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Effects of potato seed characteristics on seed-piece breakdown and poor emergence

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Serve-Ag Research Pty Ltd

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FINAL REPORT

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- Horticulture Australia Ltd
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Media Summary

This project is a feasibility study, conducted to investigate the potential of a range of seed values that may be useful indicators of potato seed quality and performance. The values examined in this study were specific gravity, seed and tissue firmness, wound-healing, nutrient elements in sap and dry tissue from tuber seeds, susceptibility to dry rot, sprouting capacity, and field performance in a replicated field trial.

This study identified several novel methods for determining seed values that have potential as seed quality indicators. These methods are wound healing, seed-piece breakdown, assessing cut seed susceptibility to dry rot, seed and tissue firmness, the nutrient elements in sap and dry tissue of tuber seeds. These methods are readily available, and relatively cheap, rapid and simple to carry out.

The seed values that showed greatest potential as quality indicators are susceptibility to dry rot, seed firmness, manganese, nitrate, phosphorous and magnesium in sap of tuber seeds, and manganese and nitrogen in dry tissue of tuber seeds.

Technical Summary

This project is a feasibility study, conducted to investigate the potential of a range of seed values that may be useful indicators of potato seed quality and performance. The values examined in this study were specific gravity, seed and tissue firmness, wound-healing, nutrient elements in sap and dry tissue from tuber seeds, susceptibility to dry rot, sprouting capacity, and field performance in a replicated field trial.

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The seed values that showed potential as quality indicators are susceptibility to dry rot, seed firmness, manganese, nitrate, phosphorous and magnesium in sap of tuber seeds, and manganese and nitrogen in dry tissue of tuber seeds.

Recommendations

Further investigations are recommended to determine the potential of the seed quality indicators identified in this study over several years to ensure their consistency and reliability.

If proven, standard protocols for the test methodology must be established, so that the tests can be conducted in a consistent manner in different facilities.

Introduction

Background

Potato seed certification currently focuses on identification of diseases in the parent crop, and visual assessment of tuber diseases. Apart from transmittable diseases, this information often does not provide information on the potential seed quality and performance. To produce a high-yielding, high-quality crop, you must start with high-quality seed, with seed-pieces that are in good condition at planting. However, there is a lack of suitable indicators to define and determine seed quality.

The current potato seed certification is mainly confined to the visual assessments of the parent crop and harvested tuber seeds for major diseases, and to ensure that disease levels are within the acceptable limits. Apart from preventing disease transmission, the certification does not provide information on the potential seed performance. As the importance of seed quality is being recognised, some attempts have been made to conduct performance testing. These include overseas studies in growing and evaluating plants with grow-out trials in greenhouses or open fields during winter (James 2000, Idaho Crop Improvement 1998, Central Science Laboratory 1999). This approach, however, is time-consuming and costly to do on a large scale. Another approach to seed testing is to conduct a range of disease presence evaluations along with an elemental or nutrient analysis of the seed (Bennett 1999). The logic behind the elemental analysis is that the seed has to supply all the nutrients for the growth of the new plant. Therefore, all the nutritional requirements for the plant need to be packaged in the seed for it to be of high quality.

Specific gravity of potatoes is an important determinant of harvest quality on potatoes destined for processing into potato chips or crisps. This attribute of a tuber is an indicator that the industry uses as a reference to judge fry quality, baking characteristics and storability. More importantly, the specific gravity measurements also reflect environmental factors and cultural management procedures that were made during the production season. While much attention has been given to the link between potato specific gravity, tuber size and its processing quality, there has been little or no study on their possible link to seed quality. A recent study conducted in Tasmania on the healing of cut seeds in 2000/01 (Horticulture Australia project PT00033) indicated that specific gravity might be a useful indicator of seed quality. In the study, seeds with a higher specific gravity tended to heal faster when cut, making them less susceptible to rot. However, further studies are needed to investigate the potential of specific gravity measurements as an indicator of seed quality.

Controlling seed-piece decay is a perennial problem, and severity can vary from year to year depending on variety, seed lot, seed condition, seed handling, and the presence of bacteria and the *Fusarium* dry rot fungal pathogen. During the initial stage of healing, the cut surface of a seed-piece is open to the entry of disease pathogens. The rapid healing of wounds on cut seeds provides a rapid and uniform sealing of the cut surface, and helps prevent moisture loss and the penetration of pathogens into the seed-piece. Rapid healing of cut wounds of seeds could be another useful indicator for seed quality.

Seed maturity and physiological age are known to be critical factors in seed quality and performance. The factors that influence physiological age are complex and involve combinations of many factors, including planting time, conditions and crop management, seed storage conditions, cutting and handling, and subsequent planting conditions (McKeown 1990, McKeown 1994, Firman et al 1992, Pavlista 2004, Schrage 2000, Struik & Wiersema 1999). A HAL funded project is currently being conducted to identify seed crop management strategies and storage conditions that affect seed physiological quality (Brown 2004).

Aims

This project was a feasibility study, conducted to investigate the potential of a range of seed values that may be useful indicators on potato seed quality and performance. For practical purposes, this project focuses on seed values that could be measured in relatively rapid analytical and laboratory tests that are available and that are cost effective to do. The values examined in this study were specific gravity, seed and tissue firmness, wound-healing, nutrient elements in sap and dry tissue from tuber seeds. Seed performance was based on susceptibility to dry rot when cut setts were challenged with spores of *Fusarium sulphureum*, sprouting capacity, and field performance of the same seed lines in a replicated field trial.

Materials & Methods

Laboratory Studies

A total of 65 seed lines were assessed for nutrient elements in sap and tissue analyses, specific gravity, sprouting capacity and seed and tissue firmness. These properties were then compared to the seed lines response to wound healing, and susceptibility to *Fusarium* dry rot.

Sap Analysis

Sap from tissue taken from the middle of six tuber seeds in each line was analysed for the macro and micro nutrient elements: nitrates, phosphorus, potassium, calcium, magnesium, zinc, boron, sulphur, copper, iron, and manganese. Sap analysis was carried out at the Serve-Ag analytical services in Tasmania.

Tissue Analysis

Four tubers from the seed lines were analysed using a dry ash method for all the macro and micro nutrient elements listed in the sap analysis, plus molybdenum and cobalt. Pivotest Laboratories in Victoria carried out the dry tissue analysis.

Specific Gravity

Approximately 5 kg of potatoes was placed into a bag. The weight of the potatoes in air was recorded. The bag of potatoes was then placed in a bucket of water, and the weight of the potatoes in water was recorded. The specific gravity of potatoes was tabulated using the formula:

$$\textit{Specific gravity} = (\textit{weight in air}) \div [(\textit{weight in air}) - (\textit{weight in water})]$$

Seed firmness

Seed and tissue firmness were measured using a penetrometer. Seed firmness was based on the pressure required to push the penetrometer through the surface of a non-peeled tuber. Tissue firmness was based on the pressure required to push through the tissues from the surface of a peeled tuber. The results were expressed as an average of 5 to 10 tubers tested per seed line.

Sprouting capacity

The sprouting capacity assessment, or the rate and pattern of sprout development under controlled conditions, was based on the methods used by Brown (2001). After 20 days, the emerging stems were removed from each tuber, then counted and weighed. The percentage sprouting capacity was then tabulated as the total sprout weight divided by total tuber weight, and multiplied by 100. The test was conducted in a room at 20^{o}C with 12 hours simulated daylight.

Wound healing

After cutting, setts were immediately placed into paper bags and kept in a half-tonne bin, covered with thick Hessian bags in order to reduce aeration and maintain high humidity, for one week. After one week, the bags were removed from the bin and allowed to air-dry; then maintained at humidity levels ranging from 70% to 83%. The number of setts with superficial and deep rot from the cut surfaces was recorded for each of the seed lines, and the percentages of setts with superficial lesions and deep lesions were tabulated.

The setts were also rated for presence of bacteria or fungal lesions on the cut surfaces, where: rating 1 = no lesions, rating 2 = less than 30% surface with lesions, and rating 3 = more than 30% surface with lesions. Using a light microscope, the width of the corky layer from the cut surfaces was measured on three setts per seed line, with one representative measurement taken from each of the ratings. The corky layer thickness index was then calculated according to the formula:

$$\textit{Corky layer thickness index} = ((A1 \times B1) + (A2 \times B2) + (A3 \times B3)) / \textit{Total number of setts},$$

where A1, A2 and A3 are the number of setts in rating 1, 2 and 3, respectively, and
B1, B2, and B3 are the corky layer thickness in rating 1, 2 and 3, respectively

Susceptibility to dry rot (*Fusarium sulphureum*)

Samples of tubers from each seed line were cut into halves. The seed-pieces from each seed line were divided into two paper bags. The seed setts were then inoculated with spores of *F. sulphureum* at two different times; one lot was inoculated at 20 hours after cutting, and the other lot was inoculated at 40 hours after cutting. The treated setts were kept moist in paper bags, and after three weeks, they were assessed for *Fusarium* dry rot on the cut surfaces.

Number of tubers used for each analysis

As remaining tuber seeds from a field trial were used for the laboratory analyses, the number of tubers used for each test varied according to the number of available tubers. Only the sap and tissue analyses used the same number of tubers for all seed lines.

Type of analysis	Average number of tubers/seed line (range)
1. Sap analysis	6 (6)
2. Tissue analysis	4 (4)
3. Specific gravity	9 (6-19)
4. Seed firmness	9 (6-10)
5. Physiological age	10 (5-10)
6. Rate of wound healing	32 (5-60)
7. Dry rot test	32 (5-60)

Field Trials

Tuber seeds from the 60 seed lines examined in laboratory studies were planted in a field trial at Riana in 2002/03, on a red ferrosol soil, to assess their field performance. The trial design was complete randomised block design; with 3 replicate plots (plot size = 10 m x 1.6 m planted with 60 setts). Setts were planted in November 2002, and harvested in June 2003. Assessments were conducted to determine the percentage plant emergence (one month after planting), mean plant height of five plants (two month after planting), and total tuber yield, tuber sizes, and disease after harvest.

Statistical Analysis

Forty sets of data values generated in analytical and laboratory tests were analysed in pair-wise correlation analysis. A step-wise multiple regression analysis was then conducted on potentially useful seed indicators with values identified in the initial pair-wise correlation analysis.

With significant relationships determined in the step-wise multiple regression analysis, where possible, seed values were categorized according to a selective range, and then analysed in a one-way analysis of variance. Pair-wise comparisons using the Fisher's least significant difference (LSD) procedure were applied to the mean values.

