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Potato yield gap investigation 2012–13. Part A: Factors limiting yield

Sinton S, Falloon R, Brown H, Tregurtha C, Michel A, Dellow S, Reid J, Shah F, Pethybridge S, Searle B.

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Executive summary

Potato yield gap investigation 2012–13. Part A: Factors limiting yield

Sinton S, Falloon R, Brown H, Tregurtha C, Michel A, Dellow S, Reid J, Shah F, Pethybridge S, Searle B.

June 2013

Potato yields in Canterbury have remained static at 50–60 t/ha (paid yield), and crop production at this level is becoming uneconomic. Computer-based modelling shows that yields of 90 t/ha (paid yield) are theoretically possible in most years suggesting there is a large gap between actual and potential yields.

A project was conducted by the NZ Institute for Plant & Food Research, during the 2012–13 growing season. The field research project aimed to identify factors responsible for the reduced actual yields (the "yield gap"). The project was funded by Potatoes New Zealand, McCain Growers Group, Ravensdown Fertiliser Co-operative Limited and Plant & Food Research.

Eleven commercial potato crops were selected for the study. They were planted with either 'Russet Burbank' or 'Innovator' cultivars. Paddocks were selected also to examine the effect of having potatoes in their cropping histories. A representative site was chosen in each crop after planting. Soil structure and the presence of soil-borne pathogens were measured at each site, which was visited every 10 to 14 days throughout the season to assess growth and development. Unhealthy plants that were identified in the field were marked for later yield assessment, when they were compared to yield of healthy plants.

A simulation model for potato maximum attainable yield under perfect conditions, conducted for each year from 2002–2013 showed that, of the last 12 years, the 2012–13 season had the greatest "potential yield" at all sites. Averaged over the 11 crops, "potential yield" was 87 t/ha and "field yield" (paid yield harvested from the entire field) was 55 t/ha. The yield gap between "potential" and "field yield" ranged between 20 and 42 t/ha. Cultivar had no significant effect on the maximum attainable yield predicted by this model.

To check for nutrient sufficiency, fertiliser trials were established in four of the crops, where grower rates of nitrogen, phosphorus and potassium were doubled, and calcium was also added as gypsum. Further applications of nitrogen during the season, conducted as part of commercial practices, were also doubled for some treatments in the fertiliser trials. Yield measured at maturity showed that nutrient supply was adequate for the current level of production, and therefore not a significant contributing factor to the yield gap in these fields. Results from this work are covered in Part B of this report: Potato yield gap investigation 2013–13. Part B: Effect of nutrient supply on yield, SPTS No 8620.

Factors that contributed to yield reduction in the crops were quantified and are presented in order of importance:

1. The presence of soil- and seed-borne diseases, Rhizoctonia stem canker (found in all crops) and *Spongospora subterranea* (five crops) and soil compaction (six crops). Plants that were less severely affected by disease, and in the absence of soil compaction, yielded to potential. However, in other crops where plants were affected by both diseases and the soil was compacted, yield was reduced by between 52 and 80%. Four crops with the highest yields also had strongest root vigour, and this was associated with the lack of soil compaction and absence of *S. subterranea*.
   Low root vigour seen in six crops was associated with the presence of *S. subterranea* and soil compaction at 25 to 30 cm depth. Six crops had wind damage, and its effect on yield have not been quantified.

2. In four crops, foliar diseases shortened canopy duration and therefore the maximum accumulation of green leaf area and carbohydrate development for tuber formation, reducing yields by between 4 and 21%.

3. Variable seed quality caused a yield reduction of 57% in some plants from the one crop that was measured. Late emerging plants from small seed tuber pieces were out-competed by neighbouring plants which had grown from larger seed. All crops were grown from cut seed. Some seed tubers had surface diseases present before planting contributing as a substantial primary inoculum source. Previous cropping history had a significant effect on pathogen levels in the soil but on average, did not affect yield. Paddocks not previously producing potatoes (over 10 years) had less pathogen inoculum than those paddocks that had included potatoes. Where the paddocks surveyed had more grass in their history, or had grass as the last crop before potatoes, the subsequent crops showed a later onset (by two to four weeks) of Rhizoctonia stem canker. At final harvest, most crops had tubers that were asymptomatic.

4. There was a 15% yield loss in parts of a crop due to direct competition effects with weeds, especially where weeds established before crop canopy closure was achieved.

5. Irrigation was missed at edges and corners of some crops. Two crops were measured and yield in these areas were reduced by 13 and 28%. The effect of crop water use efficiency on the yield gap was not formally investigated due to incomplete irrigation records. However, there was visual evidence that in some crops, run-off and/or drainage from high intensity irrigation could be lowering water and nitrogen use efficiency and increasing the chance of leaching. Additionally, continually wet soils may have provided an environment for increased disease severity.

6. Gaps in crops resulted in a yield loss of between 0 and 3% due to uneven plant density and rectangularity.

We recommend focussing on three themes as a way of addressing the yield gap in the future:

1. Quantify the impact on field yield of soil-borne diseases, particularly Rhizoctonia stem canker and *S. subterranea*.

2. Investigate how the presence of soil compaction interacts with irrigation management and soil-borne disease to reduce yield.

3. Quantify the effects of seed treatment on yield.

This and future work align with the first strategic priority of the Potatoes New Zealand draft industry strategy (August 2013) which is "*improving the competitive position of the NZ industry through productivity*", and the first strategic theme of improving grower productivity.

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1 Introduction

Quantifying yield loss is paramount for the development of cost-effective crop management tactics that maximise profitability. Potential yield is that possible if all factors contributing to yield are optimised. Actual yield is that obtained at the field level. The gap between the two is caused by stresses to the crop such as shortage of water, shortage of nutrient or damage by pests and diseases. Management strategies that minimise such stresses (yield-limiting factors) will increase crop yields. The difference between potential and actual yield from a crop is referred to as the 'yield gap'.

Potato growers in Canterbury have reported that yields have remained static for the last 10 years at 50 to 60 t/ha in spite of improvements in irrigation, fertilisation and disease control technologies. Potato production at this level is becoming uneconomic. Computer-based modelling predicts that yields of 90 t/ha are theoretically possible in most years, thus highlighting a yield gap of up to 40 t/ha in current production of processing potatoes.

Previous work conducted in Canterbury between 2002 and 2005 (Jamieson et al., 2005) showed that nitrogen supply was not limiting potato yields, but poorly scheduled irrigation could be causing yield reductions of from between 5 to 15 t/ha. Another project based in the North Island from 2005 to 2008 (Sinton et al., 2009), estimated that between 5 and 48 t/ha of yield loss was associated with inadequate water supply and subsoil compaction. A nutrient (nitrogen, phosphorous and potassium) forecasting model (PARJIB), reported yield losses in Canterbury, due to nutrient deficiency, of less than 8 percent, mainly due to nitrogen limitation (Reid et al., 2011).

A project to investigate the yield gap in Canterbury processed potato crops was carried out during the 2012–13 growing season. The objective of the study was to identify factors that are limiting yield by conducting a detailed field survey of a range of processing potato crops in Canterbury. Potato cropping in this area has changed considerably during the last 10 years, including an increase in base fertility levels, changes in cultivars grown, different irrigation management and cultivation practices, and incidence and severity of pests and diseases.

This report describes the methods used in this survey, describes observation and measurement results and outlines features in each crop which may have contributed to yield reductions. Attempts were made to quantify, and prioritise, the effects of the yield-limiting factors identified. This knowledge will be used to define key factors affecting potato crop yields, and to direct future research that may aim to adjust and/or develop crop management methods to alleviate the causes of potato yield reductions.

2 Methods

Eleven process potato crops in Mid and South Canterbury were chosen for the yield gap study (Table 1). Three were Russet Burbank (RB) crops planted in soil not previously in potatoes (new), four were RB crops in ground previously in potatoes within the last 7 years (old), two were Innovator crops planted in new ground and two were Innovator crops grown in old ground. Four of these crops (sites 9, 11, 4 and 10) also each hosted a fertiliser trial as part of this project (see fertiliser report 8620 for more detail).

Table 1. Potato crops used in the yield gap analysis survey during 2012–13.

Site No.	Location	Cultivar	History
1	Pendarves	RB	New
2	Pendarves	RB	Old
3	Pendarves	RB	Old
4	Rakaia	RB	New
5	Rakaia	Innovator	New
6	Rakaia	Innovator	Old
7	Ashburton	RB	New
8	Temuka	RB	Old
9	Temuka	RB	Old
10	Temuka	Innovator	Old
11	Temuka	Innovator	New

Crops were first visited after planting, close to the time of plant emergence. In each crop, an observation site, comprising 10 m by 8 rows, was marked out in a representative area of the field. Crops ranged in total area from 7 to 80 ha. The observations described herein do not necessarily represent the whole field for each crop. However, attempts were made to ensure the observation plots were representative of the immediately visible areas in the larger crops. Sites were visited approximately every 2 weeks (between 12–15 visits were made to each crop) and a number of activities were carried out at each visit, including the following:

1. Once the crop had emerged, an eight row by 10 m observation plot was marked out to be regularly checked and sampled throughout crop growth, with the middle six rows set aside for radiation interception measurements and a final yield assessment. Inspections of the crop were carried out in the vicinity of the plot to observe any problems or features that were not represented in the observation plot. A plant count was taken along a 60 m transect of a single row after full emergence. At harvest, distance between individual plants in 50 m of a single row was measured and stem numbers on 130 individual plants were counted.

2. During November, about 2 weeks after planting, a soil sample (300 - 500g field weight) was taken from the observation plot in each crop; air dried at 40^{o}C over 24 h and bagged according to SARDI instructions. The samples were stored until mid January 2013 and then submitted for pathogen testing to the Root Disease Testing Service, SARDI, Australia. The tests routinely identify DNA of the following pathogens (respective diseases): *Spongospora subterranea* (powdery scab), *Rhizoctonia solani* AG2.1, and AG3 (Rhizoctonia stem canker – RSC - and black scurf), *Verticillium dahliae* (one pathogen of the early dying complex), *Meloidogyne fallax* and *M. hapla* (root knot nematodes), *Streptomyces scabies* (common scab), and *Colletotrichum coccodes* (black dot).

3. At plant emergence in each crop, the ridge/furrow cross section in and between the planted rows was mapped, along with depth of seed tuber planting. The presence or absence of soil restrictions was recorded. Soil penetration resistance, soil texture, aggregate size distribution (using the dry sieve method which reports aggregate proportions in the <0.85 mm diameter, 0.85 mm–9.5 mm and >9.5 mm ranges) and aggregate stability (using the wet sieve method which reports aggregate mean weight diameter from the 0.5 mm, 1 mm, 1–2 mm and 2–4 mm diameter fractions) were measured in the ridges and furrows. These measurements were repeated at crop senescence when root vigour and distribution patterns were also recorded by digging two pits across and down through a representative ridge, and were assessed on a subjective visual scale from very poor to excellent (1 - 5).

4. At each crop visit, four plants were arbitrarily selected from each corner of the observation plot from the outside rows, and assessed for disease incidence or other problems. Plants were usually taken back to the laboratory for washing and close inspection of leaves, roots, stems and tubers, and any disease was identified and photos were taken to record disease status. Underground stems were graded for rhizoctonia stem canker (RSC), classified as healthy, diseased or dead. Presence or absence of Spongospora root galls was also recorded.

5. Remote measurements of green canopy area of the central rows of the plot in each crop were taken to assess radiation interception and canopy cover using a handheld multispectral CropScan radiometer (MSR5; CropScan Inc., Rochester, MN, USA) equipped with five narrow wavelength bands. Crop yield is often related to the amount of radiation intercepted by the plant canopy and therefore absolute measurements of green leaf area index, such as those obtained from the CropScan radiometer often have better relationships with crop yield than proportional estimates of disease intensity. Remote measurements of green leaf area were only taken when incoming radiation was over 500 W/m^2 (cloudless conditions) so measurements were only made when these conditions occurred at the time of respective crop visits. The radiometer was position 1.7 m above the soil and a spirit level mounted to the support pole was used to ensure it was positioned at the appropriate angle and height. At this height, canopy reflectance was measured from an area of the plant canopy that was 0.85m in diameter, the width of one row, furrow to furrow. Reflectance from the potato canopies was calculated as a percentage of the voltage value for the reflected radiation divided by the voltage values for the incident radiation for each corresponding wavelength. Nine readings were obtained for each plot. Readings within plots were averaged to provide a single plot value. Photographs were taken of the plot and surrounding crop, and of any problem plants or areas in the crop.

6. On one occasion before canopy closure, plant and gap numbers were recorded in six 10 m lengths of row in the vicinity of the marked plot.

7. At close to canopy closure, full canopy and midway between full canopy and crop sensecence, eight plants were removed from the observation plot to measure shoot weight, tuber yield and tuber size distribution. Shoot dry matter yield (divided into leaf, stem and branch), leaf area, numbers of stems, stem nodes, branches, and tubers, and tuber dry matter (from a 100 g fresh sample), were determined. At crop senescence a final tuber yield was estimated by hand digging four rows (two beds) by 2.5 m length of row.

8. As each crop matured, any plants of poor vigour or displaying disease symptoms were identified, the symptoms were recorded, and plants marked for later yield assessment when approaching senescence. Diseased plants usually died before being crowded out by neighbours. Adjacent healthy areas were also marked for later harvest, to give estimates of yield loss due to particular problems. If the healthy areas later showed disease symptoms, new healthy plants were identified at the time of harvest to give valid comparisons. Tubers from each marked plant were harvested, photographed, and then all tubers (including small ones) were weighed and counted. Aboveground stems were recorded as alive or dead and underground stems were taken back to the laboratory, washed and recorded as healthy, diseased or dead.

9. To quantify the effect of unhealthy plants on final crop yield, plants of this type were counted in a random 60 m length of row (a different row each visit) near the observation plot over several visits.

10. The prevalence and incidence of commonly encountered viruses was quantified by testing 100 leaves systematically collected in a “W”-shaped transect from a representative area of each crop. Serological testing for *Potato virus X* (PVX), *Potato virus Y* (PVY), *Potato virus S* (PVS), *Potato virus M* (PVM), *Potato virus A* (PVA) and *Potato leafroll virus* (PLRV), HpMV, AHLV, ArMV-H, and ApMV (H & I serotypes) used the double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) technique. Sub-samples containing equal weight portions of samples from each of the plants, were homogenized in a minimal amount of 0.01M phosphate-buffered saline (pH 7.4) containing Tween 20 (2.5 ml/L), egg albumin (2 g/L), and polyvinyl pyrrolidone (MW = 40,000; 20 g/L), using a rotary leaf press. Sap extracts (100 μL/well) were tested singly on microtiter plates using polyclonal antisera to each virus with positive, negative, and buffer only controls for each virus on each plate. Absorbance (A405 nm) was measured using a Molecular Devices microtiter plate reader. Samples with absorbance values greater than the mean of the negative control plus three times the standard deviation of the mean of the negative controls were considered virus infected.

11. Potential yields were calculated at each site for 11 growing seasons, using the method outlined in the Appendix I. This included the current season, and the ten previous seasons, to provide a reference for comparing the current season. Historic weather data were used from Ashburton and Timaru (whichever was closest to the crop site) for potential yield calculations. Simulations were started on the same day each year and this was set to the day that crops were planted at each site. The thermal time from planting to emergence was calculated for each site and this value was used to predict the time of emergence for year at each site. The tuber dry matter content measured at final harvest for each site was used to calculate fresh DM yield. The potential yield was

then reduced to account for the proportion of small tubers (<67 mm) measured at each site.

12. Regularity of plant placement was measured in Crop 9 at senescence. The distance between each plant centre was recorded in a total of 50 m of row (10 different row locations of 5 m each).

3 Results and discussion

3.1 Seed tuber size range and type

Seed tubers for the 11 crops were sourced from Canterbury seed growers (Table 2). Seed tubers were processed at two cutting facilities and the resulting size distribution was calculated from subsamples. Most cut tubers (60–75%) weighed between 45 and 85 g which is considered to be in the desirable range for planting. A small proportion (6–15%) was lighter than 30 g, and 10–28% were heavier than 85 g. However, there was no information relating to the proportion of resulting cut seed tuber types (whether stem, rose, middle or whole). Variability in seed tuber type and its influence on emergence and yield is illustrated by the results from Crop 11 in the crop history section (3.9).

Cultivars used by McCain Foods (for example Russet Burbank and Innovator) have been bred to produce large, elongated tubers and therefore sourcing uncut seed of the optimum size is difficult and not always desirable. While less prone to damage and disease during handling and planting, whole tubers are more expensive to produce and according to some in the industry can develop high stem numbers. This in turn increases numbers of daughter tubers and reduces tuber size in the resulting crop. Cutting larger seed into several pieces enables a greater planted area, reduces cartage costs and enables some control over final stem numbers. However, cutting produces a wide diversity of seed tuber type (rose, stem and middle) which introduces variability into the crop. It may also increase the risk of disease spread.
Plant developmental variability was noted within several observation crops in this study, indicating variable seed tuber quality.

If the seed tuber characteristics described here are having adverse impacts on subsequent tuber yield and quality growers could consider; reducing seed tuber variability by growing more even seed tuber crops or grading tubers before cutting and keeping the resulting seed tuber types as separate populations for planting.

Table 2. Seed tuber source, cultivar, mean seed tuber weight (g) and percent seed tuber in size classes less than 30 g, 31 - 44 g, 45 - 65 g, 66 - 85 g and more than 85 g, and cutter location. This information was not available for Crops 4, 5 and 11.

				Cut seed size distribution					
Site No.	Source	Cultivar	Tuber wt (g)	% < 30g	% 31–44g	% 45–65g	% 66–85g	% 85 +g	Cutter
1	Supplier 1	RB	62	1	10	40	28	21	Timaru
2	Supplier 1	RB	63	5	15	30	34	16	Timaru
3	Supplier 2	RB	58	5	15	30	34	16	Timaru
4	Supplier 3	RB	N/A						
5	Supplier 4	Inn	N/A						
6	Supplier 5	Inn	68	2	7	26	38	28	Timaru
7	Supplier 6	RB	59	4	10	31	39	17	Timaru

3.2 Seed tuber health

This project was instigated after most of the crops had been planted (with the exception of the crops with the fertiliser trials), so the health and quality of the seed tubers used to establish the crops was largely unknown. This information would have provided an estimate of the primary inoculum levels of seed tuber borne pathogens being introduced. However, McCain Foods had earlier planted out a sample of the seed lines in a commercial glasshouse (July 2012), in planter bags filled with potting mix, to observe growth characteristics of these lines. Additionally, spare tubers which were not planted were reserved in sacks at the same location. It should be noted that more than one seed line may have eventually been planted in a paddock (for example, Crop 10).

On 8 November, 4 months after planting in pots, five randomly selected plants from each seed line were removed from their individual planter bags and the soil was removed. Stem and tuber numbers were recorded, and the presence of diseases and other abnormalities was noted (Table 3).

Table 3. Mean numbers of stems and tubers, and root health assessments, for five glasshouse-grown potato plants from different seed tuber lines, grown in large pots at Quickset Seedlings, Halkett. Assessments carried out on 8 November 2012.

Cultivar	Seed tuber source	Mean no. stems	Mean no. tubers	Root health assessment
'Russet Burbank'	Supplier 1	1.4	10.0	Healthy
	Supplier 8	2.0	10.0	Healthy
	Supplier 2	1.8	12.4	Two plants with Spongospora galls
	Supplier 3	2.0	10.0	Healthy
	Supplier 6	1.4	7.0	Healthy
'Innovator'	Supplier 3	3.8	13.0	Healthy
	Supplier 7	3.4	10.0	Healthy
	Supplier 5	1.8	7.6	Healthy
	Supplier 4	2.0	8.0	Healthy
	Supplier 4	1.4	7.6	Healthy

For the 'Russet Burbank' lines, plants from two lines (Supplier 1, 6) had few stems (mean = 1.4) compared with the other lines (approx. 2 stems). Plants from one line (Supplier 6) also had relatively few tubers (7) compared with 10 to 12 tubers for the other lines. Two plants from one line (Supplier 2) had Spongospora root galls. This line was subsequently planted in Crop 3 (Table 3).For the 'Innovator lines', one line (Supplier 4) gave plants with few stems (mean = 1.4), two lines (Supplier 5, 4) had intermediate numbers of stems (approx. 2) and two lines (Supplier 3, 7) gave plants with more than 3 stems. Plants from three lines (Supplier 5, 4) had approx. 8 tubers, and two lines (Supplier 3, 7) gave greater numbers of tubers (mean = 10 and 13) (Table 3).

The spare non-planted tubers were removed to a laboratory for closer inspection, and presence of disease was noted for each tuber in each seed line (Table 4).

Table 4. Seed tuber "health" comments for samples of unplanted seed tuber lines left in bags in the Quickset Seedlings glasshouse, beside pots planted for seed vigour assessment. Samples were taken to a field laboratory and assessments made of tuber surface diseases on numbers of tubers indicated. Assessments carried out on 12 November 2012.

Cultivar	Seed tuber source	Number of tubers	Comment
'Russet Burbank'	Supplier 1	12	8 tubers with silver scurf, 1 tuber with gangrene, 3 tubers healthy.
	Supplier 8	10	7 tubers with silver scurf, 1 tuber also with powdery scab (confirmed with microscopy), 3 tubers healthy.
	Supplier 2	10	8 tubers with silver scurf, 2 tubers healthy.
	Supplier 3	10	10 tubers healthy
	Supplier 6	11	10 tubers healthy, 1 tuber light black scurf
'Innovator'	Supplier 3	8	4 tubers with silver scurf, 1 tuber with gangrene, 1 tuber light black scurf, 2 tubers healthy.
	Supplier 7	5	5 tubers with silver scurf, 1 tuber also with gangrene, I tuber also with light black scurf.
	Supplier 5	10	6 tubers with silver scurf, 4 tubers healthy.
	Supplier 4	10	2 tubers with silver scurf, 2 tubers with gangrene, 6 tubers healthy.
	Supplier 4	10	2 tubers with silver scurf, 8 tubers healthy.

Several tuber surface diseases were detected. Silver scurf, caused by *Helminthosporium solani* was noted on eight of the ten seed tuber lines. Gangrene caused by *Phoma exigua* var. *foveata* was found in three seed tuber lines. One seedline (cv. 'Innovator' Supplier 8) had a single tuber with powdery scab lesions. No seed tubers affected by common scab were identified.

Variable seed quality caused by seed cutting treatment produced a yield reduction of 57 percent in some plants from the one crop that was measured. Late emerging plants from small seed tuber pieces were crowded out by bigger neighbours, which had grown from larger seed. All crops were grown from cut seed.

3.3 Crop establishment and duration

The potato crops included in this study were planted between 3 October and 10 November 2012 and took between 27 and 44 days to emerge (Table 5). Crops took less thermal time to emerge the later they were planted (Figure 1). This is probably a combination of soil temperatures becoming progressively warmer than air temperatures and increased physiological seed age as planting dates got later. Crops 3, 5 and 7 emerged faster than average despite being planted in early October. Shallow planting of Crops 3 and 5 could account for this (Table 5).

Seed tuber vigour, influenced by tuber physiological age and health, also dictates time to emergence. Slow crop emergence caused by young physiological seed age and/or low soil temperatures (early planting) can give seed- and soil-borne diseases more opportunity to take hold, resulting in weaker plants and reduced yield. In extreme cases, disease can cause seed tubers can rot and die, leaving a reduced population, thus also reducing yield. Delayed emergence can also be a direct result of sprouts being killed by soil borne disease. For the crops in this survey, there was no clear evidence that time of planting or emergence rate directly affected yield. All crops had some level of RSC, regardless of planting date or emergence rate, and other yield-limiting factors such as soil compaction probably dominated yield loss at some sites. However, we did suspect that seed tuber vigour affected the yield in at least two crops. Crop 11 had variable emergence, where plants slower to emerge came from smaller seed tuber pieces. The late emerging plants had a lower yield than the early emerging plants (Section 3.9, Crop History, Crop 10, Innovator, old ground). Crop 4 appeared to have ideal conditions for growth but mean tuber weight was lowest of all crops (Figure 21), which in turn reduced potential yield. This could be related to other factors such as the use of low vigour seed, overwatering or pysillid damage.

Table 5. Planting and emergence date, days to emergence, canopy death date and days from planting to emergence for the 11 potato crops included in this study.

Site No.	Planting date	Emergence date	Average seed tuber depth (cm)	Days to emergence	Canopy death date	Days from emergence to canopy death
1	19-Oct-12	27-Nov-12	21	39	10-Apr-13	134
2	19-Oct-12	30-Nov-12	20	42	3-Apr-13	124
3	10-Oct-12	13-Nov-12	17	34	26-Mar-13	133
4	26-Oct-12	1-Dec-12	24	36	18-Apr-13	138
5	3-Oct-12	13-Nov-12	16	41	20-Mar-13	127
6	14-Oct-12	27-Nov-12	20	44	1-Apr-13	125
7	3-Oct-12	13-Nov-12	20	41	1-Apr-13	139
8	24-Oct-12	30-Nov-12	15	37	18-Mar-13	108
9	10-Nov-12	7-Dec-12	22	27	18-Apr-13	132
10	25-Oct-12	30-Nov-12	20	36	25-Mar-13	115
11	2-Nov-12	7-Dec-12	26	35	25-Mar-13	108

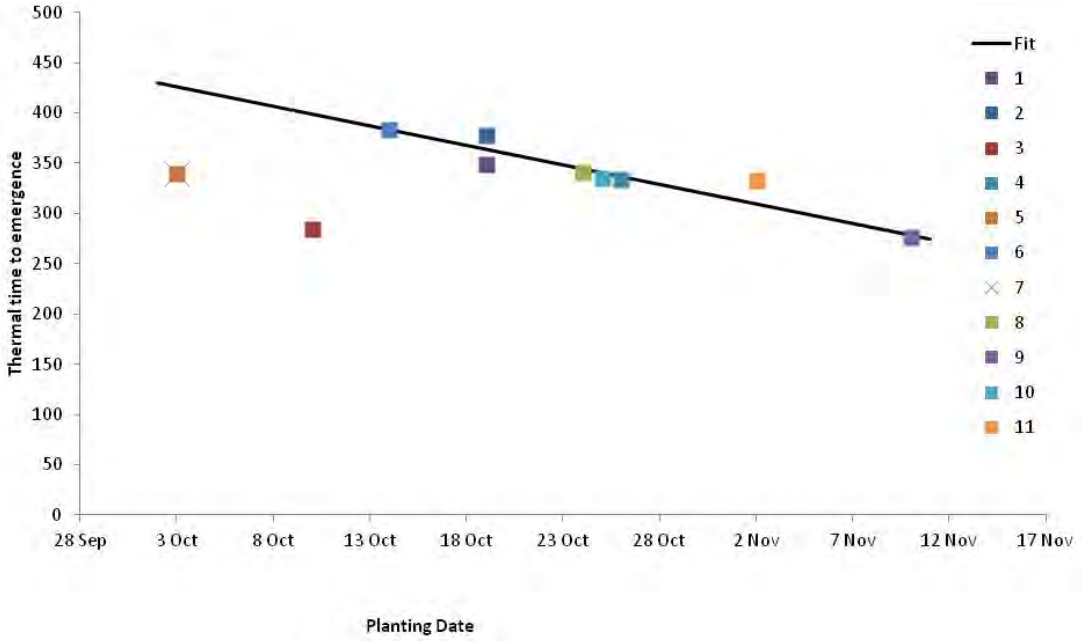


Figure 1. Thermal time to emergence (base 0°C) plotted against date of planting for each of the 11 observation crops. The black line represents the average decrease in thermal time needed to emerge as planting was delayed.

Crop canopies need to stay alive and healthy for a minimum of about 1400 degree days to ensure tuber bulking is complete (Walworth and Carling, 2002, Brown pers comm., Appendix I). Seven of the 11 crops had canopy durations of over 1400 degree days (Figure 2). Crops 2, 8, 10 and 11 each failed to maintain a healthy green canopy towards the end of crop growth and senesced between 1100 and 1349 degree days. Some of these crops were grown in soils where *V. dahliae* (one component of the early dying complex) was detected and all but Crop 11 were grown in soils that had grown potatoes previously. Crop 11 had strong weed competition which may have contributed to shortened canopy duration. Crops 8 and 10 had generalized chlorosis of an unknown origin in mid-late February along with a high incidence of early blight, caused by *Alternaria solani* of overall low severity. Shortened canopy duration would have stopped tuber growth prematurely and we noted this as a factor contributing to the yield loss of between 4 and 21 percent for these 4 crops.

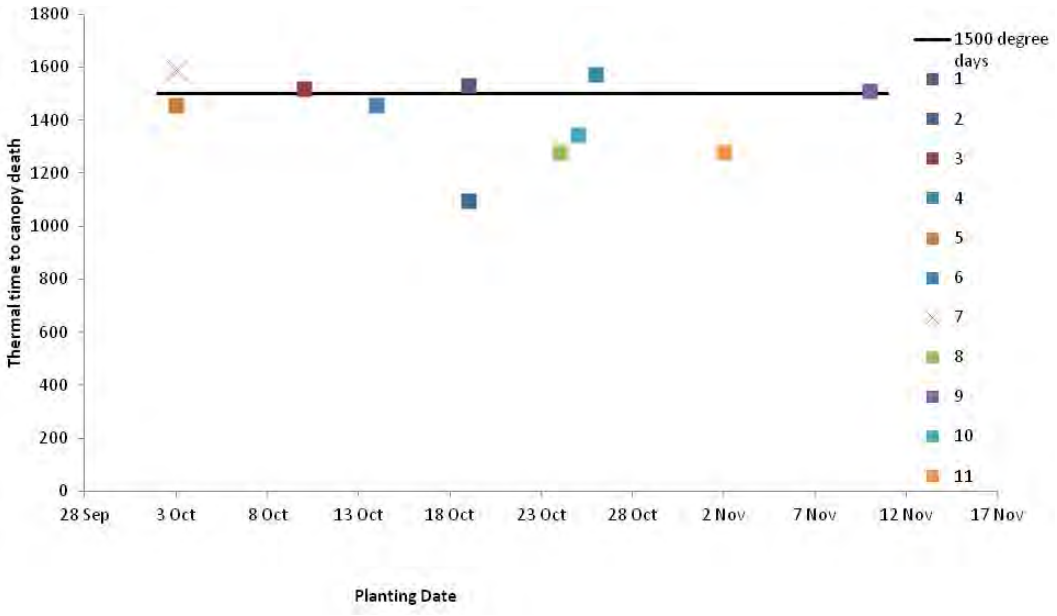


Figure 2. Thermal time to canopy death plotted against date of planting for each of the 11 observation crops. The black line represents the minimum thermal time needed from emergence to complete tuber bulking.

3.4 Plant population, seed placement and missing plants

Mean row width (an average of within- and between-bed width) for the 11 different crops ranged from 85 to 92 cm, plant spacing from 25 to 33 cm. Plant population, therefore, also ranged from a target population of 31,800 plants/ha to 45,400 plants/ha (Table 6).

Table 6. Row and plant spacings, target and estimated actual plant populations per hectare, percent population loss and plant loss per 10m of row for the 11 potato crops included in the 2012/13 study in this study.

Site No.	Mean row width (cm)	Plant spacing	Target popn plants/ha	Measured popn plants/ha	Percent popn loss	Mean plant loss/10m row
1	86	32	37000	34500	5.9	1.8
2	87	33	35200	32800	7.1	2.2
3	85	31	38700	37900	2.0	0.7
4	90	32	34400	33700	2.2	0.7
5	91	29	38700	36500	3.9	1.3
6	89	33	34700	31800	8.2	2.5
7	91	32	34200	33700	1.6	0.5
8	92	31	35200	34100	2.1	0.7
9	91	29	37800	36300	2.9	1.0
10	90	25	44300	44100	0.4	0.2
11	87	25	45400	43900	0.4	0.2

Regularity of plant spacing was measured in Crop 9 at senescence (Figure 3). While mean plant spacing was 29 cm, actual spacing ranged from 10 to 60 cm (Figure 4). About 60% of plants were spaced in the 25 to 35 cm range, 15% of plants were spaced at more than 35 cm and 25% were spaced at less than 25 cm. Often a gap larger than 40 cm was accompanied by a clump of closer-spaced plants (Figures 4 and 5), suggesting planting machinery malfunction.

When considering reasons for yield loss, plant spacing irregularity probably does not greatly contribute to this, compared to the contribution of disease, poor soil conditions and subsequent water stress. However, where these other conditions for growth are optimum, some extra yield and increased certainty of a more desirable final tuber size could be a positive result from improving planting accuracy.

