662

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	184886.8767	20542.9863	2.56	0.0383

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	184886.8767	20542.9863	2.56	0.0383

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1230782.603	136753.623	1.32	0.2857
Error	20	2065773.855	103288.693		
Corrected Total	29	3296556.458			

R-Square	Coeff Var	Root MSE	P Mean
0.373354	13.33001	321.3856	2410.994

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	1230782.603	136753.623	1.32	0.2857

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	1230782.603	136753.623	1.32	0.2857

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	236938.8768	26326.5419	1.91	0.1094
Error	20	275648.1053	13782.4053		

```
Source           DF  Sum of Squares  Mean Square  F Value  Pr > F

Corrected Total  29     512586.9821

             R-Square  Coeff Var  Root MSE    S Mean

             0.462241   6.841359  117.3985  1716.011

      Source     DF     Type I SS  Mean Square  F Value  Pr > F

      Treatment   9  236938.8768   26326.5419     1.91  0.1094

      Source     DF   Type III SS  Mean Square  F Value  Pr > F

      Treatment   9  236938.8768   26326.5419     1.91  0.1094
                      Dependent Variable: Ca
Source           DF  Sum of Squares  Mean Square  F Value  Pr > F

Model             9     38752.29854   4305.81095     2.01  0.0928

Error            20     42828.73300   2141.43665

Corrected Total  29     81581.03154

             R-Square  Coeff Var  Root MSE   Ca Mean

             0.475016   17.52218  46.27566  264.0977

      Source     DF     Type I SS  Mean Square  F Value  Pr > F

      Treatment   9  38752.29854   4305.81095     2.01  0.0928

      Source     DF   Type III SS  Mean Square  F Value  Pr > F

      Treatment   9  38752.29854   4305.81095     2.01  0.0928
                      Dependent Variable: N
Source           DF  Sum of Squares  Mean Square  F Value  Pr > F

Model             9      1.55987000   0.17331889     6.25  0.0003

Error            20      0.55480000   0.02774000

Corrected Total  29      2.11467000

             R-Square  Coeff Var  Root MSE    N Mean

             0.737642   8.160377  0.166553  2.041000

       Source     DF    Type I SS  Mean Square  F Value  Pr > F

       Treatment   9  1.55987000   0.17331889     6.25  0.0003

       Source     DF  Type III SS  Mean Square  F Value  Pr > F

       Treatment   9  1.55987000   0.17331889     6.25  0.0003
```

Table E.4: Summary of ANOVA table for Lanorma skin nutrient content

Dependent Variable: K

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	926821256	308940419	64.55	<.0001
Error	116	555221069	4786389		
Corrected Total	119	1482042324			

R-Square	**Coeff Var**	**Root MSE**	**K Mean**
0.625368	15.90498	2187.782	13755.33

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	3	926821255.7	308940418.6	64.55	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	3	926821255.7	308940418.6	64.55	<.0001

Dependent Variable: Mg

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	2077661.628	692553.876	33.29	<.0001
Error	116	2413013.658	20801.842		
Corrected Total	119	4490675.285			

R-Square	**Coeff Var**	**Root MSE**	**Mg Mean**
0.462661	11.26774	144.2284	1280.012

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	3	2077661.628	692553.876	33.29	<.0001

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	3	2077661.628	692553.876	33.29	<.0001

Dependent Variable: P

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	15255542.48	5085180.83	59.76	<.0001
Error	116	9870856.42	85093.59		
Corrected Total	119	25126398.89			

R-Square	**Coeff Var**	**Root MSE**	**P Mean**
0.607152	15.43222	291.7081	1890.253

