Crop & Food Research Confidential Report No. 1986

Contributions to an understanding of sweetpotato brown centre disorder

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July 2007

A report prepared for
Horticulture New Zealand & AgMARDT

Copy 20 of 20

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1 Executive summary

This is the final report for a research project examining the causes of the sweetpotato storage root disorder brown centre (BC). The disorder causes a light to dark brown internal necrosis that is present in roots at harvest, but shows no external symptoms. BC became generally prevalent in New Zealand with the increasing use of cultivar Owairaka Red from the 1950s.

The hypothesis that best fits the available data is that BC is caused by excessive canopy growth and a decreasing rate of photosynthesis, so that carbohydrate is remobilised from storage roots to maintain the canopy. There is robust data indicating that the BC disorder is cultivar-dependent and is not caused by a pathogen, due to tissue chilling injury or influenced by boron or calcium availability. It occurs consistently in harvests from mid-April and is modified by soil nitrogen levels.

Under the current hypothesis, the focus for BC management should be on the degree of crop canopy growth and canopy condition. Soil nitrogen level may be relatively easily managed, but it is only one of a number of canopy-limiting factors. Under growing conditions that promote a super-optimal canopy, high nitrogen levels appear to cause an increase in BC incidence through the canopy becoming a competitive carbohydrate sink. When the development of a super-optimal canopy is inhibited, the addition of nitrogen still promotes canopy longevity and efficiency, but with a relatively reduced requirement for carbohydrate remobilisation and therefore reduced BC incidence.

While the data fits the current hypothesis, the interplay of contributing factors is to be proven particularly in demonstrating the relationship between canopy-intercepted radiation and the time of BC onset.

2 Introduction

This is the final report for a research project examining the physiological mechanism that gives rise to the sweetpotato storage root disorder brown centre (BC). A comprehensive understanding of the disorder's underlying causes would allow better management of the crop. While this project makes a contribution to such an understanding, there are still significant outstanding questions. This report presents an overview of current knowledge of the disorder, with the intent to provide a basis for future crop management and research decisions.

The BC symptoms observed in sweetpotato roots have been described as light to dark brown internal necrosis (cell death), particularly evident if roots are cut in half along their length. The necrotic tissue occurs in the pith region of the root, but not in the cortical phloem tissue (relatively thin outer flesh layer). The disorder is present in roots at harvest and does not develop in sound roots during storage. Severe symptoms can result in the development of cavities within the root. However, even slightly affected roots may be inedible due to a 'woody' texture and the development of objectionable flavours. The disorder does not have a pathological cause, as evidenced by graft tests, and the incidence rate in plants derived from healthy and affected seed roots (Nielsen & Harrow 1966: Wood & Schappi 1984).

The earliest records of BC suggest the root disorder only occurred in specific sweetpotato cultivars and became generally prevalent with the increasing use of cultivar Owairaka Red from the 1950s (Gillard 1955; Coleman 1969). Owairaka Red and a number of related lines were selected as naturally derived mutants from an original 1850s introduction, Waina, which is also prone to develop BC. The disorder has became a more pressing commercial issue with the greater hectarage of Owairaka Red grown today. Owairaka Red itself or the group of characteristics it represents would be difficult to displace as it is now considered a well established traditional cultivar, having been of prime importance on the marketing landscape since the 1950s. It has been demonstrated that susceptibility to BC is not limited to Owairaka Red and related germplasm. Clones derived from segregating Asian and North American botanical seed populations were evaluated in New Zealand and found be susceptible to BC. But, when grown under the same conditions, these clones did not produce disorder symptoms with the same severity or frequency as that of Owairaka Red. The BC disorder has not been recorded in international literature, possibly due to the cultivars grown. For example, the BC disorder has not been observed in the New Zealand commercial cultivars Toka Toka Gold or Beauregard, although large hectarages have been grown over many years.

It has been well established that the BC disorder is only found in roots harvested from approximately mid-April. Even from first records it was noted that BC was found in crops where harvesting had been delayed due to heavy wet soil conditions (Gillard 1955). Based on roots examined sequentially in a three-year field study, it was suggested that the disorder could be avoided by

harvesting Owairaka Red crops by mid-April (Wood & Schappi 1984). Experience has indicated that small numbers of BC roots may be found prior to mid-April, but the level of incidence tends to become significant from that point. An early hypothesis suggested that due to this consistent time of occurrence, coincident with cooler temperatures, BC was possibly the result of tissue chilling injury. Sweetpotato roots are subject to chilling injury with cultivar-specific sensitivity. However, tests on harvested Owairaka Red roots indicated that chilling may produce similar but not identical symptoms of tissue browning and hardness on cooking (Lewthwaite et al. 1999). In chilled sweetpotato roots, tissue discolouration is more pronounced near the cambium and vascular bundles, but not in the parenchymatous storage cells where BC can be observed. The relative levels of field BC incidence did not correlate with seasonal temperature differences. Furthermore, even very severe chilling conditions could not produce symptoms of the magnitude seen in field-derived BC. After thorough evaluation of data for the tissue chilling injury hypothesis, it was concluded that it is not the cause of the BC disorder.