Results

A total of sixty-five seed lines were examined in analytical and laboratory tests, and sixty seed lines were evaluated in a replicated field trial for yield performance. Most of the tubers from the seed lines had little or no disease, and where a disease was present, it was within the acceptable seed certification limits. Diseases found on the seed lines in visual assessments were *Fusarium* dry rot (6%), common scab (12%), silver scurf (37%), black scurf (40%), and root-knot nematode (17%). Diseases caused by *Fusarium* and *Rhizoctonia* may affect seed-piece breakdown and sprouting capacity, respectively. Other diseases such as common scab, silver scurf and root-knot nematode are likely to have little or no effect on wound-healing, sprouting and seed-piece breakdown. The most common diseases on the seed lines were silver scurf by *Helminthosporium solani* and black scurf by *Rhizoctonia*. Diseases present in the seed lines were not correlated to their field performance or disease on daughter tubers.

Although 42 sets of data values generated in this study were analysed, most of the values were found to have no significant effects ($p > 0.05$) on seed performance indicators such as seed-piece breakdown, wound-healing, sprouting capacity and field performance. Therefore, only data values that were found to have significant effects on these performance indicators are discussed further.

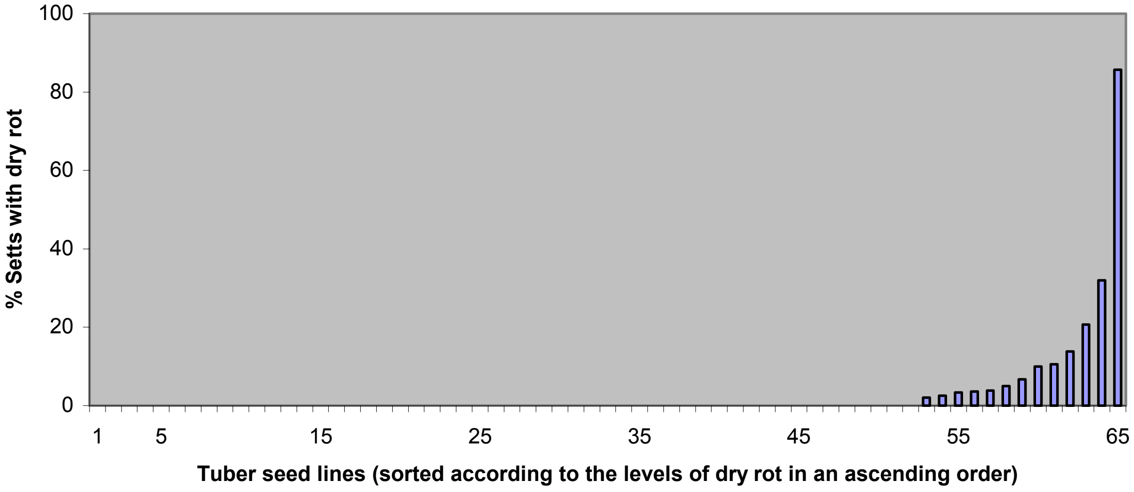
Wound-healing of seed lines

As the wound-healing test was carried out under relatively harsh conditions, with high humidity and poor aeration, 80% of the seed lines showed some rot on the cut surfaces. Most of the rot, however, was superficial and was rapidly sealed off after air-drying. On the setts affected by *Fusarium* dry rot, the lesions progressed further into the cut surfaces and became deep seated (Photograph 1). *Fusarium* dry rot was present on 20% of the seed lines, with infection ranging from 2% to 86% setts in the affected seed lines (Figure 1). This showed that the presence of *Fusarium* inoculum on seed lines posed the most serious threat to the quality of cut setts.

Photograph 1: Dry rot infected setts (left) and healthy setts (right)

The corky layer thickness on the cut surface was highly variable, even within the same seed line, as well as between different seed lines. The corky layer thickness generally increased in response to the level of bacterial and fungal growth. On a relatively clean surface with little or no organism growth, the corky layer thickness ranged from 10 to 42.5 micron. There were no relationships between the corky layer thickness and other seed values measured in this study. This indicates that the corky layer thickness is an unsuitable quality characteristic.

Figure 1: Seed lines affected by dry rot on cut setts



Susceptibility of seed lines to dry rot

In a test where cut setts were inoculated with *Fusarium* spores at 20 hours after cutting, a step-wise multiple linear regression analysis showed that the seed lines' susceptibility to dry rot were significantly affected by the magnesium (Mg) levels in sap analysis and the percentage of nitrogen (N) in dry tissue analysis ($p < 0.001$).

The multiple regression model that best describes the dry rot susceptibility is:

$Y = 143.59 – 0.114X1 – 21.968X2$, where

Y = % Setts with dry rot in a seed line challenged with *Fusarium* at 20 hours after cutting
X1 = Mg level in sap from tubers (ppm)
X2 = N level in tissues of tubers (%)

The R-squared statistic indicates that the fitted model explains 23% of the variability in the seed lines' susceptibility to dry rot. According to the model, the seed lines' susceptibilities decreased with increases in the Mg and N levels. The negative relationships between the percentage of setts affected by dry rot and the levels of Mg in sap and N in tissues are shown in Figures 2 and 3, respectively. These two nutrients may be potential indicators of a seed line's susceptibility to dry rot and seed-piece breakdown.

Figure : Seed lines susceptibility to dry rot and Mg levels in sap from tubers

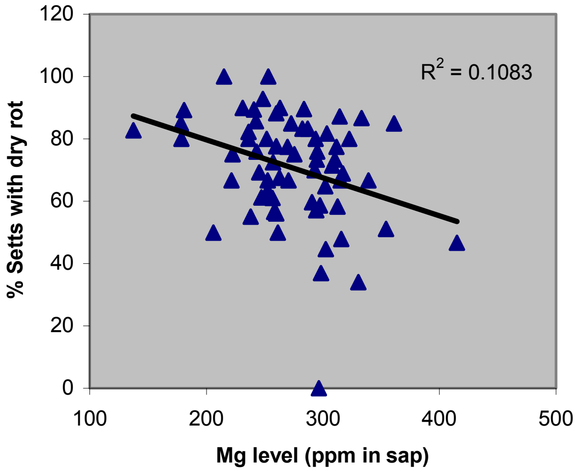
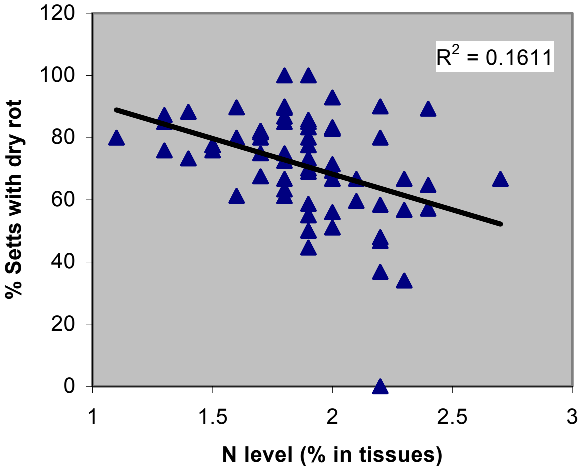


Figure 3 : Seed lines susceptibility to dry rot and N levels in tissues from tubers



Seed firmness, dry rot susceptibility and sprouting capacity

In a test where cut setts were inoculated with *Fusarium* spores at 40 hours after cutting, a step-wise multiple linear regression analysis showed that the average seed firmness was positively correlated to its susceptibility to dry rot and seed sprouting capacity.

Table 1: The relationship of seed firmness and susceptibility of cut setts to dry rot

Seed firmness rating	Pressure range for seed firmness (kPa)	The number of seed lines with seed firmness measurements within the given range	Mean % *Fusarium* dry rot (40hr) *	Standard error
1	> 9.0 to 9.5	2	36.0 a	14.0
2	> 9.5 to 10.0	3	42.0 ab	12.7
3	> 10.0 to 10.5	21	57.8 abc	4.2
4	> 10.5 to 11.0	27	62.1 bc	3.2
5	> 11.0 to 11.5	11	69.9 c	4.0
6	> 11.5 to 12.0	1	90.0 c	0

* Means followed by the same letter are not significantly different at the 5% level according to Fisher's LSD test.

Figure 4: Seed firmness and susceptibility to dry rot
(Means and 95.0 Percent LSD Intervals)

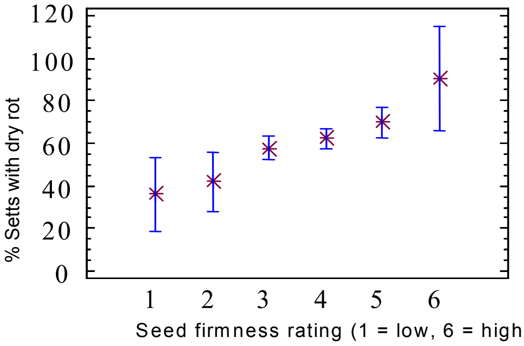
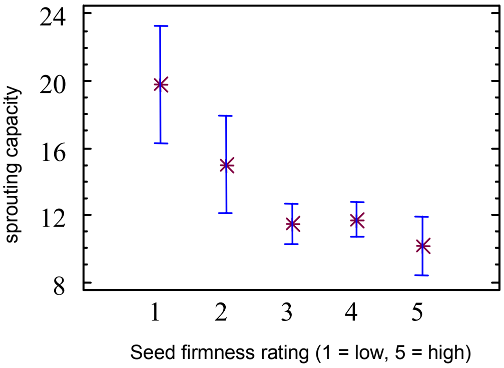


Figure 5: Seed firmness and sprouting capacity
(Means and 95.0 Percent LSD Intervals)



A further analysis using a one-way analysis of variance on the frequency of seed lines in a range of seed firmness, showed a significant difference between seed firmness and the percentage of setts infected by dry rot (Table 1, Figure 4). Generally, increases in the range of seed firmness in the seed lines were associated with increased percentages of setts with dry rot.

Table 2: The relationship between seed firmness and seed sprouting capacity

Seed firmness rating	Range of seed firmness (kPa)	The number of seed lines with seed firmness measurements within the given range	Sprouting capacity *	Standard error
1	> 9.0 to 9.5	2	19.8 a	3.5
2	> 9.5 to 10.0	3	15.0 ab	3.8
3	> 10.0 to 10.5	18	11.4 ab	0.6
4	> 10.5 to 11.0	23	11.7 bc	0.8
5	> 11.0 to 11.5	8	10.2 c	0.9

* Means followed by the same letter are not significantly different at the 5% level according to Fisher's LSD test.

In contrast to dry rot, a negative trend was shown in the analysis between the seed firmness and sprouting capacity (Table 2, Figure 5). Generally, increases in the range of seed firmness were associated with decreased seed sprouting capacity.

Some seed tubers produced sprouts, which were removed prior to the tests. The seed tubers that produced sprouts prior to the tests tended to have slightly with wrinkled skin and felt softer in texture. These tubers tended to have higher seed firmness readings compared to firm and fully hydrated tubers. These findings suggest that seed firmness may be related to the turgidity of the tubers in the different seed lines.

