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Onion skin quality: from leaf to storage

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A report prepared for
Onions New Zealand

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1 Executive summary

Over the 2005-06 growing season we undertook an experiment in Hawke's Bay measuring the response of onions (cv Early Longkeeper) to foliar calcium (Ca) application, especially during subsequent storage for 20 weeks. In addition, we monitored the response of onions to foliar Ca application at three commercial sites (two near Matamata and one near Pukekohe).

We found that foliar Ca applications did not affect yield and did not improve the quality of onions in storage. There was no evidence to link nutrient levels with storage quality.

The onions varied in skin quality between sites but were generally of good storage quality (most had two skins or more and, after curing, there were few with marked cracking/splitting). Infestations of thrips, which can cause feeding damage, were light to moderate at the start of storage on onions from a number of the sites.

Further work is required to identify the factors affecting onion skin quality in storage, and to devise strategies to prevent thrips numbers building up in storage.

2 Introduction

High-quality onions are defined by the onion industry as those with two or three tightly adhering, complete skins after storage. Very little is understood about the factors that produce such high-quality onions consistently, although we undertook some pioneering studies in the 2003 season (Brash et al. 2004. More detailed information from carefully monitored sites is required on the development and retention of onion skins.

The effect of field management, particularly nutrition, on onion skin quality is poorly understood. Copper nutrition is known to affect skin quality on peaty soils. Calcium (Ca) and nitrogen (N) are other nutrients of interest.

In New Zealand there is widespread interest and speculation on the possible benefits of foliar Ca application for onion skin quality. For the purposes of this project, we chose to test one of the most common forms of foliar Ca used in horticulture, Stopit (16% Ca). This product has Ca content but no amino acids or other nutrients that could interfere with the measurement of Ca response. We believe that the most effective time to apply foliar Ca (when aiming to enhance skin quality) is the period when the leaves are emerging that will ultimately make up the dry outer skins of the onion. Previous work (Brash et al. 2003) has indicated that leaves 4 to 9 go on to form the dry skins on a

harvested onion, therefore we aimed to test application of foliar Ca over the period of emergence of leaves 4 to 9.

We also aimed for a better understanding of how skin quality at harvest affects onion performance during post-harvest storage. In our earlier studies it was difficult to compare onion skin quality between sites because onions from each study site had different lifting and harvest dates.

Thrips infestation on onions is associated with post-harvest losses during storage, either directly from thrips feeding or indirectly by inducing fungal infection to damaged tissue. In addition, feeding damage and presence of thrips has caused rejection of onion consignments by buyers in export market. Past experience suggests that thrips damage varies greatly between lines after harvest and does not seem to be correlated with the severity of plant infestation prior to lifting. It is thought that deeply split skins allow thrips access to feed on fleshy tissue. Overseas research has shown that growth form and waxiness of leaves affect thrips breeding on leafy plants. A reference from the 1940s has also linked split onion skins to thrips infestation (D Teulon, pers. comm).

In the 2005-06 growing season we closely monitored skin quality on onions grown with and without added foliar Ca at two sites in Hawke's Bay. In addition, four similar trials were set up on commercial fields at sites in Pukekohe and Waikato (two trials in each location). Onions from all sites were cured and sent to Crop & Food Research (C&FR) in Palmerston North for storage. We measured yield at each site, thrips numbers at harvest, and onion skin quality over 20 weeks in ambient storage.

3 Methods

3.1 Calcium trial, Hawke's Bay

3.1.1 Field trial

This experiment was set up on two commercial onion fields (Moore's, Site 1; McCormack's, Site 2) in Hawke's Bay using cv Early Longkeeper (ELK). The fields were adjacent, and onions were planted on the same day (13 August 2005). In each field there were 10 plots, and five replicates of two treatments. Each plot was 10 m in length of a six-row onion bed (1.5 m wide). The treatments were:

1. Control – no foliar Ca.
2. Foliar Ca – once weekly applications of Stopit applied at 5 L/ha (in 500 L/ha of water) over the period of emergence of leaves 4 to 9.

Each foliar Ca treatment delivered the equivalent of 800 g Ca/ha. A total of eight Ca applications were made during the growth of the crop, giving a total application of 6.4 kg Ca/ha. For the trial layout see Appendix I, and for spray details at the two sites see Appendices II and III.

Crop development (including date for each leaf stage, leaf area of leaves 4-9 and date of topfall) was monitored in each field. Leaf samples collected prior to treatment applications were sent to Analytical Research Laboratories (ARL), Napier, for nutrient analysis, details of which are shown in Appendix IV.

Crop development (including date for each leaf stage, leaf area of leaves 4-9 and date of topfall) was monitored in each field. Soil samples were collected prior to planting from each field for nutrient analysis. Leaf samples were collected from each plot for nutrient analysis prior to treatment and 3-4 weeks after the final Ca application.

Onions from the trial were lifted at the same time as the surrounding field was machine-lifted, on January 9 2006 at Moore's block and on January 6 at McCormack's block. A yield assessment was made from a 2 m length of bed. Onions were left in the field until just prior to commercial harvest. Final harvest occurred on 23 January at Moore's block, 14 days after lifting, and on January 16 at McCormack's block, 10 days after lifting. Onions for storage trials were hand-clipped to a neck length of 25-30 mm. We collected about 110 onions of 65–80 mm diameter from each plot and carefully placed them into labelled 20 kg onion bags. These were transported to C&FR, Palmerston North.

During the growth of the crop, weekly measurements of leaf length and diameter at the base, where leaves emerge, were obtained for leaves 4-9 from five onions in a Control and Ca spray plot from each site. After lifting and curing, these onions were stored for 20 weeks and their skins measured for thickness, weight and area. Correlations were sought between leaf growth characteristics and physical skin quality characteristics.

3.1.2 *Storage*

The bag of onions from each plot was divided into eight sub-samples that were re-bagged (into 10 kg bags) as follows:

- Onion quality after 1, 5, 10, 15 and 20 weeks of ambient storage after harvest from the field (five bags of 15 onions).
- Onion thrips after 1 and 5 weeks (one bag of 15 onions). Onions kept for thrips counts were held in multiwall paper bags to prevent contamination between samples.
- Nutrient analysis of skins (one bag of five onions).
- Weight loss in storage (one bag of two onions).

Onions were placed in a bin in a shipping container with the door held ajar to allow plenty of ventilation. Bags of onions for onion quality assessment were placed in the large wooden bin in order of assessment (20 weeks at the bottom of the bin, 15 next, etc). Onions for thrips assessment were consolidated from each field/treatment combination, i.e. four labelled bags of 75 onions. Onions for weight loss assessment were consolidated from each field/treatment combination, i.e. four labelled bags of 10 onions). Extra onions were used as 'guards', underneath, along the sides, and on top of the study onions in the bin. The air temperature around stored onions was monitored using a datalogger.