Nutrient deficiency effects often contribute to plant tissue discolouration and necrosis, but can be difficult to identify due to interacting factors, temporal or spatial differences and subtle concentration effects. Plant tissue necrosis can be associated with calcium deficiency. However, the application of supplementary soil-incorporated calcium within well watered Owairaka Red field plots did not significantly (P = 0.96) modify the incidence of BC (Lewthwaite et al. 2006). A further hypothesis suggested that BC was the result of boron deficiency, based on records of sweetpotato boron sensitivity, symptom appearance and time of occurrence. The root symptoms of sweetpotato boron deficiency are sometimes referred to as ‘internal brown spot’. These spots are variable in size and occur throughout the flesh, but are more common in the cambial zone near the periphery of the root (Nusbaum 1946). The severity of boron deficiency symptoms varies with cultivar. Boron availability is affected by soil microbial activity on organic matter, with cooler conditions limiting such boron sources. Boron is also readily leached from soils, while increasing soil nitrogen (N) levels are known to reduce boron uptake in plants (Gupta 1979). There is some suggestion that boron is not readily transported within the sweetpotato plant (O’Sullivan et al. 1997). However, foliar boron is successfully applied to mitigate sweetpotato root symptoms in the USA. Interestingly, when supplementary boron was supplied as a foliar spray to Owairaka Red plants in a field trial, there was no significant change (P = 0.77) to BC incidence (Lewthwaite et al. 1999). When supplementary boron was supplied via the soil to Owairaka Red field plots and watered in by overhead irrigation, there was also no significant change (P = 0.75) in BC incidence (Lewthwaite et al. 2006). Consequently, there is no evidence that calcium or boron deficiency is involved in the development of BC symptoms.

Some sweetpotato growers have reported that BC is more common in fields recently out of pasture. Such land commonly has higher levels of (N) than that which has previously grown at least one sweetpotato crop. Soil nutrient analysis of commercial fields has indicated some support for a relationship between N level and BC incidence. A field experiment was conducted to evaluate the effect of increased soil N on root BC incidence. Urea was

applied as a supplementary N source and watered in by overhead irrigation. In this trial the addition of N effectively doubled ($P < 0.001$) the incidence of BC (Lewthwaite et al. 1999). There was no evidence of a foliar-applied boron x N interaction effect on BC incidence ($P = 0.95$). However, the opposite effect was observed when the influence of N was evaluated in a further field trial, where it was found that applying supplementary N halved ($P < 0.001$) the BC incidence (Lewthwaite et al. 2006). In this trial there was no evidence of a soil-applied boron x N interaction effect on BC incidence ($P = 0.71$) or a soil incorporated calcium x N effect ($P = 0.33$).

The hypothesis to be tested in the experiments reported here is that BC is caused by excessive canopy growth and a decreasing rate of photosynthesis. As the canopy ages and solar radiation levels decrease over the harvest period, carbohydrate may be remobilised from storage roots to maintain the canopy, causing localised areas of storage root tissue necrosis. The N effects previously observed in the naturally vigorous cultivar Owairaka Red conform to this hypothesis. In general, increased N levels have been shown to encourage sweetpotato canopy growth, promoting the canopy as a competitive carbohydrate sink (O'Sullivan et al. 1997). However, increased N may also increase leaf longevity, influencing the efficiency of carbohydrate production (Tsuno & Fujise 1965).

3 Experiment 1

Aim: To evaluate the effects of N and shade combinations on brown centre incidence.

3.1 Materials and methods

The soil nutrient levels for a relatively flat Pukekohe Research Centre field site consisting of Patumahoe clay loam were established prior to planting. The site was prepared by broadcasting and incorporating fertiliser (N: 0.00, P: 6.80, K: 15.00, S: 7.40, Mg: 0.00, Ca: 15.40) at 1.28 t/ha prior to moulding. Early season conditions were particularly cold and windy, so large commercial volumes of conditioned Owairaka Red plants were not available until later in the season. Commercially produced sprouts were transplanted into the field under warm still conditions on 4 January 2007, and watered-in with overhead irrigation.

Trial plots were systematically sampled for soil ammonium-N and nitrate-N analysis on 22 February 2007, just prior to applying the first N treatment. A single sample was also collected across the entire trial site, to provide a general indication of nutrient levels (Appendix I). All soil samples were retained in a frozen state until analysis.

There were 28 experimental treatments consisting of various supplementary N and shade combinations (Table 1). The first set of N applications were made on 23 February, the second on 29 March. The first shade treatments were applied on 30 March and the second on 19 April (Appendix II). Nitrogen was supplied as urea (46% N), which was broadcast by hand. Shade

treatments consisted of single thicknesses of frost cloth (30 g/m^2) attached as floating row covers to allow good air and temperature exchange. A LI-COR® Light meter with a Quantum sensor *c*. 5 cm beneath the cloth was used under natural light conditions to measure the reduction in photosynthetically active radiation. The cloth reduced light levels by 30%. The spectral distribution under natural light and the shade cloth were also compared, using an Ocean Optics USB4000 spectrometer.

The entire trial was arranged in an 8 x 14 row and column design. Within the trial there were 4 replicates of the 28 treatment combinations and each replicate consisted of a 4 x 7 row by column sub-block. Therefore, the replicate blocks were laid out in a 2 x 2 spatial arrangement. Individual plots were 4 rows wide by 6 m long, with only the 2 middle rows used for assessment. Individual rows were 0.75 m wide and within-row plant spacing was 0.30 m. The portion of each plot harvested and assessed contained a total of 40 plants, arranged in 2 rows of 20 plants each.

Shade treatments were removed and plant tops mown off on 7 May 2007, then the roots were harvested by a two-row, tractor-mounted harvester. Storage roots of marketable size (2.5 cm diameter or greater) were graded out so that plot weights of marketable and unmarketable grade roots could be recorded. Marketable roots were individually cut in half along their length and assessed for the presence/absence of the brown centre disorder (Appendix III). The data were analysed using the statistical software package GENSTAT™.

*Table 1: Treatment combinations applied in the 2007 season sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red brown centre trial.*

Treatment	1st Nitrogen application kg/ha	2nd Nitrogen application kg/ha	1st Shade application	2nd Shade pplication
1	0	0	0[a]	1[a]
2	50	0	0	1
3	100	0	0	1
4	150	0	0	1
5	200	0	0	1
6	250	0	0	1
7	300	0	0	1
8	0	0	0	0
9	50	0	0	0
10	100	0	0	0
11	150	0	0	0
12	200	0	0	0
13	250	0	0	0
14	300	0	0	0
15	0	0	1	0
16	50	0	1	0
17	100	0	1	0
18	150	0	1	0
19	200	0	1	0
20	250	0	1	0
21	300	0	1	0
22	0	50	0	0
23	0	100	0	0
24	0	150	0	0
25	0	200	0	0
26	0	250	0	0
27	0	300	0	0
28	0	350	0	0

[a]0 denotes absence of a shade treatment, while 1 denotes the presence of shading.