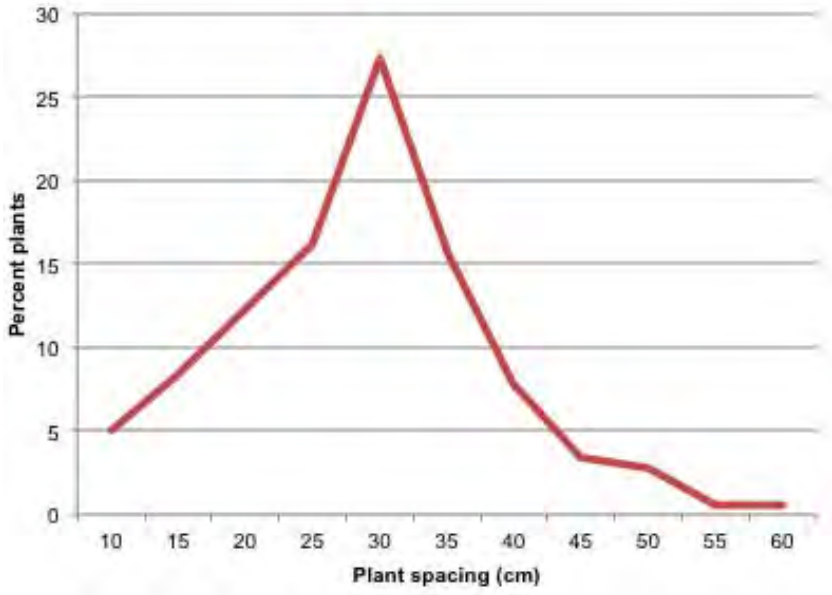


Figure 3. Frequency of potato plants in each of 11 spacing categories (5 cm increments) for Crop 9 (at senescence).

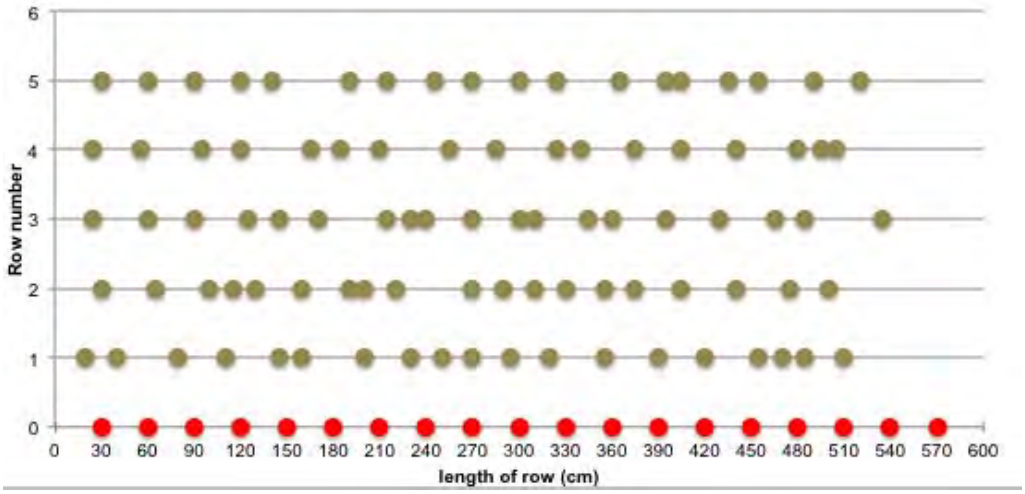


Figure 4. Two-dimensional matrix of the regularity zin plant spacing in five 5 m row lengths in Crop 9. The brown circles represent the actual plant positions and the red circles represent a perfect planting plan.

Figure 5. This planting pattern was seen in many of the observation crops; a "miss" (where the pen is located), then a group of tubers planted close together (to the left of the pen).

Plant counts in the 11 crops showed that missing plants may have reduced the intended plant population by between 0.4 and 8.2%. This is equivalent to 0.2–2.5 plants missing per 10 m of row (Table 6, Figure 6) and these gaps were soon hidden once the canopies grew. In theory gaps such as these can be compensated for by neighbouring plants which need to yield 50% more to make up for the lost plant or gap.

Ten such gaps in rows were identified after canopy senescence in the Crop 4. Here yield was individually measured in plants either side of a gap as well as measured for plants with normal spacing. Yield variability between the two types of plants was considerable but in general, plants next to gaps only yielded about 20% more than normally spaced plants. Often a gap is probably the result of a brief blockage when planting, and after this several plants can end up getting planted close together, also potentially constraining yield. Gaps where more than one plant is missing may significantly affect yield. In this way, the presence of gaps in the survey crops may have contributed to a yield loss of up to 3%.

Reasons observed for missing or late emerging plants with poor vigour:

1. Not planted;
2. Uneven planting leading to doubling;
3. Rot of the seed tuber prior to emergence (damaged during storage or planting);
4. Blind seed (i.e. absence of eyes);
5. Death of sprouts from Rhizoctonia stem canker prior to emergence;
6. Small seed piece too weak to emerge;
7. Seed piece that was stem or middle where sprouts were weakened by growing from cut edge;
8. Physiologically young/different seed piece taking longer to break dormancy;
9. Fungicide or other chemical damage (not seen, but the possibility discussed).

Figure 6. This crop looks evenly planted in the distance, but note gaps in the foreground.

3.5 Soil structural conditions and rooting vigour

All crops in the survey had rows formed into beds of two rows per bed. In some cases, fields were deep-ripped to disturb a root-impermeable zone and were also “de-stoned” (Figure 10), a method used to exclude stones and clods from the ridges before planting. Most fields were not considered to be stony (Table 9). Beds and rows were formed prior to planting into the ridges. Some growers used GPS-guidance systems cultivation for initial ground preparation and to lay out the beds. No post-planting cultivation was used in any of the surveyed crops.

Measurements showed variable planting layouts for the 11 crops (Table 7). Seed tuber planting depth (from top of ridge) ranged from 16 to 26 cm, within-bed row widths ranged from 73 to 88 cm and between-bed row widths ranged from 86 to 106 cm. Total bed width ranged from 169 to 183 cm. On average, between-bed row widths were greater than within-bed row widths. The most regular row spacing was for Crop 1 (86 cm across wheel tracks between beds and 85 cm within a bed), and the greatest difference was for Crop 9 with 106 cm across wheel tracks between beds and 77 cm within a bed (29 cm difference).

There was little root growth extending under the wheel furrow zone (between the two row beds) in Crop 9 (and most of the other crops surveyed), and this was the area where we often noted excess water draining. Other studies also report this (King 2011) and advise that wide bed planting systems (5 to 7 rows) can provide a method to improve water and nitrogen use efficiency by reducing run-off. Additionally, there is more scope to tailor plant population density for optimum tuber size.

Table 7. Seed tuber planting depths, distance between beds, distance within beds and total bed widths for each of the 11 potato crops included in this study.

Site No.	Average seed tuber depth (cm)	Ridge centres across wheel track (cm)	Ridge centres across bed (cm)	Difference between across wheel and across bed (cm)	Total bed width (cm)
1	21	86	85	1	171
2	20	91	83	8	174
3	17	97	73	24	169
4	24	94	86	8	180
5	16	96	85	11	181
6	20	91	86	5	177
7	20	96	86	10	182
8	15	100	83	17	183
9	22	106	77	29	183
10	20	91	88	3	179
11	26	90	84	6	174
Mean	20	94	85	11	178

Soil measurements also showed variation in the presence (and distance to) a root restriction layer, variation in relative root growth and vigour at crop maturity (Table 8) and variation to the ridge cross-sectional shape (Figure 7). The depth of the cultivated layers ranged from 22 to 40 cm, and these zones were generally free of root restriction through the life of the crops at all sites. However, half of the crops had a root restriction layer starting immediately at or below the cultivated layer, and two of these crops had strong visual evidence of ripping (cultivation methods not investigated in detail).

Table 8. Soil root restriction features, depth of cultivation layer (both measured from top of ridge) and root growth scores taken just before potato crop senescence. Root growth/vigour were scored for within ridge and under bed and wheel furrow, with 1 = very poor, 2 = poor, 3 = good, 4 = very good, 5 = excellent. The total score is a sum of the three individual scores, where 15 is the maximum.

				Root growth/vigour score			
Site No.	Cultivar	Start depth of the root restricting layer (cm)	Depth of cultivated layer (cm)	Within ridge	Under within-bed furrow	Under wheel track furrow	Total score (max = 15)
1	RB	24	30	3	3	2	8
2	RB	27	30	1	1	2	4
3	RB	20 (ripped)	27	2	2	2	6
4	RB	No evidence	30	4	2	2	8
5	Inn	No evidence	30	4	3	3	10
6	Inn	25, intermittent	28	4	4	2	10
7	RB	No evidence	25	5	5	4	14
8	RB	22	22	3	2	1	6
9	RB	30 (ripped)	27	4	5	2	11
10	Inn	No evidence	30	3	3	2	8
11	Inn	No evidence	40	5	5	3	13
Mean				3.5	3.2	2.3	

Most crops had good root growth within the ridges (the highest possible score was 5/5), with Crops 7 and 11 being the most vigorous. Crops 2 and 3 had the weakest roots in this zone with scores of 1 and 2, respectively. Those crops with the greatest root growth scores had little evidence of root restriction and/or had been ripped, although Crop 3 did not appear to benefit from ripping in the area measured, and this crop had a very shallow root restriction at 20 cm below the ridge top. Root growth/vigour was greatest within the ridges (mean vigour score = 3.5, good to very good), with roots getting progressively weaker at exploring under the within-bed furrows (mean score = 3.2, good), and weaker to almost non-existent under the wheel track furrows (mean score = 2.3, poor).

Relative root vigour can be illustrated using two crops with widely differing root vigour (Figures 7 and 8). Crop 8 had seed tubers planted at a depth of 15 cm, good root growth within the ridge zones, but had an impenetrable root pan at 23 cm, and no root growth extending both into the wheel tracks and within-bed furrow zones. In contrast, Crop 7 had seed tubers planted at a depth of 20 cm, excellent root growth within the ridge zone, and some root growth extending into both the wheel track and within-bed furrow zones and down into the subsoil.

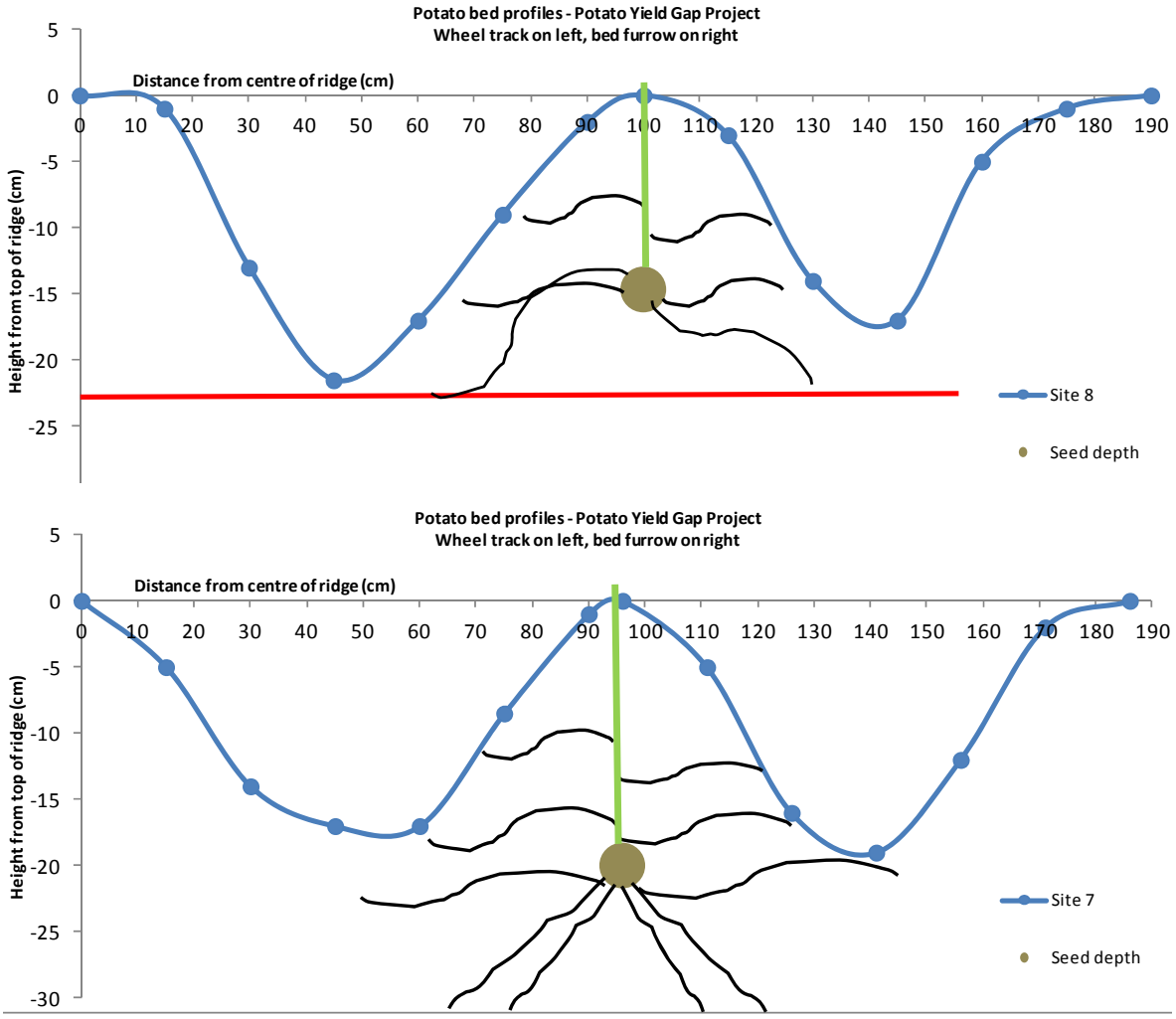


Figure 7. Potato bed profiles for Crop 8 (top) and Crop 7 (bottom), wheel track on left, bed furrow on right. On the vertical axis, zero is the top centre of one ridge. Seed tuber position is denoted by the brown circle, the green vertical line represents the underground stems. The black wavy lines represent root vigour, direction and extent. Two root lines denotes very poor root growth, 4 root lines poor root growth, 6 root lines good root growth, 8 root lines very good root growth and 10 root lines excellent root growth. The solid red line denotes a compaction zone. No red line indicates little or no root restriction was measured. Potato bed profiles for the other 9 crops surveyed are outlined in Appendix VI.

Figure 8. Photos of the root vigour of the potato plants from two crops included in this study. Plants in Crop 7 (left) had the most vigorous roots with a score of 14 out of a possible 15, and plants from Crop 8 had some of the least vigorous roots with a score of 6.

Measurements of penetration resistance in the within-bed furrow and wheel track furrow confirmed that at some sites, soil density was too great for root growth. Generally potato root penetration slows to half of its potential rate once resistance gets above 1.5 MPa, and to one-quarter of this rate at 2.4 MPa (Stalham et al. 2005). In the within-bed furrow, average penetration resistance across the crops was 1 MPa (range 0.4 to 4.7) and was 1.8 MPa in the wheel track furrow (range 0.8 to 4.8 MPa). Crop 3 had the most severe compaction levels, averaging 3.1 MPa in the within-bed furrow and 3.9 in the wheel track furrow. All other crops were under the root restriction threshold in the within-bed furrow, but penetration resistance was the same as or greater than 2 Mpa in the wheel track furrow for Crop 6 (2 MPa), and Crop 10 (4.8 MPa).

Root growth and vigour was measured in plants immediately adjacent to the final harvest area in the observation plots and was positively related to final tuber yield (Figure 9). This shows that strong root vigour is needed for a high yield. Crops 6, 7 and 9 had a root vigour score of 10 or more (Table 8) and had correspondingly higher yields than Crops 2, 4, 5 and 8, which had scores of less than 10. Where yields were reduced, we found that root vigour was negatively affected by soil compaction, and/or RSC and Spongospora infection. However, other factors that were not quantified in this survey may also be limiting yield, such as inadequate irrigation management or poor seed quality.

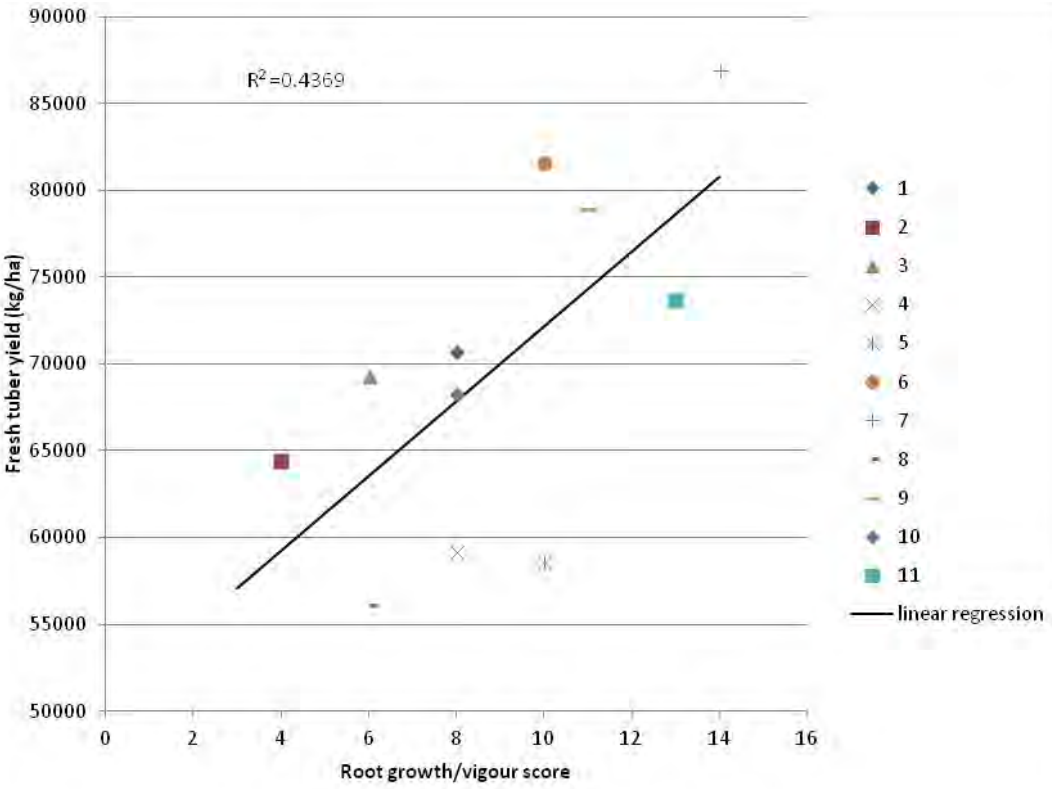


Figure 9. Relationship between the sums of root growth and vigour scores and final fresh tuber yields from the observation plots (kg/ha) across the 11 potato crops included in this study

Soil types are shown in Table 9. Most crops were planted in moderately deep, to deep silt loams with few stones, and soil textures were described as either a silt loam or a loamy silt, which have a lower percentage of clay. Theoretically, these soils should not limit yield.

Table 9. Soil types for the 11 potato crops included in this study.

Site No.	Location	Soil type of whole paddock	Consistency of paddock soil type
1	Chertsey	Chertsey moderately deep silt loam	Very consistent
2	Chertsey	Chertsey moderately deep silt loam	Very consistent
3	Chertsey	Chertsey moderately deep silt loam	Very consistent
4	Rakaia	Templeton deep silt loam and fine sandy loam	Reasonably consistent
5	Rakaia	Hatfield moderately deep silt loam	Very consistent
6	Rakaia	Templeton moderately deep silt loam	Very consistent
7	Mayfield	Mostly Eyre stony silt, small area Templeton mod deep on sandy loam	Reasonably consistent
8	Temuka	Templeton deep silt loam on sandy loam	Reasonably consistent
9	Temuka	Templeton deep silt loam on sandy loam	Very consistent
10	Temuka	Mix of Pahau deep silt, Darnley shallow silt, Darnley stony silt, Templeton deep silt and sand	Very patchy
11	Temuka	Mostly Paparua stony deep sandy loam	Consistent either side of terrace change

Soil aggregate size distribution and aggregate stability

These two indicators of soil quality were measured in this study to help quantify the soil state with respect to its likelihood of becoming structurally degraded by cultivation and wheel traffic. The structural quality of the soil is particularly important for potatoes as they are susceptible to water stress, especially as soils with poor structure tend to hold and transmit less water (McLaren & Cameron 1996) and also restrict root and tuber growth.

Compared with pre-plant ground preparation for other annual arable crops such as cereals, cultivation before planting potatoes is more intensive. Fine, loose soil is preferred for even tuber placement at planting and similarly at harvest, so that clods are not caught up in the harvesting process. After initial cultivation to incorporate previous crop residue, two-row beds are formed and these beds are then reworked to remove coarse organic material, stones and clods. Crop management during growth can cause further soil damage and includes up to 10 to 15 passes from spray and fertiliser vehicles, plus multiple passes by irrigators, although all these passes are usually permanently fixed to pre-set tracks.

Figure 10. A de-stoning machine creating a fine two row seed bed in Crop 4. Coarse organic material, clods and stones are placed in a furrow between beds.

Ideal aggregate size in the topsoil of a New Zealand soil is between 0.85 and 9.5 mm diameter (Beare et al. 2009) Typical New Zealand cropping soils have between 50 and 70% of aggregates in this size range. Another 15% of the soil comprises of aggregates of less than 0.85 mm (at risk of wind or water erosion) and the remaining 20–30% comprises of larger aggregates greater than 9.5 mm in diameter. These aggregates are often dense and restrict root penetration, thereby restricting the volume of soil from which roots can access water and nutrients.

The aggregate size distribution in the 11 surveyed potato crops fell within the typical ranges described above (Figure 11), although there was a tendency for them to have greater proportions of aggregates in the potentially erodible fraction (less than 0.85 mm diameter). For these crops, aggregates in the 0.85 - 9.5 mm size (ideal) ranged from 50 to 60% of the soils, another 15–35% of the aggregates were in the erodible fraction (less than 0.85 mm) and 15–30% of the soil had an aggregate size were greater than 9.5 mm (dense fraction).

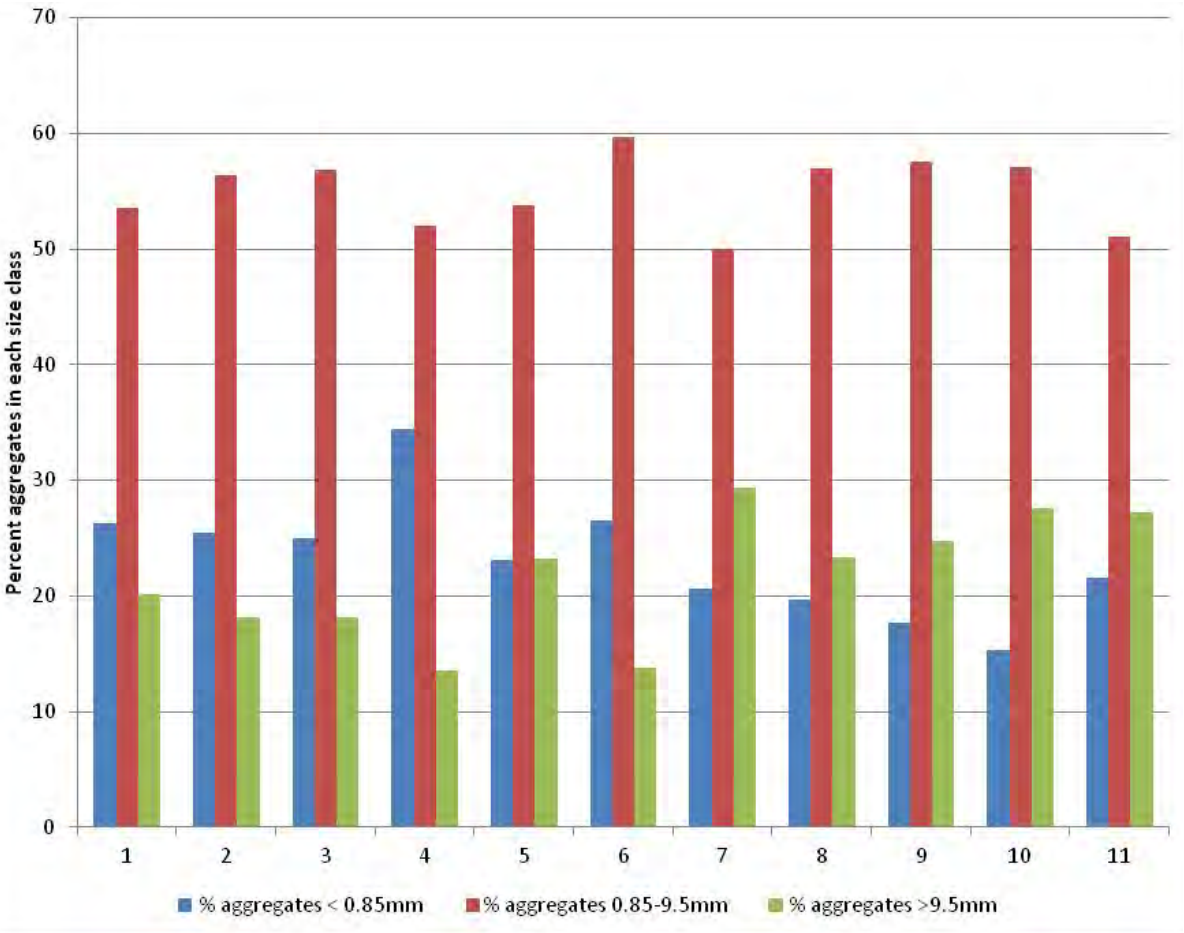


Figure 11. Percent of soil aggregates in each of three size classes (less than 0.85mm diameter, 0.85–9.5 mm and over 9.5 mm diameter) for the 11 potato crops included in this study.

Aggregate stability can range between 0.25 and 3.0 mm mean weight diameter (MWD). The structural stability of cropping soils typically ranges from 1.2 to 2.0 mm MWD, where a greater value indicates greater structural stability (stability for soils under permanent pasture typically ranges from 2.2 to 2.5 mm MWD) (Beare et al. 2009). Soils with less structural stability typically produce low crop yields. The target range for stability values is reported as >1.5 MWD, (Beare, et al. 2003; Beare & Tregurtha, 2004). In the 11 observation crops, MWD ranged from 0.6 to 2.2 mm (Figure 12). All but four crops had stabilities below this target range. The least MWD values were found in Crops 9, 10 and 11, while the greatest values were in Crops 4 and 6.

It is not known to what extent the current soil physical state in these crops affected or limited yield. However, we want to highlight the fact that current cultivation practices break down soil structure to a greater extent than they did a decade ago. This, coupled with high intensity irrigation, could be increasing the risk of waterlogging, runoff, nitrogen leaching and water wastage. It could also be creating more ideal conditions for soil borne diseases to flourish in. It is important that potatoes are included in a rotation with fine rooted crops (e.g. grass) as these return organic matter to the soil and help to restore structure.

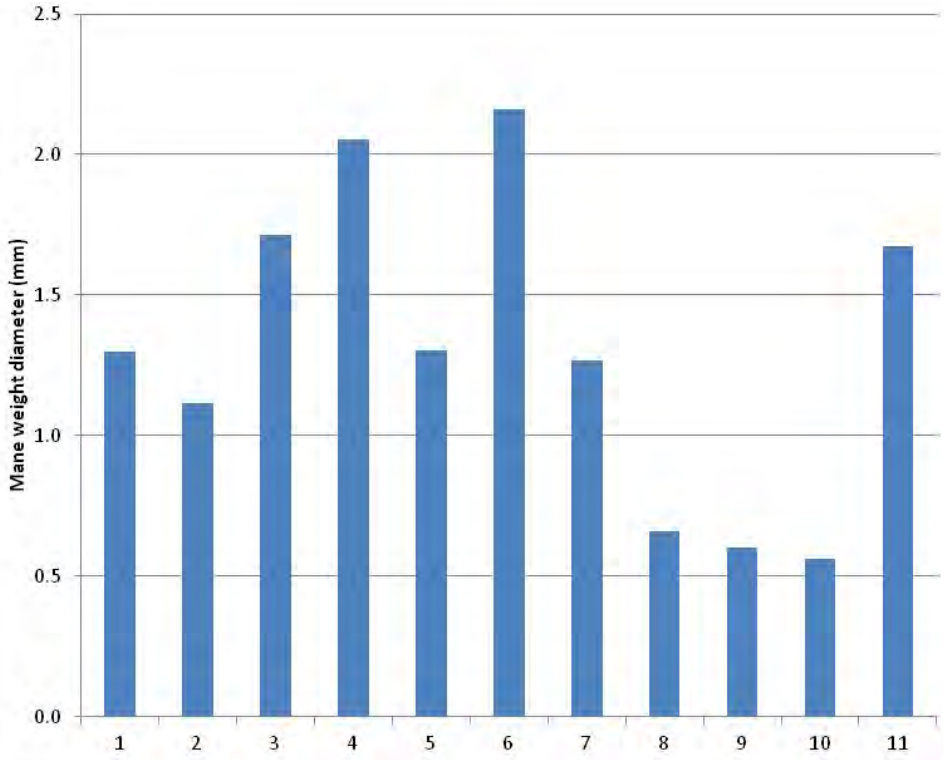


Figure 12. Aggregate stability (mean weight diameter (mm)) of the soils under the 11 potato crops included in this study. A greater value equates to a soil with greater aggregate stability.

3.6 Pathogens detected in the soil at planting and during crop growth

The SARDI tests routinely identify DNA of the following potato pathogens (with the diseases they cause in parentheses): *Spongospora subterranea* (powdery scab and root galls), *Rhizoctonia solani* AG2.1, and AG3 (RSC and black scurf), *Verticillium dahliae* (early dying), *Meloidogyne fallax* and *M. hapla* (root knot nematodes), *Streptomyces scabies* (common scab), and *Colletotrichum coccodes* (black dot).

For Crops 4, 9, 10 and 11, soil samples were taken before planting from the intended fertiliser plots, while in all the other crops, the samples were taken after planting. The results from tests showed that three pathogens were not present in the soil from any of the crops at planting, and that the occurrence and levels of others varied between the crops (Figures 13 & 14).

- There were very low levels of pathogen DNA detected for *R. solani* AG3 and root knot nematodes.
- *Rhizoctonia solani* AG2.1 was present in most fields (Crops 1, 3, 4, 5, 6, 7 and 10). Moreover, the presence of this pathogen was not associated with previous cropping history.
- *Spongospora subterranea* was detected in soil from three potato fields, all of which had previous cropping histories of potatoes (Crops, 2, 3 and 10). During crop growth, Spongospora root galls were noted in six of the crops. Powdery scab on harvested tubers was only noted for one crop, where one of the fertilizer trials was carried out. This indicates the known lack of predictive ability of the DNA soil test and also the poor relationships between incidence and severity of root galls and tuber powdery scab.

- Streptomyces scabies was detected in soil from four crops (Crops 4, 6, 10, and 11). Of these fields, two had previous cropping histories including potatoes, but the field with the greatest amount of *S. scabies* DNA had not previously grown potatoes.
- Colletotrichum coccodes was detected in all the fields with a previous cropping histories of potatoes (Crops 2, 3, 5, 6, 7, 9, 10), and was detected at low levels in two fields without potato cropping histories (Crops 5, 7).
- *Verticillium dahliae* was detected at four of the sites with a previously cropping histories including potatoes (Crops 2, 3, 9, and 10), and was not detected in four of the five new ground sites (Crops 1, 5, 7 and 11).
- None of the pathogens assayed were detected in the single plot sample collected at site 4 (4*, after planting). However, low amounts of *R. solani* (AG-2.1) and S. scabies DNA were detected at the same site from the multiple fertiliser plot samplings (before planting).
- All of the assayed pathogens were detected in only one field (Crop 10), and none of the paddocks were completely free of the soil-borne pathogens assayed.
- No late blight was observed in any of the crops. This was probably resulted from the very frequent applications to all of the crops of fungicides active against this disease, and also to the warm dry conditions predominating during 2012–13.
- The frequent fungicide applications probably gave good control of early blight. However, in some of the crops, towards the end of the growing season, early blight was noted. This was probably due to cessation of fungicide applications late in the season.

In general, pathogen DNA levels were greater in fields with previous cropping histories which included potatoes.