3.1.3 *Storage assessments*

Onions were assessed once for skin quality. Weight loss was assessed by weighing the same onions after 1, 5, 10, 15 and 20 weeks in storage. Sub-samples of 30 onions were taken after 1 and 5 weeks from the onions kept for thrips counts. The samples collected for nutrient analysis were stored for 5 weeks and then the dry skins were removed from each onion. Samples were dried off completely and sent to ARL, Napier, for nutrient analysis.

3.1.4 *Skin quality assessments*

We assessed skin quality after 1, 5, 10, 15 and 20 weeks in ambient storage. We measured:

- Skin Quality rating (10 onions per plot). This 'visual first impression' assessment was made prior to removal of skins. Onions were rated as 1 (one or more skins with no splits or cracks revealing green flesh) or 2 (onion has cracks or splits revealing green flesh).
- Skin Cracking Score (10 onions per plot). Onions were rated for skin cracking on a 1 to 5 scale as follows:

  1 - Crack through two or more layers of skin exposing green flesh and the split being part of the green flesh.

  2 - Crack through two layers of skin exposing green flesh at the neck, base or both (n+b).

  3 - Crack through two layers of skin, no green flesh is revealed.

  4 - Crack through one layer of skin but no green flesh is revealed.

  5 - Intact first layer, no cracks.
- Presence of rots (10 onions per plot). Rots were either present or not. Each onion was cut in half to look for symptoms of rotting, fungal infestation or marked skin discolouration/blackening.
- Neck length (10 onions per plot). The onion either had a neck length of 30 mm or it did not.
- Diameter (10 onions per plot). The diameter of the onion was measured in mm using digital callipers.
- Onion Weight (10 onions per plot), measured to the nearest g.
- Dry Skin Number (five onions per plot). The number of dry skins was counted on each onion. Onions were peeled until green flesh was revealed. The skin had to be dry but it could be soft (but not thick and 'wet'). If there were any patches of fleshy bulb tissue then it was not counted as a dry skin. The skin had to cover 70% or more of the onion to be counted as a dry skin. Skins that came off as the onion was removed from the bag or that fell away when the onion was first handled were not counted as dry skins. Skin number 1 was the outermost skin, skin number 2 was the one underneath, etc. We counted dry skins as far as the innermost dry skin next to the fleshy part of the onion.

- Skin adhesion (five onions per plot). Each onion was rated on a 1-3 scale for adhesion of each skin to the next innermost layer. Ratings were as follows:

  1 – Skin cracks away from the onion easily when held in the hand.

  2 – Skin comes away from the onion with some manipulation and rubbing of the onion

  3 - Skin is firmly adhered to the onion and needs to be peeled away from the onion

- Skin Thickness (two onions per plot). Skin thickness was measured using digital callipers placed between the vascular bundles near the equator of the onion.
- Skin weight (two onions per plot). Skin weight was measured in mg on a balance.
- Skin Area (two onions per plot). We collected and dried onion skins after 1 and 5 weeks in storage. We estimated the skin area per onion using a leaf area meter. For the remaining assessments (weeks 10, 15 and 20) we estimated skin area per onion using an eye estimate of the percentage cover of each skin multiplied by the total skin area. We used the formula for sphere surface area derived from the diameter measurement i.e. sphere surface area = pi x $(\text{diameter})^2$.

3.2 *Calcium trials, grower sites*

3.2.1 *Field trial*

Commercial growers undertook field Ca comparison at four sites, two in each of the major growing areas of Pukekohe and Waikato. This involved using two cultivars (cv ELK and cv Pukekohe Longkeeper, PLK) at each location over the same period of leaf emergence (leaves 4 to 9) and treating the outside of the paddock (i.e. the first spray tank) with foliar Ca (Stopit applied at 5 L/ha in 500 L/ha of water) every week. No Ca was applied to the remainder of the paddock. Details of Ca applications at the three sites are shown in Appendices V, VI and VII. Ca applications continued until close to harvest at the Matamata sites.

The Pukekohe PLK trial area had to be abandoned because of low plant numbers after four Ca applications. The late-planted crop showed good plant emergence. It missed out on an irrigation event when under moisture stress and the plant population was halved.

Leaf samples were collected for nutrient analysis from the Matamata trials. Samples were collected before Ca application began and from treated and untreated areas at both sites in mid-season. Samples were also taken after harvest from skin and from whole bulbs from both Matamata sites. No leaf samples were collected from the Pukekohe ELK site.

Lifting, curing and hand-clipping followed standard management practice as much as was practical, e.g. onions had to be collected by hand prior to machine harvest. The Pukekohe ELK crop was lifted on 17 January 2006, taken out of the paddock with tops on and dried on the ground until 30

January. Onions were hand-clipped and bagged on 30 January then stored under cover until delivery to Palmerston North. The Matamata ELK crop was lifted on 13-15 January and removed from the paddock on 23 January, and the Matamata PLK crop was lifted on 15-16 February and harvested on 28 February.

At harvest three or four bags of onions were collected from each treatment area from each site and sent to C&FR, Palmerston North. Six bags from each site (three from each treatment) were treated as plots and each bag was sub-sampled in a similar way to the Hawke's Bay trial. As there were fewer replications, we collected three or four onions/plot for weight loss assessment and 22 onions/plot for thrips counts. A skin sample was collected for nutrient analysis after 5 weeks in storage. Onion samples were bagged (five bags of 15 onions) for skin quality assessments in ambient storage.

Using the same methods as those used for the Hawke's Bay trial we assessed skin quality after 1, 5, 10, 15 and 20 weeks in ambient storage. We measured:

- Skin Quality rating (10 onions per plot);
- Skin Cracking Score (10 onions per plot);
- Dry Skin Number (five onions per plot);
- Skin adhesion (five onions per plot);
- Presence of rots (10 onions per plot).
- Data analysis

Data were interpreted using several different techniques, each outlined in the relevant section of the results below.

4 Results

4.1 Calcium trial, Hawke's Bay

4.1.1 Leaf appearance and growth

The increase in leaf number over time is shown in Figure 1. Regression analysis indicated that there was no significant Ca effect on the number of leaves recorded (P=0.31), and while there were slightly more onions per plant at Moore's block, leaf numbers were not significantly different (P=0.28) from leaf numbers recorded at McCormack's block. Bulb expansion started when there were 8-9 leaves per plant and is indicated by the arrow in Figure 1.