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Cultivar	3	15255542.48	5085180.83	59.76	<.0001

```
Source    DF    Type III SS    Mean Square    F Value    Pr > F

Cultivar   3    15255542.48     5085180.83      59.76    <.0001

                         Dependent Variable: S
Source             DF    Sum of Squares    Mean Square    F Value    Pr > F

Model               3        478261.103     159420.368       4.30    0.0065

Error             116       4302734.300      37092.537

Corrected Total   119       4780995.403

              R-Square    Coeff Var    Root MSE      S Mean

              0.100034     10.94096    192.5942    1760.305

Source    DF      Type I SS    Mean Square    F Value    Pr > F

Cultivar   3    478261.1029    159420.3676       4.30    0.0065

Source    DF    Type III SS    Mean Square    F Value    Pr > F

Cultivar   3    478261.1029    159420.3676       4.30    0.0065
                         Dependent Variable: Ca
Source             DF    Sum of Squares    Mean Square    F Value    Pr > F

Model               3       10765167.67     3588389.22     277.67    <.0001

Error             116        1499098.04       12923.26

Corrected Total   119       12264265.71

              R-Square    Coeff Var    Root MSE     Ca Mean

              0.877767     21.02128    113.6805    540.7878

Source    DF      Type I SS    Mean Square    F Value    Pr > F

Cultivar   3    10765167.67     3588389.22     277.67    <.0001

Source    DF    Type III SS    Mean Square    F Value    Pr > F

Cultivar   3    10765167.67     3588389.22     277.67    <.0001
                         Dependent Variable: N
Source             DF    Sum of Squares    Mean Square    F Value    Pr > F

Model               3        2.54682000     0.84894000      14.43    <.0001

Error             116        6.82432667     0.05883040

Corrected Total   119        9.37114667

              R-Square    Coeff Var    Root MSE      N Mean

              0.271773     10.67248    0.242550    2.272667
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	2.54682000	0.84894000	14.43	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	2.54682000	0.84894000	14.43	<.0001

Table E.5: Summary of ANOVA table for skin and pith nutrient content of both cultivars

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	926821256	308940419	64.55	<.0001
Error	116	555221069	4786389		
Corrected Total	119	1482042324			

R-Square	Coeff Var	Root MSE	K Mean
0.625368	15.90498	2187.782	13755.33

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	926821255.7	308940418.6	64.55	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	926821255.7	308940418.6	64.55	<.0001

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2077661.628	692553.876	33.29	<.0001
Error	116	2413013.658	20801.842		
Corrected Total	119	4490675.285			

R-Square	Coeff Var	Root MSE	Mg Mean
0.462661	11.26774	144.2284	1280.012

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	2077661.628	692553.876	33.29	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	2077661.628	692553.876	33.29	<.0001

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	15255542.48	5085180.83	59.76	<.0001
Error	116	9870856.42	85093.59		

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Corrected Total	119	25126398.89			

R-Square	Coeff Var	Root MSE	P Mean
0.607152	15.43222	291.7081	1890.253

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	15255542.48	5085180.83	59.76	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	15255542.48	5085180.83	59.76	<.0001

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	478261.103	159420.368	4.30	0.0065
Error	116	4302734.300	37092.537		
Corrected Total	119	4780995.403			

R-Square	Coeff Var	Root MSE	S Mean
0.100034	10.94096	192.5942	1760.305

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	478261.1029	159420.3676	4.30	0.0065

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	478261.1029	159420.3676	4.30	0.0065

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	10765167.67	3588389.22	277.67	<.0001
Error	116	1499098.04	12923.26		
Corrected Total	119	12264265.71			

R-Square	Coeff Var	Root MSE	Ca Mean
0.877767	21.02128	113.6805	540.7878

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	10765167.67	3588389.22	277.67	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	10765167.67	3588389.22	277.67	<.0001

Dependent Variable: N

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.54682000	0.84894000	14.43	<.0001
Error	116	6.82432667	0.05883040		
Corrected Total	119	9.37114667			

R-Square	Coeff Var	Root MSE	N Mean
0.271773	10.67248	0.242550	2.272667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	3	2.54682000	0.84894000	14.43	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cultivar	3	2.54682000	0.84894000	14.43	<.0001