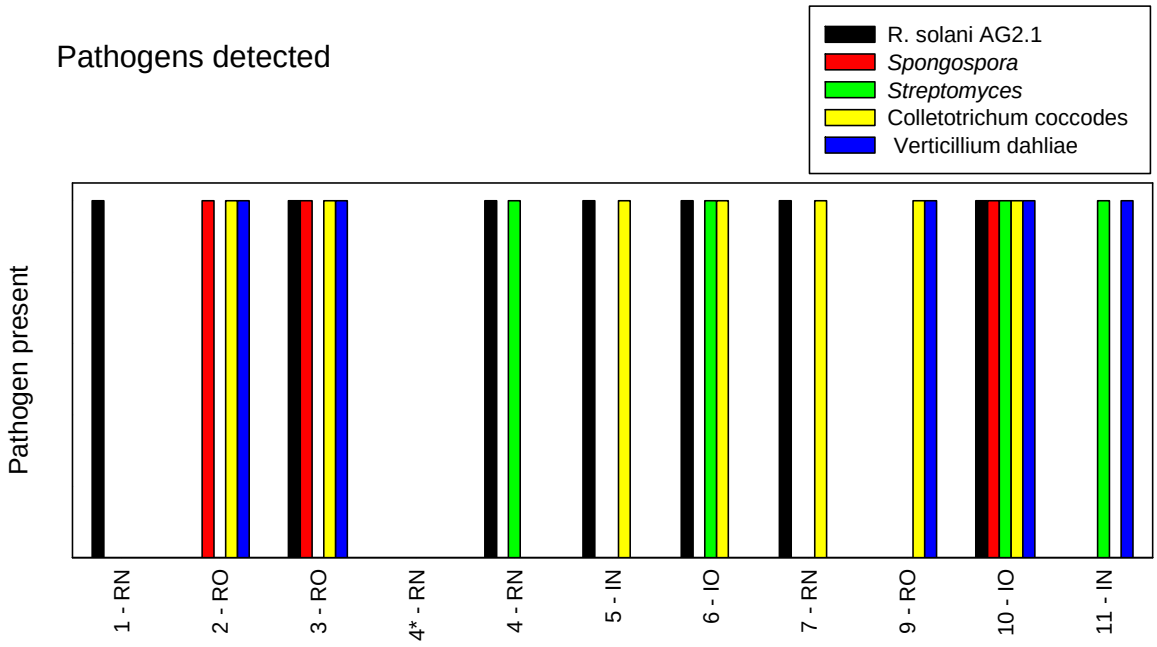


Figure 13. The presence (coloured bars) or absence (no bars) of DNA of five pathogens found in the soil at planting for 10 of the 11 crops. On the horizontal axis, the number denotes Crops 1-11 (8 has missing data), R and I denote 'Russet Burbank' and 'Innovator', N and O denote new or old ground.

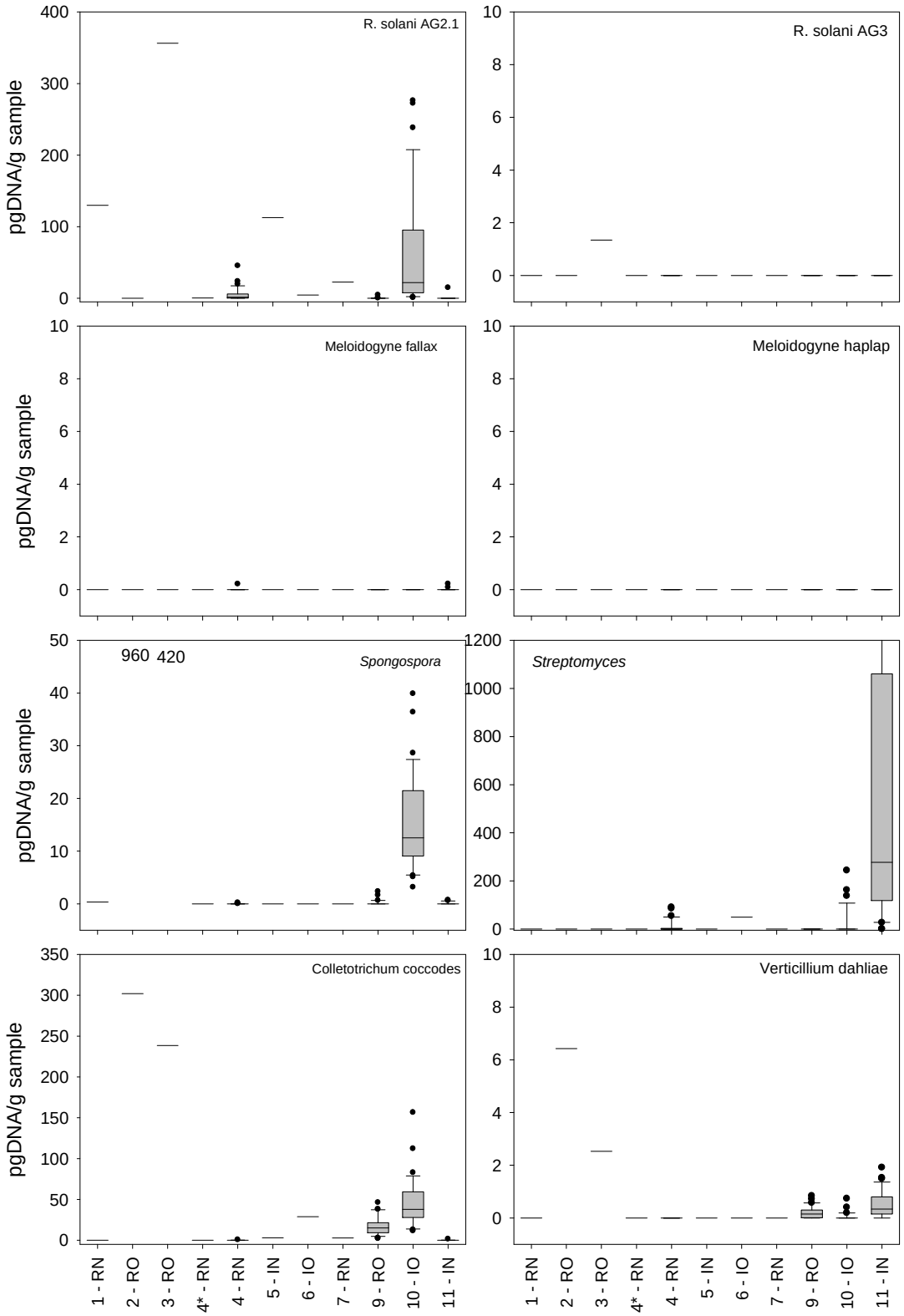
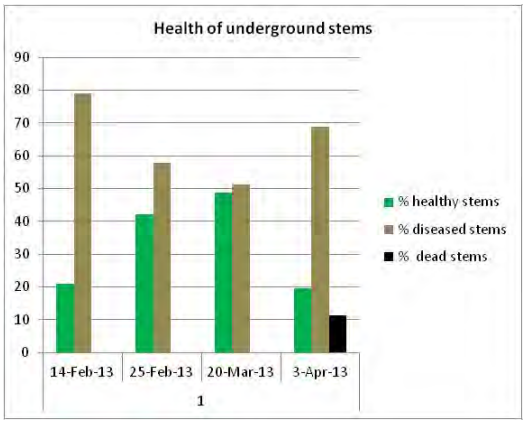
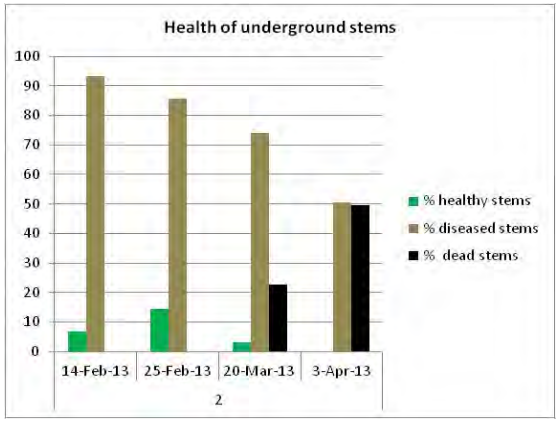


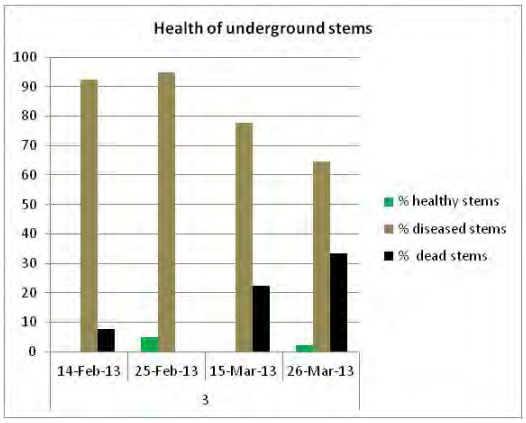
Figure 14. The amount of DNA (picogams per gram soil) of five pathogens found in the soil at planting, taken from 11 potato fields. The horizontal dash represents crops where a single assay was carried out. The box plots represent crops where multiple soil samples were assessed. For the box plots, the main part of the box represents the spread of values in the middle 50%, the line dissecting the box is the median value, and the upper and lower whiskers represent those values outside the middle 50%. The dots are individual occurrences of a pathogen that are outliers. For Crops 1 and 2, the *Spongospora* levels were off the scale and are represented by written values.

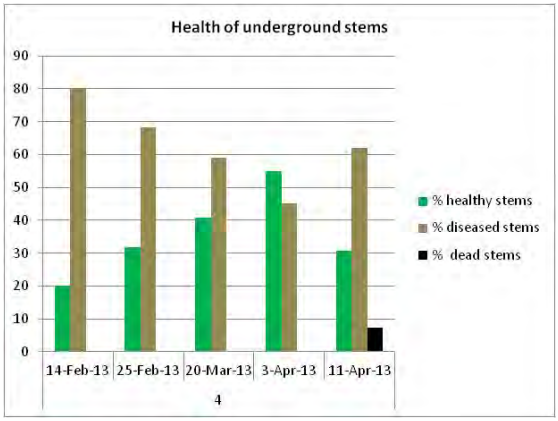
3.7 Rhizoctonia stem canker (RSC)

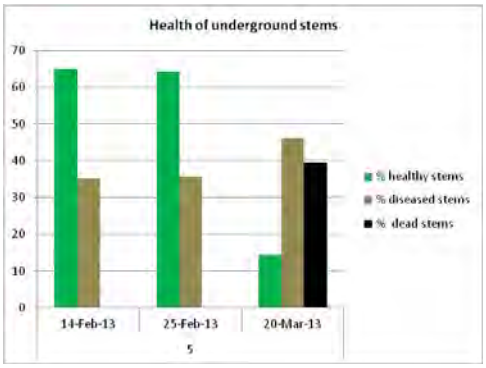
This disease was noted on the underground stems in all the surveyed crops from approximately the end of December 2012 (Figure 15). From mid-February onwards, presence/absence of this disease on underground stems was measured at each plant harvest. Stems were divided into three categories and counted: namely, free of symptoms, diseased or dead. Crops without previous cropping histories of potatoes (Crops 1, 4, 5, 7 and 11) had greater proportions of healthy stems persisting through the latter part of crop growth compared with the crops where potatoes had been previously grown (Crops 2, 3, 6, 8, 9 and 10; Figure 15). Stem death (and therefore plant death) was accelerated in the crops which had severe RSC early in crop growth.

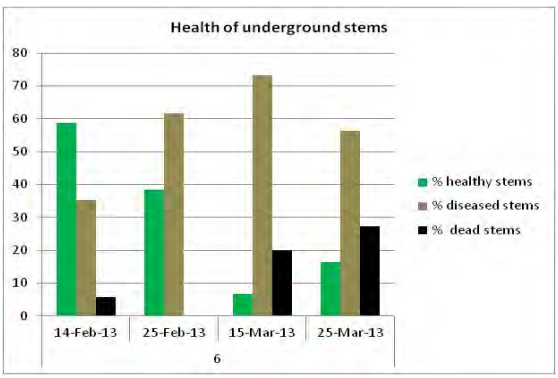












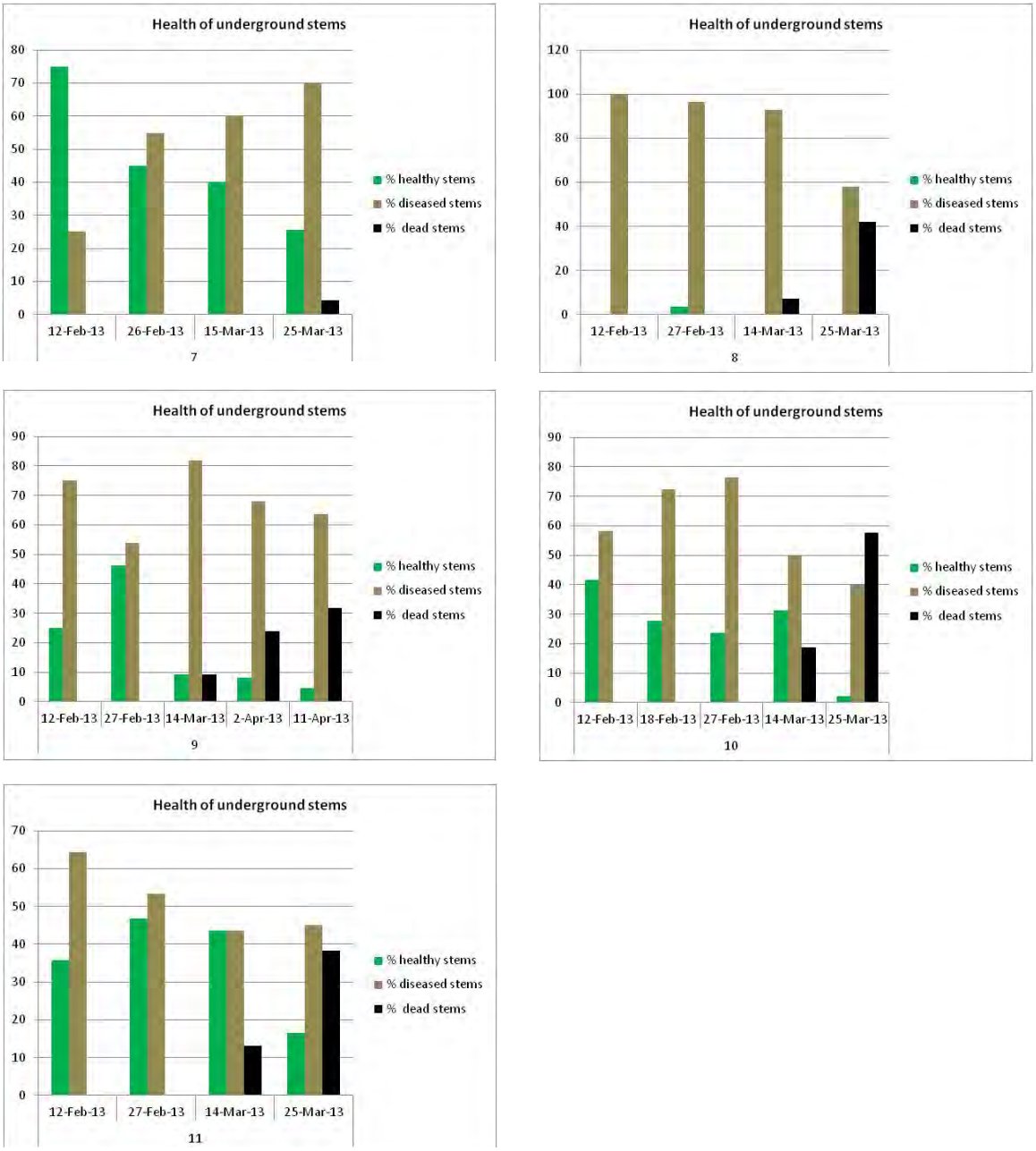


Figure 15. Incidence (%) of underground stems affected by Rhizoctonia stem canker (from four- or eight-plant samples) for each of 11 crops, from mid-February to crop death.

Rhizoctonia stem canker (RSC) is a prevalent disease of potato throughout the world and limits growth from the cankers that develop on sprouts, underground stems and stolons. An additional phase of the disease (black scurf) can also reduce tuber quality by the formation of black resting bodies of the fungus (sclerotia) on the surface of the tubers. Aerial tubers may also be formed. These diseases can also reduce or deform tubers. Symptoms begin as brown sunken lesions on stems just below the soil line which eventually develop to girdle and kill the stems ("nipping-off"). Leaf symptoms of RSC include upward rolling of the margins caused by restricted translocation of water. Most of the *R. Solani* types that are pathogenic to potato are AG3,

however the inoculum is highly persistent in the soil. Tuber-borne inoculum is also of paramount importance to the initiation of the disease cycle and may be more important than the indigenous soil population. The effects of RSC on yield are highly variable but generally significant and range between decreased tuber yields of 15% (Read et al., 1989) to 34% (Hide et al., 1985). However, the effect of RSC in a particular location is likely to depend upon a range of factors including the proportion of AG types present within the field, cultivar susceptibility, seed health, planting depth, seed treatment and cropping rotation which will influence inoculum density.

Rhizoctonia stem canker was found in all crops. Plants that were less severely affected by disease (RSC and in some cases, *S. Subterranea*), and in the absence of soil compaction, yielded to potential. However, in other paddocks where plants were affected by both diseases and the soil was compacted, yield was reduced by between 52 and 80 percent.

3.8 Virus incidence

The ELISA tests of leaf samples from the different crops yielded very low incidence of *Potato virus X* (PVX) in three crops, *Potato virus Y* (PVY) in two crops, *Potato virus A* (PVA) in two crops, and *Potato leafroll virus* (PLRV) in four crops (Table 10). Eight of the 11 crops had *Potato virus M* (PVM) infections ranging from very slight incidence to all assayed plants positive. *Potato virus S* (PVS) was found in all leaf samples from all of the crops.

Table 10. Estimated incidence (%) of different viruses in samples from 11 Mid- and South Canterbury potato crops, sampled in February 2013.

Site No.	Cultivar	*PVX	PVY	PVS	PVM	PVA	PLRV
1	‘Russet Burbank’		1	100	7		1
2	‘Russet Burbank’			100	1		
5	‘Innovator’		2.5	100	7		
4	‘Russet Burbank’			100			
3	‘Russet Burbank’			100	100		1
11	‘Innovator’	1		100	21		
10	‘Innovator’			100	21		1
9	‘Russet Burbank’			100	21	1	
6	‘Innovator’	1		100	9		
8	‘Russet Burbank’			100		2	1
7	‘Russet Burbank’	1		100			

*Potato virus X (PVX), Potato virus Y (PVY), Potato virus S (PVS), Potato virus M (PVM), Potato virus A (PVA), Potato leafroll virus (PLRV)

Potato virus S (Genus Carlavirus; PVS) is one of the most common potato viruses found world-wide (Brunt & Loebenstein, 2001). The majority of PVS infections of potato are symptomless, but nonspecific symptoms have been described, including chlorotic mottling of the leaves and rugosity on the lower leaf surface (Lambert et al., 2012). The virus is believed to be transmitted in a non-persistent manner by a range of aphid species, including Myzus persicae, Rhopalosiphum padi, Aphis fabae, and A. nasturtii. However, mechanical transmission and vegetative propagation are also considered important for virus spread (Kahlil & Shalla, 1982). PVS has been found to be highly prevalent within Canterbury potato crops at late stages of crop growth, because seed producers and growers have found this virus difficult to control (Fletcher, 2012). International studies indicated that yield losses of between 10 and 15% have been attributed to PVS, and this virus in combination with other viruses may have synergistic yield reduction effects (Lambert et al., 2012). Several strains of PVS have also been described, some of which may be more damaging to yield than others in specific varieties. The prevalence and incidence of Potato virus M (Genus Carlavirus; PVM) in NZ potato crops have also been noted to have been increasing recently. This virus has been associated with paracrinkle disease, but its effect on yield alone or synergistically with other viruses is uncertain. Potato virus X (Genus Potexvirus; PVX) is transmitted mechanically and mild symptoms have been described in potato from single infections. Both PVS and PVX are likely to be transmitted through seed cutting, by contact between plants within the field, or from machinery movement through the crop. The host range of PVS includes Chenopodium quinoa and C. amaranticolor, while PVX has a limited host range constrained to Solanaceous species such as Solanum nigrum, S. tuberosum (potato), Nicotiana spp., Petunia hybrida, Datura stramonium, Cyphomandra betacea and Lycopersicon esculentum (Brunt & Loebenstein, 2001). Potato virus A and Potato virus Y both belong to the Genus Potyvirus and are therefore disseminated by aphids, mechanically and vegetatively. There are three strains of PVY in New Zealand: PVYo, PVYN, and PVYC. PVYN is a strain that has been associated with tuber necrosis and therefore significant reductions in tuber yield and quality (Fomitcheva et al., 2009). Potato leafroll virus (Genus Luteovirus; PLRV) is a phloem-limited virus and transmitted by aphids and through vegetative propagation.

The low incidences of PVX, PVY, PVA and PLRV in the crops sampled in this survey were to be expected, particularly if 4-5th generation, certified seed tubers from well-managed seed production systems were used to establish the crops

3.9 Crop history

Cropping history of the 11 crops varied considerably in terms of crop rotation (Table 11). Six of 11 crops (2, 3, 6, 8, 9 and 10) had previously been planted in potatoes once within the last 10 years (‘old’ ground), with the exception of Crop 2 which had potatoes in both 2003 and 2008. Growing potatoes in the same ground within 10 years is known to increase the probability of inoculum levels being above those capable of causing damage. Also, paddocks previously planted with wheat and clover could be carrying over higher inoculums levels that those paddocks that were in pasture.

Crops 1, 6 & 7 had more pasture in the previous 10 years and the onset of RSC was later than the other crops. Also, those crops that were in pasture the year before (Crops 4 & 9) also had delayed onset of RSC. Crop 2 and Crop 6 were planted within 5 days of one another. Crop 2, with a long cropping history which included potatoes and no grass in its rotation, showed the first signs of RSC on 10 December. In contrast, Crop 6, with seven years of pasture between potato crops, did not show sign of RSC until 31 January. Crops 6 and 7 had higher yields than the others, and also a later onset of RSC infection.

Colletotrichum coccodes was found in all 5 ‘old’ ground sites and *Verticillium dahliae* was found 4 out 5 ‘old’ ground sites (Crops 2, 3, 9, 10), whereas ‘new’ ground crops (with the exception of Crop 11) did not have these pathogens.

In contrast, there was no apparent relationship between the levels of *R. solani* AG2, *S. subterranea* and *S. scabies* which were dependent upon cropping history and final disease intensity. For example *R. solani* AG2 was detected in the soil sample from Crop 2 (‘old’ ground), but there was high incidence of stems affected by RSC in this crop. Conversely, Crop 1 (‘new’ ground) had high levels of DNA detected in the soil but had lower incidence of diseased stems. Sampling limitations may have been problematic at paddocks where soil was taken from one small area. However, further validation work is being conducted by the Tasmanian Institute of Agriculture and the Australian Potato Nematology project to determine critical thresholds for the soil DNA levels and subsequent disease risk (F. S. Hay, pers. comm). There was shown to be a wide range of pathogen levels across a fertiliser trial in Crop 10, where 36 plots (nine samples bulked from each 8 m × 10 m plot) were sampled individually. For example, across the trial area the levels of *Rhizoctonia solani* AG2 ranged from 0 to 300 pg DNA/g.

A significant source of inoculum for many of the soil-borne pathogens and other diseases caused by fungi, bacteria, viruses and viroids may also be infected and/or asymptomatic seed tubers. Seed tuber health is therefore a critical control point for managing disease incidence and severity and for minimizing crop loss.

While not confirmed by the pathogen DNA results, higher incidence of RSC was found in sites with a cropping histories of potatoes. This suggests that soil-borne indigenous populations of other anastomosis groups may also be important determinants of final disease levels (Figure 14).

‘New’ ground sites (Crops 1, 4, 5, 7 and 11) varied in their balance of depletive and restorative crops in the previous crop histories. Depletive crops are those with a high harvest index that also often have their residues removed (e.g. wheat). Restorative crops are those which return a proportion of their residues to the soil, can be nitrogen fixing or are perennial crops, usually pastures. Only four of the 11 sites grew pasture for a reasonable length of time (at least 2–3 years) before potatoes. Crop 6 was in pasture the longest out all the sites (7 years), followed by Crop 1 (6 years), Crop 7 (5 years) and Crop 10 (4 years of fescue production). The incorporation of restorative crops is essential in order to maximise crop production. Legumes, such as white clover for seed production and peas, restore nitrogen to the soil. However, in many cases grain legumes such as peas will fix less nitrogen than what is removed as peas seed. The incorporation of crop residues helps to restore organic matter to the system and subsequently increase soil structure. The continual planting of depletive crops such as cereals and onions must be balanced by restorative crops in order to maintain production levels for future crops. Continual cropping was conducted prior to Crops 2, 3, 8, and 9, and if continued, could lead to a decline in crop production.

Table 11. Crop history for the last 10 years for each potato crop included in this study, and date when RSC was first noted in the crops (red highlight is earliest detection on underground stems, green highlight the latest detection.)

Site No.	Cultivar	History	RSC first noted	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
1	'Russet Burbank'	New	4 Jan	Potatoes	Onions	Brassica Seed	Annual RG Seed	Wheat	Pasture	Pasture	Pasture	Pasture	Pasture	Pasture
2	'Russet Burbank'	Old	10 Dec	Potatoes	Onions	Brassica Seed	Annual RG Seed	Wheat	Potatoes	Onions	Onions	Onions	Wheat	Potatoes
3	'Russet Burbank'	Old	13 Nov	Potatoes	Wheat	Clover	Wheat	Peas	Wheat	Potatoes				
4	'Russet Burbank'	New	4 Jan	Potatoes	Grass	White Clover	White Clover	Wheat	Grass	Barley	Barley	Barley	Grass	Grass
5	'Innovator'	New	21 Dec	Potatoes	Wheat	Clover	Barley	Wheat	Clover	Wheat	Peas	Wheat	Clover	Wheat
6	'Innovator'	Old	31 Jan	Potatoes	Pasture	Pasture	Pasture	Pasture	Pasture	Pasture	Pasture	Wheat	Potatoes	Wheat
7	'Russet Burbank'	New	14 Jan	Potatoes	Oats	Wheat	Maize	Kale	Pasture	Pasture	Pasture	Pasture	Pasture	Pasture
8	'Russet Burbank'	Old	31 Dec	Potatoes	Wheat	Radish	Ryegrass	Barley	Wheat	Potatoes	Ryegrass	Barley	Peas	Wheat
9	'Russet Burbank'	Old	15 Jan	Potatoes	Ryegrass	Barley	Maize	Barley	Wheat	Peas	Wheat	Potatoes	Ryegrass	Ryegrass
10	'Innovator'	Old	31 Dec	Potatoes	Wheat	Onions	Peas	Fescue	Fescue	Fescue	Fescue	Wheat	Potatoes	Barley
11	'Innovator'	New	24 Dec	Potatoes	Maize	Pasture/Ryecorn, Wheat	Wheat	Wheat	Pasture	Wheat	Wheat			

3.10 Fertiliser management

Total nitrogen application varied between sites with the lowest rate of 289 kg N/ha for Crop 5 and highest rate of 374 kg N/ha for Crop 3 (Table 12; Figure 16). Nitrogen fertiliser was primarily in the form of DAP applied as a base fertiliser and down the spout (banded), with urea and/or CAN used as later side dressings. Some growers (Crops 1, 2, 5 and 8) applied foliar sprays of urea (~ 10–25 kg N/ha) in the latter stages of crop growth.

Phosphorus application rates ranged from 69 kg P/ha for Crop 4 to 150 kg P/ha for Crop 8, primarily being received via DAP, Super and Triple Super applications.

Potassium application varied considerably, ranging from 188 kg K/ha for Crop 4 to 357 kg K/ha for Crop 10, with the bulk of the potassium coming from potassium sulphate and sulphate of potash (same formulation).

Sulphur fertiliser application ranged from 90 kg S/ha for Crops 1 and 2 to 215 kg S/ha for Crop 10, mainly in the form of potassium sulphate and sulphate of potash.

Magnesium was not applied at Crops 1 or 2 and highest application of 141 kg/ha was applied at Crop 8.

Calcium application cannot be compared between sites accurately, as lime applications were only provided for some sites.

Other micronutrients such as; copper, zinc and boron were applied in low amounts (0–13 kg/ha), with the exception of Crop 4 where 44 kg/ha of zinc was applied in the form of zinc sulphate.

We received an incomplete data set from basic soil tests which are normally taken before any fertiliser is applied before planting. However, a detailed analysis of results from fertiliser trials conducted in four of the crops surveyed show that these crops were not nutrient-limited (Michel et al, 2013). From this we have assumed that a nutrient response would also be unlikely in the other seven crops surveyed.

Table 12. Nutrients applied to the 11 potato crops included in this study.

	Nutrient Applied (kg/ha)								
Site No.	N	P	K	S	Mg	Ca	Cu	Zn	B
1	367	125	277	90	0	18	1	13	3
2	367	125	277	90	0	18	1	13	3
3	374	113	307	137	36	275	0	0	0
4	305	69	188	158	45	16	1	44	0
5	289	133	320	208	93	336	1	3	2
6	334	135	316	193	81	18	1	4	2
7	297	135	323	157	30	18	0	0	0
8	328	150	340	180	141	18	0	0	0
9	336	135	273	150	23	18	1	4	2
10	325	125	357	215	46	40	3	4	2
11	308	116	280	156	91	76	0	0	0
mean	330	124	296	157	53	77	1	8	1
Standard deviation	28	20	43	40	42	110	1	12	1

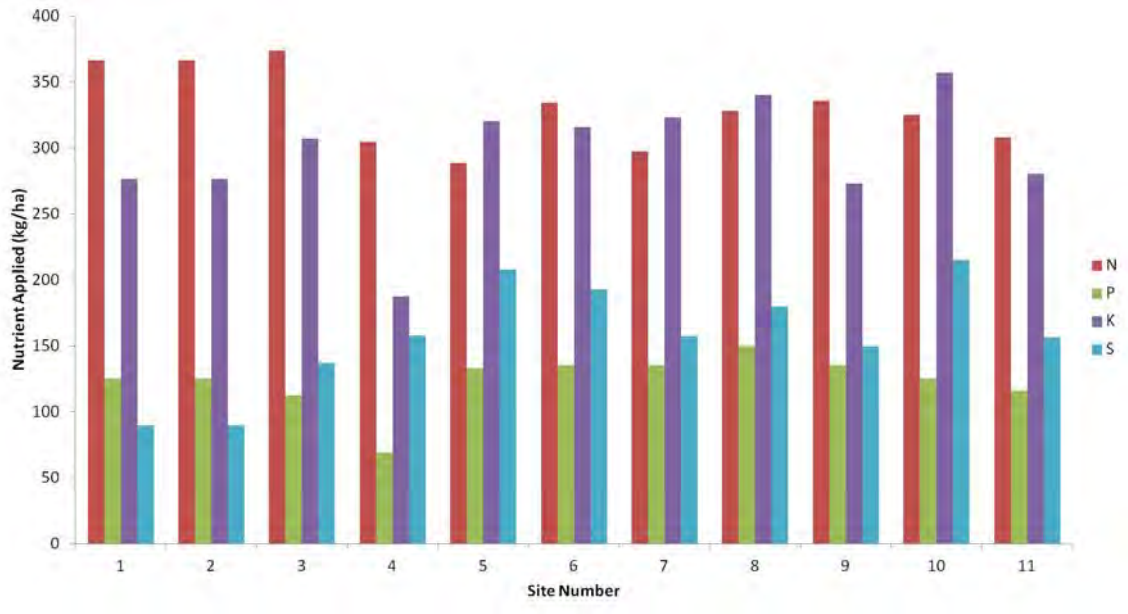


Figure 16. Amounts of nitrogen (N), phosphorous (P), potassium (K) and sulphur (S) applied to the 11 observation crops.

3.11 Irrigation management

Irrigation records were difficult to obtain, were reported too late to be included in this report. Some application amounts were only estimates. Analysis was not worthwhile for this low-quality, incomplete data set. There was visual evidence that in some crops, run-off and/or drainage from high intensity irrigation could be lowering water and nitrogen use efficiency and increasing the chance of leaching. Additionally, continually wet soils may have provided an environment for increased disease severity.

Irrigation was missed at edges and corners of some crops. Two crops were measured and yield in these areas were reduced by 13 and 28 percent.

Table 13. Monthly irrigation amounts applied to the 11 potato crops included in this study.

	Irrigation total per month (mm)					
Crop	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Total
1	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
3	N/A	N/A	N/A	N/A	N/A	N/A
4	25	50	96	96	57	324
5	0	85	126	50	0	261
6	0	110	160	120	30	420
7	15	130	150	160	20	475
8	0	50	75	75	25	225
9	0	30	65	30	33	158
10	N/A	N/A	N/A	N/A	N/A	N/A
11	N/A	N/A	N/A	N/A	N/A	N/A

3.12 Pest and disease management

Summaries of applications of fungicides, insecticides and other preparations applied to the 11 potato crops during the 2012–13 season are presented in the Appendices.

The most common wetting agent used in association with the pesticides was Actiwett (linear alcohol ethoxylate). Other wetting agents used included LI 700 (phophatidylcholine + methylacetic acid + alkyl polyoxylethylene ether), Du-wett (organo-silicone polymer) and Bond Xtra (organosilicone/latex polymer blend).