3.2 Results

In February, prior to applying experimental N treatments, the spatial arrangement of base ammonium-N and nitrate-N levels were assessed across the site. Linear regression analysis of ammonium-N levels (Figure 1) showed a significant increasing gradient ($P < 0.001$) across the trial columns, but not along rows ($P = 0.85$). Linear regression analysis of nitrate-N levels (Figure 2) showed no systematic linear gradient across columns ($P = 0.132$) or rows ($P = 0.117$). When these N sources were combined and evaluated by linear regression, the spatial array of soil mineral N levels (Figure 3) showed a significant increase across columns ($P < 0.001$) but not rows ($P = 0.070$). The arrangement of the trial's four replicates, in a two by two array, allowed for these base N trends.

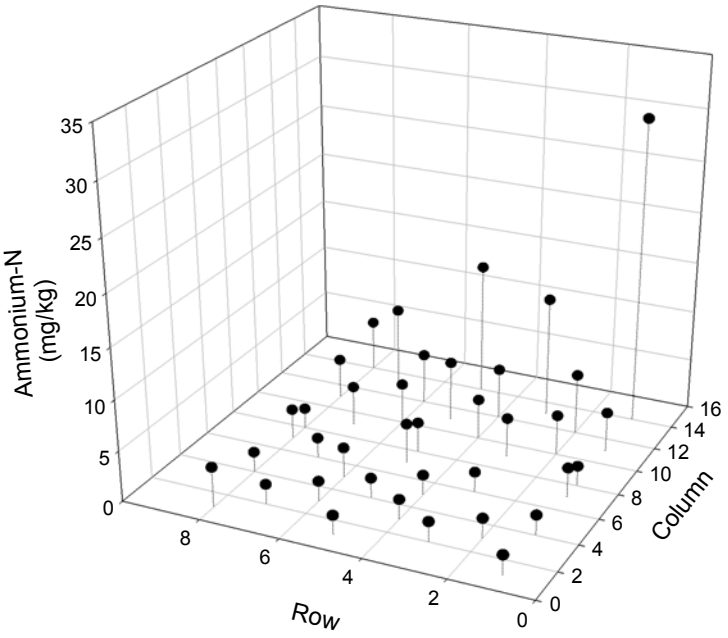

Figure 1: Spatial variation in soil ammonium-N (mg/kg) levels over the trial site prior to application of nitrogen treatments.

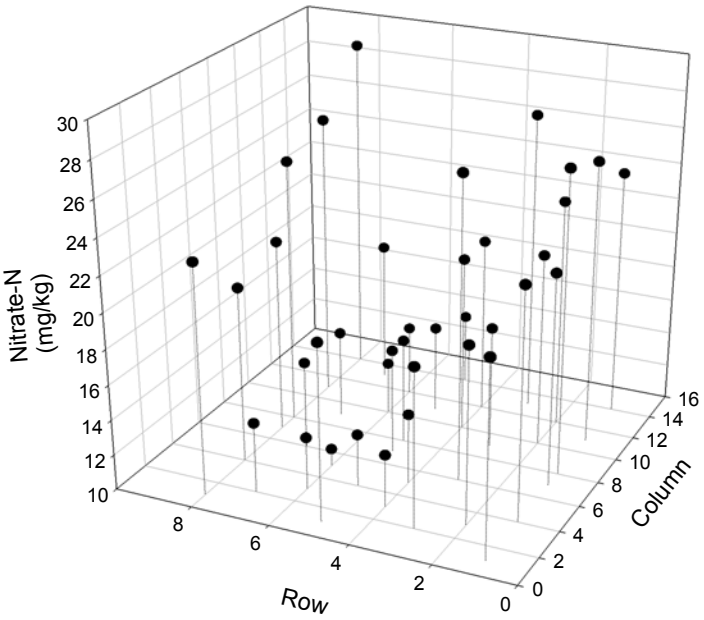

Figure 2: Spatial variation in soil nitrate-N (mg/kg) levels over the trial site prior to application of nitrogen treatments.

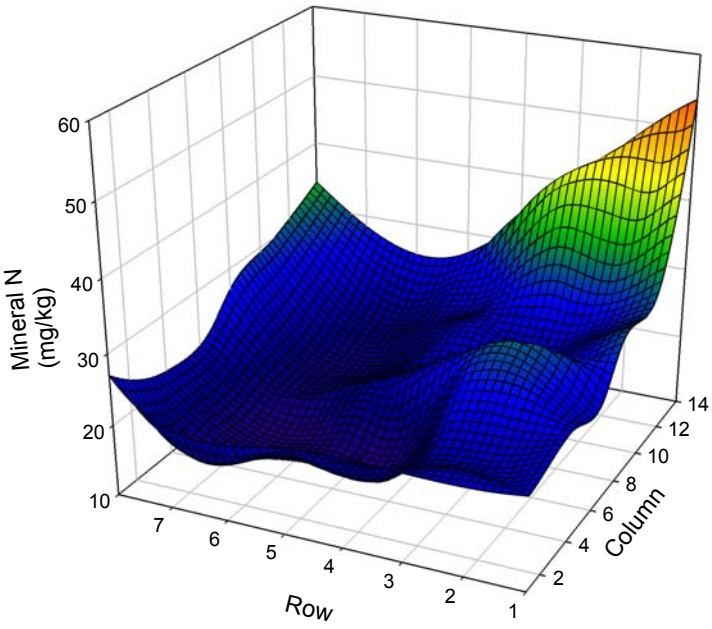

Figure 3: Surface plot showing spatial variation in soil mineral nitrogen (mg/kg) levels (sum of ammonium-N and nitrate-N sources) over the trial site prior to application of nitrogen treatments.