Nutrient effects on seed firmness

A step-wise multiple regression analyses between seed firmness and all nutrients in tuber sap and tissues, showed that only manganese (Mn) has a significant effect on seed firmness (Table 3).

Figure 6: Seed firmness and Mn in sap
(Means and 95.0 Percent LSD Intervals)

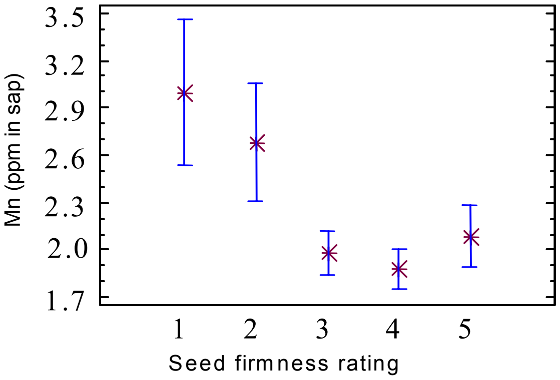
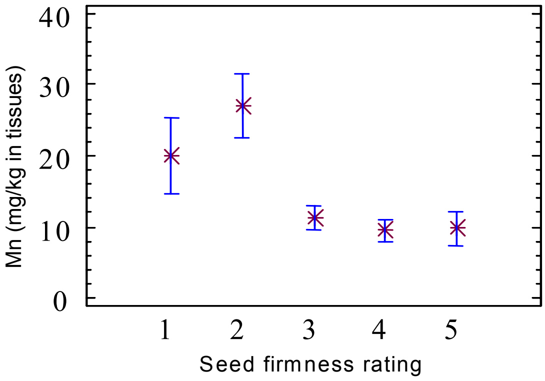


Figure 7: Seed firmness and Mn level in tissue
(Means and 95.0 Percent LSD Intervals)



A one-way analysis of variance indicated significant differences between seed firmness and the ranges of Mn levels in seeds, as determined in sap analysis and dry tissue analysis (Table 3, Figures 6 & 7). Generally, increased levels of Mn in sap and tissues were associated with a decrease in the range of seed firmness in the seed lines.

Table 3: The relationship between tuber seed skin firmness and manganese levels in sap and tissue analyses

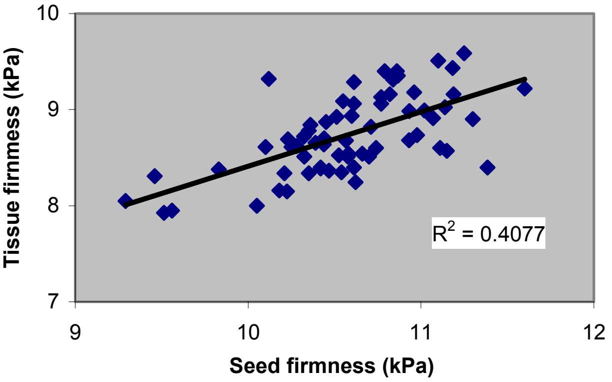
Seed firmness rating	Range of seed firmness (kPa)	The number of seed lines within the given range	Sap analysis		Dry tissue analysis	
			Mn (ppm) *	Standard error	Mn (%) *	Standard error
1	> 9.0 to 9.5	2	3.00 c	0.65	20.00 b	1.00
2	> 9.5 to 10.0	3	2.68 bc	0.28	27.00 b	14.18
3	> 10.0 to 10.5	21	1.98 a	0.10	11.38a	0.83
4	> 10.5 to 11.0	27	1.87 a	0.08	9.47a	0.42
5	> 11.0 to 11.5	11	2.09 ab	0.14	9.77a	0.95

* Means followed by the same letter are not significantly different at the 5% level according to Fisher's LSD test.

Tissue vs seed firmness

The tissue firmness measured on peeled tubers was always lower than the seed firmness. The tissue firmness was, however, closely related to the seed firmness on tubers from the same seed lines, as shown in Figure 8.

Figure 8: The relationship between tissue firmness and seed firmness



Tissue firmness and nitrogen levels in seed lines

A one-way analysis of variance indicated significant differences between tissue firmness and the ranges of nitrogen (N) and nitrate (NO3) levels determined in seed dry tissue analysis and sap analysis, respectively (Table 4, Figures 9 & 10). Generally, increased ranges of N and NO3 were associated with a decrease in the range of tissue firmness in the seed lines.

Figure 9: Tissue firmness and nitrogen levels in tissue (Means and 95.0 Percent LSD Intervals)

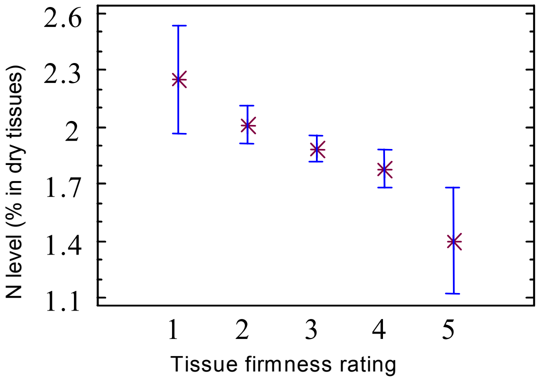


Figure 10: Tissue firmness and nitrate level in sap (Means and 95.0 Percent LSD Intervals)

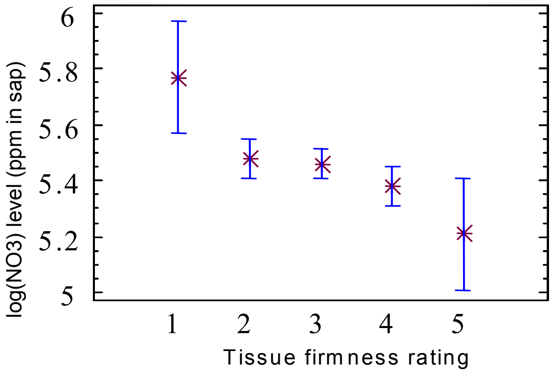


Table 4: The relationship between tuber seed skin firmness and manganese levels in sap and tissue analyses

Tissue firmness rating	Range of tissue firmness (kPa)	The number of seed lines within the given range	Total NO3 level in sap analysis		Total N level in dry tissue analysis	
			NO3 *	Standard error	Total N *	Standard error
1	> 7.5.0 to 8.0	2	5.77 b	0.13	2.25 c	0.05
2	> 8.0 to 8.5	15	5.48 ab	0.05	2.01 c	0.06
3	> 8.5 to 9.0	30	5.46 a	0.04	1.89 bc	0.06
4	> 9.0 to 9.5	16	5.38 a	0.05	1.78ab	0.06
5	> 9.5 to 10.0	2	5.21 a	0.24	1.40a	0.10

* Means followed by the same letter are not significantly different at the 5% level according to Fisher's LSD test.

Specific gravity of seeds

No significant relationships could be found between seeds' specific gravity, firmness, susceptibility to dry rot, and their performance in a field trial.

In a step-wise multiple linear regression analysis, specific gravity was significantly influenced by boron (B) and manganese (Mn) in sap nutrients. The model that best describes the relationship is:

Y = 1.164 - 0.007X1 - 0.0114X2, where

Y = Specific gravity of seed lines
X1 = B in sap analysis of tuber seeds (ppm)
X2 = Mn in sap analysis of tuber seeds (ppm)

The R-squared statistic indicates that the fitted model explains 20% of the variability in the seed lines' specific gravity. According to the model, increases in the B and Mn levels in the sap of seeds is associated with decreased specific gravity (Figures 11 and 12).

Figure 11: Seed lines specific gravity and B levels in sap

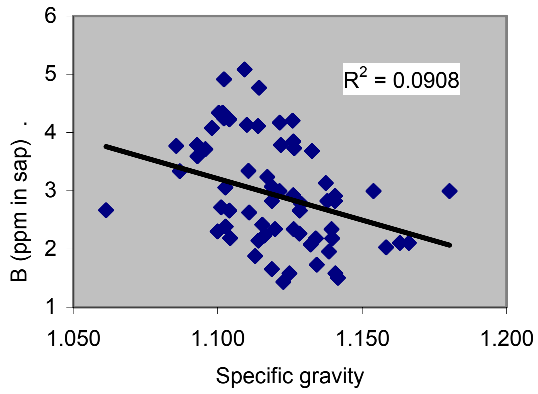
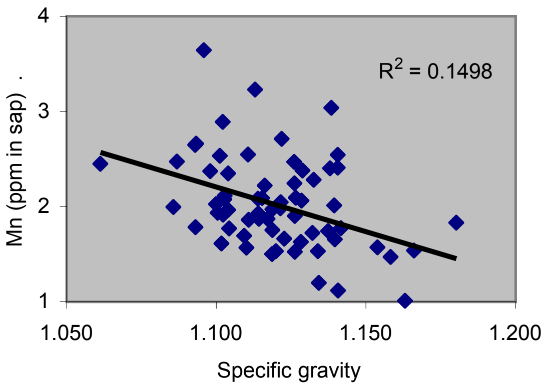


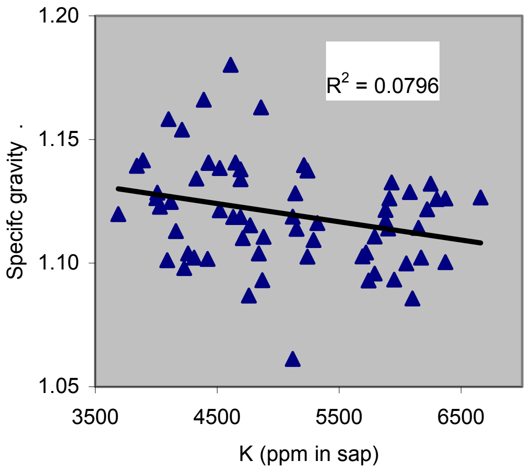
Figure 12: Seed lines specific gravity and Mn levels in sap



The relationship between specific gravity and potassium (K) was very weak, and was not significant (p = 0.520). No significant relationships could be found between the seed lines' specific gravity and any tissue nutrients in the seeds.

No other significant relationships could be found between specific gravity and any tissue nutrients or other seed characteristics (eg. seed firmness and susceptibility to dry rot), and seed performance in the field trial.

Figure 13: Seed lines specific gravity and K levels in sap



Seed values and field performance

The total yield of daughter tubers (all sizes) from the seed lines could not be significantly correlated to any seed characteristic measurements. The seed lines' sprouting capacity was also not related to yield of daughter tubers or other assessments in the field trial.

In the field trial, harvested tubers were divided into different size ranges: < 75 g, 75 – 249 g, and 250 – 850 g. In processing to French fries, larger tubers, in the range of 250 g to 850 g, are desirable. Therefore, the % large tuber yield of harvested tubers in the range 250 – 850 g could also be used as a quality indicator.