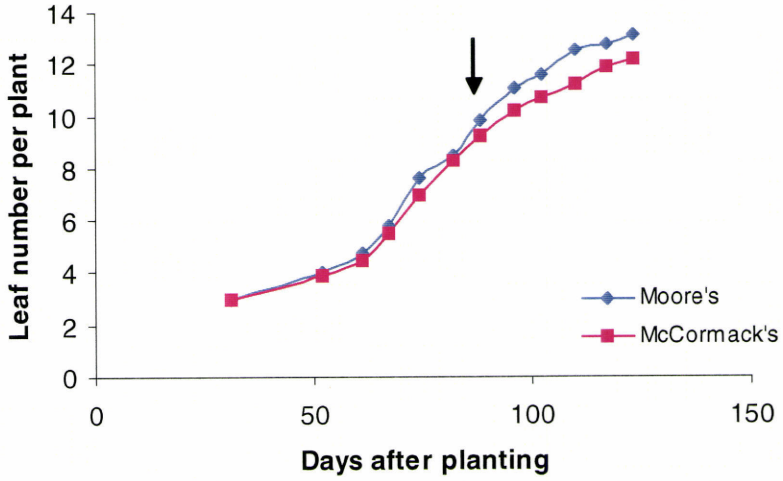

Figure 1: Increase in leaf number per plant averaged over 10 plants at the two sites in Hawke's Bay. Arrow indicates start of onion bulb expansion.

The length and diameter of leaves 5-9 measured weekly is shown in Figures 2 and 3. The change in leaf length and diameter with time followed a standard pattern and regression analysis showed that there were no significant differences caused by Ca application or site.

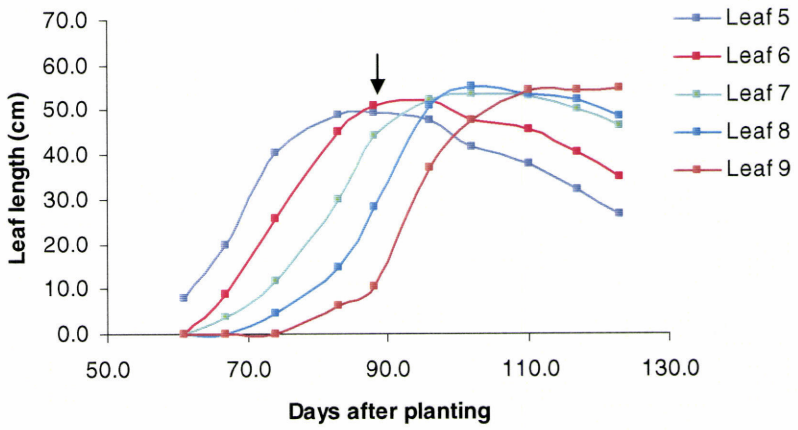

Figure 2: Increase in lengths of leaves 5-9 averaged over 20 plants grown in Hawke's Bay. Arrow indicates time of bulb expansions.

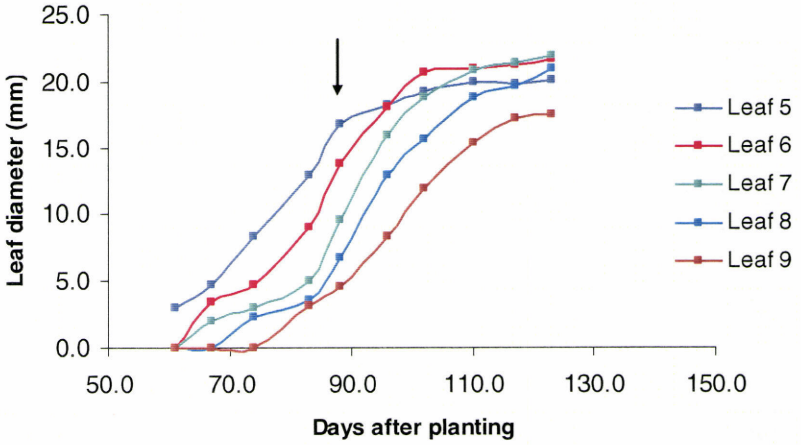

Figure 3: Increase in leaf base diameter of leaves 5-9 averaged over 20 plants grown in Hawke's Bay. Arrow indicates time of bulb expansions.

By the time onion bulbs had started to expand (indicated by the arrow in Figures 2 and 3), leaves 5 and 6 were starting to senesce. Only leaves 7-9, which had been initiated much closer to the time of bulb expansion, continued to increase in length and diameter as the bulb grew. Of these leaves, leaf 9 had the longest period of growth during bulb expansion.

4.1.2 *Which leaves became skins?*

Onion skins were formed by leaves 5-10. There was no effect of Ca or site on which leaf formed skins.

Skin 1 was formed by leaf 5-7 (Figure 4a). Leaf 5 only formed skin 1, and accounted for 30% of these outer skins (Figure 4a), and 10% of all skins (Figure 4d). Up to 50% of skin 2 were formed by leaf 7 (Figure 4b), with the rest of skin 2 formed by leaves 8 and 9. Skin 3 was formed by leaves 8-10, with approximately 40% of all skin 3 being formed by leaf 10 (Figure 4c). Leaf 7 most frequently formed skins, either skin 1 or 2 (Figure 4d), and leaf 10 most frequently formed the inner skin.

Individual skin weight, skin area and skin diameter were not correlated with leaf length, leaf diameter or leaf area.