Across the 11 crops the average number of fungicide applications was 10 (range 7 to 13). Almost all of the fungicides applied targeted early (*Alternaria solani*) and late blight *(Phytophthora infestans*). Broad spectrum strobilurin and systemic fungicides were applied early in the crop growth period, which were likely to also provide control of other diseases (e.g. white mould).

The majority of fungicide applications included two (and sometimes three) products, always with different active ingredients. Furthermore, the active ingredients mancozeb and chlorothalonil predominated, particularly late in the season. Mixing fungicides from different resistance groups

which are likely to reflect variation in modes of action is one strategy towards reducing the probability of the development of resistance to fungicides within pathogen populations. Ideally strategies should also incorporate the guidelines established by the Fungicide Resistance Action Committee for each of the various fungicides in a holistic disease management programme.

The insecticides were applied to control aphids vectoring PVY virus, and to control tomato potato pysllid (TPP) that reduce yield through feeding damage and affect tuber quality by vectoring "*Candidatus Liberibacter solanacearum",* often resulting in zebra chip. The insecticide spray regimes used would have most likely achieved these aims. All insecticides used have some efficacy against TPP, even though they may be registered only for aphids, so the registered target pest may not have been the actual target pest. The insecticides used early in growing season were likely to have the least possible effects on beneficial invertebrates, with methamidophos, which harms beneficials, only applied at the end of the season.

3.13 Weed management

A range of herbicides were applied, all at the pre-planting stage in the crops (Appendix VIII). Only one grower applied a herbicide after crop emergence (Fusilade Forte™ (128 g/L fluazifop-butyl) for Crop 6. Reglone® (200 g/L diquat, dibromide salt) was applied to most of the crops as a desiccant before tuber harvest.

Weed incidence in each of the 11 crops remained relatively low until nearing canopy senescence when exposure of the soil to sunlight triggered a flush of weeds, usually consisting of black nightshade (*Solanum nigrum*), fathen *(Chenopodium album*), and scrambling fumitory (*Fumaria muralis*). Weeds can usually be controlled until crop senescence approaches as potato crops are often sprayed with Reglone to kill all remaining top growth to make harvesting easier. However, if weed infestation beginsin early, yield will be lost through competition for space, water and nutrients.

Weeds were an extreme problem in Crop 9 with Fat Hen and Black Nightshade infestations particularly severe within the canopy in the headland, and they were also a problem in Crop 11 where they spread throughout the crop from late December onwards (Figure 17). Weed control can only be carried out before potato emergence so it is important for the crop to quickly reach canopy cover. The effect of weeds on tuber yield was measured for Crop 11. There was a 15% yield loss from an area (4 rows by 2.5m) where black nightshade and fathen had completely encompassed areas, compared to an area the same size which had remained weed free.

Figure 17. A weedy section of crop in Crop 11 on 25 March 2013. Nightshade plants are completely dominating the canopy.

3.14 Final yield, tuber size class, tuber dry matter content and stem number

Four measures of final yield were used:

- Potential yield (paid) as calculated by a potato model using 2012–13 weather data,
- Paddock yield (paid) from the whole paddock as measured by the grower,
- Plot yield (paid) as measured in one small area of the field,
- Individual plant yield (all tubers).

Final potential and paddock yields (paid, minus the undersized tuber fraction) were compared to quantify a yield gap for each crop, if it existed. Paid yield excludes tubers less than 67 mm in length and varied between 5 and 11% (4–8 t/ha) of final gross yield. Plot yield (gross) was used to track in-season growth to help determine the nature of any developing deviation from potential yield. Plant yield was used to compare yields between individual healthy or unhealthy plants within a crop.

For the 2012–13 season, the weather enabled one of the highest yield potentials for the last 11 years for all sites, although high winds did damage some canopies in January.

Potential yields ranged between 78 and 98 t/ha (Table 14) and were controlled by planting date, emergence date, daily mean temperature and radiation. Water and nutrient supply were assumed to be non-limiting. Paddock yield ranged from 49 to 66 t/ha, which confirmed current yield levels experienced by Canterbury growers.

Table 14. Potential and paddock yield (paid, t/ha) for the 11 potato crops included in this study. Yield gap was the difference between potential and paddock yield.

			Paid yield (t/ha)		
Site	Cultivar	Ground	Potential	Paddock	Yield gap
1	RB	New	83	49	34
2	RB	Old	81	49	32
3	RB	Old	95	55	40
4	RB	New	87	62	25
5	Innovator	New	98	56	42
6	Innovator	Old	86	66	20
7	RB	New	91	58	33
8	RB	Old	80	51	29
9	RB	Old	88	52	36
10	Innovator	Old	86	52	34
11	Innovator	New	78	56	22
Mean			87	55	32
Standard deviation			6	5	7

The gap between potential yield and paddock yield ranged from 20 to 42 t/ha (Table 14). There was little paddock yield variation associated with cultivar and previous cropping history (Figure 18).

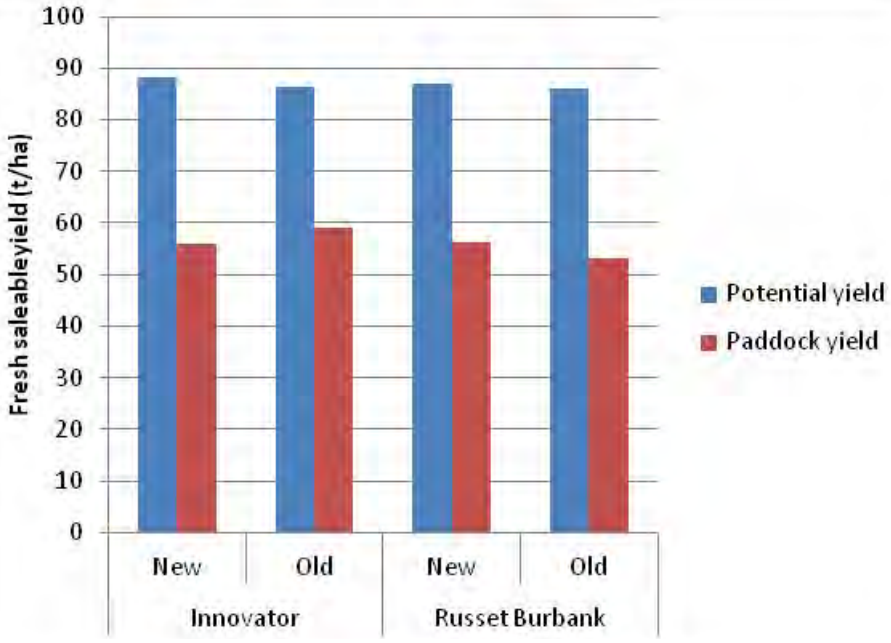


Figure 18. Fresh saleable potential and paddock yield (t/ha, tubers < 67mm removed) for 'Innovator' and 'Russet Burbank' in new and old ground.

Factors that contributed to yield reduction in parts of the crops are presented in order of importance:

- *Rhizoctonia* (cracked and cankered underground stems). This can affect individual plants and/or large areas of crops. See yield comparisons between diseased and healthy plants in the crop reports for Crop 4, 5, 6, 8 and 10.
- *Spongospora* root galling. This pathogen can harm root function (water and nutrient uptake). Galls were found in Crops 1, 2, 3, 6 and 8. Its affect on yield is known (Falloon et al) but was not measured in this study.
- Soil compaction leading to weak root systems and increased risk of crop water stress, the effect more severe when coupled with soil borne diseases (above). Compaction zones were identified in some crops but the effect on yield was not measured.
- Foliar disease causing leaf area reduction and shortened canopy duration.
- Uneven plant emergence, possibly due to variable types of cut seed tubers. Due to planting logistics, more than one seed line can be planted in a crop. See the crop report for Crop 11.
- Mismatched crop water requirements (too much water, not enough water and/or variable water application across a field) leading to crop water stress. This study was able to quantify yield loss in some obvious dry areas in crops, but the effects on yield of whole-field watering regimes was not investigated. See the crop reports for Crop 1 and 6, showing yield comparisons between the main crop and areas at the crop edges showing early signs of water shortage. Conversely, "Windscreen wiper" irrigator types resulted in areas of the crop at each end of a run becoming waterlogged
(seen in Crops 1 and 2). Plants in these areas may be more prone to disease (e.g. *Spongospora* root infection).
- Weeds – seen more commonly around crop edges but also randomly throughout some crops (Crops 10 and 11). See crop report for Crop11.

- Herbicide damage – increased rates at beginning of rows before sprayer speed is optimised (Noted in Crops 8 and 9), and remnant herbicides/pesticides from previous crops.
- Shallow planting depth reducing soil volume? (Crops 3, 5 and 8).
- Wheel/tractor underbelly damage – different contractors driving up different rows (Seen in Crops 6 and 7), irrigator wheels tracing different paths (Crop 11). Four rows are affected in some way by tractor passes, some vehicle clearances are too low and knock back tops on central two rows, wheel compaction causes waterlogging.
- Unplanted areas at entranceways or paddock corners (Crop 7).

Table 15. Factors likely to have contributed to the paddock yield reductions for each of 11 potato crops.

Site	Factors contributing to paddock yield reductions
1	Soil compaction, *Rhizoctonia*, *Spongospora* , uneven irrigation (waterlogging and dry spots), wind damage
2	Soil compaction, *Rhizoctonia*, *Spongospora*, shortened canopy duration, uneven irrigation (waterlogging and dry spots), wind damage
3	Soil compaction, *Rhizoctonia*, *Spongospora*, waterlogging, wind damage
4	*Rhizoctonia*, wind damage. Seed or psyllid problem?
5	*Rhizoctonia*, diseased canopy with low vigour, wind damage
6	Soil compaction, *Rhizoctonia*, *Spongospora*, uneven irrigation
7	*Rhizoctonia*, three spans of irrigator malfunctioning, wind damage
8	Soil compaction, *Rhizoctonia*, *Spongospora*, shortened canopy duration
9	Soil compaction, *Rhizoctonia*
10	*Rhizoctonia*, shortened canopy duration, *Spongospora,* weeds
11	*Rhizoctonia*, shortened canopy duration, poor seed quality, weeds

Combined effect of disease and water stress on gross yield was measured in individual plants in some crops (Figure 19). Some plants with less RSC disease and with an absence of soil compaction in the paddock yielded up to 90 t/ha, but in other paddocks where greater incidence of *Rhizoctonia* was associated with *Spongospora* root galls and soil compaction, yield was reduced to less than 30 t/ha.

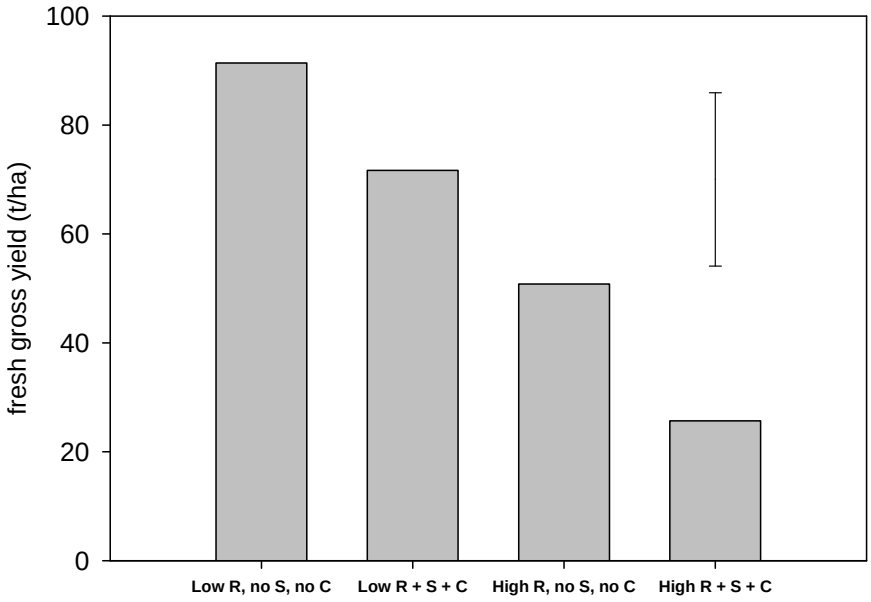


Figure 19. Averaged "plant yield" from targeted areas in 11 potato crops, categorised as having: low stem canker incidence (RSC), no Spongospora (root galls) and no soil compaction (Low R, no S, no C); low stem canker incidence, with Spongospora (root galls) and soil compaction both present (Low R + S + C); high stem canker incidence, no Spongospora (root galls) and no soil compaction (High R, no S, no C); or high stem canker incidence, with Spongospora (root galls) and soil compaction both present (High R + S + C).

Using Crop 7 to illustrate the analysis of predicted to measured growth, measured data were plotted against modelled canopy and tuber growth for each of the last 10 years (Figure 20). Crop cover in the measured plot remained mostly healthy through to mid - February, when individual plants began displaying above-ground symptoms of RSC (see Crop 7, crop history section). The model suggested that a canopy needs to remain healthy for at least 1400 degree days (base 0°C) from emergence to achieve maximum yield (see section crop establishment and duration). The canopy at Crop 7 lasted about 1590 degree days, but individual plants had died before that.

Tuber yields for Crop 7were developing as predicted towards a potential yield of 90 t/ha, but tailed off to be below that predicted by the model by final harvest. Removal of the under-sized tuber fraction reduced the yield further to a paid yield of approximately 75 t/ha. Moreover, final paddock yield was 58 t/ha. Measured yields (all tubers) of 80 t/ha were obtained from individual healthy plants, whereas plants first showing disease symptoms yielded 66 t/ha, thus explaining some of the paddock yield reduction. This may be explained by the fact that the irrigator had three spans that were not delivering the optimum amount of water. This did not affect the plot or individual plant yields, but may have reduced yield in other parts of the paddock.

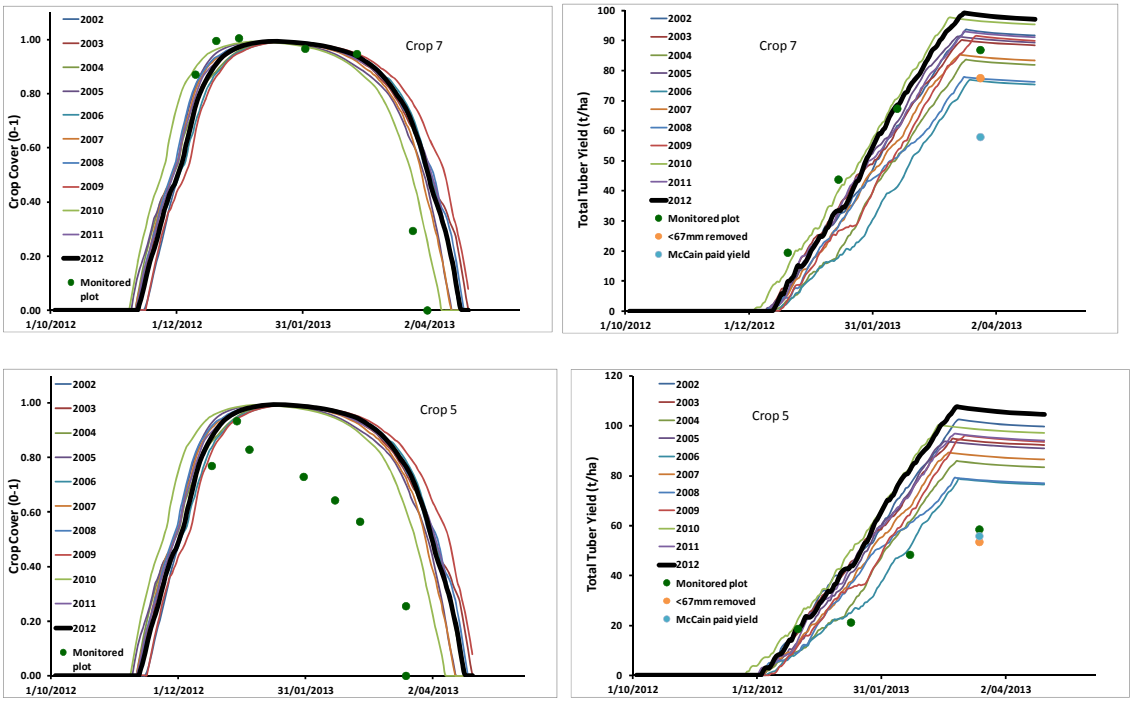


Figure 20. Crop 7; top left, modelled crop cover individually plotted for years 2002–12 (coloured lines with 2012–13 represented by the heavy black line). Complete crop cover is achieved at a value of about 0.8 on the vertical axis. Canopy cover that was measured in the monitored plot is represented by the green circles; top right, modelled (coloured line/black line) and measured (green circles) tuber yield accumulation. The orange circle represents measured plot yield minus the undersized tuber fraction and the blue circle is paid paddock yield. Crop 5 is similarly shown at lower left and right.

Crop 5 had a predicted yield of 98 t/ha, and a plot and paddock yield of about 50 t/ha. Canopy measurements showed that total crop cover was barely achieved or maintained and the canopy was diseased and had completely senesced by 1460 degree days (Figure 20, all other crops are shown in the Appendix VII). By the end of January some plants had already died from RSC and there was a high incidence and severity of early blight. The healthiest plants in the crop yielded 66 t/ha and those that senesced earliest yielded 49 t/ha. Wind damage (noted in early January) and other factors such as low vigour seed and other undiagnosed pests or diseases (e.g. pysillid may have contributed to yield decline).

Tuber size class

Tuber size distribution varied in the final plot harvest for the 11 crops (Figure 21). Tubers longer than 67 mm are the preferred size for the fry market and tubers longer than 90 mm attract a premium (pers. comm. McCain Foods). Crops 6 and 11 had the highest proportion of tubers in the premium size class, whereas Crop 4 had the lowest proportion of tubers in this class.

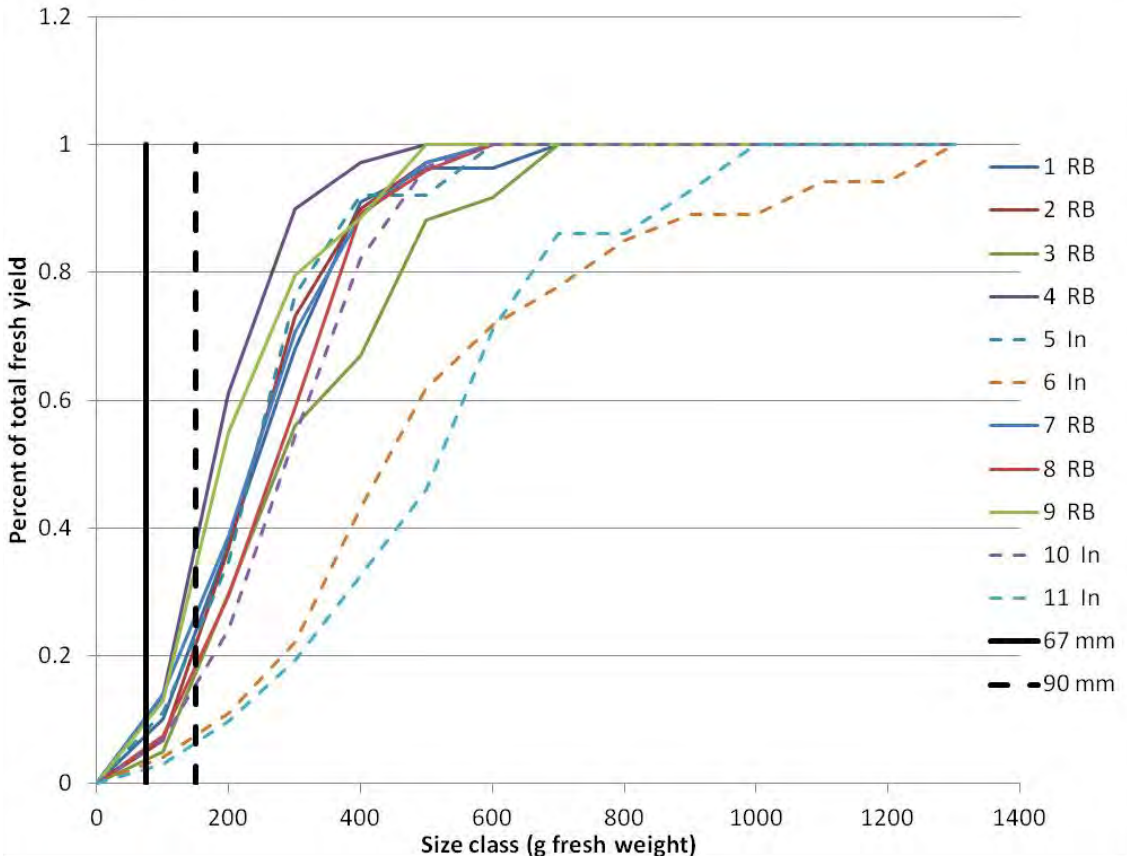


Figure 21. Tuber size class distribution (in 100g increments) as a percentage of final plot yield for each crop. Russet Burbank (RB) is the solid line and Innovator (Inn) is the dashed line. Tuber yield to the left of the vertical solid black bar is rejected by the factory, tuber yield to the right of the vertical dashed black line is paid a premium.

Tuber dry matter percent

For all crops, tuber dry matter percent increased through crop growth, and by final harvest (taken between 20 March and 11 April) ranged between 21 and 24% (Figure 22). Final dry matter percent was determined somewhere between full canopy and senescence. There was no distinction between the dry matter percent of cultivars as values throughout crop growth varied widely depending on crop.

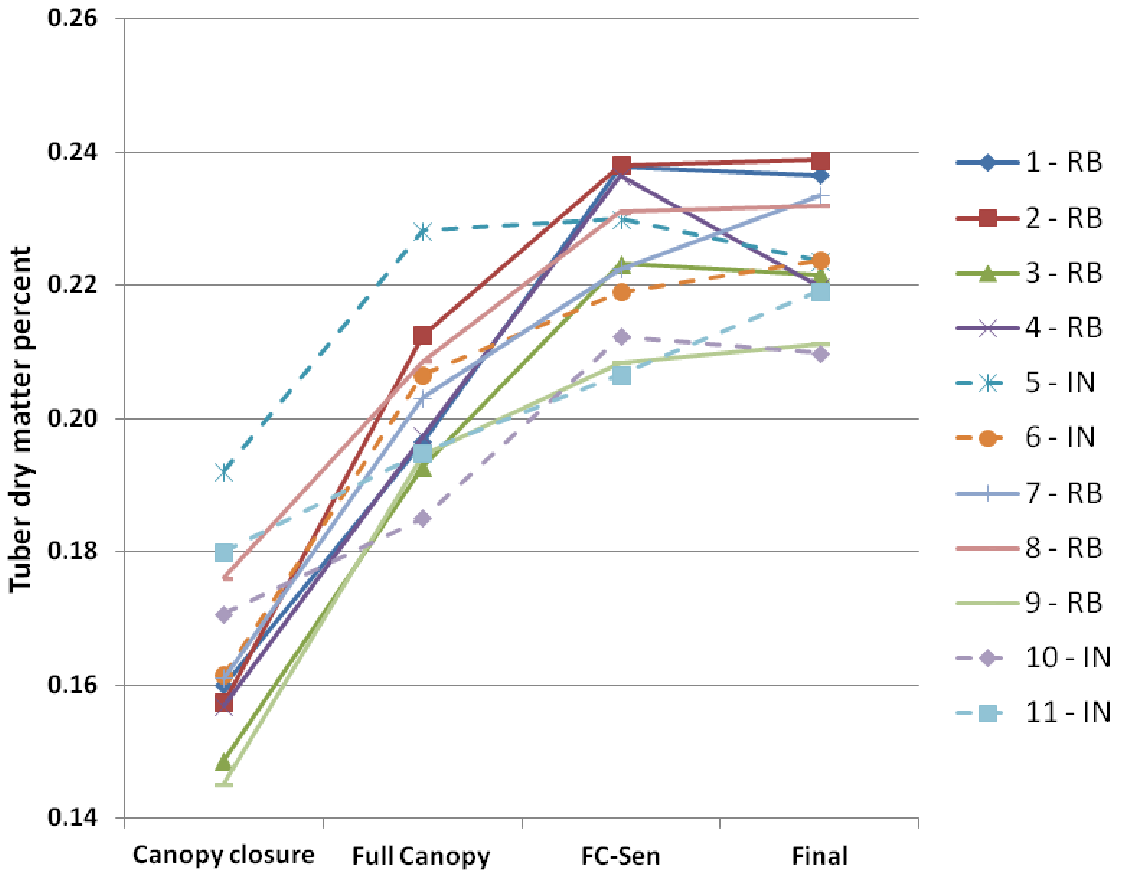


Figure 22. Tuber dry matter percent for each crop at canopy closure, full canopy, between full canopy and senescence (FC-Sen) and at final harvest, Russet Burbank (RB) is the solid line and Innovator (Inn) is the dashed line.

Stem number per plant

Tuber size distribution is affected by stem number per plant and planting density. Stem number per plant is largely determined by a combination cultivar, seed age and type (whether cut or whole). Lower stem number per plant results in larger tubers, which are paid a premium for process crops. Stem number was counted at each of four plot harvests through the season for each crop, and then averaged (Figure 23).

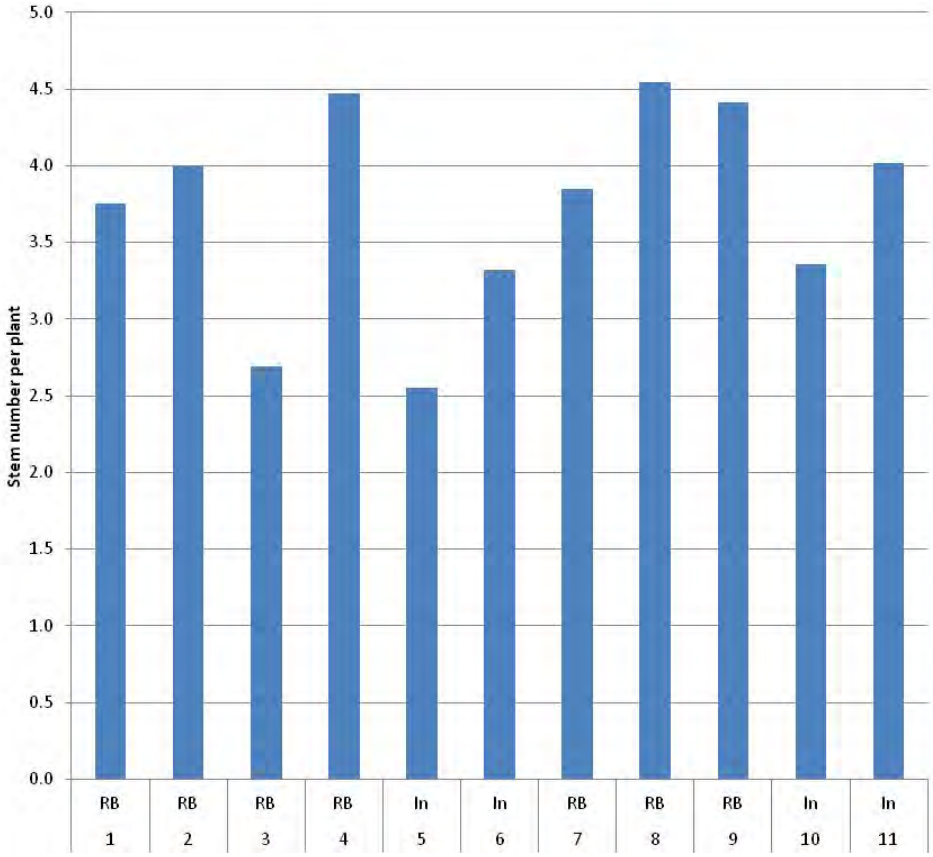


Figure 23. Stem number per plant for each crop, averaged over four sampling occasions in the plot.

For the 11 crops, plant stem number ranged from 2.5 to 4.5 stems per plant. However, within a crop, there was considerable variation between plants with respect to stem number. For example, at Crop 9, individual plant stem numbers were recorded over a total of 50 m of row (Figure 24). While nearly 30% of plants had an average of 4.5 stems per plant, the same as the whole season average, actual numbers ranged between 1 and 9 stems per plant. This variation could be contributing to an unpredictable final tuber size range, especially when coupled with the uneven planting distances (Figures 3, 4 & 5).

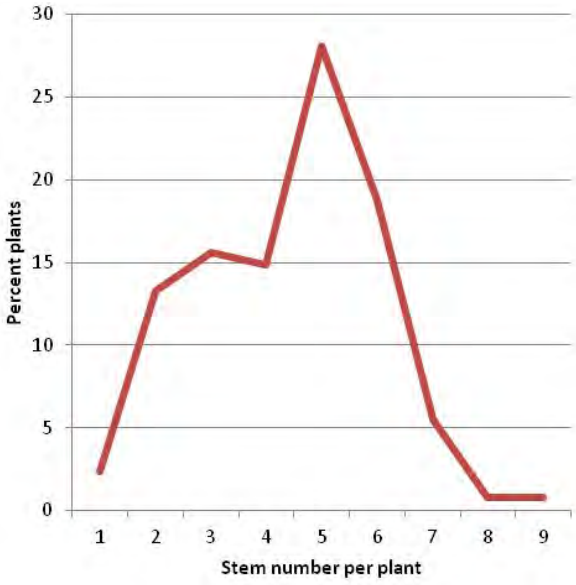


Figure 24. Distribution of stem number per plant for 128 plants over 50m of row.

Plant spacing in the 11 crops varied between 25 and 33 cm and when row spacing was taken into account, final populations ranged from 34,200 to 45,400 plants/ha (Table 6). Plant spacing did not seem to be directly related to tuber size class. Crops 6 and 11 (Innovator) both had a high proportion of tubers in the premium range, but Crop 6 had a plant spacing of 33 cm and a plant population of 34,700 plants/ha, whereas Crop 11 had a plant spacing of 25 cm and 45,400 plants/ha. Crop 4 (Russet Burbank) had a high proportion of smaller tubers and had a plant spacing of 32 cm and a plant population of 34,400 plants/ha.

3.15 Individual crop reports

These reports are summaries of key findings for each crop. For more detail, refer to the Appendices:

- Appendix II, Individual plant yield from healthy and problem areas of each crop.
- Appendix III, Proportions of diseased stems for several in-season plot harvests. These data are also presented as graphs in Figure 15.
- Appendix IV, Incidence of diseased plants in a 60 m transect, one of several taken throughout crop growth.
- Appendix V, Individual crop notes taken in the field.
- Appendix VI, Potato bed and root profiles for each crop.
- Appendix VII, Modelled and measured crop cover and tuber yield.
- Appendix VIII, Fungicide, herbicide, insecticide applications for each crop.

Crop 1, 'Russet Burbank', new ground

A potato crop was planted across a re-fenced area which had included both no previous potato crop (new ground) and a recent crop (old ground). Crop 1 was in the "new ground" area.

The crop was planted on 19 October 2012 in a Chertsey moderately deep silt loam which was very consistent throughout the paddock. There was mean row spacing (average of within and between beds) of 86 cm and a plant spacing of 32 cm, giving a target population of 37,000 plants/ha. The seed tubers were planted in the ridges at 21 cm depth and the sub-cultivated layer was 30 cm from the ridge top.

The crop was fully emerged by the end of November, and remained healthy until the first signs of RSC were seen on underground stems on 4 January 2013. Through the life of the crop, about half the underground stems from the plants in the observation plot had stem canker (Figure 25) and 1–2% of the plants in nearby rows showed above-ground symptoms. Since the crop showed few signs of above-ground problems, no diseased plots or plants were monitored in this crop. Strong winds damaged the canopy in mid January and the damage remained visible for 2–3 weeks, although the crop grew about 12 nodes beyond this damage.

Spongospora root galls were seen on some plants from the end of January onwards, although severity of galling was light.

From the pits dug near the time of crop senescence, a root restricting layer was noted at 24 cm, but above this there was good root growth within the ridge and under-bed furrow, but poor root growth in the under-wheel furrow (Table 8).