Although natural light levels under the shade cloth treatments were reduced by *c*. 30%, the spectral distribution was not significantly altered (Figure 4).

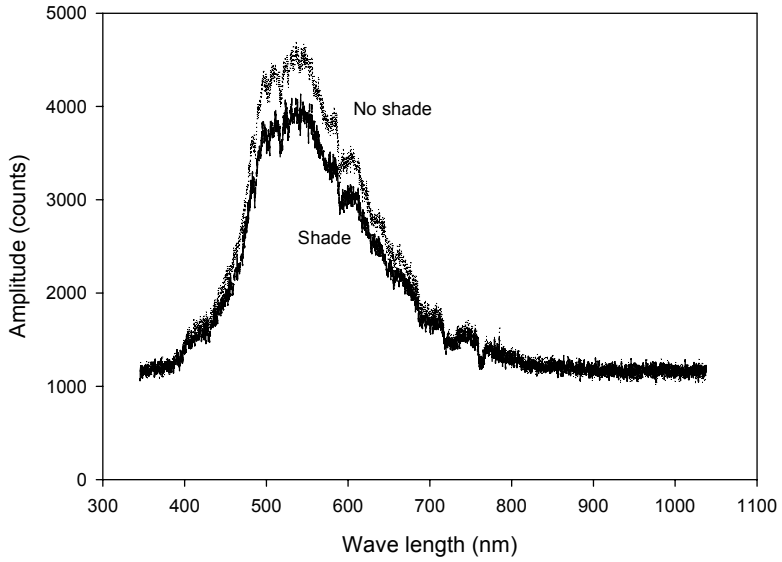

Figure 4: Comparison of spectral distribution under natural lighting and shade fabric, determined by Ocean Optics USB4000 spectrometer.

Conditions were generally dry over the growing season. However, the trial was irrigated to field capacity immediately prior to applying the N treatments and again at a low level (*c*. 15 mm) to incorporate the urea applications on each of the two treatment dates − 23 February and 29 March. Rainfall over March, April and early May was regular but at low volumes (Figure 5).

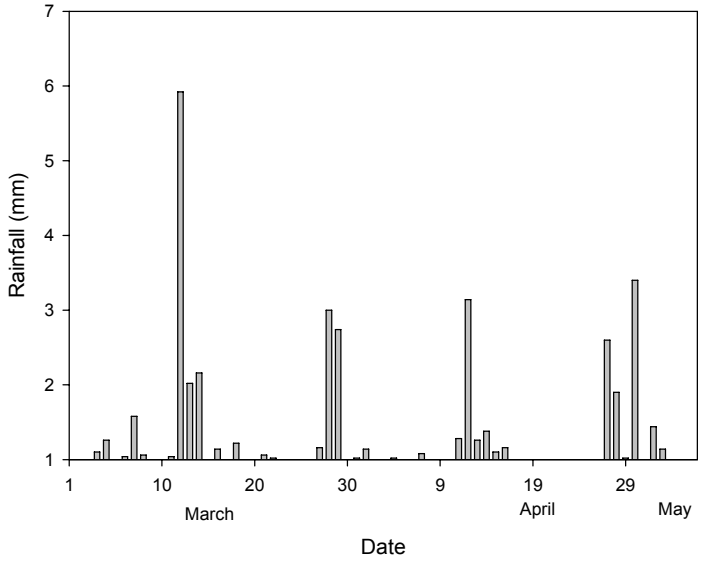

Figure 5: Rainfall (mm) recorded at the Pukekohe Research Center for March, April and early May 2007. Data courtesy of NIWA.

The 2007 growing season remained warm well into May, indicating radiation levels *c*. 6% higher than those observed the previous year (Figure 6).

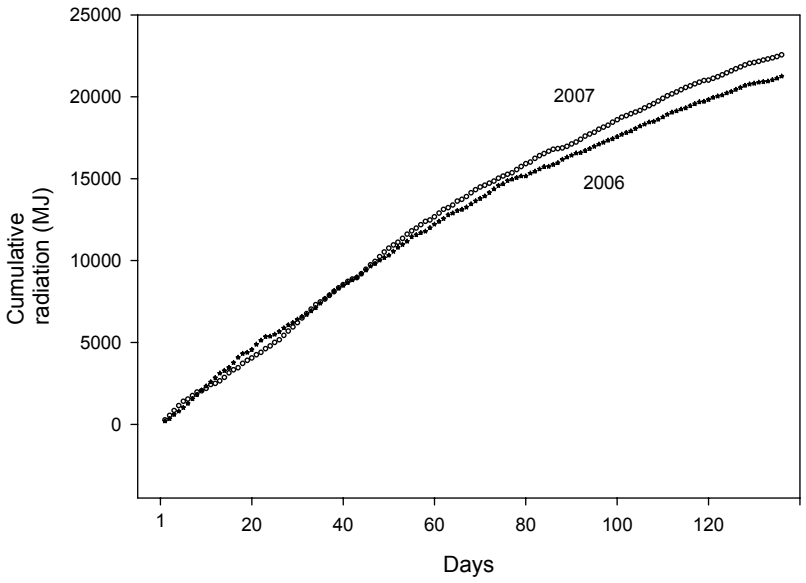

Figure 6: A comparison of cumulative radiation (MJ) at the Pukekohe Research Center, from 1 January 2006 and 2007. Data courtesy of NIWA.