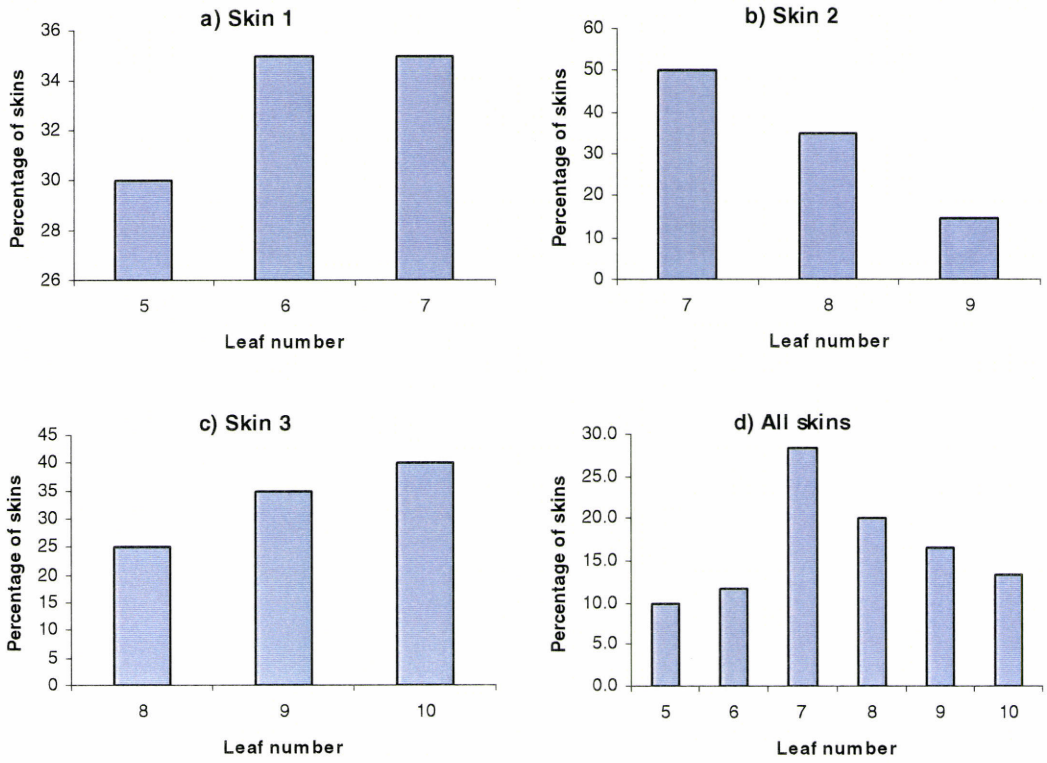

Figure 4: Percentage of skins formed by different leaves for a) skin 1 – the outer skin, b) skin 2, c) skin 3 – the innermost skin and d) all skins, for onion crops grown in Hawke's Bay.

4.1.3 *Yield*

Applying Ca had no significant effect on yield (P=0.95, Table 1). Foliar Ca has little effect on leaf expansion and light interception and therefore should not be expected to significantly increase yield. Yields did not differ between sites (P=0.28) There was no effect of site on yield (Table 1), which was not surprising since crops were planted on the same day, and in adjacent fields were subject to the same environmental conditions.

Table 1: Treatment effect on yield of onions grown at two sites in Hawke's Bay.

	Yield t/ha	
Treatment	Moore's	McCormack's
Control	73.6	74.5
Calcium	76.5	71.7
LSD 5% compare treatments		3.8
LSD 5% compare sites		5.4

The LSD value is the least significant difference for treatment differences at *P*=0.05.

4.1.4 *Storage conditions*

Onion temperatures during storage are shown in Figure 5.

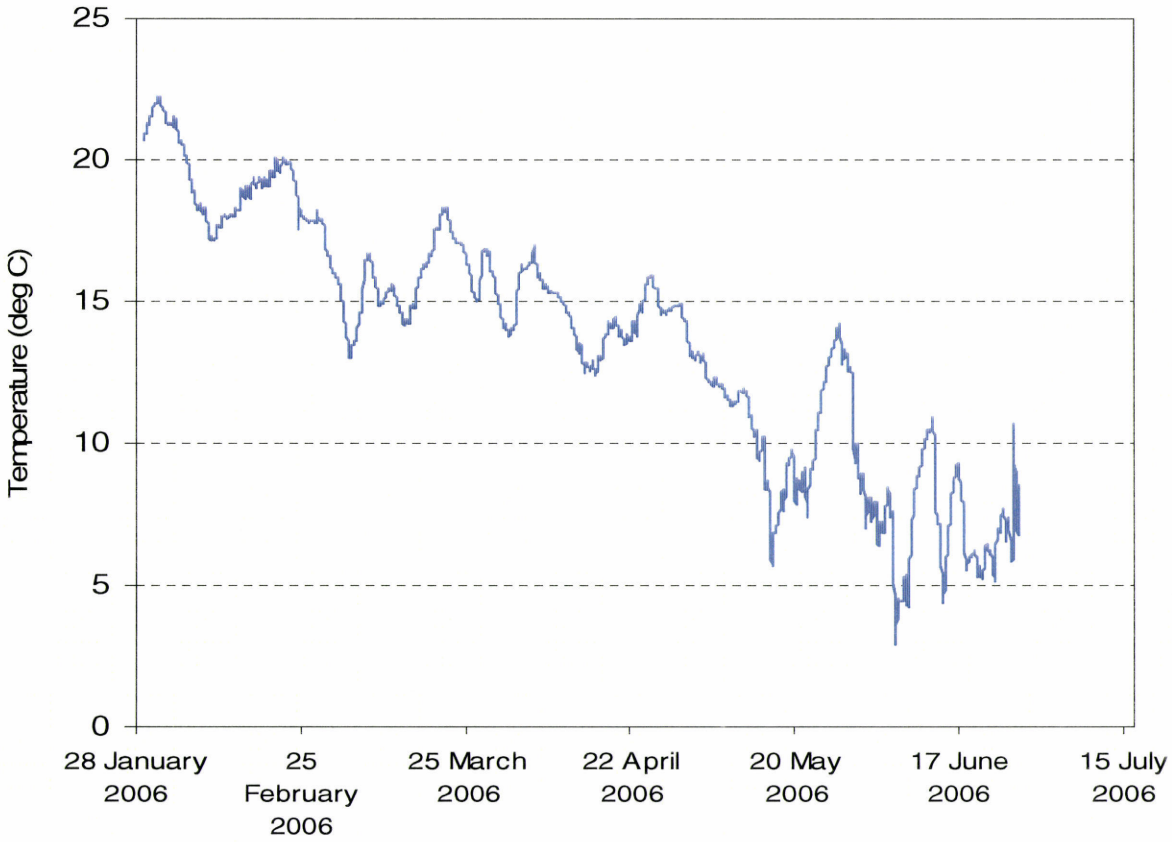

Figure 5: Temperature of onions during ambient storage, January to July 2006.

Weight loss of onions during storage was low. Onions lost 2.8% of their original weight during 19 weeks of storage (from Week 1 to 20).

4.1.5 *Skin quality in storage*

Skin quality rating (1–2)

An onion with a score of 1 was rated as a 'good' onion. The proportion of onions with a skin quality score of 1 was analysed using a binomial generalised linear model (GLM).

The Ca treatment had no effect on the proportion of onions with score 1 (P=0.33, Table 2) whereas the proportion changed significantly with time (P<0.001, Table 3).

Table 2: Proportions of onions treated with foliar Ca or not (Control) with a skin quality score of 1 (best quality). Predicted means and 95% confidence intervals (C.I.) obtained from a binomial GLM analysis.

Treatment	Mean	95% C.I.
Control	0.92	(0.89, 0.94)
Ca	0.93	(0.91, 0.95)

Table 3: Proportions of onions with a skin quality score of 1 (best quality) after storage for 1–20 weeks. Predicted means and 95% confidence intervals (C.I.) obtained from a binomial GLM analysis.

Storage time (weeks)	Mean	95% C.I.
1	0.76	(0.70, 0.83)
5	0.96	(0.93, 0.98)
10	0.96	(0.93, 0.98)
15	0.97	(0.94, 0.99)
20	0.98	(0.95, 0.99)

We assume that the lower rating at Week 1 was because the onions had not completed curing (i.e. green flesh exposed at Week 1 dried off before the next assessment at Week 5).