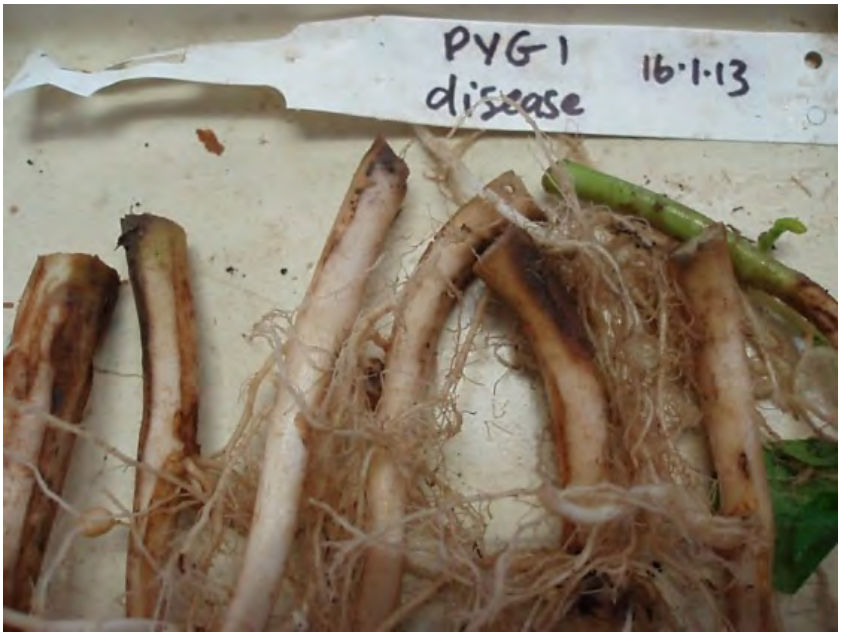


Figure 25. Stems with *Rhizoctonia* stem canker found within Crop 1, 16 January 2013.

Water stress

By mid-February, plants in rows along the south headland started to die back, and it appeared that water from the irrigator was not reaching this area (Figure 26). Random plants (tops dead) were harvested on 25 February from a marked area and yielded 1554 g tubers per plant (equivalent to 56 t/ha) and had 13 tubers per plant with a mean weight of 132 g. Plants that received more water (tops live) yielded 2166 g tubers per plant (equivalent to 78 t/ha) and had 12 tubers per plant with a mean weight of 190 g.

Figure 26. Crop 1, water stressed plants on left, fully irrigated plants on right.

Crop 2, 'Russet Burbank', old ground

This crop was in an area of a larger field where potatoes had been planted before ("old ground", see Crop 1 "new ground" above). The crop was planted on 19 October 2012 in a Chertsey moderately deep silt loam which was very consistent throughout the paddock. There was a mean row spacing (average of within and between beds) of 87 cm and a plant spacing of 33 cm, giving a target population of 35,200 plants/ha. The seed tubers were planted in the ridges at 20 cm depth and the sub-cultivated layer was 30 cm from the ridge top.

The crop was fully emerged by the end of November, and remained healthy until the first sign of RSC on 10 December 2012, seen as brown lesions on underground stems from the observation plot. Most of the underground stems from excavated plants had stem canker symptoms through February and March (Figure 27) and 2 - 5% of the plants in the nearby rows showed above-ground symptoms. Since the crop showed few signs of above-ground problems until well after full canopy, no disease plots or plants were monitored in this crop. Strong winds damaged the canopy in mid January and the damage remained visible for 2 - 3 weeks.

Figure 27. Left, diseased underground stems Crop 2, 16 January 2013, right, a plant with *Verticillium* (early dying, the complex between *Pratylenchus penetrans* and *Verticillium dahlia*), 20 March.

Spongospora root galls were seen on most excavated plants from the end of January onwards, and root galling was severe through to final harvest. Some galls were found at the ends of deep roots, indicating that the pathogen was present throughout the cultivated zone of the soil.

From the pits dug near the time of crop senescence, a root restricting layer was noted at 27 cm, and above that there was very poor root growth within the ridge and under-bed furrow, and poor root growth in the under-wheel furrow (Table 8).

The canopy began yellowing off from mid March and signs of “early dying” (the complex between damage from lesion nematode, *Pratylenchus* spp. and *Verticillium* spp.) began showing in the crop. This pathogen was present in the soil at planting.

Crop 3, ‘Russet Burbank’, old ground

The crop was planted on 10 October 2012 in a Chertsey moderately deep silt loam which was very consistent throughout the paddock. There was a mean row spacing (average of within and between beds) of 85 cm, a plant spacing of 31 cm, giving a target population of 38,700 plants/ha. The seed tubers were planted in the ridges at 17 cm depth and the sub-cultivated layer was 27 cm from the ridge top.

The crop was fully emerged by 13 November and this was when *Rhizoctonia* stem canker lesions were first noted on underground stems in the plants from the observation plot (Figure 28). The plant shoots appeared healthy until the end of January, when individual plants began to show symptoms of *Rhizoctonia* infection with leaf curl, wilting and blackening of above ground stems near the soil surface. There was also some wind damage in the canopy. Increasingly severe cracking and browning of the underground stems of these plants was also evident at this time. From mid - February nearly all the underground stems of the plants had stem cankers. About 20% of plants in nearby rows showed wilting symptoms consistent with Rhizoctonia infection.

At the end of January, *Spongospora* root galls were first noted (Figure 30, right).

From the pits dug near the time of crop senescence, a root restricting layer was noted at 20 cm with evidence of ripping (deep cultivation). There was good root growth within the ridge, the under-bed furrow and in the under-wheel furrow (Table 8). Some roots were growing into the subsoil through the channels created by deep ripping.

Figure 28. Underground stems with mild stem canker symptoms, Crop 3, 20 November 2012.

Diseased plants

On 14 February, a diseased (approximately 2 rows by 10m) and a healthy area of plants were separately marked out in the crop (Figure 29) and six randomly selected plants within those areas were individually assessed for health and yield at crop maturity on 15 March. The area of diseased plants did not necessarily represent the crop, where more commonly the diseased plants were dotted through the crop or present in waterlogged areas such as spray lines and pugged areas near farm tracks (Figure 30, left).

Figure 29. "Healthy" plants in Crop 3 (top left) with associated tubers from one plant (bottom left), and "diseased" plants (top right) and associated tubers from one "diseased" plant (bottom right), 25 February. The plants were individually harvested on 15 March.

The plants from the "diseased" area had average fresh tuber yield of 428 g per plant (equivalent to 16 t/ha), an average of four tubers per plant, a mean tuber weight of 100 g and less than one live stem above ground. There were also many rotten tubers on these plants. The plants from the "healthy" area had an average fresh tuber yield of 2130 g per plant (equivalent to 82 t/ha), an average of 11 tubers per plant, a mean tuber weight of 216 g and about two live stems. Although these plants had live above-ground stems, all the below-ground portions had RSC lesions.

Figure 30. Diseased area in Crop 3 on 14 February (yellowing patch in middle of photo on left, note waterlogging in wheel tr ack). Root galls (right) were found on plants from the crop from the end of January.

Crop 4, 'Russet Burbank', new ground

The crop was planted on 26 October 2012 in a Templeton deep silt loam and fine sandy loam which was reasonably consistent throughout the paddock. There was a mean row spacing (average of within and between beds) of 90 cm, a plant spacing of 32 cm, giving a target population of 34,400 plants/ha. The seed tubers were planted in the ridges at 24 cm depth and the sub-cultivated layer was 30 cm from the ridge top.

The crop was fully emerged by late November and remained healthy until light *Rhizoctonia* stem canker was first noted in early January. The infection remained light until a few wilting plants (about 4%; probably caused by Rhizoctonia infections) were observed at the end of February (29). By then more than half the underground stems in plants from the observation plot had brown stem canker lesions but no cracking. An area of these infected plants was marked on 25 February for later health and yield assessment. By the end of March there were increasing numbers of plants with leaf curl and wilting observed throughout the crop, symptoms consistent with below ground *Rhizoctonia* infection. By this stage, the ratio of healthy to diseased underground stems in plants from the observation area remained at about 50:50.

No *Spongospora* root galls were observed on plants from the observation plot at any stage during crop growth.

From the pits dug near the time of crop senescence, there was no obvious root restricting layer and some roots were venturing into the sub soil. There was very good root growth within the ridge and poor root growth in under-bed furrow and in the under-wheel furrow (Table 8).

Figure 31. First above-ground symptoms Rhizoctonia infection (left) in Crop 4, 25 February – wilting tops in foreground. Severe stem canker on an underground stem (right).

Diseased plants

In early April, it was noted that plants in the crop headland had remained free of above-ground *Rhizoctonia* symptoms compared with the plants in the main part of the crop (Figure 31). Each of six plants from this area and six plants from the earliest infected area were harvested individually. The plants where disease was first noticed had an average fresh tuber yield of 1520 g per plant (equivalent to 50 t/ha), an average of 13 tubers per plant, a mean tuber weight of 112 g, and all stems above ground were still alive. Eighty percent of the below-ground stems had brown lesions and 20% were healthy. The relatively healthy plants had an average fresh tuber yield of 2834 g per plant (equivalent to 93 t/ha), 19 tubers per plant, a mean tuber weight of 151 g and about 75% of stems were still alive. 50% of the below-ground stems had brown lesions, 34% were healthy and 20% were dead.

Yield discrepancy between headland and rest of crop

The healthy plants used for the yield determination all came from the headland alongside the road (32, left). Near the end of crop growth, most of the headland was healthier than the rest of the paddock and it was unclear why. There were three possibilities for this:

- The insecticide spiromesifen sprayed around the edges of the crop at the end of January (not the rest of the crop) protected the canopy for damage. However this effect was only noted on the headland and not on other crop edges.
- There was a lower irrigation rate along the headland compared to the rest of the paddock. Less water per application may have limited disease in this area.
- Row orientation may have caused the effect. The headland rows were at right angles to those in the rest of the field, and may have sustained less damage in the strong westerly winds in January.

Figure 32. Crop 4, 13 April 2013. Aging but healthy plants with no above-ground *Rhizoctonia* symptoms in a headland (left), unhealthy plants. These were marked on 25 February 2013, when they first showed signs of disease.

Crop 5, 'Innovator', new ground

The crop was planted on 3 October 2012 in a Hatfield moderately deep silt loam which was very consistent throughout the paddock. There was a mean row spacing (average of within and between beds) of 91 cm, a plant spacing of 29 cm, giving a target population of 38,700 plants/ha. The seed tubers were planted in the ridges at 16 cm depth and the sub-cultivated layer was 30 cm from the ridge top.

The crop was fully emerged by early November, and remained healthy until brown stem canker lesions (*Rhizoctonia*) were first noted on underground stems on 21 December. The number of wilting and dying plants increased from 2 to 16% in assessed 60 m rows from early January to the end of February. By the end of February about one third of the underground stems on plants from the observation plot were had stem cankers, (*Rhizoctonia*), and by final harvest on 20 March 2013 the number of healthy stems had decreased from 60% to less the 20%, with the remaining stems being either having stem canker lesions, or were dead.

The canopy in this crop never closed and stems remained upright through to senescence (Figure 33, left). Wind damage along the western edges of rows was seen in mid-January.

After this, branches became dominant and stayed green until the end of February. Early blight (*Alternaria solani*) came into the crop around mid February and by the end of February this disease was severe.

No evidence of *Spongospora* root galls was found in plants from the observation plot throughout crop growth.

From the pits dug near the time of crop senescence, there was no obvious root restricting layer and some roots were venturing into the sub soil. There was very good root growth within the ridge and good root growth in the under-bed furrow and in the under-wheel furrow (Table 8).

Figure 33. Crop 5, using a Cropscan to measure canopy cover (left), 30 January 2013. This crop never achieved full canopy closure. Typical plant die-back from Rhizoctonia infection (right), 14 February. This plant was marked and its yield compared with that of healthier plants on 20 March.

Diseased plants

Yields were depressed in the plants identified with early disease, compared with relatively healthy plants chosen at random in the nearby area at the time of final harvest (20 March). The healthier plants had an average tuber yield of 1835 g per plant (equivalent to 66 t/ha), and had 14 tubers per plant, with a mean tuber weight of 138 g. The diseased plants (first identified on 14 February) had died by 20 March, and were individually scattered through the crop rather than being in large patches (Figure 33, right). Diseased plants were first identified and marked 14 February and yielded 1372 g of tubers per plant (equivalent to 49 t/ha), had 9 tubers per plant with a mean weight of 158 g.

Crop 6, 'Innovator' old ground

The crop was planted on 14 October in a Halkett deep sand/Templeton deep silt loam and fine sandy loam (trial area) with a mix of Halkett sand, Templeton sand, Templeton silt and Eyre silt of throughout the paddock. The paddock was subsoiled and grubbed three times before preparing the ground for potatoes. There was a mean row spacing (average of within and between beds) of 89 cm, and a plant spacing of 33 cm, giving a target population of 35,000 plants/ha. The seed tubers were planted in the ridges at 20 cm depth and the sub-cultivated layer was 28 cm from the ridge top.

The crop emerged between 20–27 November 2012 and stayed healthy until the end of January 2013, when stem canker (*Rhizoctonia*) and Spongospora root galls (Figure 34) were first noted in plants from the observation plot.

Figure 34. Crop 6. Spongospora galls root were first noted at the end of January.

These diseases were also present in a patch (approximately 10 m by four rows) on nearby low ground (Figure 35). Here, all plants developed died off quickly. By March, most underground stems of plants from the observation plot had stem canker (*Rhizoctonia*) symptoms, and 9% of plants in nearby rows had above-ground symptoms.

Figure 35. Crop 6. A diseased patch (top left) was first noted and marked on 30 January, and by 15 March most plants were dead (lower left). These plants were later compared to those from a more healthy area nearby (top and lower right).

From the pits dug near the time of crop senescence, an intermittent root restricting layer was noted at 25cm, with some roots penetrating into the subsoil. There was good root growth within the ridge and under-bed furrow, but poor root growth in the under-wheel furrow (Table 8).

Diseased plants

Diseased and relatively healthy plants were dug on 15 March (Figure 36). The plants from the disease patch yielded an average of 762 g of tubers per plant (equivalent to 26 t/ha), and had seven tubers per plant, with a mean tuber weight of 121 g. No underground stems were disease-free. The healthier plants in the nearby crop (still with a green canopy, Figure 35, lower right) yielded an average of 1887 g tubers per plant (equivalent to 65 t/ha), and had eight tubers per plant with a mean weight of 247 g. Forty-three percent of their below-ground stems were diseased.

From the pits dug near the time of crop senescence, an intermittent root restricting layer was noted at 25 cm, with some roots penetrating into the subsoil. There was good root growth within the ridge and under-bed furrow, but poor root growth in the under-wheel furrow (Table 8).

Figure 36. Crop 6. Underground stems of the relatively healthy plants (left) from a final individual plant harvest on 15 March, compared with underground stems from diseased plants (right).

Water stress

The crop canopy had died back in several rows along crop edges where the irrigator had probably not applied water as well as it did in the main part of the paddock. Where irrigation was apparently insufficient, plants yielded 1635 g of tubers per plant (equivalent to 57 t/ha), and had an average nine tubers per plant with a mean tuber weight of 200 g. With just 11% of their underground stems diseased, disease incidence was less than for the well-irrigated plants (43% of stems diseased). However, stems in the poorly irrigated area had senesced earlier by mid February, making disease identification difficult. The well irrigated plants in the nearby crop yielded 1887 g tubers per plant (equivalent to 65 t/ha), and had eight tubers per plant with a mean tuber weight of 247 g. Forty-three percent of their below-ground stems were diseased.

Crop 7, 'Russet Burbank', new ground

The crop was planted on 3 October 2012, in an Eyre stony silt loam (trial area) with patches of Eyre stony silt, Templeton silt and Lismore silt throughout the paddock. There was a mean row spacing (average of within and between beds) of 91 cm, a plant spacing of 32 cm, giving a target population of 34,200 plants/ha. The seed tubers were planted in the ridges at 20 cm depth and the sub-cultivated layer was 25cm from the ridge top.

The crop was fully emerged by mid November and plants remained healthy until they reached full canopy (approximately 14 January), when the first stem canker (*Rhizoctonia*) lesions were noted on underground stems on from plant from the observation plot. At the same time, strong winds had severely damaged the top part of the crop canopy (Figure 37, left), giving an overall browning-off appearance to the crop. By the end of January branches had grown and filled in most gaps, and the crop had a light infection of early blight (*Alternaria solani*). In mid-February wilting plants dotted through the crop revealed increasing incidence of Rhizoctonia infection and six representative plants were marked for later health assessment. In mid March healthy branches gave the crop an overall green appearance, although the older lower leaves had severe early blight (Figure 38, lower photo).

A final yield measurement was taken on 25 March, although the crop was still quite green. Weeds were beginning to take over the crop at that time.

No *Spongospora* root galls were observed on plants from the observation plot throughout crop growth.

From the pits dug near the time of crop senescence, a\there was no obvious root restricting layer and numerous roots were growing into the subsoil. There was excellent root growth within the ridge and under-bed furrow, and good root growth in the under-wheel furrow (Table 8).

Figure 37. Crop 7. Wind damage in the crop in mid January (left) and first above-ground symptoms of Rhizoctonia infection in the crop in mid-February.

Diseased plants

Yields were depressed in the plants identified with early disease, compared to relatively healthy plants chosen at random in the nearby area at the time of harvest (15 March). The healthier plants yielded 2452 g tubers per plant (equivalent to 80 t/ha), and had an average of 17 tubers per plant with a mean tuber weight of 157 g. The diseased plants had died off and were scattered individually through the crop (Figure 37, right) rather than being in a large patches. They were first identified and marked with flags on 12 February, and yielded 2031 g per plant (equivalent to 66 t/ha), and had an average of 15 tubers per plant with a mean tuber weight of

135 g. Even the healthier plants were not free of stem cankers (Figure 38, top left), indicating that yields may have been compromised in these plants also.

Figure 38. Crop 7. Healthy and diseased stems (above) at the time of final harvest (15 March), and a late infection of early blight (below, 15 March).

Crop 8, Russet Burbank, old ground

The crop was planted on 24 October 2012 in a Templeton deep silt loam on sandy loam which was reasonably consistent throughout the paddock. There was a mean row spacing (average of within and between beds) of 92 cm, a plant spacing of 31 cm, giving a target population of

35,200 plants/ha. The seed tubers were planted in the ridges at 15 cm depth and the sub-cultivated layer was 22 cm from the ridge top.

The crop was fully emerged by the end of November and remained healthy until canopy closure (end of December, Figure 39, lower left), when severe stem canker (*Rhizoctonia*) lesions were seen on some underground stems on the plants from the observation plot. In mid-January, possible herbicide damage (yellow leaf vein chlorosis) was observed on leaves in some plants near the edge of the crop. Full canopy closure occurred near the end of January, and the crop looked uneven, with a mixture of upright flowering plants and collapsing older plants. A number of bolting plants also became more obvious as the crop matured. This unevenness in the crop could indicate a problem with the seed tuber line.

On 12 February, *Spongospora* root galls were first seen on the four plants dug from the observation plot, and these roots and underground stems were heavily affected by stem cankers (there were no healthy, white stems). A diseased and relatively healthy area of the crop was marked with flags for later health and yield assessments. Disease on roots and stems remained severe through to final harvest on 25 March, with powdery scab (*Spongospora*) lesions were observed on several tubers harvested from the observation plot.

From the pits dug near the time of crop senescence, a dense, root restricting layer was noted at 22 cm, with no roots growing below that. There was good root growth within the ridge, poor root growth in the under-bed furrow, and very poor root growth in the under-wheel furrow (Table 8).

Diseased plants

On 12 February, a diseased (two rows by ten plants) and healthy area (two rows by 4 m) of plants were separately marked out in the crop (Figure 39, top left and top right). Six plants within those areas were individually assessed for health and yield at crop maturity on 14 March. The plants where disease was first noticed had an average fresh tuber yield of 1103 g per plant (equivalent to 36 t/ha), an average of 10 tubers with a mean tuber weight of 112 g. The relatively healthy plants (in a very atypical part of the crop) had an average fresh tuber yield of 2284 g per plant (equivalent to 75 t/ha), an average of 11 tubers per plant, a mean tuber weight of 208 g.

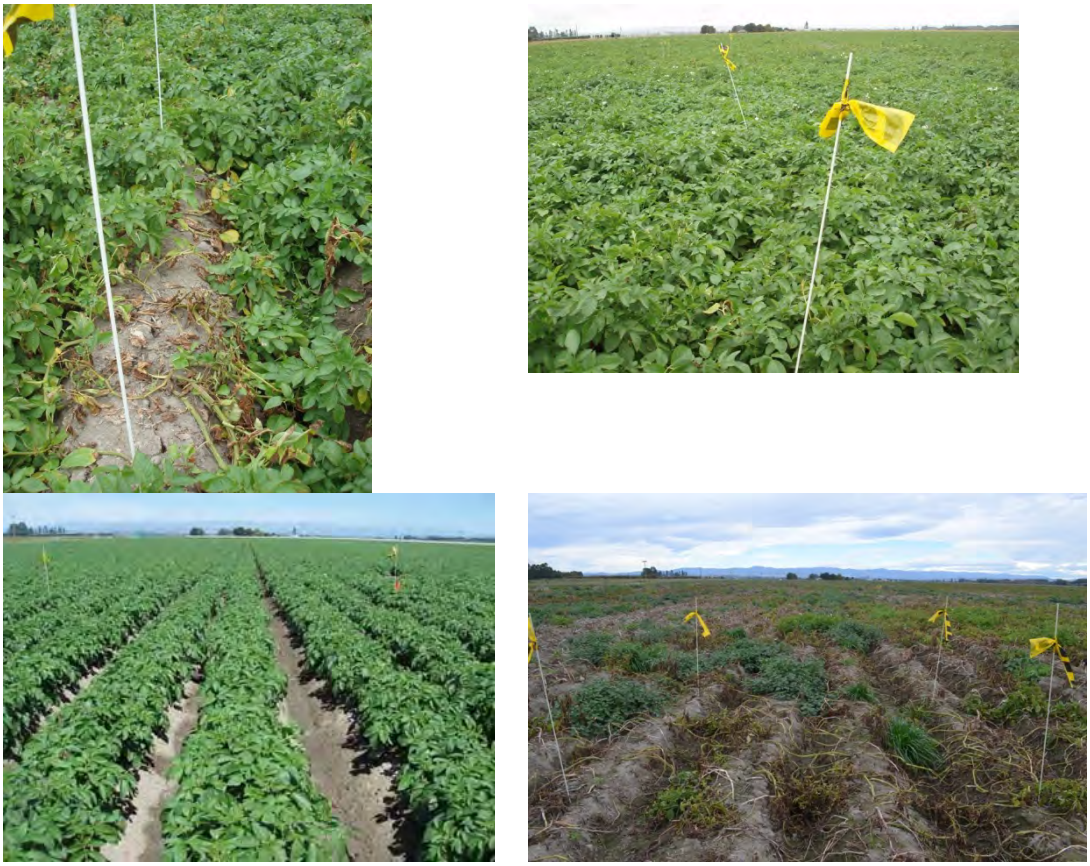


Figure 39. Crop 8. A diseased plot (top left) and a healthy plot (top right) marked out on 12 February. The observation plot appeared healthy in mid December (lower left), and the same plot prematurely killed by disease in March (bottom right), where only weeds are green. A small healthier patch is visible top right in photo where individual "healthy" plants were measured).

Crop 9, 'Russet Burbank', old ground

The crop was planted on 10 November 2012 in a Templeton deep silt loam on sandy loam which was very consistent throughout the paddock. There was a mean row spacing (average of within and between beds) of 91 cm, a plant spacing of 29 cm, giving a target population of 37,800 plants/ha. The seed tubers were planted in the ridges at 22 cm depth and the sub-cultivated layer was 27 cm from the ridge top.

The crop was fully emerged by mid - December and remained healthy until mid - January when stem canker (*Rhizoctonia*) lesions were seen on some underground stems on plants that were wilting under the hot conditions (Figure 40, top right and lower right). The tops remained mostly healthy through to full canopy closure, with the occasional plant dying back (about one in every 100 plants) as a result of severe stem canker (Figure 38, lower left). From full canopy (12 February) onwards, most plants that were dug from the observation plot had developed brown lesions on their underground stems and had dead stems. By 2 April, about 12% of plants in nearby rows were visibly affected with typical symptoms of *Rhizoctonia* infections.

No *Spongospora* root galls were found on plants from the observation plot throughout crop growth.

Some areas around the edges of the crop showed leaf yellowing, which was diagnosed as possible herbicide damage (Figure 38, top left).

From the pits dug near the time of crop senescence, a root restricting layer was noted at 30 cm and evidence of ripping (deep cultivation). Some roots were seen penetrating the subsoil through the deep ripping channels. There was very good root growth within the ridge, excellent root growth in the under-bed furrow, but poor root growth in the under-wheel furrow (Table 8).

Figure 40. Crop 9. Herbicide damage (top left), and plants wilting on a hot day immediately after irrigation (top right): first sign of root/stem disease. Plants beginning to collapse due to disease (lower left), and stem damage caused by Rhizoctonia (lower right), possibly affecting water uptake by plants.

Crop 10, 'Innovator', old ground

Soil conditions were wetter than desirable for pre-plant cultivation, and extra passes were needed to reduce clod size. A fine tilth is needed for even planting, and this was not achieved very successfully, which has happened in the past for this paddock. The crop was planted on 25 October 2012 in a Pahau moderately deep silt loam (trial area) with a mix of Pahau deep silt, Darnley shallow silt, Darnley stony silt, Templeton deep silt and sand throughout the paddock. There was a mean row spacing (average of within and between beds) of 90 cm, a plant spacing of 25 cm, giving a target population of 34,300 plants/ha. The seed tubers were planted in the ridges at 20 cm depth and the sub-cultivated layer was 30 cm from the ridge top.

The crop was fully emerged by the end of November and remained healthy (Figure 41, top left) until the end of December at about canopy closure, when stem canker lesions (*Rhizoctonia*) were seen on some underground stems of plants from the observation plot (figure 41, top right). At this stage there were no above-ground symptoms. From full canopy (mid January) onwards, there was high incidence of brown lesions on underground stems, and from mid February until final harvest, more than half the stems had lesions or were dead. The first foliar symptoms of *Rhizoctonia* were noted in mid February (figure 41, lower left).

Weed infestation was a serious problem along the headland and in other parts of the crop (figure 41, lower right). When weeds dominate the canopy in this way, yield is reduced (see report for Crop 11, where weed infestation reduced yield by 15%).

From the pits dug near the time of crop senescence, there was no obvious root restricting layer, and there was good root growth within the ridge and under-bed furrow, but poor root growth in the under-wheel furrow (Table 8).

At harvest, areas of tuber rot were noted across the paddock. In one case, the irrigator stalled during a pass, causing waterlogging, and this probably accelerated tuber rot later. Some of the fertiliser trial plots were in this area and yield in these plots was much reduced by rot. The grower noted that areas of rot in other parts of the paddock had defined borders which probably reflected a change in seed lines.

Figure 41. Crop 10. Top left, healthy underground stems, 10 December (top left). First signs of that underground stem lesions, 31 December (top right). Typical foliar symptoms of below ground Rhizoctonia stem canker, 12 February (lower left). Weed infested headland, 27 February (bottom right).

Crop 11, 'Innovator', new ground

The crop was planted on 2 November 2012 in a Wakanui deep silt loam loam (trial area) and a mostly Paparua stony deep sandy loam, consistent either side of a terrace. There was a mean row spacing (average of within and between beds) of 87 cm, a plant spacing of 25 cm, giving a target population of 45,400 plants/ha. The seed tubers were planted in the ridges at 26 cm depth and the sub-cultivated layer was 40 cm from the ridge top.

Early and late emerging plants

Crop emergence extended over about a month starting from late November, and by mid-December early emerged plants were almost at the canopy closure stage while late plants were still emerging (Figure 42). Extremes of these plants (20 of each type) were dug up on

21 December, plant characteristics recorded and other similar plants (late and early were adjacent to one another) marked for a yield harvest at crop maturity. Fresh top weight from the 20 plant sample averaged 42 g per plant for the late emerged plants and 375 g for the early emerged plants (a nine-fold difference).

Seed tuber type was also different for the two plant categories. For the early emerging plants, 57% came from rose-end seed tubers, with the rest coming from equal amounts of stem-end and “middle” seed tubers. None of the late emerging plants came from rose-end seed tubers; 60% were stem-end types and the rest were middles. At this 21 December harvest, the early emerging plants had between 3-30 tuber initials (average fresh weight of 2 g), while the late emerging plants had no tuber initials.

The early and late emerging plants were harvested on 25 March 2013, and most plants had few live stems at that stage. The average early emerging plants yielded an average of 2230 g tubers per plant (equivalent to 93 t/ha), and had an average of 10 tubers per plant with a mean tuber weight of 250 g. These early emerging yields were similar to a subset of “healthy” plants in the disease study (below). The average late emerging plants had an average yield of 950 g per plant (equivalent to 40 t/ha), an average of six tubers per plant and a mean weight of 180 g.

Figure 42. Crop 11. Variable emergence on 14 December (left), where plants on the left are at the tuber initiation stage, those on the right have just emerged. The crop appearance (right).

Discussion – Because the early emerging plants were growing next to late emerging plants, the difference in yield between the two categories was probably accentuated, as the larger plant canopies took over the resources in the local area. For a planting configuration such as this, tuber production per plant could become skewed and lead to a more variable tuber size distribution. This comparison demonstrates the benefit of even seed tuber size and type, to ensure even crop emergence.

Diseased plants

Stem canker (*Rhizoctonia*) was first noted on underground stems of plants from the observation plot on 24 December, and about half the stems continued to show symptoms throughout crop growth, with disease incidence increasing to over 80% stems affected near crop senescence at the end of March (Appendix III). Wilting tops (typical symptoms of below ground of *Rhizoctonia* infection) were first seen on 24 December, and during the maximum canopy stage about 20% of the plants in assessed rows had visible symptoms.

Yields were depressed in the plants identified with early disease, compared with relatively healthy plants in the nearby area at the time of harvest (14 March). The healthier plants yielded an average of 2633 g tubers per plant (equivalent to 110 t/ha), and had an average of 10 tubers per plant with a mean weight of 285 g. The diseased plants had died off before being crowded out by neighbours and were scattered through the crop as individuals rather than occurring in patches. They were first identified and marked with flags on 12 February and yielded an average of 816 g tubers per plant (equivalent to 34 t/ha), and had an average of five tubers per plant with a mean weight of 134g.

From the pits dug near the time of crop senescence, there was no obvious root restricting layer, with plenty of roots penetrating into the subsoil. There was excellent root growth within the ridge and under-bed furrow, and good root growth in the under-wheel furrow (Table 8).

4 General discussion

The results of this study identified the major factors which were most likely associated with the difference between maximum attainable yield and actual yields harvested from the paddock. Maximum attainable yield was estimated from the potato model developed by Plant & Food Research and varied between 78 and 95 t/ha. Moreover, the actual yields were significantly lower, ranging between 20 to 42 t/ha less than those predicted under theoretically 'perfect' conditions. Through intensive monitoring of the 11 fields included in this study and using a survey-type approach, we were able to describe and quantify the prevalence, incidence and severity of a range of biotic and abiotic factors which may have contributed to this yield 'gap' (i.e. difference between maximum attainable and paddock actual yields). Edaphic factors such as cultivar and whether potatoes were included in the rotation in the last ten years were discounted as important. Moreover, complementary replicated trials examining the role of the availability of nitrogen, phosphorus, potassium, and calcium suggested that the supply of these nutrients were also not limiting factors to potato growth and development, and yield.

However, in general, across all fields disease incidence and severity was high. The most prevalent diseases were Rhizoctonia stem canker, and Spongospora root galls. Both these diseases contribute to constraining the amount of carbohydrates to the tubers due to reduced green leaf area and root system development, and thereby tuber number and size. Rhizoctonia stem canker was identified as one of the major diseases affecting potato within this study. However, high variability within *R. Solani* isolates is likely due to differences in anastomosis groupings, which may reflect variation in virulence and aggressiveness of isolates, associations with the various phases and symptoms of the disease on different parts of the potato plant, and fungicide sensitivity profiles. Further work is necessary to conduct a comprehensive assessment of the losses caused by this pathogen in potato production.

The high disease intensity occurred in the presence of "optimal" commercial recommendations for disease management being followed by all growers. This suggests that inoculum density and disease pressure is so high that management strategies are suboptimal leading to disease development and crop damage. Moreover, it could also suggest that current tactics for disease management require optimizing due to factors such as suboptimal application times, and the presence of pesticide resistance within the pathogen populations. For example, one of the fungicides used as an in-furrow treatment, azoxystrobin (Amistar® 250 SC) is a member of the strobilurin or quinone outside inhibitors (Q0I) fungicide group. These fungicides inhibit respiration by binding to the Q0 centre of the cytochrome b, part of the electron transport chain in the inner mitochondrial membrane. Reduced sensitivity to strobilurins has been observed in a number of plant-pathogenic fungi and resistance has been shown to develop rapidly due to a single point mutation required within the sensitive gene to shift an isolate from being sensitive to resistant to all members of the strobilurin group. The efficacy of disease management tactics were not studied in this project and would require the establishment of replicated trials.

Other factors identified as contributing to this yield gap were poor soil physical properties such as soil compaction leading to reduced root volumes. Moreover, poor soil physical properties may also exacerbate conditions which may be suitable for pathogen infection, especially for the soil-borne diseases observed in this study. Synergistic effects may therefore occur between the direct effects of either of these factors and conditions which exacerbate the reduced plant development from an association of these factors.