3.2.1 Storage root yield

The only experimental treatment that significantly affected the yield of sweetpotato storage roots was shade. This was true whether root yield was examined at the fresh ($P < 0.001$), dry matter ($P < 0.001$) or marketable ($P < 0.001$) levels. There were no significant interactions between the shade and N treatments for fresh ($P = 0.113$), dry matter ($P = 0.095$) or marketable ($P = 0.311$) yields. The first shade treatment, applied on 30 March 2007, decreased fresh (Table 2), dry matter (Table 3) and marketable (Table 4) yields. However, the second shade treatment, applied on 18 April 2007, had no significant effect on any of the measured parameters relative to the unshaded controls.

*Table 2: Effect of shade treatments on the total fresh yield (t/ha) of sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red.*

Shade treatment	0	1	2
Total fresh yield (t/ha)	9.9	7.9	10.0
$LSD_{0.05}$ (df = 92.5)	0.94		

*Table 3: Effect of shade treatments on the root dry matter yield (t/ha) of sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red.*

Shade treatment	0	1	2
Total dry matter yield (t/ha)	2.2	1.7	2.2
$LSD_{0.05}$ (df = 92.2)	0.21		

*Table 4: Effect of shade treatments on the marketable yield (t/ha) of sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red.*

Shade treatment	0	1	2
Marketable yield (t/ha)	7.6	5.7	7.6
$LSD_{0.05}$ (df = 92.7)	0.90		

3.2.2 Storage root dry matter content

Changes to root dry matter (%) due to shading (P = 0.024) were consistent across the N treatments, N-time x N-rate x Shade (P = 0.45). The N application time (P < 0.001) and rate (P = 0.004) significantly affected root dry matter content (Table 5). While the first addition of N, on 23 February 2007, provided a small but significant reduction in dry matter content; the second application, on 29 March 2007, had no significant effect on dry matter content (%).

Table 5: Effect of nitrogen application on sweetpotato (Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red root dry matter content (%).*

Nitrogen applied (kg/ha)	0	50	100	150	200	250	300	350
First N application	22.5	21.7	21.3	21.3	20.9	21.6	21.4	
Second N application		21.7	21.8	22.6	22.3	22.6	22.4	22.4
$LSD_{0.05}$ (df = 86.4)	0.99							

3.2.3 Brown centre incidence

Of the 112 plots in the trial 92.9% had the brown centre disorder to some degree. The individual plot root incidence of brown centre varied from 0.0 to 28.3%, so data required transformation to the logit scale for analysis. The Shade treatment had no significant effect on the incidence of the brown centre disorder (P = 0.70). There was no significant interaction between N-time x N-rate x Shade (P = 0.84) with regard to brown centre incidence.

However, the time of N application caused significantly differing responses in brown centre incidence (P = 0.004). There were also significant differences in the effect of N concentration on the incidence of brown centre (P = 0.025). The first set of N applications, on 23 February 2007, provided a reduction in brown centre incidence of up to 24.5%, while the second set of applications, on 29 March 2007, produced no significant changes (Table 6). Separate linear regressions were calculated for the N application rate data at the two application dates (first – 23 February) and (second – 29 March). The first application showed a significantly decreasing incidence of brown centre with increasing nitrogen (slope, P = 0.043), while the second application showed no response (Figure 7).

Table 6: Effect of nitrogen application on the incidence of brown centre disorder in the roots of sweetpotato (Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red. Data were transformed (logit) to stabilise the variance.*

Nitrogen applied (kg/ha)	0	50	100	150	200	250	300	350
First N application	-2.2 (10.2) [a]	-2.6 (7.2)	-3.3 (3.7)	-3.1 (4.3)	-3.2 (3.8)	-2.8 (5.6)	-3.7 (2.5)	
Second N application		-2.1 (10.9)	-2.2 (9.9)	-2.2 (9.8)	-2.8 (5.6)	-2.3 (8.8)	-2.2 (9.8)	-2.7 (6.4)
$LSD_{0.05}$ (df = 86.4) 1.00								

[a]Back-transformed means.

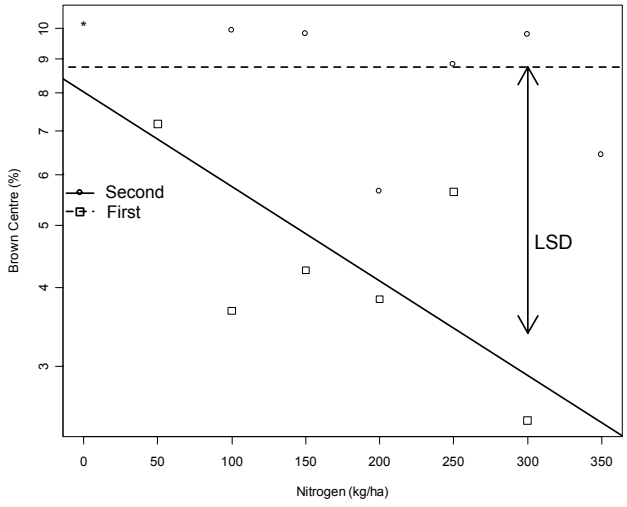

*Figure 7: Incidence of the brown centre disorder in roots of sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red under varying nitrogen rates at two separate application dates.*

4 Experiment 2

Aim: To evaluate brown centre incidence under varying supplemental N concentration patterns.

4.1 Materials and methods

A Pukekohe Research Centre field site was prepared as for experiment 1. Commercially produced Owairaka Red sprouts were transplanted into the field on 4 January 2007 and watered-in with overhead irrigation. Selected trial plots were systematically sampled for soil ammonium-N and nitrate-N analysis on 22 February, just prior to applying the first N treatment. All soil samples were retained in a frozen state until analysis. There were 9 experimental treatments consisting of various supplementary N combinations (Table 7). The first set of N applications were made on 23 February, the second on 29 March 2007. Nitrogen was supplied as urea (46% N), which was broadcast by hand. The trial was irrigated to field capacity immediately prior to applying the N treatments and again at a low level (*c*. 15 mm) to incorporate the urea applications on each of the two treatment dates.