Skin cracking scores (1–5)

The onions were given a skin cracking score from 1 (worst) to 5 (best). Mean skin cracking scores were analysed using analysis of variance (ANOVA) and results are shown in Table 4. The mean scores were not affected by the addition of Ca (P=0.63), but increased with storage time (P<0.001). As reported earlier for the skin quality ratings (see Table 3) we expect the low (poorer) skin cracking score at Week 1 to be related to incomplete curing at this time (green fleshy tissue which has not cured). There was a tendency for

an interaction between the Ca treatment and the storage time (P=0.067). This interaction was because at the first week of storage, the Control onions had a lower (poorer) skin cracking score than the foliar Ca-treated onions: 32% of Control onions had a score of 1 or 2 (green flesh exposed) compared with 19% for Ca treated onions. In subsequent weeks there were no differences between the Control and Ca-treated onions.

Table 4: Mean skin cracking scores (1=worst, 5=best) for onions treated with foliar Ca or not (Control) and stored for different periods. 5% LSD: Treatment 0.10, Storage time 0.15, Treatment×Time 0.21.

Storage time	Treatment		
(weeks)	Control	Ca	Mean
1	2.99	3.30	3.15
5	3.52	3.46	3.49
10	3.74	3.74	3.74
15	3.60	3.51	3.56
20	3.78	3.74	3.76
Mean	3.53	3.55	3.54

Number of dry skins

The mean numbers of dry skins were compared using ANOVA. Onions typically had two dry skins (14% had one dry skin, 59% had two, 26% had three and 1% had four). There were no significant differences in number of dry skins between the control and Ca-treated onions (P=0.21), but there were differences in skin numbers with storage time (P<0.001, Table 5). The number of skins was fewer at Week 1 than in the other weeks.

Table 5: Mean number of dry skins of onion bulbs following treatment with foliar Ca or not (Control) and storage for different periods. 5% LSD: Treatment 0.11 skins, Storage time 0.19 skins, Treatment×Time 0.26 skins.

Storage time	Treatment		
(weeks)	Control	Ca	Mean
1	1.80	1.70	1.75
5	2.10	2.20	2.15
10	2.38	2.08	2.23
15	2.42	2.40	2.41
20	2.16	2.16	2.16
Mean	2.17	2.11	2.14

Skin adhesion scores

Scores were given separately for each skin on each onion (up to four skins present on an onion). The mean adhesion scores were compared using residual maximum likelihood (REML) and were analysed separately for each skin number.

Skin 1

There were no significant differences in adhesion scores for the first (outer) skin between the control and Ca-treated onions (P=0.63), but there were differences in adhesion with storage time (P<0.001, Table 6). The skin adhesion score for the first skin was higher in Week 1 than in the other weeks.

Table 6: Mean skin adhesion scores for the first skin of onion bulbs following treatment with foliar Ca or not (Control) and storage for different periods. Approx 5% LSD: Treatment 0.18, Storage time 0.24, Treatment×Time 0.35.

Storage time	Treatment		
(weeks)	Control	Ca	Mean
1	2.42	2.35	2.38
5	1.70	1.94	1.82
10	1.72	1.72	1.72
15	1.86	1.70	1.78
20	1.64	1.86	1.75
Mean	1.87	1.91	1.89

Skin 2

A majority (427, 85% of 500) of onions had two skins. There were no significant differences in adhesion scores for the second skin between the control and Ca-treated onions (P=0.16), but there were differences in adhesion with storage time (P<0.001, Table 7). The skin adhesion score for the second skin was higher in Week 1 than in the other weeks, and the mean scores in weeks 5 and 10 were higher than in weeks 15 and 20 (Table 7, approximate 5% LSD = 0.14). There was a tendency for a Treatment×Time interaction (P=0.086). At weeks 15 and 20, the Ca-treated onions had a second skin that had lower adhesion than the control onions.

Table 7: Mean skin adhesion scores for the second skin of onion bulbs following treatment with foliar Ca or not (Control) and storage for different periods. Approx. 5% LSD: Treatment 0.14, Storage time 0.14, Treatment×Time 0.22.

Storage time	Treatment		
(weeks)	Control	Ca	Mean
1	3.00	2.95	2.98
5	2.77	2.82	2.80
10	2.73	2.75	2.74
15	2.60	2.39	2.50
20	2.67	2.41	2.54
Mean	2.76	2.67	2.71

Skin 3

Only 132 onions (26% of 500) had three skins. There were no significant differences in adhesion scores for the third skin between the control and Ca-treated onions (P=0.26), nor were there were differences in adhesion with storage time (P=0.30, Table 8).

Table 8: Mean skin adhesion scores for the third skin of onion bulbs following treatment with foliar Ca or not (Control) and storage for different periods. Approx. 5% LSD: Treatment 0.18, Storage time 0.24, Treatment×Time 0.35.

Storage time	Treatment		
(weeks)	Control	Ca	Mean
1	3.00	3.00	3.00
5	3.00	3.00	3.00
10	2.95	3.00	2.98
15	3.00	2.81	2.91
20	3.00	3.00	3.00
Mean	2.99	2.96	2.98

Skin 4

Only six onions (1.2% of 500) had four skins. These were too few for further statistical analysis.

Skins 1-4

Higher skin adhesion on the first skin would be expected during curing (Week 1). Adhesion of the outer two skins slowly decreased during storage. Adhesion of the third skin remained at the highest score for the duration of 20 weeks in storage.

Neck length

We noted many short-necked onions during our storage evaluation. The number of onions with necks greater than 30 mm long differed between the two fields in Hawke's Bay. Field 1 had 47% (234 of 500) onions with long necks, while field 2 had 60% (300 of 500). However, the results also differed markedly between the plots within each field. The 10 plots in each of the fields were laid out in two beds. Bed 1 in Field 1 had only 12% with long necks, whereas the adjacent bed had 82% with long necks. We can conclude that operator error resulted in a proportion of onions having short necks. However, subsequent analysis showed this to have no effect on onion skin quality in storage.

Onions with rots

Only two of 1000 onions sampled from the two Hawke's Bay fields had any rot present. Both onions were found after 1 week of storage. Because of the low (0.2%) incidence of rot, no further statistical analysis was practical.

Onion weight and diameter

The mean weights and diameters were compared using ANOVA. There were no significant differences in onion weight (mean = 190 g) and diameter (mean = 71.5 mm, 50% of onions were in the 68-75 mm range) between the control and Ca-treated onions. There were no differences in onion diameter with storage time but there were differences in onion weight with storage time (P=0.008). We would expect onions to lose weight in storage and this has been reported elsewhere (see section 4.1.4).

Skin thickness

Skin thicknesses were measured separately for each skin on each onion (up to four skins present on an onion). The mean skin thicknesses were compared using residual maximum likelihood (REML) and were analysed separately for each skin number. Most onions had two skins (85%) and only 26% had three. There were too few onions with four skins (three out of 200 measured) for further statistical analysis.