Severe weed infestations were identified as contributing negatively to plant growth and canopy development due to direct competition effects. The efficacy of the weed management program through the application of herbicides in potatoes is usually considered routine but highly influenced by timing of applications, and the presence of target weed species within the same genus to potatoes making selection of products that are effective problematic (e.g. black nightshade, *Solanum nigrum*). Presence of weeds within a canopy will also exacerbate conditions that favour infection by foliar pathogens, which is akin to the disease development driven by extensive host canopies and factors that increase yield potential but also soil moisture.

An additional factor contributing to the yield gap is seed quality. High variation was identified in the emergence of potato plants from seed pieces that were translated into differences in green leaf area and canopy development, and thereby yield potential. This study identified the variation to be due to differences in seed lots, however further work is needed to further assess the factors responsible for this variation. Replicated trials would be needed to target specific factors associated with the seed piece size, quality, pesticide treatments to influence primary inoculums for the soil-borne and other diseases, and other factors.

Therefore, this research has identified potential risk factors that may contribute to the yield gap which is widening over time within New Zealand potato production. Further research should focus on quantifying the magnitude of the crop losses associated with individual factors to enable the establishment of cost/benefit analyses to be able to manipulate variable costs for their management. Following the survey-type approach with variable spatial resolution could enable the identification of factors for a risk algorithm to identify the most important factors influencing yield and those that need to be optimized to realize canopy development and maximum attainable yield.

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Appendices

Appendix I – Predicting potential yield.

Potential biomass production

Potential yield calculations were base on daily calculations of the potential increase in total DM (ΔTotalDM):

$$\Delta Total\ DM = R \times I/I_o \times RUE$$

Where R is total solar radiation (MJ/m^2/d), I/I_o is the proportion on incoming solar radiation that is intercepted by the crop (0 meaning bare soil and 1 meaning full canopy) and RUE is the radiation use efficiency of the crop representing how much biomass the crop produces with intercepted radiation. A value of 1.4 g DM/MJ was used for RUE, daily values of R were taken from local weather stations and I/I_o was calculated from green area index (GAI, representing the size of the canopy) as:

$$I/I_o = 1 - e^{-0.8 \times GAI}$$

GAI was calculated from thermal time accumulation (Tt) from emergence with a linear increase up to a maximum GAI followed by a linear decrease as shown in the figure below:

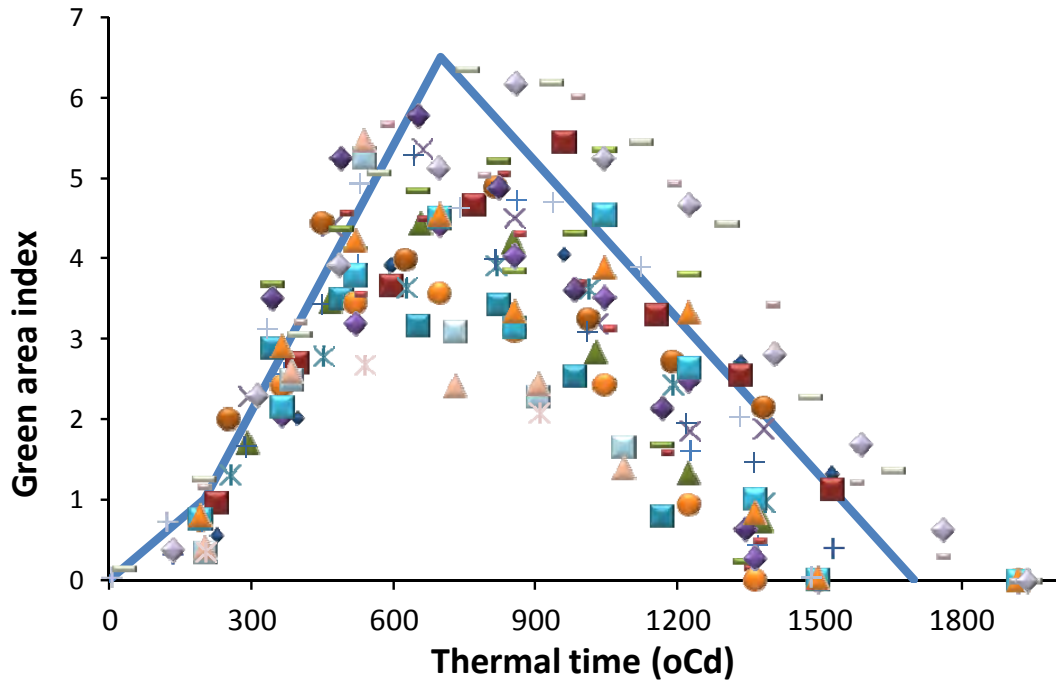


Figure 1. The GAI relative to accumulated thermal time for Russet Burbank potatoes grown in a range of conditions. The blue line was fitted to the outer limits of this data to represent potential GAI.

Thermal time was calculated with a base temperature of 2°C.

Partitioning of biomass

Top biomass production was related to GAI by calculating the daily increase in tops DM (ΔTopsDM) from the daily change in GAI using a specific tops area (see figure below). Thus, tops DM increased as GAI increased up to 700 °Cd after emergence and then decreased as GAI declined and specific top area (STA) increased beyond this time.

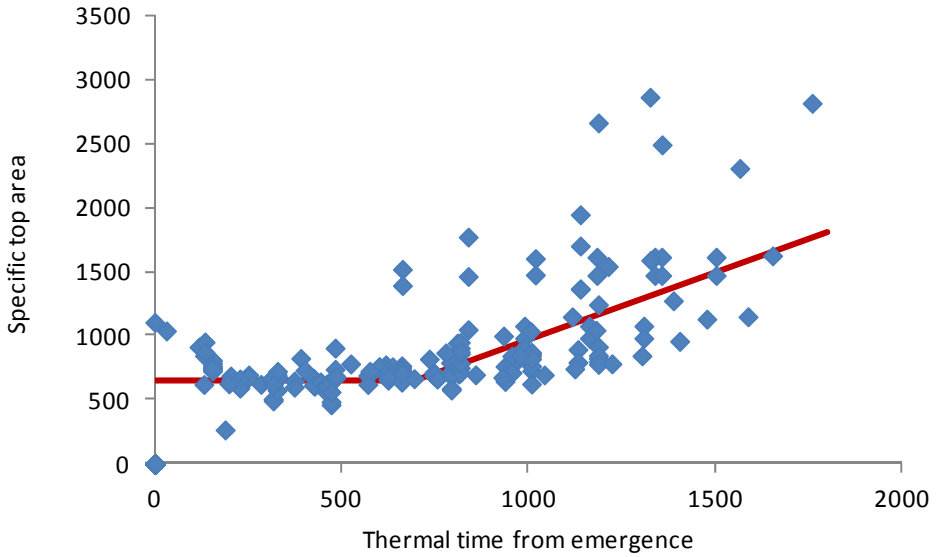


Figure 2. Specific tops area (m2 GAI/g top DM) relative to thermal time for Russet Burbank potatoes grown in a range of situations.

Partitioning of DM to tubers begins 200 °Cd after emergence for Innovator and 300 °Cd for Burbank and continued for 1000 °Cd. During tuber filling the daily change in tuber DM (ΔTuberDM) was calculated as:

$$\Delta TuberDM = \Delta TotalDM - \Delta TopsDM$$

It is important to note that ΔTopsDM has a negative value when GAI is decreasing which increases ΔTuberDM above ΔTotalDM.

Tuber yields

Daily ΔTuberDM is accumulated throughout the season to give total TuberDM and converted to fresh yield using the dry matter content (DMC):

$$Yield = TuberDM \times 1/DMC$$

DMC begins at lower values close to tuber initiation and increases as tuber grow. The change in DMC throughout the season was calculated from Tt accumulation throughout the season using the relationship shown below.

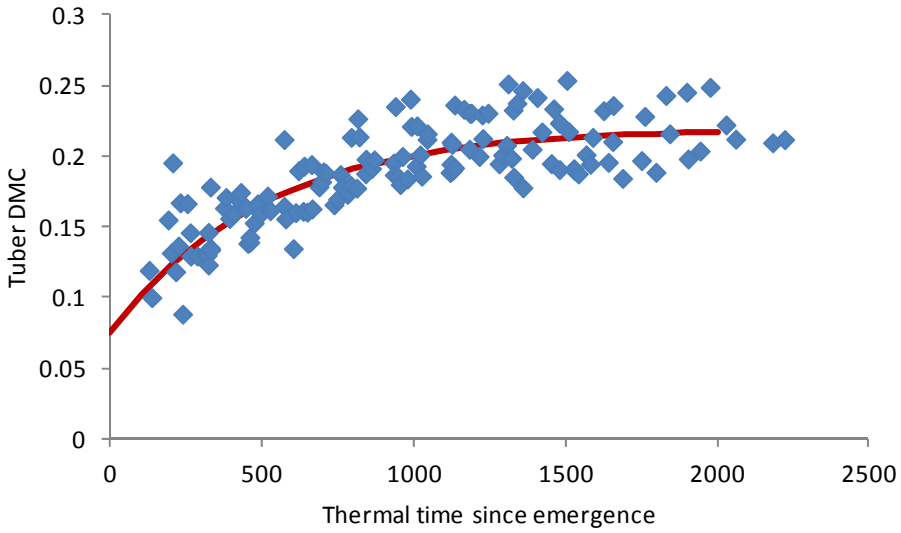


Figure 3. Dry matter content (DMC) of Russet Burbank potatoes relative to thermal time accumulation throughout the season. Fitted line is given by the formula DMC = (0.075 + 1-exp(Tt × -0.002)) × (Harvest_DMC – 0.075).

Potential yields at each site.

Potential yields were calculated at each site using the method outlined above for 11 years. This included the current year and the 10 years previous to provide a reference for comparing the current season. Historic weather data was used from the Ashburton and Timaru (which ever was closest to the site) for potential yield calculations. Simulations were started on the same day each year and this was set to the day that crops were planted for each site. The thermal time from planting to emergence was calculated for each site and this value was used to predict the time of emergence for year at each site. The DMC measured at final harvest (Harvest_DMC) for each site was used to calculate (see equation in figure above) fresh DM yield. The potential yield was then reduced to account for the proportion of small tubers (<67 mm) measured at each site.

Appendix II – Individual plant yield

Explanation of table: when first noticed, problem plants were marked for later individual yield assessment at crop senescence. This was carried out in 9 of the 11 crops. Usually 6 plants with the same problem were marked and the table presents the mean of the 6 plants, for tuber weight and number, mean tuber weight and yield equivalent to t/ha. Percentage of diseased, healthy and dead above- and below- ground stems are shown. Yields for the problem plants were then compared to nearby plants that were still healthy immediately prior to crop natural sensecence. Problem categories were:

- Plants in areas that had less irrigation (Irrig missed vs Irrig normal).
- Plants showing early above-ground *Rhizoctonia* disease symptoms (Early disease vs Most alive).
- Plants that emerged weeks after early emerging ones (Late emerge vs Early emerge).

Site No., plant category	Date	Tuber wt per plant (g)	Tuber no. per plant	Mean tuber wt (g)	t/ha clean	Percent yield reduction	% above ground stems live	% above ground stems dead	% Below ground healthy stems	% Below ground diseased stems	% Below ground dead stems
Crop 1											
Irrig missed	20-Mar-13	1554	13	132	54	28	9	91	0	22	78
Irrig normal	20-Mar-13	2166	12	190	75		88	13	10	90	0
Crop 3											
Early disease	15-Mar-13	428	4	100	16	80	38	62	0	22	78
Most alive	15-Mar-13	2130	11	216	78		88	12	0	93	7
Crop 4											
Early disease	3-Apr-13	1520	13	112	50	46	100	0	21	79	0
Most alive	3-Apr-13	2834	19	151	93		74	26	34	48	17
Crop 5											
Early disease	20-Mar-13	1372	9	158	49	25	9	91	6	31	63
Most alive	20-Mar-13	1835	14	138	66		91	9	38	57	5
Crop 6											
Early disease	15-Mar-13	762	7	121	25	60	23	77	0	19	81
Most alive	15-Mar-13	1887	8	247	62		61	39	50	43	7
Irrig missed	15-Mar-13	1635	9	200	54	13	88	12	32	11	58

Site No., plant category	Date	Tuber wt per plant (g)	Tuber no. per plant	Mean tuber wt (g)	t/ha clean	Percent yield reduction	% above ground stems live	% above ground stems dead	% Below ground healthy stems	% Below ground diseased stems	% Below ground dead stems
Crop 7											
Early disease	15-Mar-13	2031	15	135	66	17	63	37	13	63	25
Most alive	15-Mar-13	2452	17	157	80		100	0	63	37	0
Crop 8											
Early disease	14-Mar-13	1103	10	112	36	52	0	100			
Most alive	14-Mar-13	2284	11	208	75		83	17			
Crop 10											
Early disease	14-Mar-13	1308	10	144	55	49	34	66	0	22	78
Most alive	14-Mar-13	2575	10	271	108		67	33	0	95	5
Crop 11											
Early disease	14-Mar-13	816	5	134	34	69	17	83	0	19	81
Most alive	14-Mar-13	2633	10	285	110		100	0	58	38	4
Late emerge	25-Mar-13	953	6	182	40	57	29	71	0	63	38
Early emerge	25-Mar-13	2230	10	249	93		17	83	3	29	68

Appendix III – Proportions of diseased stems at each plot harvest

Explanation of sampling occasion:

4 plant sample: four plants were dug from the perimeter of the observation plot and underground stems were scored with stem canker (*Rhizoctonia*) either present or absent.

FC-sen: At a point about half way between full canopy and senecence, eight plants were harvested for yield analysis and stems scored as for 4 plant sample above.

Final harvest: An area 2.5m by 4 rows was harvested for yield determination and all stems were scored as above.

Crop, sampling occasion	Date	Plant no.	Stem no. /plant	% below ground healthy stems	% below ground diseased stems	% below ground dead stems
Crop 1						
4 plant sample	14-Feb-13	4	4.8	21	79	0
4 plant sample	25-Feb-13	4	4.8	42	58	0
FC-sen	20-Mar-13	8	4.9	49	51	0
Final harvest	3-Apr-13	31	4.3	20	69	11
Crop 2						
4 plant sample	14-Feb-13	4	3.8	7	93	0
4 plant sample	25-Feb-13	4	3.5	14	86	0
FC-sen	20-Mar-13	8	3.9	3	74	23
4 row x 2.5m final hvst	3-Apr-13	32	3.5	0	50	50
Crop 3						
4 plant sample	14-Feb-13	4	3.3	0	92	8
FC-sen	25-Feb-13	8	2.5	5	95	0
4 plant sample	15-Mar-13	4	2.3	0	78	22
Final harvest	26-Mar-13	34	2.9	2	65	33
Crop 4						
4 plant sample	14-Feb-13	4	5.0	20	80	0
4 plant sample	25-Feb-13	4	5.5	32	68	0
FC-sen	20-Mar-13	8	5.5	41	59	0

Crop, sampling occasion	Date	Plant no.	Stem no. /plant	% below ground healthy stems	% below ground diseased stems	% below ground dead stems
4 plant sample	3-Apr-13	4	5.0	55	45	0
Final harvest	11-Apr-13	28	4.9	31	62	7
Crop 5						
FC-sen	14-Feb-13	8	2.5	65	35	0
4 plant sample	25-Feb-13	4	3.5	64	36	0
Final harvest	20-Mar-13	37	2.5	14	46	40
Crop 6						
4 plant sample	14-Feb-13	4	4.3	59	35	6
FC-sen	25-Feb-13	8	3.3	38	62	0
4 plant sample	15-Mar-13	4	3.8	7	73	20
Final harvest	25-Mar-13	34	3.0	17	56	27
Crop 7						
FC-sen	12-Feb-13	8	3.0	75	25	0
4 plant sample	26-Feb-13	4	5.0	45	55	0
4 plant sample	15-Mar-13	4	2.5	40	60	0
Final harvest	25-Mar-13	32	3.7	26	70	4
Crop 8						
4 plant sample	12-Feb-13	4	3.8	0	100	0
FC-sen	27-Feb-13	8	3.6	3	97	0
4 plant sample	14-Mar-13	4	3.5	0	93	7
Final harvest	25-Mar-13	32	4.3	0	58	42
Crop 9						
FC	12-Feb-13	8	5.5	25	75	0
4 plant sample	27-Feb-13	4	3.3	46	54	0
FC-sen	14-Mar-13	8	4.1	9	82	9
4 plant sample	2-Apr-13	4	6.3	8	68	24

Crop, sampling occasion	Date	Plant no.	Stem no. /plant	% below ground healthy stems	% below ground diseased stems	% below ground dead stems
Final harvest	11-Apr-13	34	4.5	5	64	32
Crop 10						
4 plant sample	12-Feb-13	4	3.0	42	58	0
FC-sen	18-Feb-13	8	3.6	28	72	0
4 plant sample	27-Feb-13	4	4.3	24	76	0
4 plant sample	14-Mar-13	4	4.0	31	50	19
Final harvest	25-Mar-13	36	3.8	2	40	58
Crop 11						
4 plant sample	12-Feb-13	4	3.5	36	64	0
FC-sen	27-Feb-13	8	3.8	47	53	0
4 plant sample	14-Mar-13	4	5.8	43	43	13
Final harvest	25-Mar-13	40	3.3	17	45	38

Appendix IV – Incidence of diseased plants in 60m row transect for each crop

Crop	History	Date	% visibly diseased plants in random 60m row
1	New	4-Jan-13	1
		14-Feb-13	2
		25-Feb-13	1
2	Old	4-Jan-13	0
		14-Feb-13	2
		25-Feb-13	6
3	Old	4-Jan-13	0
		14-Feb-13	3
		25-Feb-13	20
4	New	4-Jan-13	0
		14-Feb-13	1
		25-Feb-13	4
5	New	4-Jan-13	2
		14-Feb-13	8
		25-Feb-13	16
6	Old	4-Jan-13	0
		14-Feb-13	1
		25-Feb-13	9
7	New	31-Dec-12	0
		18-Feb-13	0

Crop	History	Date	% visibly diseased plants in random 60m row
		26-Feb-13	10
8	Old	31-Dec-12	1
		18-Feb-13	18
		27-Feb-13	4
9	Old	31-Dec-12	1
		18-Feb-13	1
		27-Feb-13	1
		2-Apr-13	12
10	Old	31-Dec-12	0
		18-Feb-13	10
		27-Feb-13	1
		14-Mar-13	19
11	New	31-Dec-12	3
		18-Feb-13	18
		27-Feb-13	20

Appendix V – Individual crop field notes

Crop 1, Russet Burbank, new ground

13 Nov 12	Tubers just sprouted underground
20 Nov 12	Not emerged
27 Nov 12	Most plants emerged. Soil quality measurements taken. Low compaction.
10 Dec 12	Tuber initiation started, healthy root and stems, largest tuber 3cm
20 Dec 12	No small plants in plot area
4 Jan 13	Canopy closure sample taken (8 plants). Six plants with mild Rhizoc lesions. Roots white, no galls. Can't find mother tuber in row gaps, neighbour sending out small rhizome. 60m plant count shows 6.8% gaps/small plants. Largest tuber is 8cm.
16 Jan 13	Wind damage to top leaves. One or two more leaves to come, crop still upright. Frosting on upper leaves could also be a symptom of wind damage. Water running down wheel channels. Cracking and dark Rhizoc lesions on outer of underground stems. Some brown centre in tubers. Lower leaves yellowing, assume senescence. Browning of lower above-ground stem.
30 Jan 13	Full canopy harvest (8 plants). Wind damage ~5 nodes down. Root galls found. Brown lesions and cracking present on underground stems.
14 Feb 13	4 diseased plants visible in random 60m. Crop lumpy, upper canopy in good condition, wind damage 12 nodes down. Root galls present, light infection. In health-check 4 plant sample, 4 stems healthy, 15 stems with brown lesions.

25 Feb 13	2 diseased plants visible in random 60m. 2 out of 4 plants in health-check sample had light root gall infection, 2 had none. 8 stems healthy, 11 with brown lesions/split stems. Tubers healthy. Crop lumpy/flattened, full ground cover, younger leaves healthy. Set up "drought" and "irrig" plot at headland.
20 Mar 13	Full canopy-senescence yield sample taken (8 plants). From this, 19 stems were healthy and 20 had brown lesions. High blight incidence but low severity. Large single nightshade plants starting dominate local plants. 6 water-stressed and 6 average plants yield measurement. Root galls present.
3 Apr 13	Crop yellow/green. Severe blight on top leaves, lots of galls. Final harvest in yield gap plot (4 rows by 2.5m). From this, 26 stems were healthy, 91 had brown lesions and 15 were dead. 2 tubers from a 36 tuber subsample had light powdery scab.

Crop 2, Russet Burbank, old ground

13 Nov 12	Tubers just sprouted underground
20-Nov 12	Not emerged
27 Nov 12	Soil quality measurements taken. Low compaction.
30 Nov 12	Most emerged
10 Dec 12	Very early tuber initiation, healthy roots, slight stem lesions
20 Dec 12	Small plants with blackened stems in area around plot.
4 Jan 13	Canopy closure sample taken (8 plants). Plants younger than Crop 1. 60m plant count showing 7.1% gaps/small plants. Small plants are either diseased or have small mother tuber. White roots, no galls, one plant has Rhizoc stem crack, others slight browning. Largest tuber is 8cm
16 Jan 13	Wind damage to top leaves. One or two more leaves to come, crop still upright. Frosting on upper leaves could also be a symptom of wind damage. Some lower leaves yellowing, above ground stems look healthy. Underground stems have lots of Rhizoc cracking, some browning apparent in root cross section. One tuber hollow heart.
30 Jan 13	Full canopy harvest (8 plants). Root galls found on 7 of 8 plants. Brown lesions and cracking present on underground stems. Six rows of poor plants on eastern border – water issue?
14 Feb 13	4 diseased plants visible in random 60m. Crop at lumpy stage. Root galls on all 4 health-check plant sample, 1 stem healthy, 14 stems with brown lesions, some severe.
25 Feb 13	10 diseased plants visible in random 60m. Root galls on all 4 health-check plant sample. Galls are on deep roots, indicating heavy (?) soil infection. 2 stems healthy, 12 stems with brown lesions. Tubers healthy inside but 4 out of 29 tubers (just a partial sample of the 4 plants) have light powdery scab infection.
20-Mar 13	Full canopy-senescence yield sample taken (8 plants). From this, 1 stem were healthy, 23 had brown lesions and 7 stems were dead. Galls on some plants, signs of Verticillium wilt.

3 Apr 13	Crop mostly dead, some plants completely dead. Lots of galls on the plants still alive. Final harvest in yield gap plot (4 rows by 2.5m). From this, 0 stems were healthy, 56 had brown lesions and 55 were dead. 15 tubers from a 53 tuber subsample had light to severe powdery scab.

Crop 3, Russet Burbank, old ground

13 Nov 12	Most plants just emerged. Brown lesions on stems.
20 Nov 12	Early leaf yellowing from pre-emergence herbicide.
27 Nov 12	Soil quality measurements taken. Low compaction, stones.
10 Dec 12	Tuber initiation underway, some Rhizoc stem lesions, largest tuber 3cm, tops clean of disease.
24 Dec 12	Canopy closure yield sample taken (8 plants).
4 Jan 13	Roots white, healthy, no galls. Strong stems with slight Rhizoc browning. Largest tuber 8cm, some severe “brown centre”. Tops mostly healthy, some wind damage, yellow leaves at base of plants. 60m plant count showing 2% gaps/small plants.
16 Jan 13	Full canopy yield sample taken (8 plants). Wind damage to upper leaves, crop a mixture of upright thinner stems and collapsed larger stems. Dying (yellow) plant near observation plot (aerial stem rot?). Underground stems have light Rhizoc cracking.
30 Jan 13	Crop at “lumpy” stage. Old wind damage evident ~5 nodes down. All 4 health-check plants have galls. Rhizoc symptoms - leaf curling and blackened stems.
14 Feb 13	Crop lumpy with green patches and dead (older?) plants. 5 diseased plants visible in random 60m. 3 out of 4 health-check plant sample heavily galled, 1 with light gall infection. No galls on nightshade. One disease and 1 healthy plot set up. In 4 “disease” plant sample, 1 dead stem, 0 healthy stems, 12 stems with brown lesions (splits and rots)
25 Feb 13	Full canopy-senescence yield sample taken (8 plants). From this, 1 stem was healthy and 19 had brown lesions. One plant had aerial tubers (Rhizoc). 38 diseased plants visible in random 60m of row. Crop down apart from some late tall stems. High incidence of root galls. One tuber had hollow heart.
15 Mar 13	Crop at late senescence stage, light covering of low green stems. Galls present in all 4 health-check plant sample, which had 2 dead stems and 7 stems with severe brown lesions. Tubers had no internal defects, but 2 tubers had light powdery scab (>2% surface area affected).
26 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 2 stems were healthy, 64 had brown lesions and 33 were dead. In the 8 plant subsample, galls present on all plants, tubers deformed from Rhizoctonia. Brown centre noted.

Crop 4, Russet Burbank, new ground

13 Nov 12	Not emerged
20 Nov 12	Not emerged
27 Nov 12	Crop just emerging (~25%).
13 Dec 12	Early tuber initiation, white roots, very slight stem Rhizoc lesions, healthy leaves.
21 Dec 12	Most of crop appears to be large, even-sized plants.Small plants are either Rhizoc infected or have very small mother tubers.
4 Jan 13	Canopy closure sample taken (8 plants), although crop a little past this stage. Crop finished flowering, almost going down. Roots white, no galls, underground stems have slight Rhizoc browning and cracking. Strong above-ground stems, largest tuber 6cm. 60m plant count showing 2.2% gaps/small plants.
16 Jan 13	Crop has upright appearance, but is made up of collapsed main stems (darker green), branches taking over (lighter green), giving the crop a striped appearance. Light wind damage to some upper leaves. One or two nodes yet to expand. Slight Rhizoc cracking on underground stems.
30 Jan 13	Full canopy harvest (8 plants), branching continuing to fill out canopy. Brown lesions and cracking present on underground stems.
14 Feb 13	Green crop, good cover, old wind damage below. 2 diseased plants visible in random 60m. No root galls found, roots clean and white. 4 stems healthy, 16 stems brown lesions in 4 health-check plant samples.
25 Feb 13	No root galls in 4 health-check plant samples, 7 stems healthy, 15 with brown lesions (no cracks). 8 diseased plants (just the very early wilting signs) visible in random 60m of row. Marked approx area for disease monitoring – at early wilting stage. No root galls, tubers healthy.
20 Mar 13	Full canopy-senescence yield sample taken (8 plants). Crop green and not that far past full canopy. From this, 18 stems were healthy, 23 stems had brown lesions at soil surface but healthy tissue below and 3 stems had brown lesions the full length of stem. Increasing numbers of Rhizoctonia infected plants showing up. No root galls found. Light early blight severity, high incidence.
3 Apr 13	No root galls in 4 health-check plant samples, 11 stems healthy, 9 with brown lesions (at soil surface and deeper). No tuber defects.
11 Apr 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 42 stems were healthy, 85 had brown lesions and 10 were dead. In the 8 plant subsample, no galls were present.

Crop 5, Innovator, new ground

13 Nov 12	90% emerged
20 Nov 12	Some plant misses and double-ups. Tuber initiation has begun on the bigger plants.
13 Dec 12	White healthy roots, healthy leaves. Largest tuber 7cm
21 Dec 12	Canopy closure sample taken (8 plants), some stem canker (Rhizoc)
4 Jan 13	60m plant count showing 5.7% gaps/small plants. Gaps appear to be planter misses/double-ups, or blind seed (latter found in Crop 6). small plants due to Rhizoc infection. The crop has a sprinkling of “rogue” larger, later plants. White healthy roots, no galls, very strong stems, no disease. Largest tuber 10cm, no “brown centre”. Healthy tops alhough some wind damage.
16 Jan 13	Full canopy sample taken (8 plants), although canopy never closed. Rows brown/green striped – eastern stems greener than western stems (wind damage). Silver-backed leaves – effect of wind damage. Light rhizoc infection (dark stems and cracking) on underground stems.
30 Jan 13	Small battered yellowing canopy. Some fresh leaves from branches. Dead plants dotted throughout (Rhizoc). Brown lesions and cracking present on underground stems, although some stems healthy.
14 Feb 13	Full canopy-senscence yield sample taken (8 plants). No galls found on the 8 plant sample. Target spot present. 16 diseased plants visible in random 60m. 6 diseased plants marked. 13 stems healthy, 7 with brown lesions. Roots healthy, some stems have severe rotting near tuber. Tubers healthy.
25 Feb 13	34 diseased plants (mostly dead) visible in random 60m of row. Overall look of crop – more than half dead. High incidence of severe early blight. No root galls in 4 health-check plant samples, 9 stems healthy, 5 with brown lesions Early plant death triggered by an event early in crop’s life? Plants that missed becoming infected look ok now. No root galls, tubers healthy.
20 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 13 stems were healthy, 42 had brown lesions and 36 were dead. Most plants remained upright throughout crop growth with canopy closure barely achieved and these plants now marbled green/brown. Severe early blight incidence. 6 diseased and 6 average-health plants yield measurement. No galls.

Crop 6, Innovator, old ground

13 Nov 12	One or two plants emerged
20 Nov 12	About 30% emerged. Lots of grass weeds emerging (twitch)
27 Nov 12	90% emerged. Lots of roots.
13 Dec 12	Starting to flower, tuber initiation continuing, white roots, largest tuber 4cm.
24 Dec 12	Canopy closure sample taken (8 plants)
4 Jan 13	60m plant count showing 8.2% gaps/small plants, no obvious disease in field. Roots white, healthy, no galls, stem strong, healthy, white stems, tuber have no "brown centre", biggest tuber 8cm. Some early blight in yellowing lower leaves of canopy.
16 Jan 13	Full canopy yield sample taken (8 plants). Crop gone down with some older-looking plants (seed age different to start with?). Black lesion on isolated stem where it has bent at ground surface (Rhizoc, Blackleg)
30 Jan 13	Poor rows on outer edged of crop – irrigator doesn't reach? Canopy green and even with branches filling in gaps. Root galls on ¼ "disease" plants. Set up "drought" and disease plots. Brown lesions and cracking present on underground stems.
14 Feb 13	Even green canopy dotted with large nightshade plants. Lower leaf senescence under the thick canopy (as expected), no recent top-canopy damage. Root galls present. 2 disease plants visible in random 60m of row. One "drought" plot (Rotorainer might be missing areas?), 1 disease plot and 1 healthy plot set up. No galls found on nightshade. On 4 plant health-check sample 1 stem dead, 6 stems with brown lesions and 10 stems healthy. Tubers healthy. One plant with botrytis grey mould.
25 Feb 13	Full canopy-senescence yield sample taken (8 plants). 16 diseased plants visible in random 60m of row. Root galls present (low severity) in 7 out of 8 plants in yield sample. 10 stems healthy, 16 with brown lesions. Many plants have green vein yellow leaf mottling on upper leaves. Deficiency? Tubers healthy
15 Mar 13	Crop yellowing, soil showing through. On 4 health-check plants, 1 healthy stem, 11 stems with brown lesions, 3 dead stems. Tubers healthy. Disease, healthy and drought plant individual yield assessment (6 plants each).
25 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 17 stems were healthy, 58 had brown lesions and 28 were dead. Crop yellow/green. Severe root galls present.

Crop 7, Russet Burbank, new ground

13 Nov 12	90% plants emerged.
20 Nov 12	Tuber initiation started.
27 Nov 12	Soil quality measurements taken, obvious compaction zone. Crop looking water stressed.
10 Dec 12	Healthy white roots, tops clean, largest tuber 4cm.
20 Dec 12	Canopy closure sample taken (8 plants). One tuber with 'brown centre"
31 Dec 12	60m plant count shows 1.6% gaps/small plants. Strong stems, white roots, no galls, some tubers with "brown centre". Yellow leaves at base of tops – some late blight/senescence.
14 Jan 13	Full canopy yield sample taken (8 plants). Extensive wind damage. Field sprinkled with younger flowering plants. Low severity Rhizoc found on stems. Some tubers with "hollow heart" and "brown centre".
30 Jan 13	Even canopy with branches filling the gaps. High incidence of Target Spot but low severity. Root galls present.
12 Feb 13	Full canopy-senescence yield sample taken (8 plants). 18 stems healthy, 6 with brown lesions (low severity). Even green canopy. Rhizoctinia infected plants dotted through crop – 6 plants marked. No root galls, root systems mostly white and healthy.
26 Feb 13	Crop generally green with scraggy tall stems. 18 diseased plants visible in random 60m Soil appearing under more mature vines. Low incidence and severity of early blight. 2 plants of the health-check 4 plant sample had visible wilting of tops. 9 stems healthy, 11 stems with brown lesions. No root galls. Marked disease plants ranging from dead to half dead.
15 Mar 13	Crop generally green with scraggy tall stems, weeds taking over. High incidence of severe early blight on lower leaves, newer leaves are blight free. 4 plant health-check sample had 4 healthy stems, 6 stems with brown lesions, no root galls. One tuber with hollow heart. Disease and healthy plant individual yield assessment (6 plants each).
25 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 30 stems were healthy, 82 had brown lesions and 5 were dead. Crop still green but weeds greatly taking over. Some misshapen Rhizoctonia-infected tubers. No galls.