The entire trial was arranged in a 3 x 9 row and column design. Within the trial there were three replicates of the 9 treatment combinations and each replicate consisted of a 3 x 3 row by column sub-block. Individual plots were four rows wide by 6 m long, with only the two middle rows used for assessment. Individual rows were 0.75 m wide and within-row plant spacing was 0.30 m. The portion of each plot harvested and assessed contained a total of 40 plants, arranged in two rows of 20 plants each.

Plant tops were mown off on 7 May 2007 and the roots harvested by a two-row, tractor-mounted harvester. Storage roots of marketable size (2.5 cm diameter or greater) were graded out so that plot weights of marketable and unmarketable grade roots could be recorded. Marketable roots were individually cut in half along their length and assessed for the presence/absence of the brown centre disorder (Appendix III). The data were analysed using the statistical software package GENSTAT™.

*Table 7: Nitrogen treatment combinations applied in the 2007 season sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red brown centre field trial - experiment 2.*

Treatment	1st Nitrogen application kg/ha	2nd Nitrogen application kg/ha
1	100	50
2	100	150
3	100	300
4	200	50
5	200	150
6	200	300
7	300	50
8	300	150
9	300	300

4.2 Results

The pre-treatment soil levels of ammonium-N (Figure 8), nitrate-N (Figure 9) and their combined values (Figure 10) indicated similar variation to that found in the adjacent portion of the experiment 1 site. Although a relatively small trial, the row and column design with replication was employed to limit site variation. However, there were no significant differences in root yield amongst the various treatments at the first (P = 0.571) or second (P = 0.837) N application (Table 8). There was no significant yield interaction effects between the two N treatments (P = 0.418).

Of the 27 trial plots 24 had some BC and individual plot incidence ranged from 0.0 to 16.3% of the roots, so the data required transformation to the logit scale for analysis. There was no significant effect on BC incidence from the supplementary N at the first (P = 0.320) or second application (P = 0.920), nor was there an interaction effect (P = 0.405).

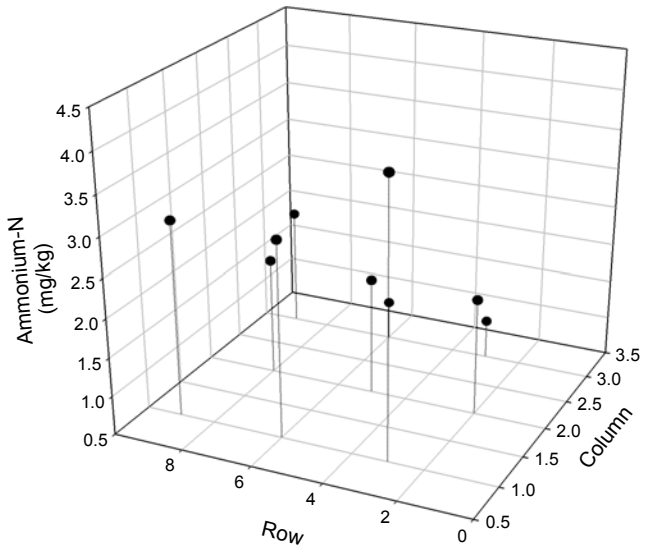

Figure 8: Spatial variation in soil ammonium-N (mg/kg) levels over experiment 2 trial site prior to application of nitrogen treatments.

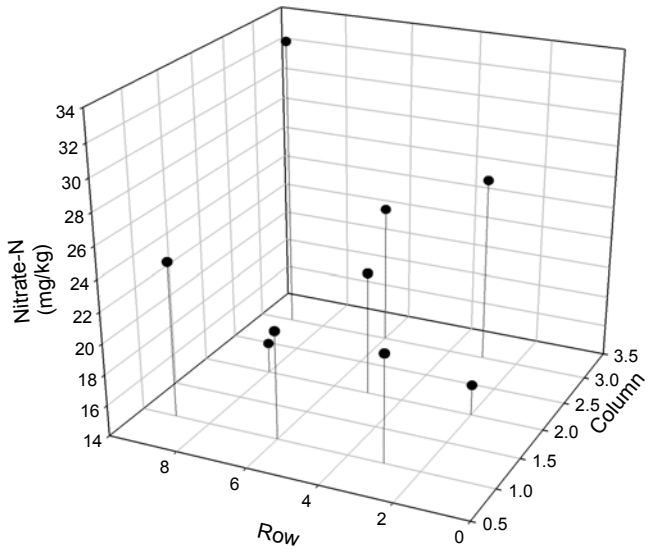

Figure 9: Spatial variation in soil nitrate-N (mg/kg) levels over experiment 2 trial site prior to application of nitrogen treatments.

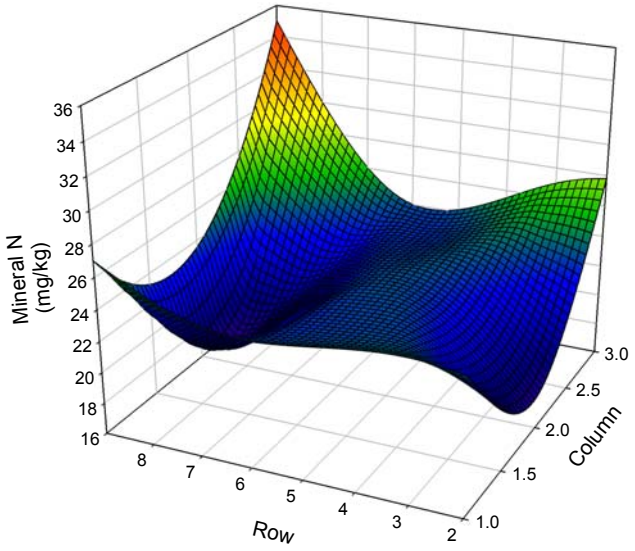

Figure 10: Surface plot showing spatial variation in soil mineral nitrogen (mg/kg) levels (sum of ammonium-N and nitrate-N sources) over experiment 2 trial site prior to application of nitrogen treatments.