In a step-wise multiple linear regression analysis, the main factors that significantly affected % large tuber yield were nitrogen (N) in the tissue analysis and phosphorous (P) in the sap analysis. The model that best describes the % large tuber yield is:

Y = 27.847 + 0.0324X1 + 9.7476X2, where

Y = % Large tuber yield
X1 = P in sap analysis of tuber seeds (ppm)
X2 = N level in tissues of tuber seeds (%)

The R-squared statistic indicates that the fitted model explains 40% of the variability in the % large tuber yield. According to the model, the % large tuber yield increased with an increase in the P and N levels. The positive relationships between % large tuber yield and the levels of P in sap and N in tissues are shown in Figures 13 and 14, respectively. These two nutrients may be useful indicators on a seed line's potential to produce a high proportion of large tubers.

Figure 14: P levels in sap of seed tubers and yield of large daughter tubers

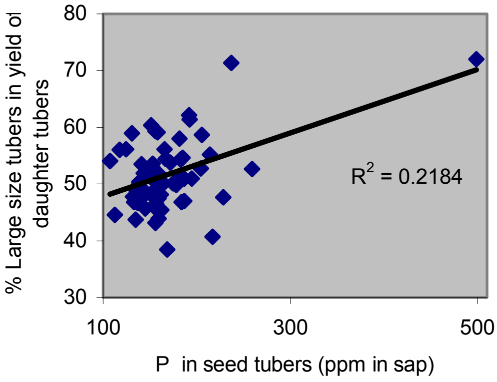
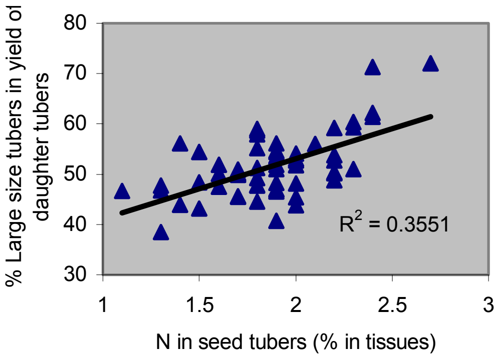


Figure 15: N levels in tissues of seed tubers and yield of large daughter tubers



In a step-wise multiple linear regression analysis, the mean plant height measured at two months after planting was significantly related to total daughter tuber yield and % large tuber yield. The model that best describes the relationships is:

Y = 190.64 + 5.306X1 – 2.735X2, where

Y = Mean plant height (cm)
X1 = Total tuber yield
X2 = % Large tuber yield

The R-squared statistic indicates that the fitted model explains 49% of the variability in the mean plant height. According to the model, the mean plant height was associated with increases in total yield and decreases in % large tuber yield. The plant height was also related to early or late plant emergence (p = 0.013). Therefore, rapid plant emergence and growth appeared to be associated to high total tuber yield, while slow emergence was associated to high proportion of large tuber yield.

In a further one-way analysis of variance, significant differences were found between the ranges of N and P levels in tuber seeds, and the % large size daughter tubers were examined as listed in Tables 5 and 6. Generally, increased in the ranges of N and P in tuber seeds were associated with increases in the % large size daughter tubers (Figures 15 & 16).

Table 5: The relationship of N levels in seed lines and the proportion of large daughter tuber yield in a field trial

Range of N-level (% in seed tissue analysis)	The number of seed lines with seed firmness measurements within the given range	Average % large daughter tubers *	Standard error
1.0 – 1.5	9	47.3 a	1.81
> 1.5 – 2.0	36	50.45 a	0.72
> 2.0 – 2.5	14	56.21 b	1.71
> 2.5 – 3.0	1	72.00 c	0.00

* Means followed by the same letter are not significantly different at the 5% level according to Fisher's LSD test.

Figure 15: The effects of N levels in the seed lines on large daughter tuber yield (Means and 95.0 Percent LSD) Intervals

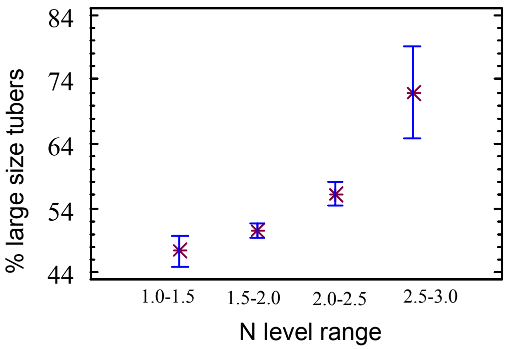


Figure 16: The effects of P levels on seed lines on the large daughter tuber yields (Means and 95.0 Percent LSD Intervals)

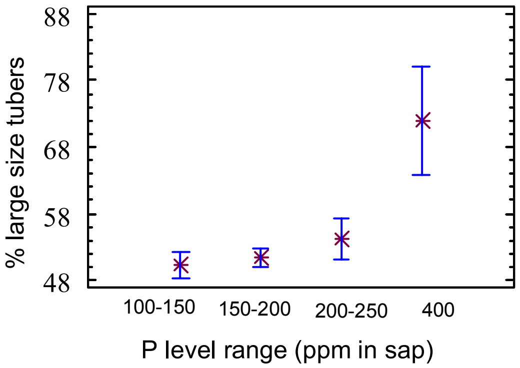


Table 6:The relationship of P levels in seed lines and the proportion of large daughter tuber yield in a field trial

Range of P level (ppm in seed sap analysis)	The number of seed lines with seed firmness measurements within the given range	Average % large daughter tubers *	Standard error
100 - 150	18	50.32 a	0.99
> 150 - 200	34	51.29 a	0.95
> 200 – 250	7	54.16 a	3.59
400	1	72.00 b	0.00

* Means followed by the same letter are not significantly different at the 5% level according to Fisher's LSD test.

Discussions

This study identified several novel methods for determining seed values that may be useful as seed quality indicators. These methods are wound healing, seed-piece breakdown, assessing cut seed susceptibility to dry rot, seed and tissue firmness, the nutrient elements in sap, and dry tissue analyses of tuber seeds.

Dry rot caused by *F. sulphureum* appeared to be the most serious threat to seed-piece breakdown. Spores of *F. sulphureum* can germinate, penetrate through cells and spread rapidly on the cut surfaces. Unless the freshly cut seed pieces or setts can seal the wound rapidly, they are vulnerable to *Fusarium* infection. If a high level of *Fusarium* inoculum is present in a seed line, then it is highly susceptible to dry rot unless a fungicide seed treatment is applied after cutting. In this study, 20% of the seed lines were infected by dry rot after cutting. The presence of high levels of *Fusarium* spores may be detected in a simple test by cutting a representative sample of seeds and incubating, as shown in this study. This test can help determine whether fungicide seed treatment for dry rot control is required.

In the absence of *Fusarium* inoculum, the cut seed pieces appeared to have a greater tolerance to decay by soil bacteria and other non-pathogenic fungi. When setts affected by these non-pathogenic organisms were allowed to air-dry, the superficial decay stop and the setts were able to seal off the damaged surfaces. The corky layer thickness on the cut surfaces was found to be highly variable within the same seed line as well as between different seed lines. The variability may be due to the test conditions in this study, and the cell response to decay under anaerobic and moist conditions. The corky layer thickness, therefore, appeared to be an unsuitable seed indicator.

The breakdown of cut potato seed-pieces is a major concern to potato growers, and can seriously reduce crop density and crop vigour. Seed-piece breakdown is determined by the conditions of the seeds, their capacity to heal after cutting, storage conditions, and presence of pathogenic organisms. Under the same storage conditions and presence of pathogens, different seed lines could have different susceptibility to seed-piece breakdown (Pung et al 2001). This indicates that there may be differences between seed lines, particularly in the levels of sap produced after cutting, and their wound-healing capacity to seal and protect the cut surfaces. This study showed a high variability of seed lines' susceptibility to dry rot when challenged with *F. sulphureum* spores after cutting and then incubating under ideal conditions for the pathogen. This variability may be related to the inherent seed properties and their effects on wound-healing and susceptibility to infection. The nutrient levels of magnesium in sap and nitrogen in dry tissues of seed lines were shown to be negatively correlated to their susceptibility to dry rot on setts inoculated at 20 hours after cutting. The nature of the effects of these nutrients in tuber seeds and on wound healing is unknown. Further investigations are required to determine their potential use as seed quality indicators.

Seed firmness, the level of pressure required to push a penetrometer through the skin of a tuber, is another interesting value that may be a useful seed quality indicator. Seed firmness was correlated to the setts' susceptibility to dry rot when challenged with *Fusarium* spores 40 hours after cutting, and the seeds' sprouting capacity. Generally, increases in the range of seed firmness, increased their susceptibility to dry rot and decreased the seeds' sprouting capacities. The levels of manganese in sap and dry tissues were negatively correlated to seed firmness; whereby decreases in the manganese levels increased the seed firmness.

The sprouting capacity gives an indication of a seed's physiological age, where physiological young seeds tend to have slow emergence, fewer stems per tuber, lower tuber set and larger tubers at harvest (Blaesing & Kirkwood 2004). However, in this study, the physiological age of the seed lines may have been altered as the samples were moved in and out of cold storage during the sorting process. Seed tubers that produced sprouts prior to the tests tended to have slightly with wrinkled skin and felt softer in texture. These tubers tended to have higher seed firmness readings compared to firm and fully hydrated tubers. These findings suggest that seed firmness may be related to the turgidity of the tubers in the different seed lines. The relationships determined in this study suggest that pre-sprouted seeds tend to have lower sprouting capacity and greater susceptibility to diseases.

Tissue firmness, the level of pressure required to push a penetrometer through a peeled tuber, was closely related to the seed firmness. Nitrogen appeared to be a critical factor in the tissue firmness, where the levels of nitrate in sap and the percentage of nitrogen in the dry tissue of tuber seeds were negatively correlated to tissue firmness. Of the two, seed firmness appeared to be more useful than tissue firmness as a seed quality indicator, as it showed stronger relationships with other seed quality values such as sprouting capacity and susceptibility to dry rot.

Although specific gravity is a useful quality indicator for processing potato tubers, its usefulness as a seed quality indicator could not be demonstrated in this study.

In field studies, only the percentage of large size tubers, in the range of 250 to 850 g per tuber, was significantly correlated to the phosphorous and nitrogen levels in tuber seeds. Generally, both increased N levels in dry tissues and P levels in the sap of tuber seeds were associated with increases in the proportion of large size daughter tubers. This indicates that the reserves of these two macronutrients in tuber seeds may be vital in producing large size daughter tubers. Large size tubers are desirable for processing potatoes.

Conclusions

This study identified several novel methods and seed values that warrant further investigations to establish their usefulness as seed quality indicators. These values can be determined in methods that are readily available, and are relatively cheap, rapid and simple to carry out.