Crop 8, Russet Burbank, old ground

20 Nov 12	20% emergence
30 Nov 12	90% emergence
10 Dec 12	Healthy white roots, tuber initiation underway, clean stems. Largest tuber 3cm
20 Dec 12	Plant samples taken – no problems reported
31 Dec 12	Canopy closure sample taken (8 plants). White roots on 7 of 8 plants, plant no. 8 had severe rhizoc lesions. Tops fine but some yellowing on lower leaves. One late blight incidence. 60m plant count shows 3.1% gaps/small plants. Plants either missing, doubled up or diseased.
14 Jan 13	Some flowering, possible linuron damage – bright yellow patches on leaves (photo). Brown lesions and cracking present on underground stems.
28 Jan 13	Full canopy yield sample taken (8 plants). Lumpy crop, mixture of seed tuber age? Some plants fading, other still flowering.
12 Feb 13	Crop down, green and yellowing patches in the crop. PYG plot badly affect by disease. Marked 2 disease plots and 1 healthy. Root galls present, roots heavily diseased, tubers healthy. On 4 health-check plants, 0 stems healthy, 15 stem with brown lesions.
18 Feb 13	35 diseased plants visible in random 60m of row. Half the row with severe disease, other half relatively clear. Set up 2 more disease rows of 20m each. Healthy plot does not represent most of the immediate area. Root galls present.
27 Feb 13	Full canopy – senescence yield sample taken (8 plants). Crop very yellow, but some green patches with healthier plants. 8 diseased plants visible in random 60m of row. High incidence but low severity of late blight. Yellow vein, green leaf syndrome (as opposed to some crops with green vein, yellow leaf!) – herbicide? All 8 plants have severe incidence of root galls. Some deformed tubers on 1 plant (which was dead) – rhizoc. 1 stem healthy, 28 stems with severe brown lesions. Powdery scab present on one tuber.
14 Mar 13	Crop has large patches of dead, small patches of green. On 4 health-check plants, 0 stems healthy, 13 stem with brown lesions and 1 stem was dead. Root galls present. 3/16 tubers with very light powdery scab infection. Disease and healthy plant harvest
25 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 0 stems were healthy, 80 had brown lesions and 58 were dead. Crop largely dead, weeds green and thriving. Bolters still growing – massive root systems.

Crop 9, Russet Burbank, old ground

20 Nov 12	No plants emerged
30 Nov 12	No plants emerged – 10cm long underground sprouts.
4 Dec 12	50% emergence
10 Dec 12	Newly emerged, no stolons, clean stems, roots and tops.
31 Dec 12	Canopy closure sample taken (8 plants) although still some rows not quite joined. Some leaf browning (water/sun damage?). 60m plant count shows 3.9% gaps/small plants. Roots white, no galls, strong stems, tops healthy (one plant with leaf lesions (photo). Largest tuber 3cm.
14 Jan 13	Preplant hebicide damage showing in sections of the crop (yellow veins in leaves), stressed plants (upward rolling leaves) around crop edges and low lying patches – waterlogging. Hot day – noticed flipped top leaves (look white-ish as showing underside) as if water stressed (stems less turgid). Rhizoc cracking on underground stems.
28 Jan 13	Not quite full canopy. Herbicide damaged plants dying off in worst affected area – could be affecting plots in NW rep. 4 health-check plants healthy tops, leaves still expanding, some lower leaf senescence as canopy is thick. Branch and mainstem of equal quality.No leaf disease or wind damage.
12 Feb 13	Full canopy yield sample (8 plants). No root galls, 33 stems with severe Rhizoc lesions, 11 without. Canopy (leaves) healthy overall. Patches of disease near north headland. Rhizoc plants easy to spot, but there are also patches of general yellowing. Light infection of early blight.
18 Feb 13	3 diseased plants visible in random 60m of row. No root galls. Crop green overall, dotted with diseased plants (low incidence). Yellowing area near road looks yellower. Fert plots have different greens.
27 Feb 13	Crop green and healthy, still at max canopy. 3 diseased (mild wilting) plants visible in random 60m of row. No root galls found on 4 health-check plant sample. 6 stems healthy, 7 stems with brown lesions. Tubers healthy.
14 Mar 13	Full canopy – senescence yield sample taken (8 plants).14 diseased (seen as mild wilting) plants visible in random 60m of row. From the 8 plants 3 stems were healthy, 27 stems with severe brown lesions and 3 stems dead. No root galls noted.
2 Apr 13	25 diseased (seen as stem blackening or premature stem death, severe cupping of leaves) plants visible in random 60m of row. Plenty of other plants showing milder symptoms. No root galls found on 4 health-check plant sample. 2 stems healthy, 17 stems with brown lesions, 6 dead stems.
11 Apr 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 7 stems were healthy, 98 had brown lesions and 49 were dead. No root galls were found.

Crop 10, Innovator, old ground

20 Nov 12	2% emerged
30 Nov 12	70% emerged
10 Dec 12	Early tuber initiation, white roots, clean stems and tops.
31 Dec 12	Canopy closure sample taken (8 plants). Crop flowering, grower finding it difficult to supply enough water. Pysilld controlled around the edges. 60m plant count shows no gaps/small plants. Roots white, no galls, 2 plants from CC have cracked stems, largest tuber 5 cm. Small plant from paddock – immature seed tuber caused delay?
14 Jan 13	Full canopy yield sample taken (8 plants). Flowering nearly finished. Rhizoc found on collapsed plant. High incidence of Rhizoc cracking on underground stems. Even though crop recently irrigated, drier spots are obvious.
28 Jan 13	Strong canopy, crop down but branches filling in the gaps. Even yellowing of the lower leaves. Crop recovered from earlier wind damage (have 2-3 more nodes now). Fert plots look the same. Large (50m2) patches of the crop looking lower and yellower. Brown lesions and cracking present on underground stems.
12 Feb 13	Large areas of even, green canopy dotted with diseased plants. 6 diseased plants marked. No root galls on 4 health-check plant sample, 5 stems healthy, 7 stems have brown lesions No lesions on or in tubers.
18 Feb 13	Full canopy-senescence yield sample taken (8 plants). One whole plant dead from Rhizoc. 8 stems healthy, 21 severely infected with brown lesions. Crop yellowing. 23 diseased plants visible in random 60m of row. High early blight incidence of low severity.
27 Feb 13	Crop yellowing (green veins, yellow leaves at top of plants) but some very green areas. High incidence, low severity of late blight. No root galls. 3 diseased plants visible in random 60m of row. From 4 plant health-check sample 4 stems healthy, 13 stems brown lesions 4 of these severe.
14 Mar 13	Crop yellowing, soil showing. Light gall infection in ¾ plants. High incidence of moderate severity blight. Measured yield in the 6 diseased and 6 average-health plants. From 4 plant health-check sample 5 stems healthy, 8 stems brown lesions, 3 stems dead. 3/14 tubers very light powdery scab.
25 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 3 stems were healthy, 54 had brown lesions and 78 were dead.

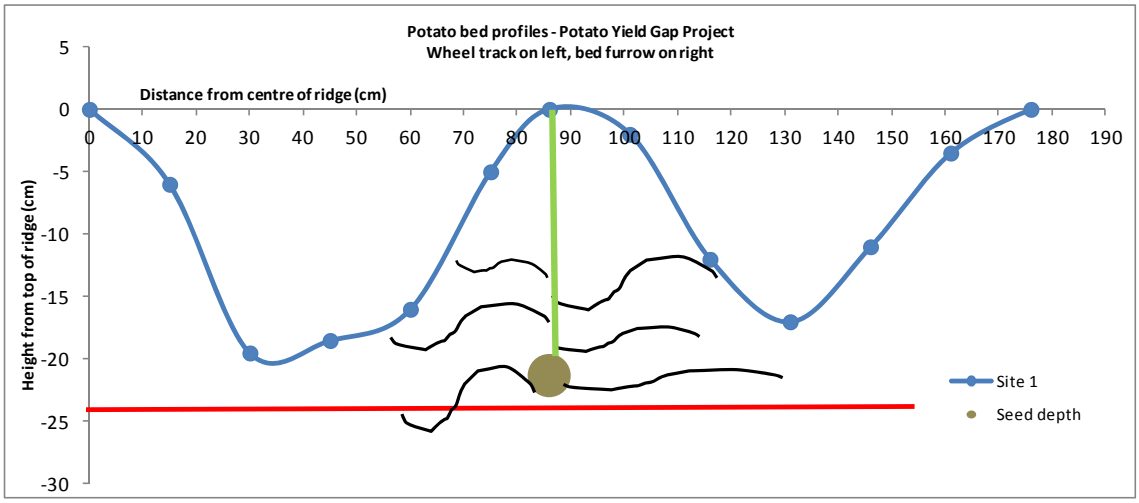
Crop 11, Innovator, new ground

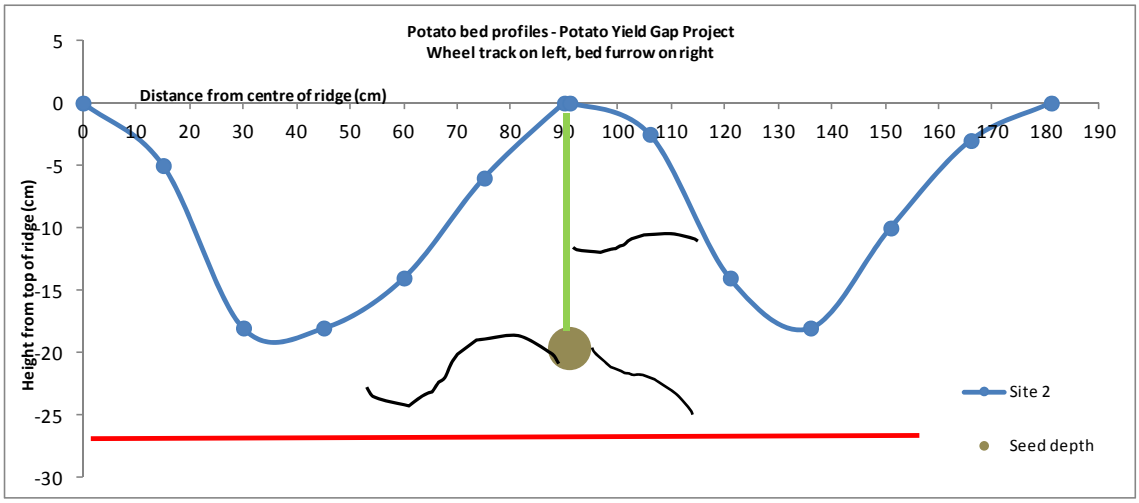
20 Nov 12	Not emerged
30 Nov 12	30 % emerged but very patchy
4 Dec 12	50% emerged
10 Dec 12	White healthy roots, early hook stage

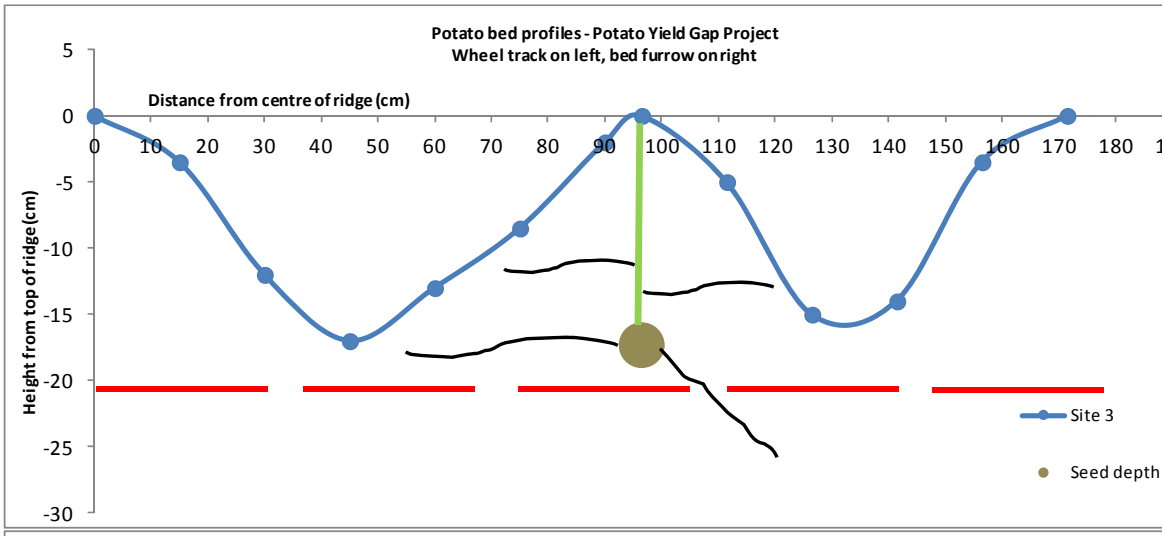
21 Dec 12	Small (not long emerged)and large plants (almost canopy closure) marked to monitor growth effects. Small and large plants collected. Large plants mostly have rose-end/large mother tubers with multiple stems. Small plants have mostly stem/middle mother tubers with fewer stems growing from mid-section eyes. Some of these mother tubers have rotted prematurely.
24 Dec 12	Canopy closure sample taken (8 plants). Gappy crop. Sample plants have healthy white roots, no galls, tops very healthy, strong stems. Largest tuber 4cm. A wilted plant from paddock shows typical Rhizoc symptoms plus some late blight..
31 Dec 12	60m plant count shows 3.4% gaps/small plants. Small marked plants are about half the size of their big neighbours. Rhizoc infected plants are identifiable through wilting tops.
14 Jan 13	Crop near full canopy but only diseased plants have collapsed so far. Small marked plants range from 30-50% smaller (mean = 56%) than the large plants. Smaller plants sometimes same height as big ones but are less vigorous. Rhizoc cracking on underground stems.
28 Jan 13	Full canopy yield sample taken (8 plants). Lumpy crop, some tall plants. Some plants collapsed and yellowing – older plants? Big fathen and nightshade plants competing with crop. Leaf vein yellowing in upper part of a few plants – herbicide still? Brown lesions and cracking present on underground stems.
12 Feb 13	Solid even green canopy, odd disease plant visible (a lot going on underneath this as with most crops?). Marked 6 diseased plants for harvest at crop maturity. No root galls on 4 plant health-check sample, 5 stems healthy, 9 stems have brown lesions, root systems moderately diseased. No lesions on or in tubers.
18 Feb 13	43 diseased plants visible in random 60m of row. These have severe stem rot, leaf curl and wilting. 8 random plants have no root galls. Weediest site of all PYG crops. No disease on upper foliage.
27 Feb 13	Full canopy-senescence yield sample taken (8 plants). Moved PYG plot to avoid weeds. Crop yellowing evenly. At least 47 diseased plants visible in random 60m. From the 8 plant sample, 1 plant was dead, 1 very small and 3 stems were dead. No root galls on 4 health-check plants tested. 14 stems were healthy 16 stems had brown lesions, 2 very severe.
14 Mar 13	Yellowing crop, very weedy. Leaf sample taken for virus assay. No root galls found on 4 health-check plants, 10 healthy stems, 10 stems with brown lesions, 3 dead stems. No powdery scab on tubers.
25 Mar 13	Final harvest in yield gap plot (4 rows by 2.5m). From this, 22 stems were healthy, 60 had brown lesions and 51 were dead.

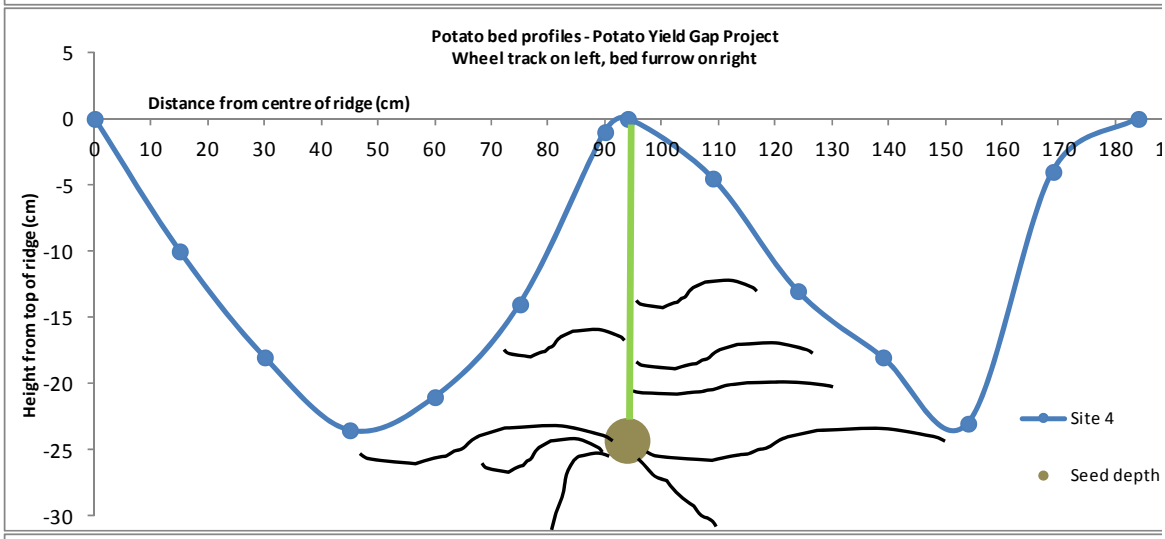
Appendix VI – Potato bed and root profiles for each crop

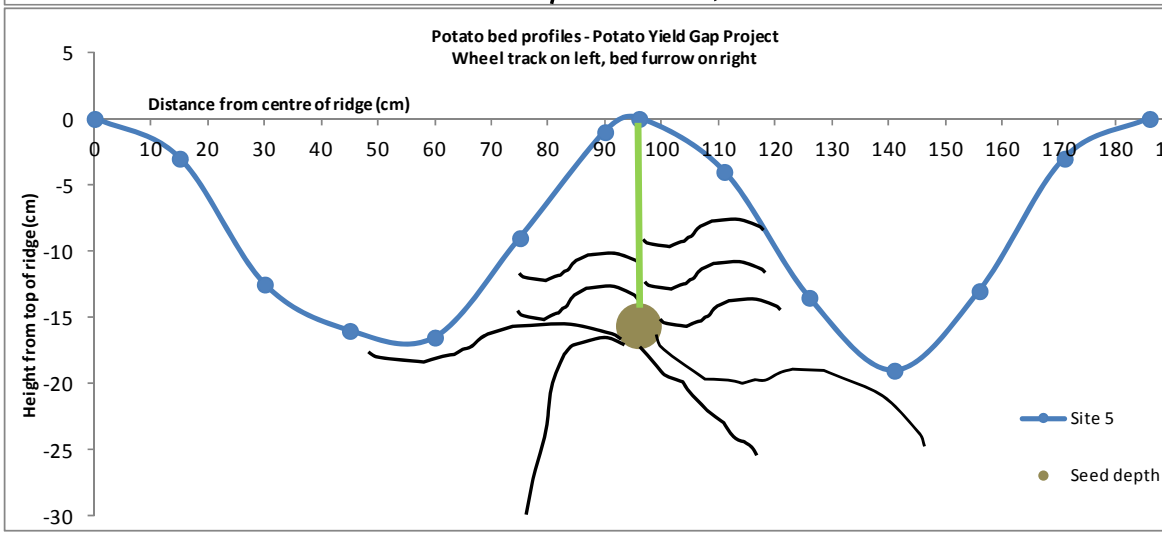
Explanation of graphs: Potato bed profiles, wheel track on left, bed furrow on right. On the y axis, zero is the top centre of one ridge. Seed tuber position is denoted by the brown circle, the green vertical line represents the underground stem. The black wavy lines represent root vigour, direction and extent. Two roots denotes very poor root growth, 4 roots poor root growth, 6 roots good root growth, 8 roots very good root growth and 10 roots excellent root growth. The solid red line denotes a compaction zone (thinner red line is a less severe compaction zone, the dotted red line shows breaks in the zone made by cultivation equipment). No red line indicates little or no root restriction was measured.