Appendix F

Table F.1: Summary of ANOVA table for Innovator field trial SG, chip colour, dry matter content and yield

The GLM Procedure

Class Level Information

Class	Levels	Values
N	3	N160 N230 N300
K	4	K0 K160 K230 K300
Rep	3	1 2 3
Treatment	10	1 2 3 4 5 6 7 8 9 10

Number of Observations Used 30

Dependent Variable: SG Specific gravity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.00016684	0.00001854	13.24	<.0001
Error	20	0.00002801	0.00000140		
Corrected Total	29	0.00019485			

R-Square	Coeff Var	Root MSE	SG Mean
0.856265	0.109709	0.001183	1.078637

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	0.00016684	0.00001854	13.24	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	0.00016684	0.00001854	13.24	<.0001

Dependent Variable: Colour Chip colour

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	63.84700000	7.09411111	6.33	0.0003
Error	20	22.40000000	1.12000000		
Corrected Total	29	86.24700000			

R-Square	**Coeff Var**	**Root MSE**	**Colour Mean**
0.740281	1.945763	1.058301	54.39000

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	63.84700000	7.09411111	6.33	0.0003

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	63.84700000	7.09411111	6.33	0.0003

Dependent Variable: DM Dry matter content (%)

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	5.40908000	0.60100889	2.54	0.0394
Error	20	4.72606667	0.23630333		
Corrected Total	29	10.13514667			

R-Square	**Coeff Var**	**Root MSE**	**DM Mean**
0.533695	2.379240	0.486110	20.43133

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	5.40908000	0.60100889	2.54	0.0394

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment	9	5.40908000	0.60100889	2.54	0.0394

Dependent Variable: Yield Yield in t/ha

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	9	528.9112533	58.7679170	52.09	<.0001
Error	20	22.5638667	1.1281933		
Corrected Total	29	551.4751200			

R-Square	**Coeff Var**	**Root MSE**	**Yield Mean**
0.959085	2.444792	1.062164	43.44600

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	528.9112533	58.7679170	52.09	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	528.9112533	58.7679170	52.09	<.0001

Table F.2: Summary of ANOVA table for Lanorma field trial SG, chip colour, dry matter content and yield

Class Level Information

Class	Levels	Values
N	3	N160 N230 N300
K	4	K0 K160 K230 K300
Rep	3	1 2 3
Treatment	10	1 2 3 4 5 6 7 8 9 10

Number of Observations Read	30
Number of Observations Used	30

Dependent Variable: SG Specific gravity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.00013737	0.00001526	13.88	<.0001
Error	20	0.00002200	0.00000110		
Corrected Total	29	0.00015937			

R-Square	Coeff Var	Root MSE	SG Mean
0.861954	0.098225	0.001049	1.067767

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	0.00013737	0.00001526	13.88	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	0.00013737	0.00001526	13.88	<.0001

Dependent Variable: Colour Chip colour

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	88.9603333	9.8844815	5.91	0.0005

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Error	20	33.4333333	1.6716667		
Corrected Total	29	122.3936667			

R-Square	Coeff Var	Root MSE	Colour Mean
0.726838	2.356923	1.292929	54.85667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	88.96033333	9.88448148	5.91	0.0005

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	88.96033333	9.88448148	5.91	0.0005

Dependent Variable: DM Dry matter content (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3.40732000	0.37859111	5.15	0.0011
Error	20	1.47080000	0.07354000		
Corrected Total	29	4.87812000			

R-Square	Coeff Var	Root MSE	DM Mean
0.698490	1.553521	0.271183	17.45600

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	3.40732000	0.37859111	5.15	0.0011

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	3.40732000	0.37859111	5.15	0.0011

Dependent Variable: Yield Yield in t/ha

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1907.636163	211.959574	177.52	<.0001
Error	20	23.879933	1.193997		
Corrected Total	29	1931.516097			

R-Square	Coeff Var	Root MSE	Yield Mean
0.987637	2.120941	1.092702	51.51967

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	9	1907.636163	211.959574	177.52	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	9	1907.636163	211.959574	177.52	<.0001

Table F.3: Summary of ANOVA table across levels of N and K for Innovator

The ANOVA Procedure

Dependent Variable: SG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	0.00017074	0.00001220	16.46	<.0001
Error	12	0.00000889	0.00000074		
Corrected Total	26	0.00017963			

R-Square	Coeff Var	Root MSE	SG Mean
0.950515	0.079817	0.000861	1.078296

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	0.00000274	0.00000137	1.85	0.1994