There was no effect of Ca on skin thickness for each skin layer. Skin thicknesses varied with storage time (see Table 9) and means were variable. A single measurement lowered mean skin thickness for skin 1 at Week 15 and raised mean skin thickness for skin 3 at Week 1.

Table 9: Mean skin thickness (mm) for the first three skin layers of onion bulbs stored for different periods.

Storage time	Skin number		
(weeks)	1	2	3
1	0.093	0.128	0.235
5	0.096	0.092	0.089
10	0.084	0.088	0.122
15	0.075	0.084	0.114
20	0.085	0.086	0.100
Mean	0.087	0.096	0.132
Approx LSD 5%	0.015	0.019	0.04

To try to gauge the value of skin thickness measurements we examined the link between skin thickness and skin weight, assuming that thicker skins will be heavier skins. The correlation was very poor (correlation coefficient r = 0.16). We conclude that skin thickness measurement was not a useful guide to skin quality.

Skin weight

Skin weights were measured separately for each skin on each onion (up to four skins present on an onion). The mean skin weights were compared using residual maximum likelihood (REML) and were analysed separately for each skin number. Most onions had two skins (85%) and only 26% had three. There were too few onions with four skins (three out of 200 measured) for further statistical analysis. We also calculated total dry skin weights for each onion.

There was no effect of Ca on skin weight for each skin layer. Skin weights varied with storage time (see Table 10) and means were variable. As noted earlier for skin thickness, a single high or low measurement influenced the means considerably, especially for the third skin layer. Onion skin weights were significantly lighter at Week 1 ($P<0.001$) than in other weeks (we have not shown a 5% LSD in Table 10 for these data as they needed to be transformed for statistical analysis).

Table 10: Mean skin weight (g) for the first three skin layers and total skin weight for onion bulbs stored for different periods.

	Weight of skin (g)			
Storage time (weeks)	1	2	3	Total skin weight (g)
1	0.70	1.40	2.77	1.84
5	0.75	1.19	1.49	2.25
10	0.85	1.15	1.64	2.51
15	0.83	1.16	1.47	2.41
20	0.89	1.17	1.47	2.17
Approx 5% LSD	0.07	0.19	0.47	-

Skin coverage

The dry skin coverage at weeks 1 and 5 was measured using a leaf area meter. Mean skin areas were analysed using analysis of variance (ANOVA). There was no effect of Ca application on skin area but skin area increased significantly ($P< 0.001$) from Week 1 (154 cm^2) to Week 5 (208 cm^2).

We estimated skin area for Weeks 10, 15 and 20 from visual estimates of the percentage cover of each skin multiplied by the total area of each skin (calculated using onion diameter). The calculated estimates of total skin area were overestimates of the skin area when compared with areas measured using a leaf area meter (from Weeks 1 and 5). Since the measured areas were on average 70% of the calculated values, the calculated estimates were corrected downwards (by multiplying by 70%). Mean skin areas were analysed using analysis of variance (ANOVA). There was no effect of Ca application or of storage time (comparing Weeks, 10, 15 and 20) on calculated skin area.

The estimated percentage skin cover was given separately for each skin on each onion (up to four skins present on an onion). The mean estimated percentage skin areas were compared using residual maximum likelihood (REML) and were analysed separately for each skin number. There were no significant differences in estimated percentage cover between control and Ca-treated onions for all skin layers analysed (skins 1 to 3). There were differences in percentage skin cover with storage time (P=0.004) for skin 1 but not for skins 2 and 3. The percentage cover for the first skin was higher in Week 20 (92%) than in the other weeks (88% in Week 10 and 86% in Week 15). Mean skin cover was 99% for skin 2 and 100% for skin 3.

Effect of onion size on skin quality

We examined the effect of onion size on skin quality by comparing the smallest quartile of onions (25% of onions smaller than 67 mm diameter) with the largest quartile (25% of onions larger than 75 mm diameter). Skin cracking score was significantly higher (more intact skins and less green flesh exposed) for the smaller onions (a mean score of 3.81 for small onions and 3.51 for large onions, approx 5% LSD = 0.17). The number of dry skins was no different between the smallest and largest diameter onions.

4.1.6 *Thrips counts*

Thrips counts are shown in Table 11. We found thrips on onions from both field sites. There were more at Site 1, nearly three per onion (including nymphs) after 5 weeks in storage. We suggest that thrips were not found in Site 2 at Week 1 because the onions were very green and thrips must have been at the egg stage. Under the microscope light thrips feeding damage, particularly in the neck area, was noted on about half the onions examined for thrips.

Table 11: Thrips counts on onions from Hawke's Bay trial after storage (Weeks 1 and 5).

Site	Treatment	Weeks storage	Date checked	No. onions	Live nymphs	Dead nymphs	Live adults	Dead adults	Silvering on onions
1	Control	1	24 Jan	30	18	0	0	1	8
	Ca	1	24 Jan	30	12	0	1	0	7
	Control	5	20 Feb	30	33	3	10	6	18
	Ca	5	21 Feb	30	55	3	30	7	16
2	Control	1	24 Jan	30	0	0	0	0	0
	Ca	1	24 Jan	30	0	0	0	0	0
	Control	5	20 Feb	28	6	4	14	6	12
	Ca	5	21 Feb	27	7	2	4	4	12

4.1.7 *Leaf and onion skin nutrient analysis*

Leaf nutrient levels for onions sampled prior to Ca treatment application (3 leaf stage) are shown in Appendix IV.

Leaf nutrient levels in onion skins were analysed with ANOVA, and showed that Ca application had no significant effect on nutrient levels in skins (Table 12), but there were differences between sites. Onion skins from Moore's block had larger amounts of sulphur, sodium and copper, but less manganese and zinc than skins from McCormack's block (Table 12).

Relationships between any nutrient level and onion skin quality, expressed as percentage of onions with a quality score of 1, onion cracks expressed as percentage of onions with crack score of 4 or 5, and adhesion expressed as percentage of skins with adhesion score of 3 were examined with regression analysis. There were no significant relationships between any nutrient level and these skin quality characteristics.

Table 12: Site and treatment effects on nutrient content of onion skins sampled after 5 weeks of storage.