*Table 8: Effect of two nitrogen applications on root yield of sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red. The first application was made on 23 February and the second on 29 March 2007.*

	Second application (kg/ha)			
First application (kg/ha)	50	150	300	Mean
100	11	10	10	11
200	10	10	13	11
300	12	10	11	11
Mean	11	10	12	
$LSD_{0.05}$ (df=14.6) 5.4				

5 Experiment 3

Aim: To investigate if brown centre root symptoms arise in standard container grown plants.

5.1 Materials and methods

Owairaka Red cuttings were transplanted into plastic plant pots filled with freshly blended potting mix on 21 December 2006. The commercial peat-pumice potting mix was supplemented with 6-month slow release Osmocote®. Three container sizes were used 2.0, 0.5 and 0.045 L, the smaller size being that of plug trays. One hundred plants were grown at each container size. The plants were watered daily, in a greenhouse programmed to vent at 25°C. Two hundred storage roots were harvested from each of the three pot sizes and cut along their length on 8 June 2007.

5.2 Results

Despite the root harvest being conducted in June, none of the roots showed definitive brown centre disorder symptoms.

6 Discussion

The first experiment showed no significant N effects on total (P = 0.589) or marketable (P = 0.928) root yield. This is in contrast to the result of the previous season, in which additional N produced a reduced root yield (P = 0.003). A reduction of root yield under high N conditions would be expected if plant canopy growth was super-optimal, the canopy becoming a competitive carbohydrate sink (O'Sullivan et al. 1997). The lack of a N yield response suggests that canopy growth was restricted by other limiting parameters.

Plant shading had a significant effect on total root yield (P < 0.001). But while the first shade application decreased root yield, the second application had no effect due to its late application relative to plant growth stage and growing conditions. The yield reduction due to the first shade treatment suggests it was successful in appreciably decreasing carbohydrate production. All shade treatments visibly affected both leaf health and chlorophyll levels (Appendix II). Leaves under the shade cloth appeared healthy and greener than those exposed to natural conditions.

Root dry matter content (%) was modified by both shading (P = 0.024) and N treatments, but there were no significant interaction effects, N-time x N-rate x Shade (P = 0.45). However, N application time (P < 0.001) and rate (P = 0.004) significantly affected root dry matter content. While the first addition of N provided a small but significant reduction in dry matter content, the second application had no effect. The slight reduction in root dry matter

content seen from the first N application was consistent with that seen under supplementary N the previous season (Lewthwaite et al. 2006). This effect on root dry matter content is also consistent with international experience (Hammett & Miller 1982).

While most of the trial plots had some BC, the range of incidence levels was not extensive. The shade treatments had no significant effect on BC incidence (P = 0.70) nor was there a significant interaction with N, N-time x N-rate x Shade (P = 0.84). However, the time of N application caused significantly differing BC responses (P = 0.004), with the first applications reducing BC incidence while the second applications produced no significant response. The first set of N applications also showed a significantly decreasing BC incidence with increasing supplementary N concentration (regression slope, P = 0.043). This result is consistent with last season's response, where supplementary N reduced the level of BC incidence (Lewthwaite et al. 2006).

The intention was to test the hypothesis that BC is caused by excessive canopy growth and a decreasing rate of photosynthesis so that carbohydrate is remobilised from storage roots to maintain the canopy. However, this season's environmental conditions were not generally conducive to generating high experimental rates of BC. This is supported by the lack of a significant yield response to supplementary N, although the change in root dry matter content did indicate low level effects. The trial was planted late due to the particularly cold spring and the summer was relatively dry. These two factors would limit the ability of plants to develop super-optimal plant canopies, even under excess N conditions. The relatively low level of BC within indicative cultivars in adjacent variety trials, which had been planted early but were exposed to the cold spring and dry summer, reinforce this conclusion. A further factor potentially affecting BC incidence was the warm autumn, with relatively high radiation levels. Although the shade treatment was effective in reducing carbohydrate production, it also protected the canopy from the environment, visibly improving canopy health relative to that of exposed plants. In a season of limited canopy growth, a shaded but effective canopy would have a reduced need for carbohydrate remobilisation. To maintain comparable canopy health, further work might consider modifying the canopy by removing leaves, reducing carbohydrate production while leaving the vines as a potential carbohydrate sink.

This experiment has indicated that while high soil N levels are a significant factor in producing super-optimal canopies, excessive growth is conditional on a number of environmental parameters. When canopy growth is not super-optimal, the addition of supplementary N may reduce the incidence of BC. A significant reduction in BC incidence with supplementary N has been observed over two seasons. Under limited canopy growth, BC incidence decreased with increasing levels of supplementary N. Further work is required to evaluate the contribution of canopy photosynthetic rate to the timing and degree of BC incidence.

As stated above, work conducted the previous season showed the addition of supplementary N significantly reduced the incidence (P < 0.001) of BC (Lewthwaite et al. 2006). The second experiment reported here was designed to evaluate the effectiveness of different supplementary N concentration

patterns in reducing BC incidence. There were no significant differences in root yield amongst the various treatments at the first (P = 0.571) or second (P = 0.837) N application. While 88.9% of the plots contained roots with BC symptoms and the incidence of BC symptoms within plots ranged from 0 to 16.3%, there was no significant effect on BC incidence from the first (P = 0.320) or second N application (P = 0.920), nor was there an interaction effect (P = 0.405) between the two. The season's environmental conditions limiting plant vigour and BC incidence, in conjunction with the relatively small scale of experiment 2, appear to have undermined the usefulness of this trial.