N	2	0.00010319	0.00005159	69.65	<.0001
Rep*N	4	0.00000104	0.00000026	0.35	0.8391
K	2	0.00003674	0.00001837	24.80	<.0001
N*K	4	0.00002704	0.00000676	9.13	0.0013

Dependent Variable: Colour

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	66.89185185	4.77798942	4.40	0.0071
Error	12	13.02666667	1.08555556		
Corrected Total	26	79.91851852			

R-Square	Coeff Var	Root MSE	Colour Mean
0.837001	1.911483	1.041900	54.50741

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	5.38296296	2.69148148	2.48	0.1255
N	2	4.20518519	2.10259259	1.94	0.1866
Rep*N	4	1.38370370	0.34592593	0.32	0.8601
K	2	14.62740741	7.31370370	6.74	0.0109
N*K	4	41.29259259	10.32314815	9.51	0.0011

Dependent Variable: DM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	5.92444444	0.42317460	1.40	0.2818
Error	12	3.62222222	0.30185185		
Corrected Total	26	9.54666667			

R-Square	Coeff Var	Root MSE	DM Mean
0.620577	2.682959	0.549410	20.47778

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	0.37555556	0.18777778	0.62	0.5533
N	2	4.74888889	2.37444444	7.87	0.0066
Rep*N	4	0.72222222	0.18055556	0.60	0.6710
K	2	0.01555556	0.00777778	0.03	0.9746
N*K	4	0.06222222	0.01555556	0.05	0.9943

Dependent Variable: Yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	468.7932444	33.4852317	22.78	<.0001
Error	12	17.6361556	1.4696796		
Corrected Total	26	486.4294000			

R-Square	Coeff Var	Root MSE	Yield Mean
0.963744	2.759416	1.212303	43.93333

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	0.0868222	0.0434111	0.03	0.9710
N	2	436.6424889	218.3212444	148.55	<.0001
Rep*N	4	3.9184889	0.9796222	0.67	0.6273
K	2	12.9481556	6.4740778	4.41	0.0368
N*K	4	15.1972889	3.7993222	2.59	0.0907

Table F.4: Summary of ANOVA table for Lanorma per level of N and K

Dependent Variable: SG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	0.00007252	0.00000518	3.73	0.0140
Error	12	0.00001667	0.00000139		
Corrected Total	26	0.00008919			

R-Square	Coeff Var	Root MSE	SG Mean
0.813123	0.110424	0.001179	1.067259

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	0.00000230	0.00000115	0.83	0.4610

Source	DF	Anova SS	Mean Square	F Value	Pr > F
N	2	0.00005252	0.00002626	18.91	0.0002
Rep*N	4	0.00000237	0.00000059	0.43	0.7867
K	2	0.00000141	0.00000070	0.51	0.6148
N*K	4	0.00001393	0.00000348	2.51	0.0976

Dependent Variable: Colour

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	79.28444444	5.66317460	4.57	0.0060
Error	12	14.86222222	1.23851852		
Corrected Total	26	94.14666667			

R-Square	Coeff Var	Root MSE	Colour Mean
0.842138	2.016912	1.112887	55.17778

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	0.96222222	0.48111111	0.39	0.6863
N	2	24.74888889	12.37444444	9.99	0.0028
Rep*N	4	17.20222222	4.30055556	3.47	0.0418
K	2	12.90888889	6.45444444	5.21	0.0235
N*K	4	23.46222222	5.86555556	4.74	0.0159

Dependent Variable: DM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	2.38996296	0.17071164	2.88	0.0371
Error	12	0.71222222	0.05935185		
Corrected Total	26	3.10218519			

R-Square	Coeff Var	Root MSE	DM Mean
0.770413	1.401680	0.243622	17.38074

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	0.11522963	0.05761481	0.97	0.4067
N	2	0.85514074	0.42757037	7.20	0.0088
Rep*N	4	0.39668148	0.09917037	1.67	0.2209
K	2	0.16267407	0.08133704	1.37	0.2910
N*K	4	0.86023704	0.21505926	3.62	0.0370

Dependent Variable: Yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	1202.034319	85.859594	108.29	<.0001
Error	12	9.514178	0.792848		
Corrected Total	26	1211.548496			

R-Square	Coeff Var	Root MSE	Yield Mean
0.992147	1.675285	0.890420	53.15037

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Rep	2	1.628541	0.814270	1.03	0.3875
N	2	1095.632274	547.816137	690.95	<.0001
Rep*N	4	10.752148	2.688037	3.39	0.0448
K	2	54.616919	27.308459	34.44	<.0001
N*K	4	39.404437	9.851109	12.42	0.0003

Tests of Hypotheses Using the Anova MS for Rep*N as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr > F
N	2	1095.632274	547.816137	203.80	<.0001

Table F.6: summary of ANOVA table for Lanorma mass loss after storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	217.6120000	24.1791111	131.17	<.0001
Error	20	3.6866667	0.1843333		
Corrected Total	29	221.2986667			

R-Square	Coeff Var	Root MSE	Innovatorloss Mean
0.983341	4.919869	0.429341	8.726667

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treatment	9	217.6120000	24.1791111	131.17	<.0001

Table F.7: summary of ANOVA table for Innovator mass loss after storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	217.6120000	24.1791111	131.17	<.0001
Error	20	3.6866667	0.1843333		
Corrected Total	29	221.2986667			

R-Square	Coeff Var	Root MSE	Innovatorloss Mean
0.983341	4.919869	0.429341	8.726667

Source	DF	Anova SS	Mean Square	F Value	Pr > F

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