	Total nitrogen % w/w	Phosphorus % w/w	Potassium % w/w	Sulphur % w/w	Calcium % w/w	Magnesium % w/w	Sodium % w/w	Iron mg/kg	Manganese mg/kg	Copper mg/kg	Zinc mg/kg	Boron mg/kg
Moore's												
Control	0.255	0.02	0.32	0.132	2.466	0.124	0.042	148	21.4	7.52	8.24	23.6
Ca	0.229	0.02	0.34	0.114	2.382	0.12	0.04	130.2	20.8	6.88	9.24	23.2
McCormack's												
Control	0.198	0.018	0.36	0.094	2.518	0.126	0.03	132	30.4	5.38	10.1	23.8
Ca	0.198	0.018	0.36	0.094	2.518	0.126	0.03	132	30.4	5.38	10.1	23.8
Treatment effects												
P value.	*0.86*	*0.99*	*0.20*	*0.23*	*0.29*	*0.28*	*0.62*	*0.54*	*0.61*	*0.94*	*0.09*	*0.56*
LSD 5%	0.05	0.003	0.06	0.02	0.13	0.01	0.009	30.9	4.5	1.04	0.99	1.14
Site effects												
P value	*0.13*	*0.11*	*0.06*	*0.002*	*0.23*	*0.83*	*0.01*	*0.63*	*0.001*	*0.007*	*0.003*	*0.56*
LSD 5% t	0.05	0.003	0.06	0.02	0.13	0.01	0.009	30.9	4.5	1.04	0.99	1.14

The *P* value is the probability that the observed differences between treatment or sites are due to chance. The LSD or least significant difference is the smallest difference required between two means for them to be statistically different at the 5% level.

4.2 Calcium trials, grower sites

4.2.1 Yield

We had a verbal report that there was no yield difference between the Ca-treated area and the adjacent untreated area at the Matamata sites. Yield was not assessed at the Pukekohe site.

4.2.2 Storage performance

The onions were stored under similar conditions to the Hawke's Bay onions (see 4.1.2 for temperature record in ambient storage). There were delays in getting onions to the store from Matamata and Pukekohe. This meant that weight loss during storage was lower (2.1%) than for the Hawke's Bay onions (2.8%).

4.2.3 Skin quality in storage

We were unable to carry out Week 1 assessments of skin quality because of the delay in delivering onions from Pukekohe and Matamata. We assessed the Pukekohe PLK onions at Week 3 and those at all sites at Weeks 5 to 20.

Skin Quality rating

The proportion of onions with a skin quality rating of 1 (i.e. best quality) for the commercial sites is shown in Table 13. We compared skin quality ratings at each site using binomial generalised linear model (GLM) analysis. There was a small significant effect of Ca treatment on skin quality rating at one site (Matamata PLK site, P=0.033). There was an effect of storage time on skin quality rating at two sites, Matamata PLK and Pukekohe ELK).

Table 13: Proportion of onions with best skin quality rating for commercial sites (means of 30 onions).

		Time (weeks)						
Site	Ca	3	5	10	15	20	Mean	Site mean
Matamata, ELK	Control		0.80	0.83	0.90	0.83	0.84	0.83
	Ca		0.87	0.80	0.77	0.87	0.83	
Matamata, PLK	Control		0.93	0.93	0.93	1.00	0.95	0.96
	Ca		0.90	1.00	1.00	1.00	0.98	
Pukekohe, ELK	Control	0.90	0.77	1.00	0.83	1.00	0.90	0.91
	Ca	0.80	0.93	0.93	0.97	0.97	0.92	

Skin Cracking Score

There was no effect of Ca application on skin cracking scores on onions from the three commercial sites (Table 14).

Table 14: Mean skin cracking scores for commercial sites (means of 30 onions).

Site	Ca	Time (weeks) 3	5	10	15	20	Mean	Site mean
Matamata, ELK	Control		3.37	3.30	3.43	3.40	3.37	3.40
	Ca		3.60	3.47	3.13	3.47	3.42	
Matamata, PLK	Control		3.93	3.63	3.67	4.13	3.84	3.76
	Ca		3.63	3.53	3.83	3.73	3.68	
Pukekohe, ELK	Control	3.43	3.37	3.57	3.40	3.87	3.53	3.52
	Ca	3.47	3.33	3.23	3.77	3.77	3.51	

Dry Skin Number

We measured the number of dry skins on onions from each site (Table 15). Results were similar to those from Hawke's Bay where about 85% of onions had two or more skins.

Table 15: Percentage of onions with one to four skins from commercial sites (from 120 onions for Matamata sites and from 150 onions for Pukekohe site).

Site	% of onions with: 1 skin	2 skins	3 skins	4 skins
Matamata ELK	17.5	61.7	20.0	0.8
Matamata PLK	11.7	58.3	26.7	3.3
Pukekohe ELK	16.0	48.0	31.3	4.7

There was no effect of Ca application on the number of dry skins on onions from the three commercial sites (Table 16). Pukekohe ELK onions had the most skins (mean of 2.25) and Matamata ELK onions the fewest (mean of 2.04).

Table 16: Mean numbers of dry skins for commercial sites (means of 15 onions).

Site	Ca	Time (weeks) 3	5	10	15	20	Mean	Site mean
Matamata, ELK	Control		1.73	2.27	2.20	2.40	2.15	2.04
	Ca		1.93	2.00	2.07	1.73	1.93	
Matamata, PLK	Control		1.87	2.07	2.60	2.20	2.18	2.22
	Ca		2.13	2.27	2.33	2.27	2.25	
Pukekohe, ELK	Control	2.13	2.07	2.73	2.00	2.40	2.27	2.25
	Ca	1.73	2.33	2.67	2.60	1.80	2.23	

Skin adhesion

Mean skin adhesion scores are summarised in Table 17 (detailed results in Appendices VIII and IX) for skins 1 and 2. Skin adhesion scores for skin 3 were very close to 3 (means of 2.9-3.0). No statistical analysis was done. Skin adhesion scores for the Hawke's Bay onions were similar to those for Matamata PLK onions and slightly higher than those for ELK from the commercial sites.

Table 17: Mean skin adhesion scores for skins 1 and 2 on onions from the commercial sites (means of 15 onions).

Site	Skin number	Time (weeks) 3	5	10	15	20	Mean
Matamata, ELK	1		1.8	1.5	1.3	1.6	1.6
	2		2.8	2.5	2.1	2.5	2.5
Matamata, PLK	1		2.0	1.5	1.7	1.6	1.7
	2		2.9	2.6	2.5	2.8	2.7
Pukekohe, ELK	1	1.5	1.4	1.3	1.5	1.4	1.4
	2	2.7	2.5	2.1	2.6	2.6	2.5

Presence of rots

We found only one onion with rots during storage (out of 780).

4.2.4 *Thrips counts*

Thrips counts are shown in Table 18. The fewest live nymphs and adults were reported from the Matamata sites.

Table 18: Thrips counts on onions from Pukekohe and Matamata sites during storage.