The ability to produce BC symptoms in container grown Owairaka Red plants would allow a more efficient approach to research. Experiments could be on a more economically viable scale and factors contributing to BC could be more sensitively manipulated. But as demonstrated in experiment 3, although root harvest was extremely late in the season, BC symptoms were not produced in container grown plants. While discrete aspects of crop management that affect BC incidence have been observed and tested by modification, the relative interplay of these contributing factors is not yet fully understood. Appreciation of these relationships would allow production of BC symptoms on demand.

7 Conclusions

Based on the available data, the hypothesis of best fit is that BC is caused by excessive canopy growth and a decreasing rate of photosynthesis, so that carbohydrate is remobilised from storage roots to maintain the canopy. There is robust data indicating that the BC disorder is cultivar-dependent and that it is not caused by a pathogen, due to tissue chilling injury or influenced by boron or calcium availability. Further, it occurs consistently in harvests from mid-April and is modified by soil N levels. This current project has particularly indicated that in BC management the focus should be on the degree of crop canopy growth and canopy condition. Soil N level may be relatively easily managed, but it is only one of a number of canopy-limiting factors. Under growing conditions that promote a super-optimal canopy, high N levels appear to increase BC incidence through the canopy becoming a competitive carbohydrate sink. When the development of a super-optimal canopy is inhibited, the addition of N still promotes canopy longevity and efficiency, but with a relatively reduced requirement for carbohydrate remobilisation and therefore reduced BC incidence. While the data fits the current hypothesis, the interplay of contributing factors is still to be proven, particularly data demonstrating the relationship between canopy-intercepted radiation and the time of BC onset.

8 Acknowledgements

The support and funding of this project by Horticulture New Zealand and AGMARDT has been much appreciated. Moe Jeram and John Scheffer are thanked for their help with various phases of the trial work. John Seelye is thanked for evaluating the light properties of the shade cloth used in this project.

9 References

Coleman BP 1969. The history of the Owairaka Red kumara. New Zealand Commercial Grower 25: 21.

Gillard SO 1955. Commercial kumara cultivation. New Zealand Department of Agriculture, Bulletin No. 294. 11 p.

Gupta UC 1979. Boron nutrition of crops. In: Brady NC, ed. Advances in Agronomy Vol. 31. London, Academic Press Inc. Pp. 273–307.

Lewthwaite SL, Fisher KJ, Nichols MA, Woolley DJ, Triggs CM, Fletcher JD 1999. Investigation into the causes of brown centre in sweetpotato. CropInfo Confidential Report No. 663. Lincoln, New Zealand Institute for Crop & Food Research Ltd. 41 p.

Lewthwaite SL, Triggs CM 2006. Soil nutrition effects on kumara root yield & quality. Crop & Food Research Confidential Report No. 1677. Lincoln, New Zealand Institute for Crop & Food Research Ltd. 17 p.

Nielsen LW, Harrow KM 1966. Observations of an internal necrosis of a New Zealand sweetpotato. Plant Disease Reporter 50: 730–731.

Nusbaum CJ 1946. Internal brown spot, a boron deficiency disease of sweetpotato. Phytopathology 36: 164−167.

O'Sullivan JN, Asher CJ, Blamey FPC 1997. Nutrient disorders in sweet potato. Australian Centre for International Agricultural Research, Canberra, Monograph No. 48. 136 p.

Tsuno Y, Fujise K 1965. Studies on the dry-matter production of sweet potato. Bulletin of the National Institute for Agricultural Science (Japan), D13: 1–131.

Wood RJ, Schappi R 1984. Internal browning of kumara. New Zealand Commercial Grower 39: 36.

Appendices

Appendix I Soil nutrient analysis

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ANALYSIS RESULTS

The following table gives a brief description of the analysis methods for this job. The COV (coeffient of variation) gives a measure of precision and is sometimes referred to as the Relative Standard Deviation, ie the standard deviation expressed as a percentage of the absolute value.

For further details and explanations, please contact the laboratory.
These samples were collected by yourselves (or your agent) and analysed as received at this laboratory.

Analyte	Method	COV(%)
Soil		
Potassium, Calcium, Magnesium, Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES.	4
Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry.	6
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH.	1
Volume Weight	The weight/volume ratio of dried, ground soil.	2
Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	4
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity.	4
Soil Preparation (Dry and Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2 mm screen.	-
Dry Matter*	Weight loss on drying at 105 °C for 24 hours.	-
Moisture*	Moisture is calculated from the Dry Matter.	-
Sample Registration*	Samples were collected by yourselves and analysed as received in the laboratory.	-
Mineral N*	Sum of Nitrate N and Ammonium N, calculated on a dry weight basis.	-
Nitrate-N*	Analysed on an 'as received' fraction but reported on a dry weight basis. 2M KCl extraction followed by Cd reduction and NED colorimetry.	-
Ammonium-N*	Analysed on an 'as received' fraction but reported on a dry weight basis. 2M KCl extraction followed by Berthelot colorimetry.	-

* Indicates a non-accredited test.

Signatory:

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Signatory:

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Appendix II Experimental treatments

(a) Plant growth stage at which the first nitrogen application was made, 23 February, 2007.

(b) Light reduction cloth used to shade plots, lowering light levels by 30%.

(c) First application of shade treatment, 30 March 2007.

(d) Second application of shade treatment, 18 April 2007.

(e) Overview of leaf condition in plots under shade treatments immediately prior to harvest, 7 May 2007.

(f) Detail of leaf condition, with (upper half) and without (lower half) shading.

Appendix III Disorder symptoms

(a) Visual symptoms of severe chilling injury in a longitudinal root section of kumara cultivar Owairaka Red.

(b) Pithy or spongy centre in a stored Owairaka Red root. Breakdown can occur through water and respirational losses.

(c) A longitudinal section of a freshly harvested Owairaka Red storage root, illustrating the brown centre disorder.

(d) Detail of the brown centre disorder in an Owairaka Red storage root.