The potential seed quality indicators are:

- Cut seed-piece susceptibility to dry rot
- Seed firmness
- Sap analysis for Mn, NO3, P and Mg
- Tissue analysis for Mn and N

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Serve-Ag Research staff who assisted in this project include Pam Cox and Susan Cross.

Appendix i – Statistical analysis

Susceptibility to dry rot on setts (inoculated 20 hours after cutting)

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: dryrot20hr
-----------------------------------------------------------------------------
                                       Standard          T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                  143.59       15.8867         9.03836         0.0000
Mg_sap                   -0.1144     0.0405556        -2.82081         0.0064
N_drytissue             -21.9679        6.2405         -3.5202         0.0008
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     4909.16      2      2454.58      10.68       0.0001
Residual                  14255.1     62      229.921
-----------------------------------------------------------------------------
Total (Corr.)             19164.2     64

R-squared = 25.6162 percent
R-squared (adjusted for d.f.) = 23.2168 percent
Standard Error of Est. = 15.1631
Mean absolute error = 11.2811
Durbin-Watson statistic = 1.89056
The equation of the fitted model is
dryrot20hr = 143.59 - 0.1144*Mg_sap - 21.9679*N_drytissue
```

Seed firmness and seed quality

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: seed firmness
-----------------------------------------------------------------------------
                                       Standard          T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                 10.5305      0.337573         31.1948         0.0000
Dryrot40hr            0.00756185    0.00344801         2.19311         0.0329
Sprout capacity       -0.0371685      0.015659        -2.37362         0.0214
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     2.96533      2      1.48267       9.96       0.0002
Residual                   7.5948     51     0.148918
-----------------------------------------------------------------------------
Total (Corr.)             10.5601     53

R-squared = 28.0804 percent
R-squared (adjusted for d.f.) = 25.2601 percent
Standard Error of Est. = 0.385898
Mean absolute error = 0.309988
Durbin-Watson statistic = 1.8421
The equation of the fitted model is
Seed firmness = 10.5305 + 0.00756185*dryrot40hr - 0.0371685*sproutcapacity
```

Seed firmness and influence of nutrients on seed tubers

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: seed firmness
-----------------------------------------------------------------------------
                                       Standard         T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                 10.7464       0.139606        76.9764         0.0000
Cu_sap                  0.196654      0.0852945        2.30559         0.0245
Mn_drytissue          -0.0335003      0.0074524       -4.49524         0.0000
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     4.27433      2      2.13716      14.18       0.0000
Residual                  9.34617     62     0.150745
-----------------------------------------------------------------------------
Total (Corr.)             13.6205     64

R-squared = 31.3816 percent
R-squared (adjusted for d.f.) = 29.1681 percent
Standard Error of Est. = 0.388259
Mean absolute error = 0.296548
Durbin-Watson statistic = 1.67953
The equation of the fitted model is
Seed firmness = 10.7464 + 0.196654*Cu_sap - 0.0335003*Mn_drytissue
```

Tissue firmness and influence of nutrients on seed tubers

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: tissue firmness
-----------------------------------------------------------------------------
                                       Standard         T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                 10.1765       0.301965        33.7008         0.0000
NO3_sap              -0.00220526    0.000916374        -2.4065         0.0191
N_drytissue            -0.484617       0.154589       -3.13486         0.0026
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     2.93257      2      1.46629      11.72       0.0000
Residual                   7.7588     62     0.125142
-----------------------------------------------------------------------------
Total (Corr.)             10.6914     64

R-squared = 27.4293 percent
R-squared (adjusted for d.f.) = 25.0884 percent
Standard Error of Est. = 0.353754
Mean absolute error = 0.292354
Durbin-Watson statistic = 1.83149
The equation of the fitted model is
Tissue firmness = 10.1765 - 0.00220526*NO3_sap - 0.484617*N_drytissue
```

Specific gravity vs nutrients on seed tubers

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: SGseed
-----------------------------------------------------------------------------
                                       Standard          T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                 1.16402      0.0107958        107.821         0.0000
B_sap                -0.00700288     0.00265112       -2.64148         0.0105
Mn_sap                -0.0114085     0.00485739       -2.34869         0.0221
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                  0.00613409      2   0.00306704       8.91       0.0004
Residual                0.0209933     61  0.000344152
-----------------------------------------------------------------------------
Total (Corr.)           0.0271274     63

R-squared = 22.6122 percent
R-squared (adjusted for d.f.) = 20.0749 percent
Standard Error of Est. = 0.0185513
Mean absolute error = 0.0138116
Durbin-Watson statistic = 1.49635
SGseed = 1.16402 - 0.00700288*B_sap - 0.0114085*Mn_sap
```

% Large tuber yield

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: harvest_%
-----------------------------------------------------------------------------
                                       Standard          T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                 27.8472        3.91321        7.11621         0.0000
P_sap                   0.032399      0.0132804        2.43962         0.0178
N_drytissue                     9.74762        2.22089        4.38906         0.0001
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     977.798      2      488.899      20.27       0.0000
Residual                   1374.9     57       24.121
-----------------------------------------------------------------------------
Total (Corr.)              2352.7     59

R-squared = 41.5607 percent
R-squared (adjusted for d.f.) = 39.5102 percent
Standard Error of Est. = 4.91132
Mean absolute error = 3.96924
Durbin-Watson statistic = 2.00834
The equation of the fitted model is
%large tubers = 27.8472 + 0.032399*P_sap + 9.74762*N_drytissue
```

Plant height vs tuber yield in the field trial

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: mean plant height
-----------------------------------------------------------------------------
                                       Standard          T
Parameter               Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                  190.64       59.4089         3.20894         0.0022
Total tuber yield        5.30609      0.844426         6.28366         0.0000
% large tubers          -2.73507      0.563676         -4.8522         0.0000
-----------------------------------------------------------------------------

                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     44561.4      2      22280.7      29.90       0.0000
Residual                  42475.2     57      745.178
-----------------------------------------------------------------------------
Total (Corr.)             87036.6     59