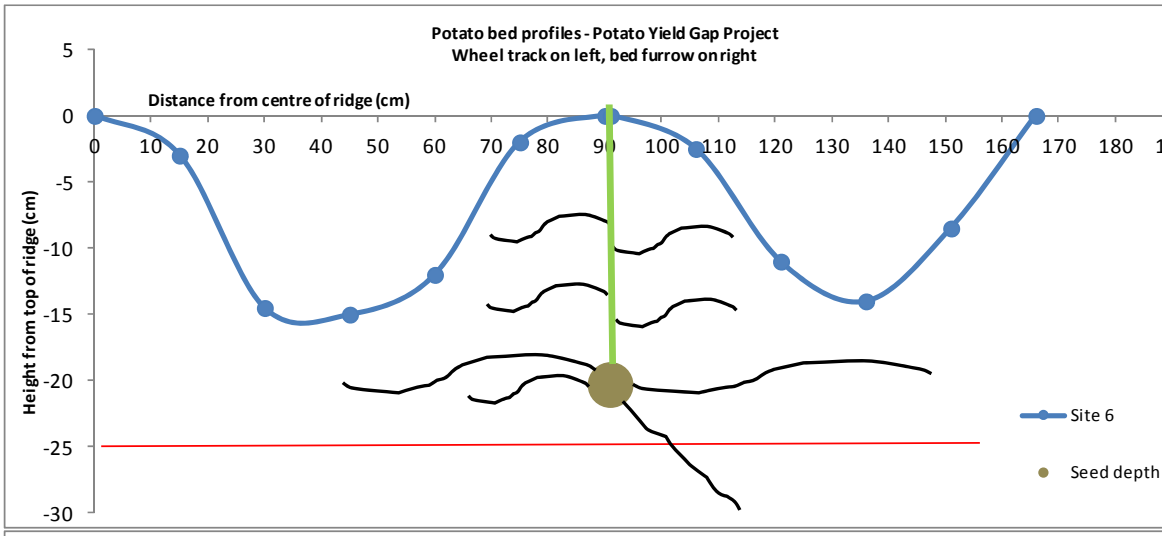


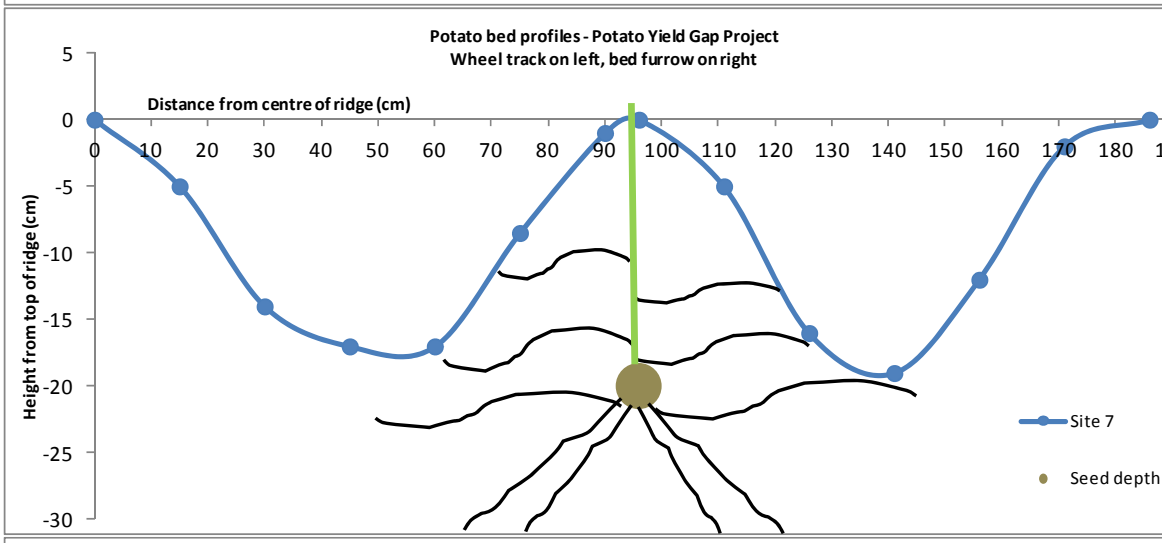


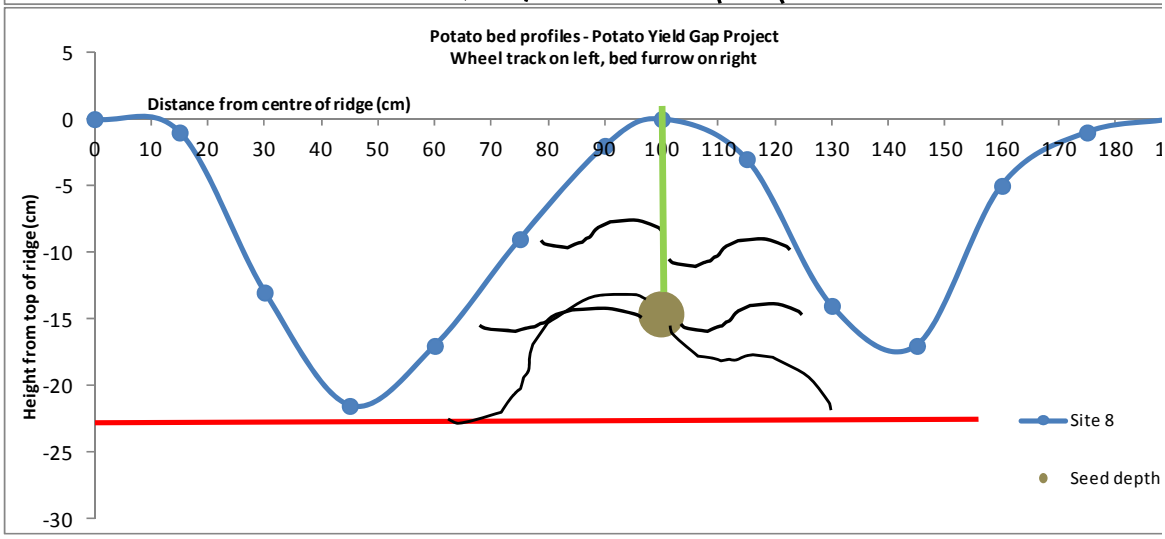


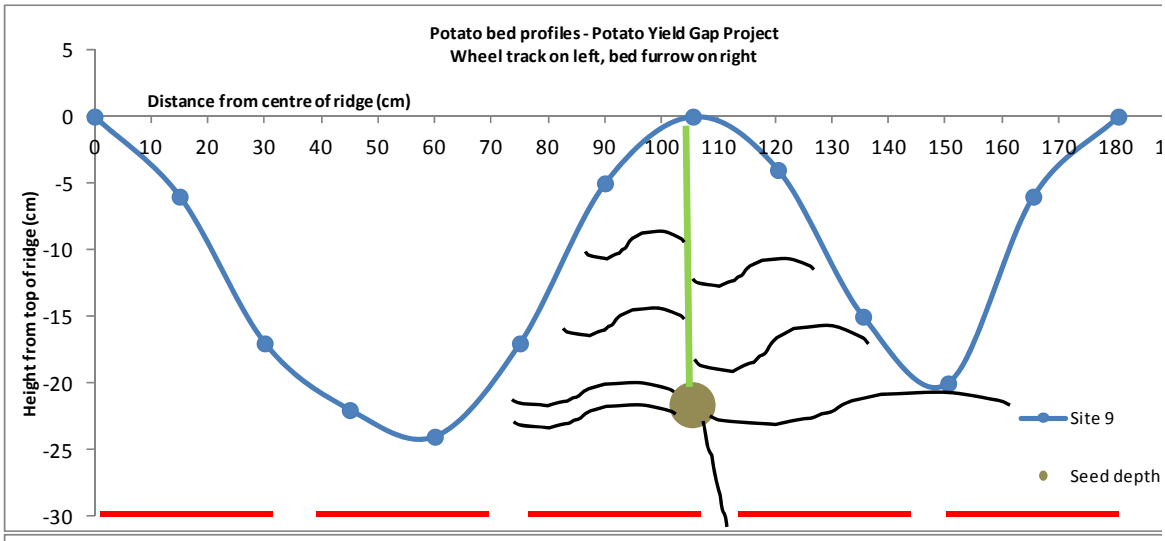


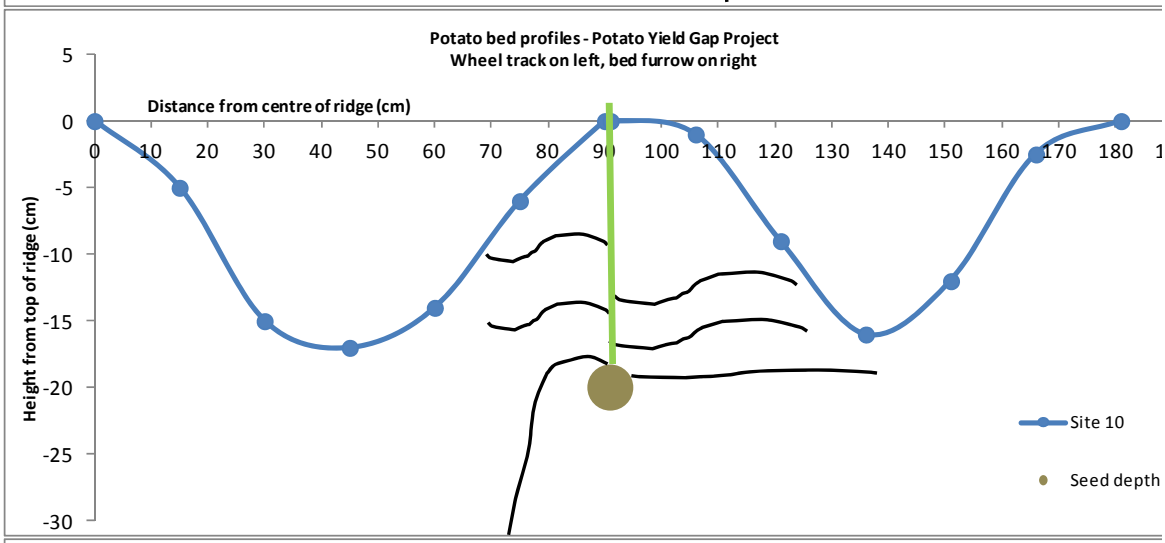


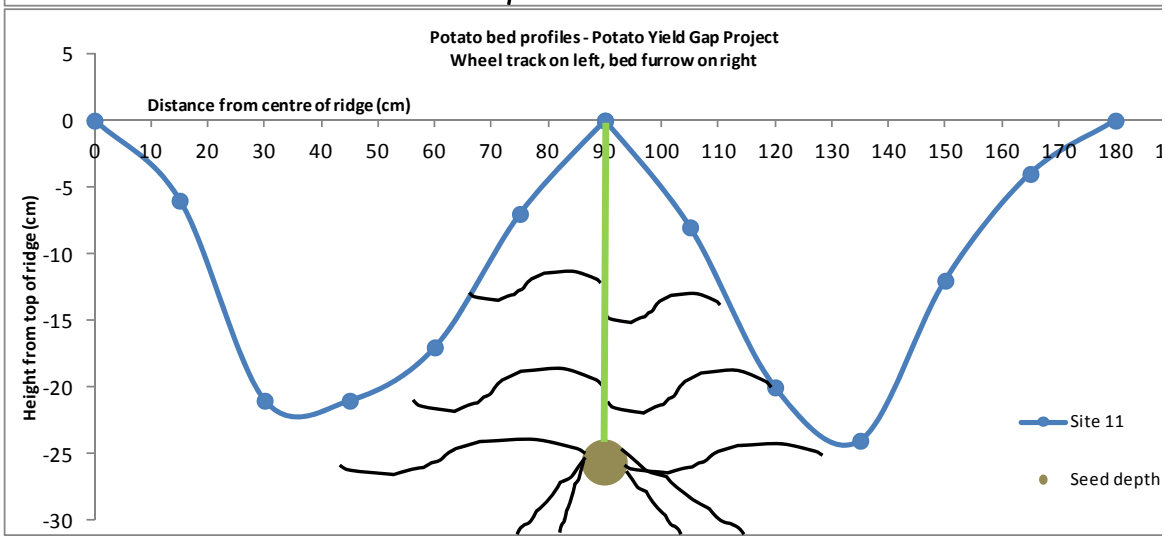






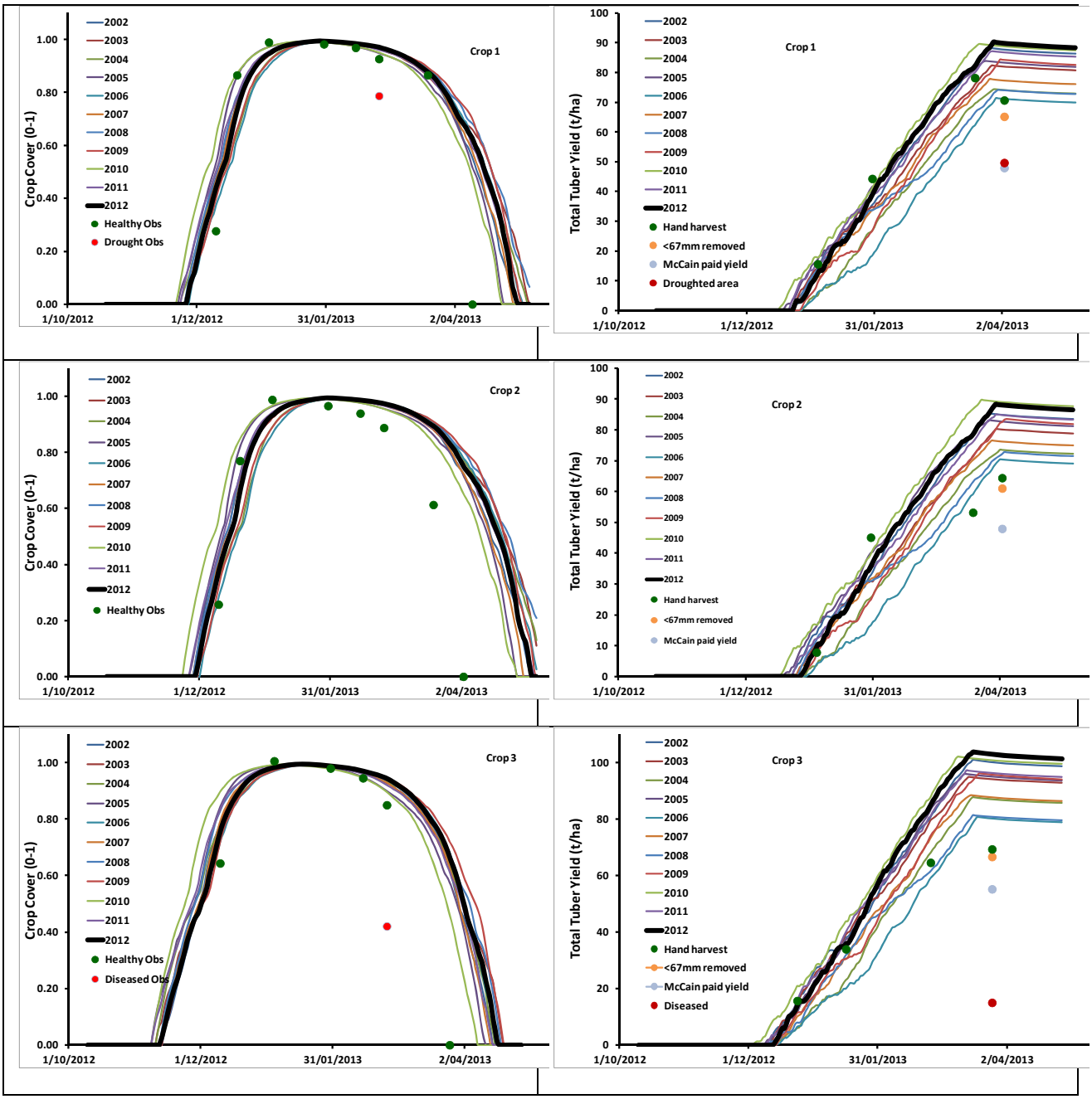


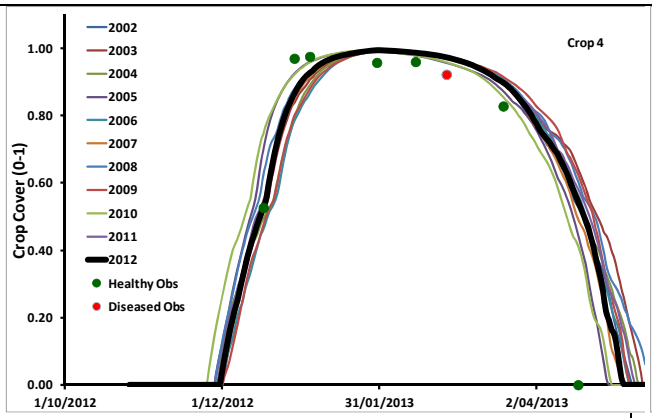


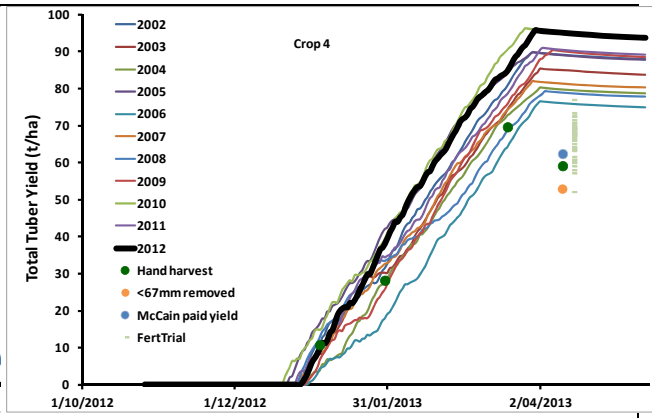


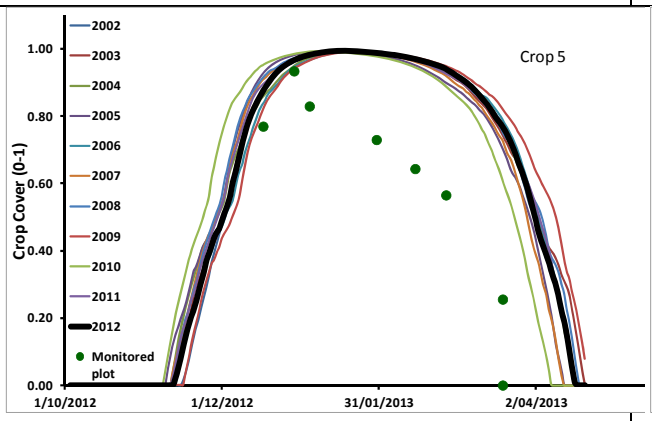
Appendix VII – Modelled and measured crop cover and tuber yield.

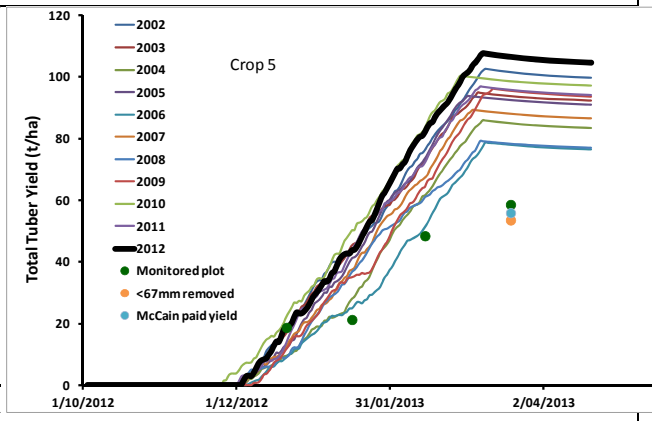
Modelled crop cover individually plotted for years 2002–12 (coloured lines with 2012–13 represented by the heavy black line). Complete crop cover is achieved at a value of about 0.8 on the vertical axis. Canopy cover that was measured in the monitored plot is represented by the green circles; modelled (coloured line/black line) and measured (green circles) tuber yield accumulation. The orange circle represents measured plot yield minus the undersized tuber fraction and the blue circle is paid paddock yield. Where fertiliser trials were carried out, individual plot yields (36 at each site) are shown by the coloured bars.

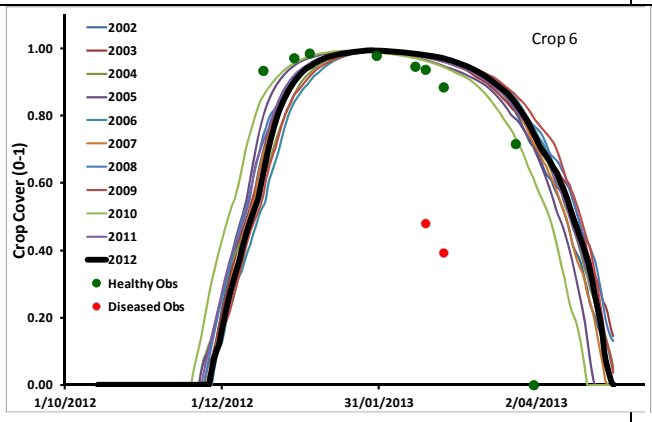


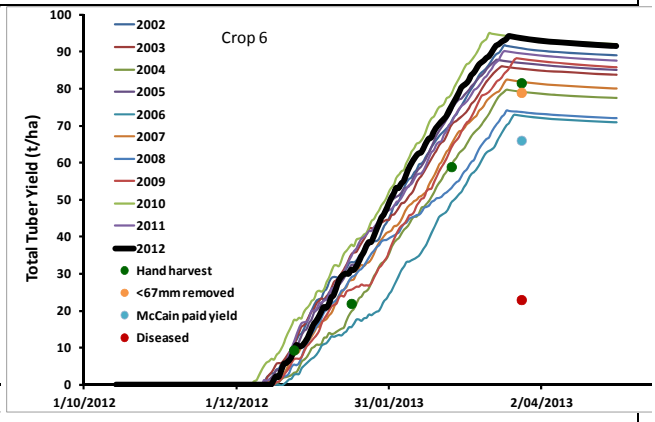


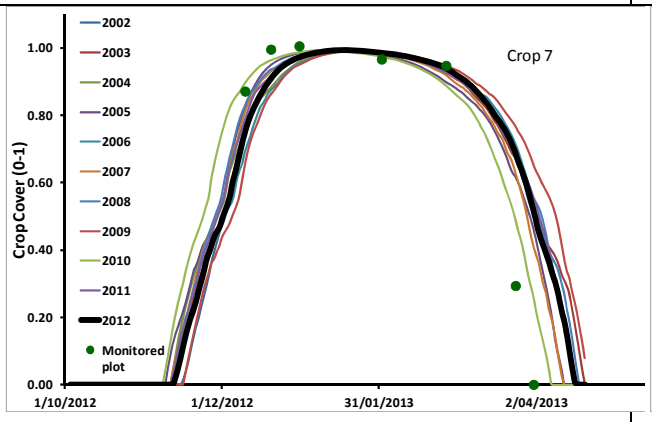


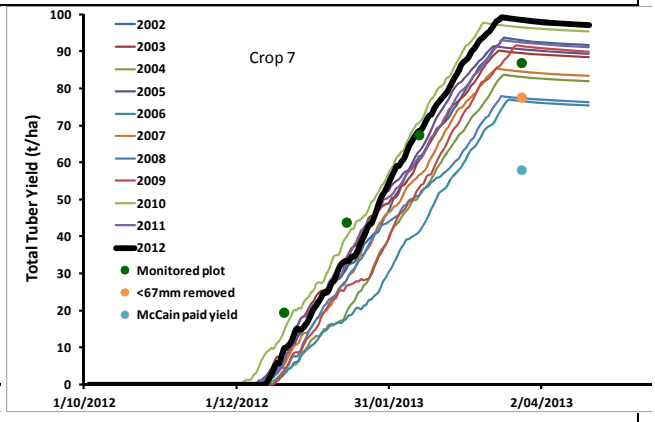


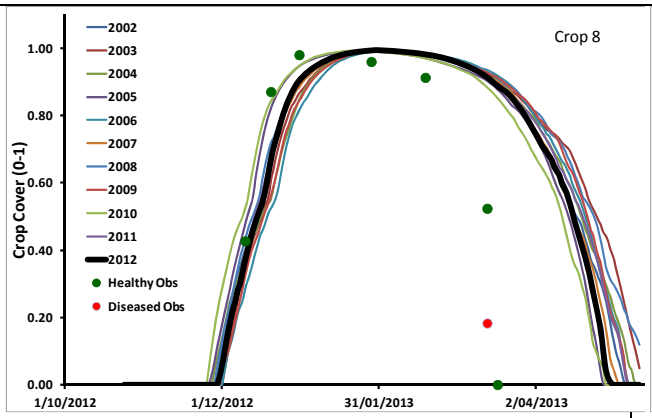


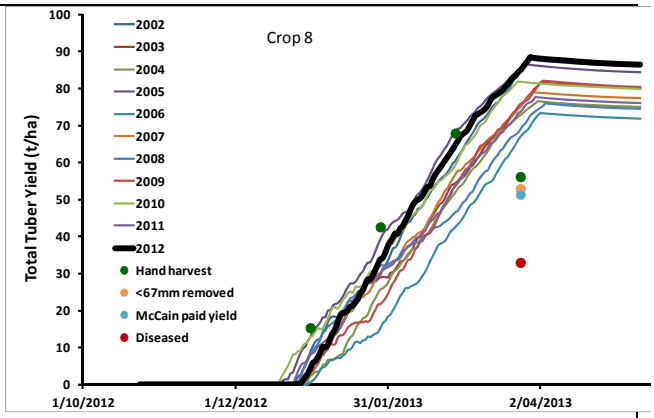


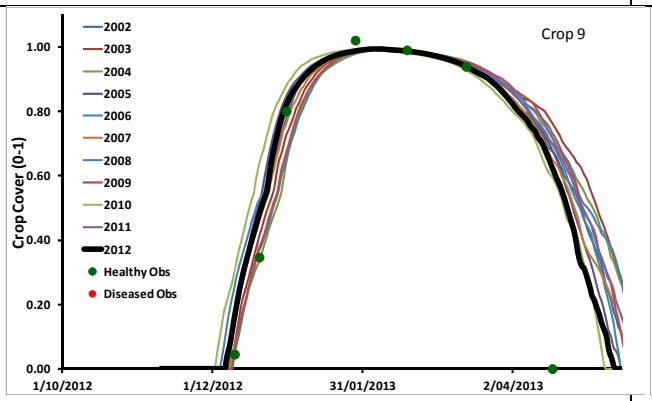


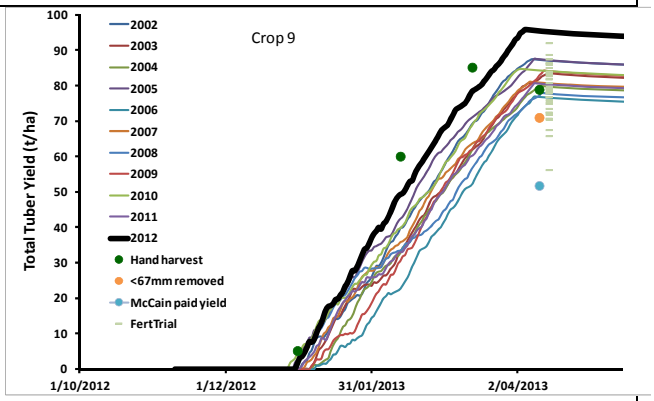


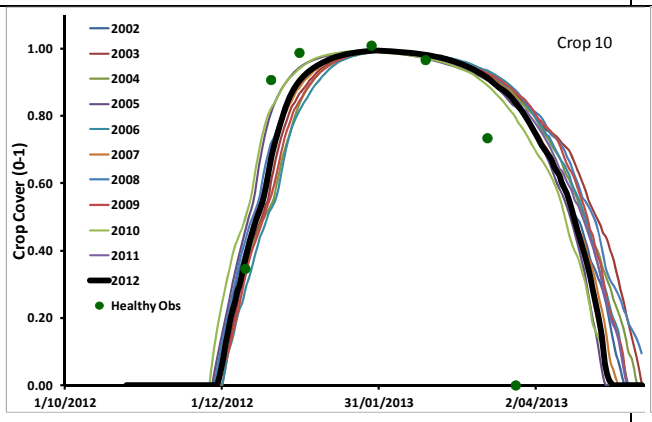


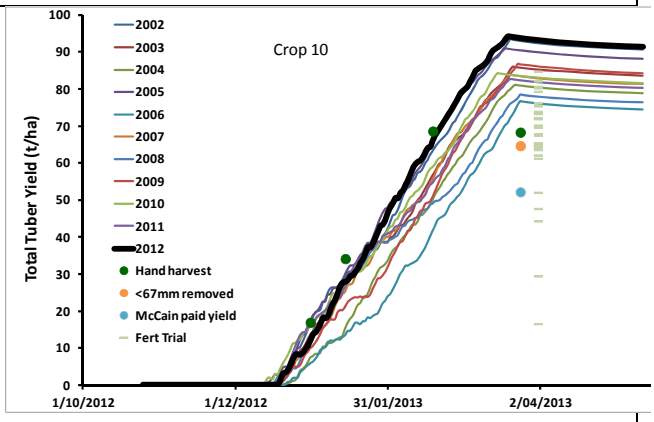


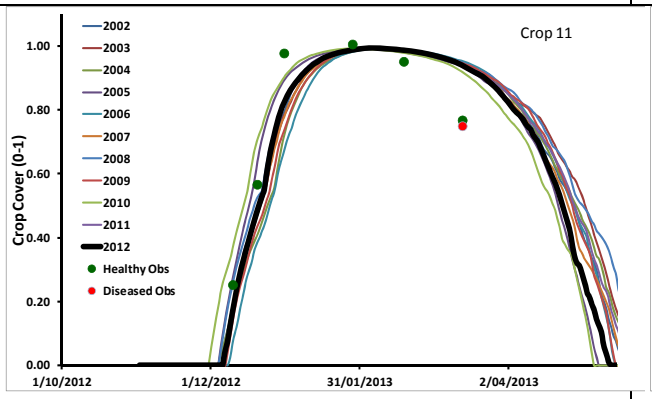


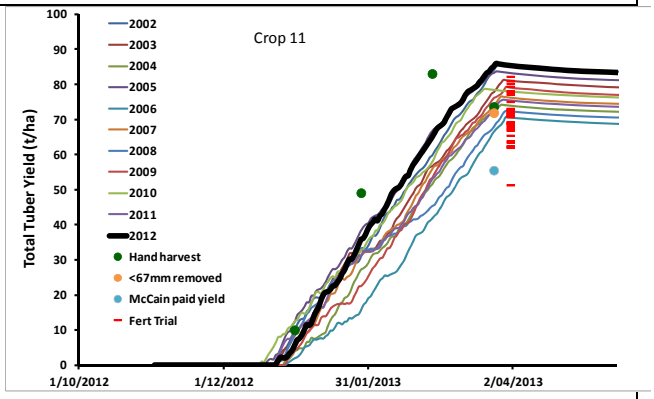












Appendix VIII – A sumary of fungicide and insecticide management for each crop.

Crops 1 and 2

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
19 Oct		Amistar Nebijin	azoxstrobin flusulfamide	broad spectrum powdery scab	Actara	thiamethoxam	aphids	
14 Nov	Bruno Magister Sencor Preeglone Linflo Roundup							LI700 wetting
18 Dec		Nando	fluazinam	early blight late blight white mould				Epsom salts (MgSO4)
22 Dec		Nando Amistar Mancozeb	fluazinam azoxstrobin mancozeb	early blight late blight white mould				
3 Jan		Reason Mancozeb	fenamidone mancozeb	early blight late blight	Movento	spirotetramat	t/p psyllid	

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
11 Jan		Pristine Mancozeb	pyraclostrobin + boscalid mancozeb	early blight late blight				
22 Jan		Pristine, Mancozeb Emperor	pyraclostrobin + boscalid mancozeb tebuconazole	early blight late blight	Chess	pymetrozine	aphids	AQ-K
7 Feb		Mancozeb Dyfen	mancozeb difenconazole	late blight early blight				Urea 10 kg/ha, AQ-K, Inner-G*
15 Feb		Barrachlor Mancozeb	chlorothalonil mancozeb	early blight late blight				Urea 10 kg/ha
23 Feb		Mancozeb Dyfen	mancozeb difenconazole	late blight early blight				Urea 10 kg/ha
1 Mar					Tripsol	acrinathrin + abamectin	t/p psyllid	
4 Mar		Mancozeb Dyfen	mancozeb difenconazole	late blight early blight				Urea 10 kg/ha
11 Mar		Mancozeb Thalonil	mancozeb chlorothalonil	early blight late blight				
10 Apr	Reglone							

*InnerG - apparently “contains micronutrients, vitamins, enzymes, and stimulants to achieve more growth and balance in the plant”. http://www.intbiosysinc.com/fnp.php

Crop 3

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar 2l/ha in furrow						
2 Nov 12	Afalon Bruno Metzin Magister Glyphosate				Agpro Green**			
1 Dec 12		Pinnacle Emperor Promanz	fluazinam tebuconazole mancozeb	early blight late blight				
17 Dec 12		Pinnacle Amistar	fluazinam azoxystrobin	early blight late blight	Movento	spirotetramat	t/p psyllid	
24 Dec 12		Reason Promanz	fenamidone mancozeb	early blight late blight				
28 Dec 12		Promanz Pristine	mancozeb pyraclostrobin + boscalid	early blight late blight				
7 Jan 13		Promanz Barrack	mancozeb chlorothalonil	early blight late blight	Chess	pymetrozine	aphids	
12 Jan 12		Promanz Pristine	mancozeb pyraclostrobin +	early blight late blight				

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
			boscalid					
9 Jan 13		Score Barrack	difenconazole chlorothalonil	early blight	Oberon	spiromesifen	t/p/psyllid	
12 Jan 13					Movento	spirotetramat	t/p psyllid	
21 Jan 13		Score Promanz	difenconazole mancozeb	early blight late blight				
30 Jan 13		Score Barrack	difenconazole chlorothalonil	early blight late blight				
4 Feb 13					Oberon	spiromesifen	t/p/psyllid	
6 Feb 13		Promanz Barrack	mancozeb chlorothalonil	early blight late blight				
21 Feb 13		Promanz Barrack	mancozeb chlorothalonil	early blight late blight				
25 Feb 13		Thalonil Promanz	chlorothalonil mancozeb	early blight late blight	Methafos Agpro	methamidophos	aphids tubermoth	Big Spread Organo***
7 Mar 13		Penncozeb	mancozeb	early blight late blight	Methafos	methamidophos	aphids tubermoth	
3 Apr 13	Reglone							

**Organic insect repellent, ***Organosilicone

Crop 4

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
11 Dec		Nando	fluazinam	early blight late blight				Epsom salts (Mg SO_4)
19 Dec		Shirlan Promanz	fluazinam mancozeb	early blight late blight				Epsom salts (Mg SO_4)
29 Dec		Revus Promanz	mandipropamid+ difencoazole mancozeb	early blight late blight				
7 Jan		Reason Promanz	fenamidone mancozeb	early blight late blight				
16 Jan		Nando Promanz	fluazinam mancozeb	early blight late blight	Chess	pymetrozine	aphids	“Solupotash”
30 Jan		Promanz Amistar	mancozeb azoxystrobin	early blight late blight broad spectrum	Oberon	spiromesifen	t/p/psyllid	“Solupotasse”

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
11 Feb		Promanz	mancozeb	late blight				“Emperor Copper”
		Difen	difenconazole	early blight				
		Amistar	azoxystrobin	broad spectrum				

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
19 Feb		Pencozeb	mancozeb	late blight	Tripsol	acrinathrin + abamectin	t/p psyllid	Urea (25 kg / ha)
		Dyfen	difenconazole	early blight				
20 Feb								

Crop 5

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
Late Sept	Sencor, linuron, bladex							
10 Dec								Epsom salts**** ($MgSO_4$) 5kg/ha
19 Dec		Reason Promanz	fenamidone mancozeb	early blight late blight	Movento	spirotetramat	t/p psyllid	
28 Dec		Reason Promanz	fenamidone mancozeb	early blight late blight				
4 Jan		Balear Promanz	chlorothalonil mancozeb	early blight late blight	Chess	pymetrozine	aphids	
16 Jan		Score Promanz	difenconazole mancozeb	early blight late blight				Solupotasse[#] 5kg/ha
28 Jan		Promanz Barrack	mancozeb chlorothalonil	early blight late blight				AQ-K[#] 0.4l/ha
7 Feb		Dyfen Promanz	difenconazole mancozeb	early blight late blight				Solupotasse
19 Feb		Dyfen	difenconazole	early blight				Urea 25kg/ha

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Penncozeb	mancozeb	late blight				
20 Feb					Tripsol,			
28 Feb		Bravo Penncozeb	chlorothalonil mancozeb	early blight late blight	Methafos	methamidophos	aphids tubermoth	Urea 25kg/ha
22 Apr	Reglone							

****According to : http://www.epsomsaltcouncil.org Epsom salts –magnesium sulphate – “helps seeds germinate, makes plants grow bushier, produces more flowers, increases chlorophyll production and deters pests, such as slugs and voles. It also provides vital nutrients to supplement your regular fertilizer”

[#] Both AQ-K and Solupotasse “helps the uptake of K”

Crop 6

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
5 Nov	Afalon, Bruno, Glyphosate, Sencor							
11 Dec	Fusilade	Nando	fluazinam	late blight				Crop near flowering
19 Dec		Pinnacle, Promanz	Fluazinam mancozeb	early blight late blight				
27 Dec		Promanz, Reason	mancozeb fenamidone	early blight late blight	Movento	spirotetramat	t/p psyllid	
6 Jan		Promanz, Mirador	mancozeb azoxystrobin	early blight late blight broad spectrum				
14 Jan		Promanz Barrack	mancozeb chlorothalonil	early blight late blight	Chess	pymetrozine	aphids	
18 Jan		Promanz Mirador	mancozeb azoxystrobin	early blight late blight broad spectrum				
1 Feb		Dyfen Promanz	difenconazole mancozeb	early blight late blight	Oberon	spiromesifen	t/p/psyllid	

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
6 Feb								Super Sprout Stop
9 Feb		Dyfen Promanz	difenconazole mancozeb	early blight late blight				AQ-K
18 Feb		Penncozeb Barrack	mancozeb chlorothalonil	early blight late blight				KTS[##] 3 l/ha
27 Feb		Dyfen, Penncozeb	difenconazole mancozeb	early blight late blight	Methafos	methamidophos	aphids tubermoth	
7 Mar		Penncozeb, Thananil	mancozeb chlorothalonil	early blight late blight	Methafos	methamidophos	aphids tubermoth	
27 Mar	Reglone							

[##] KTS is for potassium and sulphur supply (foliar)

Crop 7

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
15 Oct	Bruno Linex Sencor Transorb x							
28 Nov		Nando	fluazinam	late blight				
6 Dec		Nando Promanz	fluazinam mancozeb	early blight late blight				
15 Dec		Promanz Reason	mancozeb fenamidone	early blight late blight				
22 Dec		Promanz Reason	mancozeb fenamidone	early blight late blight	Movento	spirotetramat	t/p psyllid	
3 Jan		Promanz Amistar	mancozeb azoxystrobin	early blight late blight broad spectrum				
14 Jan		Promanz Amistar	mancozeb azoxystrobin	early blight late blight broad spectrum	Chess	pymetrozine	aphids	
24 Jan		Promanz	mancozeb	early blight				AQ-K

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Score	difenconazole	late blight				
2 Feb		Promanz	mancozeb	early blight				AQ-K
		Barrack	chlorothalonil	late blight				
11 Feb		Promanz	mancozeb	early blight	Oberon	spiromesifen	t/p/psyllid	AQ-K
		Dyfen	difenconazole	late blight				
20 Feb		Promanz	mancozeb	early blight				KTS
		Barrack	chlorothalonil	late blight				
28 Feb		Penncozeb	mancozeb	early blight	Methafos	methamidophos	aphids	KTS
		Dyfen	difenconazole	late blight			tubermoth	
9 Mar		Super Manz	mancozeb	early blight	Methafos	methamidophos	aphids	
		Thananil	chlorothalonil	late blight			tubermoth	
28 Mar	Reglone							

Crop 8

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
14 Nov	Sencor Bruno Linex Magister Glyphosate							
21 Dec		Nando Mancozeb	fluazinam mancozeb	early blight late blight				MgSO4 5 kg/ha
27 Dec		Pinnacle Mirador Mancozeb	fluazinam azoxystrobin mancozeb	early blight late blight broad spectrum	Movento	spirotetramat	t/p psyllid	
7 Jan		Pinnacle Mancozeb	fluazinam mancozeb	early blight late blight				MgSO4
16 Jan		Pristine Mancozeb	pyraclostrobin + boscalid mancozeb	early blight late blight	Chess	pymetrozine	aphids	Solutpotasse
20 Jan		Pristine Mancozeb	pyraclostrobin + boscalid mancozeb	early blight late blight				Solutpotasse
7 Feb		Kocide	copper hydroxide	early blight	Oberon	spiromesifen	t/p/psyllid	AQ-K

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Barrack	chlorothalonil	late blight				
19 Feb		Dyfen	difenconazole	early blight	Oberon	spiromesifen	t/p/psyllid	
		Mancozeb	mancozeb	late blight				
28 Feb		Dyfen	difenconazole	early blight				Urea 10kg/ha
		Mancozeb	mancozeb	late blight				
6 Mar		Dyfen	difenconazole	early blight				Urea 7kg/ha
1 Apr	Reglone							

Crop 9

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
11 Oct	Roundup Pulse							
22 Nov	Sencor Bruno Linex Magister							
29 Nov	Preeglone							
27 Dec		Pinnacle	fluazinam	early blight late blight				
5 Jan		Promanz Mirador Nando	mancozeb azoxystrobin fluazinam	early blight late blight broad spectrum				
18 Jan		Manzate Reason	mancozeb fenamidone	early blight late blight	Chess	pymetrozine	aphids	
24 Jan					Movento	spirotetramat	t/p psyllid	
30 Jan		Pristine Penncozeb	pyraclostrobin + boscalid mancozeb	early blight late blight				

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
12 Feb		Pristine Penncozeb	pyraclostrobin + boscalid mancozeb	early blight late blight				
22 Feb		Promanz Dyfen	mancozeb difenconazole	early blight late blight	Oberon	spiromesifen	t/p/psyllid	
5 Mar		Promanz Dyfen	mancozeb difenconazole	early blight late blight				
16 Mar		Promanz Dyfen	mancozeb difenconazole	early blight late blight				
Early May	Reglone							

Crop 10

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
15 Nov	Bruno Magister Linex Sencor Glyphosate							
13 Dec		Nando	fluazinam	early blight late blight				
23 Dec		Mirador Promanz Pinnacle	azoxystrobin mancozeb fluazinam	broad spectrum early blight late blight	Movento	spirotetramat	t/p psyllid	
7 Jan		Promanz Reason	mancozeb fenamidone	early blight late blight				
22 Jan		Promanz Reason	mancozeb fenamidone	early blight late blight				
28 Jan					Movento	spirotetramat	t/p psyllid	
12 Feb		Promanz Thalonil	mancozeb chlorothalonil	early blight late blight				
22 Feb								Super Sprout Stop

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
28 Feb		Penncozeb Dyfen	mancozeb difenconazole	early blight late blight	Chess	pymetrozine	aphids	
5 Mar					Oberon	spiromesifen	t/p/psyllid	
12 Mar		Penncozeb Thalonil	mancozeb chlorothalonil	early blight late blight				
15 Mar	Reglone							

Crop 11

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
		Amistar in furrow						
17 Nov	Afalon Bruno Metzin Magister Glyphosate				Agpro Green**			
14 Dec		Pinnacle	fluazinam	early blight late blight				
21 Dec		Pinnacle Emperor Promanz	fluazinam tebuconazole mancozeb	early blight late blight				
28 Dec		Promanz	mancozeb	early blight late blight				
5 Jan		Promanz Pristine	mancozeb pyroclostrobin	early blight late blight broad spectrum				
10 Jan		Score Promanz	difenconazole mancozeb	early blight late blight	Movento	spirotetramat	t/p psyllid	
15 Jan								Headland Emperor[# ##] 0.4l/ha

Date	Herbicides	Fungicides	a.i.	Target disease	Insecticides	a.i.	Target pest	Other
21 Jan		Score Promanz	difenconazole mancozeb	early blight late blight	Movento	spirotetramat	t/p psyllid	Big Spread Organo
30 Jan		Promanz Barrack	mancozeb chlorothalonil		Chess	pymetrozine	aphids	
4 Feb		Score Promanz	difenconazole mancozeb	early blight late blight				
9 Feb					Oberon	spiromesifen	t/p/psyllid	
13 Feb		Thalonil	chlorothalonil		Agpro Green			
19 Feb		Thalonil	chlorothalonil		Agpro Green			
1 Mar		Thalonil Promanz	chlrorthalonil mancozeb	early blight late blight	Agpro Green			
7 Mar		Penncozeb	mancozeb	early blight late blight	Methafos			
27 Mar	Reglone							

Headland Emperor is copper nitrate, used to supply copper as a trace element

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