R-squared = 51.1985 percent
R-squared (adjusted for d.f.) = 49.4862 percent
Standard Error of Est. = 27.298
Mean absolute error = 21.261
Durbin-Watson statistic = 1.88672
Mean plant height = 190.64 + 5.30609*total tuber yield - 2.73507*%large tubers
```

Appendix ii – Laboratory data

Tuber disease on seed lines

Seed line	Fusarium dry rot	Common scab	Silver scurf	Nematode	Rhizoctonia
1	N	N	N	N	N
2	N	N	N	N	N
3A	N	N	N	N	N
3B	Y	N	N	N	Y
4	N	N	N	N	N
5	N	N	N	N	N
6	N	N	N	Y	N
7	N	Y	N	Y	N
8	N	N	N	N	N
9	N	N	N	N	N
10	N	N	N	N	Y
11	N	N	N	N	N
12	N	N	N	N	Y
13	N	N	N	Y	Y
14	N	N	N	N	N
15	N	N	N	N	N
16	N	N	N	N	N
17	N	N	Y	Y	N
18	N	N	Y	Y	N
19	N	N	Y	N	Y
20	N	N	N	Y	N
21	N	N	N	N	N
22	N	Y	N	N	Y
23	N	N	N	N	Y
24	N	N	N	N	Y
25	N	Y	N	N	N
26	N	N	N	N	N
27	N	Y	N	Y	Y
28	N	N	N	N	Y
29	N	N	N	N	Y
30	N	N	N	N	N
31	N	N	Y	N	N
32	N	N	N	N	N
33	N	N	N	N	N
34	N	N	N	N	Y
35	N	N	Y	N	Y
36	N	Y	N	Y	Y
37	N	N	N	N	Y
38	N	N	N	N	N
39	N	N	Y	Y	Y
40	N	N	Y	N	N
41	N	N	N	N	N
42	Y	N	Y	N	N
43	N	N	Y	N	N
44	N	N	Y	N	N
45	N	N	N	N	N
46	N	N	N	N	Y
47	N	N	Y	N	N
48	N	N	N	N	N
49	N	N	Y	N	Y
50	N	N	Y	Y	Y
51	Y	Y	Y	N	N
52	N	N	Y	N	N
53	N	N	Y	N	N
54A	N	N	Y	Y	Y
54B	N	N	N	N	Y
55	N	N	Y	N	Y
56	N	N	N	N	Y
57	Y	N	Y	N	N
58	N	N	N	N	N
59	N	N	Y	N	Y
60	N	N	Y	N	N
61	N	N	Y	N	Y
62	N	Y	Y	N	N
63	N	Y	Y	N	Y

Firmness tests

	Firmness test; seed firmness = with skin; tissue firmness = without skin			Seed-piece breakdown (after cutting & incubation)		
Seed line	**Total no. tubers assessed for firmness**	**Seed firmness (Average with skin) (Kpa)**	**Tissue firmness (Average without skin) (Kpa)**	**Total no. setts assessed**	**% Setts with superficial and deep rot**	**% Setts with deep *Fusarium* dry rot**
1	10	10.44	8.70	44	0	0
2	10	10.66	8.54	50	24	0
3A	10	10.58	8.54	30	0	0
3B	10	10.42	8.39	47	4	0
4	10	10.77	9.13	18	11	0
5	10	10.96	9.18	40	0	0
6	9	10.60	8.93	38	5	0
7	10	10.74	8.60	29	7	0
8	10	10.77	9.06	30	7	0
9	8	11.19	9.16	14	14	0
10	10	10.45	8.87	40	43	3
11	8	11.25	9.59	40	5	0
12	10	11.15	8.57	40	3	0
13	8	10.55	9.09	30	3	0
14	6	11.30	8.90	14	93	86
15	10	10.21	8.34	37	8	0
16	7	11.39	8.40	20	15	0
17	8	10.61	8.40	49	4	0
18	9	10.58	8.51	48	6	0
19	10	10.79	9.40	56	5	0
20	10	10.71	8.82	20	0	0
21	8	10.51	8.93	30	0	0
22	10	10.36	8.84	20	0	0
23	10	9.29	8.05	50	60	32
24	10	10.12	9.32	28	43	0
25	6	10.47	8.37	5	0	0
26	10	10.54	8.35	30	17	7
27	10	11.02	8.99	46	7	0
28	6	11.18	9.43	15	13	0
29	9	10.87	9.36	45	22	0
30	10	10.93	8.68	50	2	0
31	8	10.61	9.06	20	15	0
32	10	11.10	9.51	38	8	0
33	8	10.23	8.15	20	10	5
34	10	10.35	8.78	37	3	0
35	9	10.39	8.66	39	5	0
36	9	10.98	8.73	20	10	0
37	10	11.07	8.91	19	11	0
38	9	10.32	8.72	20	5	0
39	9	10.57	8.68	16	25	0
40	8	10.10	8.61	29	3	0
41	10	9.46	8.31	30	7	0
42	10	10.23	8.69	78	54	4
43	9	11.11	8.60	30	0	3
44	8	9.51	7.93	14	0	0
45	10	10.05	8.00	20	0	0
46	6	10.93	8.98	49	0	0
47	10	9.56	7.95	48	2	0
48	9	10.62	8.24	30	3	0
49	10	10.25	8.61	29	69	14
50	8	11.14	9.03	18	6	0
51	8	10.53	8.53	29	52	21
52	10	9.83	8.38	46	63	0
53	8	10.33	8.51	30	27	10
54A	10	10.42	8.40	48	2	2
54B	8	10.70	8.51	15	7	0
55	10	10.28	8.62	50	8	0
56	8	10.84	9.31	30	0	0
57	8	10.35	8.34	30	0	0
58	10	10.86	9.40	28	0	4
59	8	10.44	8.64	19	11	11
60	8	10.61	9.29	40	15	0
61	5	10.82	9.16	9	11	0
62	5	10.18	8.16	19	0	0
63	5	11.60	9.22	10	30	0

Wound healing

Seed line	Sett 1	Sett 2	Sett 3	No. setts Rating 1	No.setts Rating 2	No. setts Rating 3	Total no. setts assessed	Corky layer Thickness index
1	27.5	32.5	60	17	15	12	44	38
2	17.5	25	32.5	30	15	5	50	21
3A	17.5	27.5	37.5	27	1	2	30	19
3B	30	27.5	50	12	29	8	47	32
4	35	27.5	37.5	4	12	2	18	30
5	32.5	57.5	57.5	25	10	5	40	42
6	20	22.5	35	32	6	0	38	20
7	22.5	27.5	30	16	9	4	29	25
8	22.5	27.5	50	13	14	3	30	28
9	17.5	25	42.5	5	5	4	14	27
10	22.5	27.5	35	34	12	4	40	25
11	20	30	37.5	25	14	1	40	24
12	20	27.5	30	25	14	1	40	23
13	17.5	35	25	15	13	2	30	26
14	20	30	37.5	2	8	4	14	31
15	22.5	32.5	35	29	8	0	37	25
16	25	30	32.5	8	9	3	20	28
17	30	32.5	30	26	21	3	49	31
18	15	25	45	35	11	1	48	18
19	22.5	35	47.5	37	17	4	56	28
20	22.5	22.5	42.5	24	5	0	20	23
21	17.5	22.5	45	14	13	3	30	22
22	25	47.5	57.5	1	9	10	20	51
23	15	42.5	35	23	17	10	50	28
24	42.5	32.5	32.5	0	18	10	28	33
25	20	27.5	25	1	4	0	5	26
26	27.5	32.5	42.5	15	11	4	30	31
27	15	35	27.5	32	18	1	46	22
28	22.5	30	32.5	8	7	0	15	26
29	20	35	42.5	37	6	2	45	23
30	20	27.5	42.5	41	7	1	50	22
31	25	30	37.5	10	10	0	20	28
32	25	35	25	17	18	3	38	30
33	22.5	25	25	17	3	0	20	23
34	15	22.5	35	13	23	2	37	21
35	25	30	30	23	15	1	39	27
36	22.5	42.5	35	9	11	0	20	34
37	25	27.5	37.5	13	5	0	19	26
38	12.5	17.5	30	15	5	0	20	14
39	20	30	30	8	7	0	16	25
40	25	40	37.5	11	16	2	29	34
41	30	30	32.5	13	15	2	30	30
42	15	35	32.5	11	26	2	78	29
43	22.5	27.5	32.5	15	15	0	30	25
44	17.5	22.5	27.5	14	0	0	14	18
45	27.5	22.5	42.5	19	1	0	20	27
46	17.5	25	37.5	27	21	2	49	21
47	22.5	25	25	42	6	0	48	23
48	30	30	37.5	19	11	0	30	30
49	32.5	22.5	32.5	20	9	0	29	29
50	25	25	32.5	6	12	0	18	25
51	25	25	50	11	15	3	29	28
52	22.5	25	30	24	21	1	46	24
53	22.5	22.5	50	9	14	3	30	26
54A	27.5	37.5	37.5	10	31	7	48	35
54B	17.5	27.5	25	14	1	0	15	18
55	25	35	37.5	31	17	2	50	29
56	15	37.5	30	19	10	0	30	23
57	25	22.5	42.5	21	9	0	30	24
58	35	30	35	13	7	0	28	33
59	30	25	32.5	4	9	5	19	28
60	20	25	35	23	17	0	40	22
61	22.5	25	25	8	1	0	9	23
62	20	27.5	37.5	9	9	1	19	24
63	25	27.5	30	8	2	0	10	26

Physiological age and stem cankers

Seed line	No. tubers assessed	Total sprout weight (g)	Total tuber weight (g)	Sprouting capacity (sprout wt/tuber wt) (%)	Average sprout weight per sprout	No. sprouts per tuber	% *Rhizoctonia* stem cankers
1	10	108	1544	7.0	2.1	5.7	11
2	10	150	1773	8.5	2.2	6.8	0
3A	10	153	1674	9.2	2.7	5.6	0
3B	10	74	868	8.6	1.6	9.4	0
4	10	191	1576	12.1	3.5	5.5	0
5	10	158	1532	10.3	2.7	5.9	0
6	10	248	1687	14.7	3.0	8.3	0
7	10	140	1800	7.8	1.8	7.6	0
8	10	89	1498	6.0	1.8	4.9	0
9	*						
10	10	189	1634	11.6	2.1	8.9	20
11	10	97	1683	5.8	1.7	6.2	0
12	10	140	1531	9.2	4.3	4.1	0
13	10	274	1748	15.7	4.4	6.2	20
14	*						
15	10	267	1684	15.9	2.9	9.2	0
16	10	220	1820	12.1	2.6	8.4	0
17	10	307	2040	15.0	3.5	8.9	0
18	10	194	1766	11.0	3.7	5.9	0
19	10	203	1277	15.9	4.2	4.8	20
20	10	121	1077	11.2	2.5	6.1	0
21	10	237	1864	12.7	2.8	8.4	0
22	10	161	1129	14.3	3.2	5.1	0
23	10	183	788	23.2	3.1	6.7	0
24	10	192	1892	10.1	3.3	5.8	0
25	*						
26	10	406	1754	23.2	4.7	8.7	0
27	10	113	1391	8.1	1.9	6.6	22
28	*						
29	10	140	1460	9.6	3.7	3.8	10
30	10	64	1447	4.4	0.7	9.6	0
31	10	181	1983	9.1	2.8	6.5	0
32	10	160	1620	9.9	2.8	5.8	10
33	10	165	1564	10.5	2.1	7.7	50
34	10	189	1497	12.7	2.8	6.8	0
35	10	111	1509	7.3	2.1	7.6	0
36	10	224	1731	13.0	2.8	8.1	30
37	10	231	1794	12.9	3.7	6.2	20
38	10	142	1080	13.1	2.7	5.2	0
39	10	67	1424	4.7	1.0	6.7	0
40	10	298	1895	15.7	4.5	6.6	0
41	10	286	1752	16.3	4.3	6.7	0
42	10	220	1900	11.6	2.3	9.7	0
43	10	176	1412	12.5	3.1	5.7	0
44	10	416	1847	22.5	4.6	9.0	0
45	10	69	1011	6.8	1.3	5.5	0
46	10	269	1945	13.8	4.3	6.2	0
47	10	156	1334	11.7	2.6	6.0	0
48	10	100	1171	8.6	2.4	5.3	0
49	10	209	1566	13.3	2.8	7.5	20
50	10	200	1860	10.8	2.0	10.2	30
51	10	205	1920.8	10.7	3.4	6.7	0
52	10	140	1300	10.8	2.8	5.6	22
53	10	260	2020	12.9	2.8	9.4	0
54A	10	160	1960	8.2	2.5	6.5	0
54B	5	140	960	14.6	3.4	8.2	0
55	10	171	1280	13.4	3.3	5.2	0
56	10	260	2200	11.8	2.0	12.8	10
57	10	220	2240	9.8	2.2	10.0	0
58	10	100	1840	5.4	1.0	10.1	0
59	10	180	1800	10.0	2.3	8.8	11
60	10	160	1560	10.3	2.6	6.1	20

* not tested

Specific gravity, dry matter and black scurf incidence

Seed line	No. tubers for specific gravity	Average dry weight g/tuber	Specific Gravity	% Dry Matter	% Black scurf on seed
1	10	142.0	1.061	16.2	0
2	10	138.6	1.103	24.8	0
3A	10	120.1	1.116	27.6	0
3B	10	146.6	1.111	26.5	60
4	9	153.4	1.128	30.1	0
5	10	115.1	1.137	32.0	0
6	10	143.2	1.119	28.2	0
7	10	144.6	1.126	29.7	0
8	10	132.4	1.133	31.0	0
9	8	156.4	1.132	30.9	0
10	10	151.9	1.100	24.2	20
11	8	191.1	1.122	28.8	0
12	10	131.3	1.104	25.2	13
13	8	164.3	1.126	29.7	10
14	6	218.2	1.127	29.8	0
15	11	123.5	1.102	24.7	0
16	7	164.9	1.121	28.7	0
17	8	162.9	1.126	29.7	0
18	9	140.9	1.114	27.2	0
19	19	102.4	1.093	22.9	30
20	10	104.3	1.129	30.2	0
21	8	179.5	1.100	24.3	0
22	10	110.6	1.117	27.8	20
23	16	77.9	1.096	23.4	11
24	10	162.2	1.086	21.3	10
25	6	207.8	1.093	22.8	0
26	10	117.5	1.093	22.8	0
27	12	105.9	1.114	27.2	89
28	7	179.3	1.098	23.8	0
29	9	154.6	1.102	24.7	30
30	10	122.1	1.104	25.1	20
31	8	146.5	1.114	27.2	0
32	10	132.3	1.111	26.5	0
33	8	174.6	1.102	24.6	30
34	10	124.8	1.109	26.2	20
35	9	170.3	1.110	26.4	0
36	9	121.4	1.120	28.4	20
37	10	160.2	1.119	28.2	30
38	9	135.8	1.126	29.7	0
39	9	136.7	1.128	30.2	20
40	8	172.0	1.121	28.7	0
41	10	175.2	1.104	25.1	0
42	10	160.5	1.115	27.5	0
43	9	119.7	1.138	32.3	0
44	8	171.1	1.113	27.0	0
45	10	103.8	1.139	32.5	0
46	6	248.5	1.123	29.0	20
47	11	123.7	1.138	32.2	0
48	9	129.9	1.142	32.9	0
49	10	143.6	1.141	32.7	10
50	8	199.1	1.119	28.1	30
51	8	145.8	1.134	31.4	0
52	10	127.4	1.141	32.7	0
53	8	195.9	1.154	35.5	0
54A	10	182.8	1.140	32.5	10
54B	8	131.6	1.166	38.0	0
55	10	122.8	1.134	31.3	0
56	8	176.9	1.125	29.4	10
57	8	140.0	1.180	40.9	0
58	8	161.4	1.163	37.4	0
59	8	179.4	1.141	32.7	0
60	9	143.1	1.158	36.4	0
61	6	181.3	1.101	24.5	-
62	8	169.0	1.087	21.5	-
63	8	252.1	1.103	24.8	-

Appendix iii – Analytical test data

Sap analysis of seed tubers for plant nutrients

Seed line	NO_3	P	K	Ca	Mg	Zn	B	S	Cu	Fe	Mn
1	326	135.95	5120	141.28	296.75	3.78	2.66	330.31	1.27	3.63	2.45
2	313	151.15	5240	97.99	270.55	3.67	3.06	351.55	1.30	4.13	2.08
3A	334	117.80	5320	110.13	315.27	3.61	2.23	309.10	0.80	2.32	2.22
3B	247	170.00	4880	138.02	290.58	5.73	3.34	436.20	1.70	5.35	2.55
4	249	153.25	5140	126.59	272.59	3.74	2.26	377.09	1.03	2.33	1.63
5	208	130.55	5240	130.07	256.75	4.08	3.13	389.73	1.35	2.18	1.74
6	231	134.85	5120	92.23	245.24	3.14	3.07	305.96	0.59	2.03	1.97
7	247	124.36	5910	104.04	310.15	4.03	3.85	270.87	1.26	2.07	2.25
8	225	156.68	5930	118.52	297.34	3.84	3.68	343.78	1.24	2.45	2.28
9	261	112.76	6250	128.34	333.09	5.16	2.08	342.51	1.04	2.96	1.72
10	230	107.31	6050	94.37	354.32	3.31	2.30	304.92	0.97	3.31	2.03
11	232	182.50	6220	88.76	311.57	4.44	3.78	357.89	2.40	5.45	2.71
12	220	498.62	5720	86.41	252.62	4.64	2.19	360.18	0.90	2.25	1.77
13	211	138.60	6300	81.71	414.93	4.43	4.21	266.56	1.55	2.95	2.47
14	200	152.75	6660	97.66	322.53	4.72	3.73	329.49	3.05	3.10	2.09
15	240	174.42	6170	79.92	298.35	4.41	4.24	397.71	1.55	2.19	2.89
16	210	138.60	5880	76.85	275.43	4.10	4.17	298.09	2.34	3.07	2.05
17	214	160.13	6370	71.38	259.79	4.57	2.92	339.50	2.23	1.97	1.90
18	236	172.04	6150	83.38	315.89	3.94	4.77	309.18	1.53	2.21	1.87
19	252	150.93	5950	85.10	302.48	3.58	N/A	N/A	1.80	7.50	2.66
20	207	141.02	6080	59.67	317.23	3.55	2.78	303.98	1.49	4.60	2.38
21	182	161.64	6370	94.81	286.93	5.21	4.34	339.50	1.90	6.10	1.94
22	183	214.12	5880	92.75	222.62	3.76	3.23	322.79	0.93	4.07	1.87
23	414	191.72	5790	79.06	302.22	4.55	3.71	263.01	0.46	5.15	3.64
24	163	168.53	6100	98.47	295.21	4.78	3.77	274.57	1.80	3.55	2.00
25	190	152.38	5740	78.33	338.91	5.44	3.78	265.13	1.40	4.50	2.65
26	176	155.68	4870	76.65	258.08	4.48	3.59	355.62	1.40	3.80	1.78
27	180	157.89	5150	86.85	312.49	3.88	4.11	342.61	1.11	2.11	2.08
28	163	159.39	4230	98.04	293.82	3.98	4.08	318.15	0.51	2.86	2.37
29	163	181.27	4310	89.88	263.30	3.81	4.91	339.50	0.70	3.13	1.91
30	145	164.68	4260	78.89	247.08	4.11	4.22	332.44	0.48	3.74	1.97
31	163	133.15	5900	86.82	360.82	3.31	2.14	297.26	0.95	3.20	1.93
32	144	141.02	5790	80.72	314.46	3.99	2.63	366.06	1.06	1.88	1.86
33	222	192.58	4420	93.74	294.41	4.85	4.34	394.81	0.73	2.33	1.61
34	187	145.93	5290	77.32	269.63	4.71	5.08	345.77	0.66	2.31	1.69
35	195	182.09	4710	75.77	257.20	3.49	4.13	330.47	0.73	3.18	1.57
36	228	137.22	3690	68.99	178.51	3.49	2.34	293.41	1.50	3.75	1.53
37	275	159.31	4690	95.85	260.04	4.14	2.83	315.42	1.00	3.10	1.75
38	329	184.93	4000	121.48	237.85	3.91	2.34	326.97	1.04	3.18	1.52
39	241	186.60	4010	123.48	242.56	4.13	2.66	369.48	0.80	3.48	2.06
40	292	138.93	4520	96.99	252.59	4.62	2.99	276.65	0.71	2.82	1.98
41	264	184.09	4840	109.27	282.25	5.00	2.66	318.24	0.73	0.99	2.35
42	295	162.31	4770	117.75	262.85	5.21	2.42	337.18	2.10	1.75	2.09
43	302	165.36	4520	98.75	294.85	4.09	1.95	332.00	1.00	2.38	3.04
44	364	204.52	4160	81.68	236.12	4.54	1.88	304.54	0.28	3.36	3.23
45	245	216.68	3840	67.35	206.22	3.97	2.34	321.10	0.26	3.93	2.01
46	233	186.60	4030	94.05	261.33	4.09	1.44	337.18	1.01	3.33	1.66
47	282	194.73	4690	54.59	330.48	4.22	2.83	335.09	0.50	2.61	2.40
48	278	156.71	3890	72.18	231.31	4.04	1.51	314.49	1.18	3.94	1.77
49	216	155.60	4650	59.06	243.06	3.88	2.91	381.38	1.01	2.39	2.54
50	241	132.17	4630	81.80	253.08	4.70	1.65	312.64	1.08	2.35	1.50
51	222	236.85	4330	70.81	181.01	4.30	1.73	308.10	0.31	1.61	1.20
52	282	166.51	4430	115.48	260.05	4.29	2.83	341.44	1.34	2.85	2.41
53	222	145.53	4210	118.91	251.81	3.47	2.99	391.33	1.30	3.91	1.57
54A	240	144.83	5210	109.97	303.63	4.42	2.18	380.01	0.74	3.22	1.66
54B	227	167.28	4390	75.87	248.78	3.83	2.11	343.60	0.51	2.80	1.54
55	282	158.93	4690	76.11	307.97	3.50	2.18	344.70	0.68	2.52	1.53
56	232	259.04	4120	87.65	137.62	4.67	1.58	269.12	0.40	2.89	0.87
57	241	177.95	4610	85.13	236.27	4.64	2.99	310.81	0.44	3.13	1.83
58	244	143.08	4860	41.34	283.66	4.02	2.11	334.06	0.42	2.89	1.01
59	227	205.43	4430	86.90	178.19	3.98	1.58	314.49	0.36	2.29	1.12
60	265	228.55	4100	104.18	221.65	4.40	2.03	353.71	0.44	4.19	1.47
61	251	154.60	4090	114.54	215.08	5.25	2.72	366.24	1.01	3.61	2.53
62	205	141.05	4760	90.87	240.62	5.51	3.33	382.10	0.63	2.95	2.47
63	228	110.29	5690	134.12	292.98	4.49	2.38	399.32	0.73	1.64	2.11

Dry tissue analysis of seed tubers for plant nutrients

Seed line	Total N (%)	P (%)	K (%)	S (%)	Mg (%)	Na (%)	Cl (%)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Mo (mg/kg)	B (mg/kg)	Co (mg/kg)
1	2.2	0.3	2.2	0.2	0.1	0.0	0.3	14.0	130.0	5.9	18.0	0.1	4.7	0.1
2	2.3	0.3	2.2	0.2	0.1	0.0	0.2	13.0	97.0	4.8	19.0	0.5	5.0	0.1
3A	2.1	0.2	2.0	0.1	0.1	0.0	0.2	11.0	63.0	3.0	14.0	0.1	4.4	0.2
3B	2.1	0.3	1.8	0.2	0.1	0.0	0.3	9.2	30.0	2.4	18.0	0.1	3.7	0.1
4	1.9	0.2	1.6	0.2	0.1	0.0	0.2	10.0	162.0	4.5	16.0	0.1	4.3	0.3
5	1.8	0.3	1.8	0.2	0.1	0.0	0.3	9.4	98.0	5.8	16.0	0.1	3.8	0.1
6	2.0	0.3	2.3	0.2	0.1	0.0	0.3	9.5	164.0	2.4	14.0	0.1	5.0	0.2
7	1.9	0.2	2.0	0.1	0.1	0.0	0.3	13.0	70.0	4.3	14.0	0.1	4.2	0.2
8	1.9	0.2	2.1	0.1	0.1	0.0	0.2	8.6	58.0	4.8	15.0	0.1	4.1	0.1
9	1.8	0.2	2.9	0.2	0.1	0.0	0.3	8.9	234.0	3.6	20.0	0.1	5.4	0.1
10	2.0	0.3	2.5	0.1	0.1	0.0	0.3	15.0	130.0	3.4	15.0	0.1	4.9	0.4
11	1.5	0.2	1.9	0.1	0.1	0.0	0.2	12.0	86.0	3.6	13.0	0.1	4.6	0.2
12	2.7	0.3	1.8	0.2	0.1	0.0	0.3	9.0	46.0	1.8	19.0	0.1	4.9	0.1
13	2.2	0.3	2.1	0.2	0.1	0.0	0.2	13.0	100.0	4.1	16.0	0.1	4.5	0.1
14	1.7	0.2	2.1	0.1	0.1	0.0	0.2	9.2	84.0	4.8	14.0	0.1	4.4	0.1
15	2.2	0.2	1.7	0.2	0.1	0.0	0.2	20.0	86.0	3.9	17.0	0.1	5.8	0.1
16	1.7	0.2	1.6	0.1	0.1	0.0	0.3	13.0	84.0	5.0	15.0	0.1	4.3	0.1
17	2.0	0.3	2.1	0.1	0.1	0.0	0.3	12.0	71.0	4.2	16.0	0.1	4.0	0.3
18	2.2	0.2	2.0	0.2	0.1	0.0	0.3	11.0	91.0	3.7	16.0	0.1	4.9	0.1
19	1.9	0.2	1.8	0.1	0.1	0.0	0.2	12.0	164.0	4.1	15.0	0.1	4.7	0.1
20	1.9	0.2	2.5	0.1	0.1	0.0	0.3	11.0	62.0	4.9	14.0	0.1	4.5	0.1
21	2.0	0.3	2.1	0.2	0.1	0.0	0.3	9.7	97.0	6.0	20.0	0.1	4.1	0.1
22	1.8	0.3	1.4	0.1	0.1	0.0	0.2	10.0	84.0	2.6	13.0	0.1	3.9	0.1
23	2.4	0.3	2.5	0.1	0.1	0.0	0.5	21.0	50.0	1.0	16.0	0.1	4.8	0.1
24	1.3	0.2	1.7	0.1	0.1	0.0	0.3	8.2	87.0	3.1	13.0	0.1	3.6	0.1
25	2.0	0.3	2.0	0.1	0.1	0.0	0.2	14.0	80.0	5.5	16.0	0.1	3.9	0.1
26	2.3	0.3	1.9	0.2	0.1	0.0	0.2	11.0	100.0	3.7	17.0	0.1	3.8	0.2
27	2.2	0.3	2.0	0.2	0.1	0.0	0.2	7.9	62.0	2.2	15.0	0.1	3.8	0.1
28	1.6	0.2	1.7	0.1	0.1	0.0	0.1	9.6	68.0	3.5	13.0	0.1	3.9	0.1
29	1.8	0.2	1.5	0.1	0.1	0.0	0.2	10.0	54.0	1.3	14.0	0.1	3.3	0.1
30	1.6	0.2	1.4	0.1	0.1	0.0	0.1	7.9	32.0	1.0	12.0	0.1	3.4	0.1
31	1.3	0.2	1.7	0.1	0.1	0.0	0.2	7.2	110.0	3.2	9.7	0.1	4.0	0.1
32	1.3	0.2	1.5	0.1	0.1	0.0	0.3	5.7	47.0	3.9	11.0	0.1	3.7	0.1
33	2.4	0.4	2.2	0.2	0.1	0.0	0.2	10.0	56.0	4.6	20.0	0.1	4.3	0.1
34	1.5	0.2	1.6	0.1	0.1	0.0	0.2	8.1	84.0	3.8	16.0	0.1	3.4	0.1
35	1.8	0.2	1.7	0.1	0.1	0.0	0.3	10.0	55.0	4.5	12.0	0.1	3.7	0.1
36	1.1	0.2	1.3	0.1	0.1	0.0	0.3	5.2	45.0	1.7	9.6	0.1	3.1	0.1
37	1.4	0.2	1.6	0.1	0.1	0.0	0.2	7.3	50.0	3.0	13.0	0.1	3.2	0.1
38	1.9	0.3	1.8	0.2	0.1	0.0	0.3	9.2	56.0	3.9	18.0	0.1	4.1	0.1
39	1.9	0.3	1.1	0.1	0.1	0.0	0.1	8.4	42.0	3.0	14.0	0.1	3.3	0.1
40	1.8	0.2	1.7	0.1	0.1	0.0	0.3	17.0	99.0	2.8	16.0	0.1	3.5	0.1
41	1.9	0.3	1.6	0.1	0.1	0.0	0.2	19.0	108.0	1.8	14.0	0.1	3.8	0.1
42	1.7	0.2	1.7	0.1	0.1	0.0	0.3	8.8	95.0	2.6	14.0	0.1	4.0	0.1
43	1.4	0.2	1.6	0.1	0.1	0.0	0.2	17.0	82.0	3.4	11.0	0.1	3.5	0.1
44	2.2	0.4	2.1	0.1	0.1	0.0	0.4	55.0	42.0	1.0	20.0	0.1	3.8	0.2
45	1.9	0.3	1.6	0.1	0.1	0.0	0.3	19.0	31.0	1.0	14.0	0.1	4.1	0.1
46	1.9	0.3	1.5	0.2	0.1	0.0	0.1	9.9	90.0	3.8	14.0	0.1	3.4	0.1
47	2.3	0.2	1.9	0.1	0.1	0.0	0.3	17.0	38.0	1.6	16.0	0.1	4.6	0.2
48	2.2	0.3	1.9	0.1	0.1	0.0	0.3	9.4	55.0	5.7	15.0	0.1	3.9	0.1
49	1.5	0.2	1.7	0.1	0.1	0.0	0.4	11.0	26.0	2.7	11.0	0.1	3.5	0.1
50	1.8	0.2	1.8	0.1	0.1	0.0	0.2	7.9	50.0	4.4	16.0	0.1	3.8	0.1
51	2.4	0.3	1.8	0.2	0.1	0.1	0.7	6.3	32.0	3.0	18.0	0.4	4.7	0.4
52	1.9	0.3	1.8	0.1	0.1	0.0	0.2	9.0	50.0	4.3	13.0	0.1	3.7	0.1
53	1.9	0.2	1.8	0.2	0.1	0.0	0.1	13.0	152.0	4.6	12.0	0.1	3.7	0.1
54A	1.7	0.3	1.9	0.2	0.1	0.0	0.1	7.5	41.0	1.1	12.0	0.1	3.3	0.1
54B	2.0	0.2	1.5	0.1	0.1	0.0	0.2	9.1	46.0	2.1	25.0	0.1	4.7	0.1
55	2.0	0.3	2.3	0.1	0.1	0.0	0.2	11.0	316.0	3.2	15.0	0.1	5.0	0.1
56	2.0	0.4	2.0	0.2	0.1	0.0	0.8	6.6	27.0	1.8	23.0	0.1	3.3	0.1
57	1.7	0.2	1.9	0.1	0.1	0.0	0.6	9.8	40.0	2.3	17.0	0.1	3.7	0.1
58	1.6	0.2	1.9	0.1	0.1	0.0	0.3	7.5	50.0	1.9	15.0	0.3	3.8	0.1
59	1.8	0.3	1.8	0.1	0.1	0.0	0.4	6.6	37.0	1.5	13.0	0.1	3.6	0.1
60	1.8	0.2	1.3	0.1	0.1	0.0	0.2	6.7	37.0	1.0	15.0	0.1	3.6	0.1
61	1.9	0.2	1.4	0.1	0.1	0.0	0.2	7.2	25.0	3.7	20.0	0.1	4.2	0.1
62	1.8	0.2	1.2	0.1	0.1	0.0	0.3	7.5	26.0	1.7	19.0	0.1	3.2	0.1
63	1.9	0.2	1.9	0.1	0.1	0.0	0.3	6.7	67.0	2.0	18.0	0.1	4.1	0.4

Appendix iv – Field data

Field performance – average of three replicate plots

	Plant emergence (4 weeks after planting)			Plant growth (8 weeks after planting)	Harvest assessment			
Seed line	Total plants/plot	% Plants with late emergence	No. stems/plant	Mean plant height	Mean scab rating	Total tuber yield (t/ha)	% Large tubers	Harvest specific gravity
1	53	48	2.8	371	1.3	69.3	48.8	1.089
2	53	64	2.3	382	1.3	65.9	60.4	1.087
3	54	54	2.6	399	3.0	69.8	56.0	1.071
4	56	15	3.5	469	1.0	75.8	53.6	1.091
5	53	44	2.3	410	2.0	66.6	59.0	1.084
6	54	64	2.8	365	1.3	58.4	43.8	1.089
7	53	34	2.7	382	1.0	64.0	56.1	1.091
8	55	34	2.9	414	3.3	67.8	46.6	1.087
9	54	20	3.0	433	1.3	67.6	44.6	1.093
10	51	55	2.7	349	3.0	58.2	54.1	1.090
11	54	50	2.8	407	2.0	63.9	54.4	1.089
12	55	13	2.2	243	1.7	60.2	72.0	1.087
13	51	62	2.6	354	4.0	60.0	50.4	1.088
14	55	30	2.8	400	3.0	66.8	51.0	1.087
15	55	40	2.5	419	1.3	64.4	50.1	1.087
16	59	36	3.0	415	1.0	63.2	50.2	1.087
17	54	33	3.0	384	1.3	62.9	51.7	1.092
18	56	47	2.6	388	1.0	60.7	53.8	1.093
19	57	29	2.9	424	3.0	64.9	48.2	1.090
20	53	46	2.4	369	1.7	59.7	53.5	1.093
21	56	22	3.1	450	3.7	67.7	48.1	1.093
22	49	51	2.4	337	3.0	58.5	55.2	1.090
23	54	32	2.6	410	1.3	68.7	62.1	1.086
24	56	44	2.6	376	1.7	61.3	38.5	1.086
25	40	69	2.3	262	2.0	55.9	53.0	1.087
26	54	42	2.6	384	3.0	63.6	59.3	1.089
27	41	54	2.3	341	1.7	60.0	59.2	1.086
28	55	52	2.5	365	1.3	59.8	47.5	1.086
29	53	42	2.4	403	2.0	66.2	58.0	1.087
30	54	39	2.9	427	1.7	67.7	50.1	1.089
31	54	42	2.9	409	2.0	59.1	46.8	1.086
32	54	39	2.7	408	1.0	62.1	47.7	1.091
33	50	62	2.6	347	1.0	64.6	61.4	1.089
34	55	41	2.7	404	1.0	65.8	48.4	1.089
35	55	50	2.9	416	1.3	64.5	51.2	1.085
36	53	33	3.2	368	2.0	63.4	46.6	1.091
37	52	47	2.5	370	2.0	63.2	44.0	1.087
38	55	47	2.6	409	1.3	65.9	54.6	1.091
39	50	44	2.7	357	3.0	67.0	47.0	1.089
40	57	39	2.3	393	1.7	64.1	49.2	1.089
41	56	36	2.7	390	1.0	55.9	46.8	1.089
42	57	44	2.7	428	1.0	60.3	45.5	1.089
43	53	43	2.8	382	2.7	69.8	56.1	1.091
44	55	64	2.5	368	2.3	64.0	52.8	1.088
45	59	42	2.7	412	1.0	69.2	40.7	1.093
46	54	53	2.5	400	1.3	62.4	51.0	1.088
47	56	46	2.8	398	3.0	62.2	51.0	1.089
48	55	30	2.9	424	4.0	68.8	50.3	1.090
49	49	59	2.5	342	1.3	55.2	43.2	1.089
50	54	40	3.1	385	3.7	61.4	47.8	1.088
51	50	30	2.4	295	2.3	60.4	71.3	1.089
52	49	47	2.6	385	1.3	61.0	54.4	1.087
53	57	43	3.0	382	3.0	57.0	51.9	1.087
54	54	64	2.8	376	0.7	62.9	45.7	1.090
55	55	52	3.0	385	1.0	61.6	45.3	1.090
56	52	44	3.0	366	1.0	60.1	52.7	1.086
57	55	43	2.9	381	1.0	55.6	49.8	1.091
58	54	37	3.2	392	3.0	64.4	51.9	1.085
59	53	40	2.9	362	1.0	59.6	58.7	1.088
60	53	41	2.8	392	2.0	57.2	47.7	1.090