Site	Treatment	Weeks storage	Date checked	No. onions	Live nymphs	Dead nymphs	Live adults	Dead adults	Silvering on onions
Pukekohe, ELK	Control	3	21 Feb	30	35	11	14	13	19
	Ca	3	21 Feb	30	15	10	4	8	19
	Control	7	20 Mar	30	12	8	9	6	21
	Ca	7	20 Mar	30	6	1	1	5	18
Matamata, ELK	Control	5	21 Feb	30	0	0	0	0	1
	Ca	5	21 Feb	30	0	0	1	1	3
	Control	9	20 Mar	30	0	1	0	0	7
	Ca	9	20 Mar	30	0	0	2	0	3
Matamata, PLK	Control	4	17 Mar	30	6	0	2	2	5
	Ca	4	17 Mar	30	1	0	3	1	7

4.2.5 *Leaf, bulb and skin nutrient analysis*

Leaf nutrient analysis results are shown in Appendix X. In addition, skin and whole bulb nutrient analysis was done on samples collected after harvest (Appendix XI). The results indicated that the Ca levels in leaf, skin and bulb were not raised by application of foliar Ca.

Data for skin nutrient contents of onions grown at commercial sites are shown in Table 19. There was no significant effect of Ca treatment on any nutrient level of skins at any sites. However, there were site differences, with onion grown at the Matamata ELK site having higher nitrogen and zinc levels, onions grown at Pukekohe having higher iron and sodium than those grown at other sites.

Table 19: Nutrient levels in skins of onions grown in commercial fields in Matamata and Pukekohe with foliar-applied Ca.

	Matamata-PLK		Matamata-ELK		Pukekohe		
	Ca	Control	Ca	Control	Ca	Control	Lsd 5%
Total nitrogen % w/w	0.135	0.171	0.226	0.208	0.170	0.141	0.06
Phosphorus % w/w	0.013	0.017	0.020	0.017	0.017	0.013	0.01
Potassium % w/w	0.533	0.567	0.467	0.467	0.333	0.333	0.11
Sulphur % w/w	0.057	0.063	0.077	0.077	0.053	0.047	0.02
Calcium % w/w	1.92	1.87	2.11	2.46	2.15	2.09	0.28
Magnesium % w/w	0.14	0.15	0.157	0.167	0.147	0.137	0.03
Sodium % w/w	0.017	0.013	0.027	0.030	0.063	0.090	0.02
Iron mg/kg	44.7	68.7	98.3	111	113.3	118	44.70
Manganese mg/kg	61.3	88.3	82.3	88.3	50.7	37.3	15.40
Copper mg/kg	3.63	3.87	1.87	2.27	1.53	1.47	1.20
Zinc mg/kg	12.0	12.0	22.7	31.7	16.7	13.3	6.70
Boron mg/kg	21.70	22.30	22.30	22.00	19.70	18.00	2.80

The LSD or least significant difference is the smallest difference required between two means for them to be statistically different at the 5% level.

There was no consistent relationship between nutrient levels and skin quality characteristics. A combined analysis using onions from the two Hawke's Bay sites together with the commercial sites shows no consistent relationship between skin number, skin cracking or skin adhesion with any nutrient level (Figures 6-8).

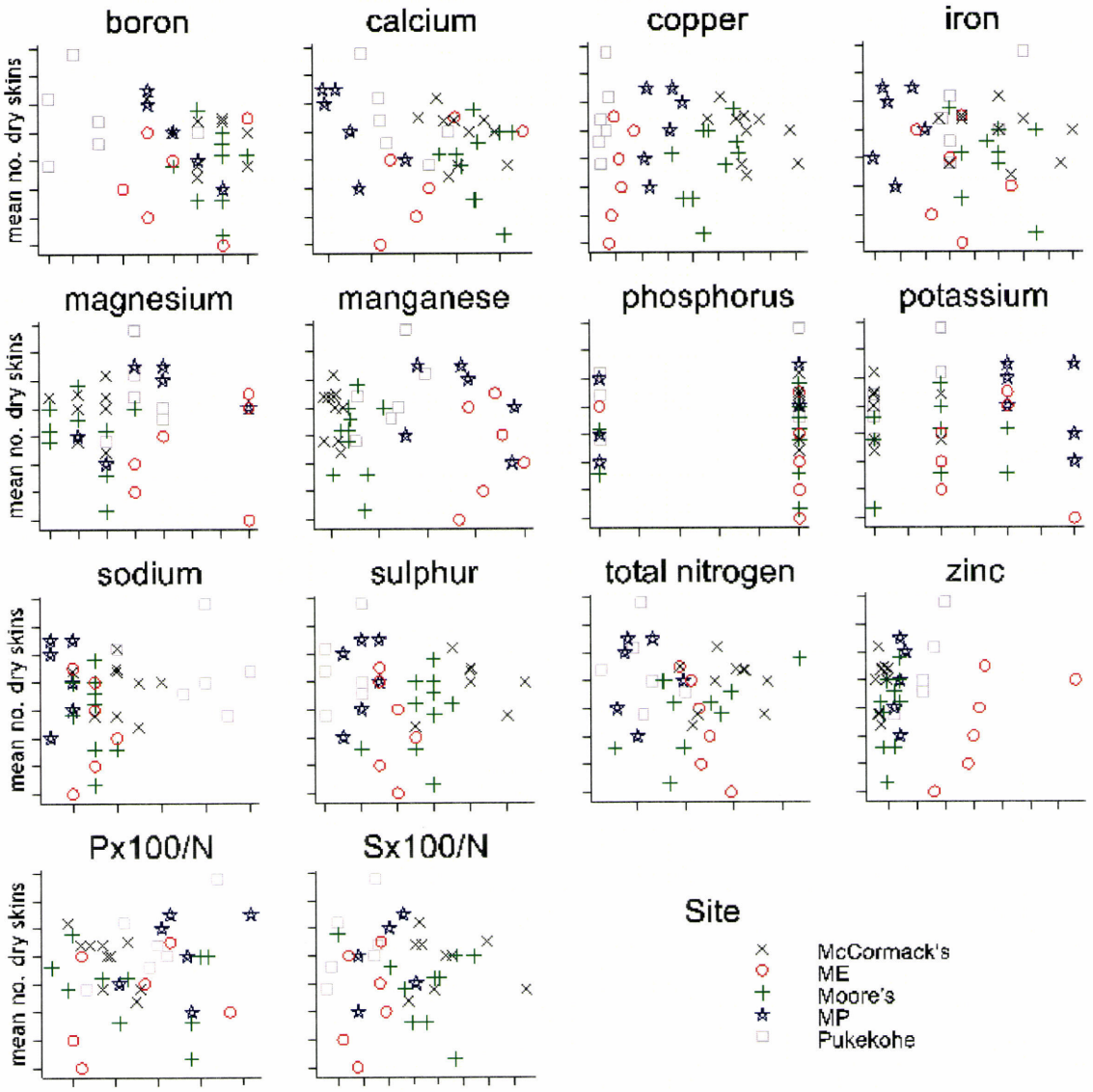

Figure 6: Scatter graphs showing relationships between nutrient levels in skins and the mean number of dry skins for onions grown at five different sites: Moore's and McCormack's sites in Hawke's Bay; ELK (ME) and PLK (MP) onions in Matamata; one site in Pukekohe.

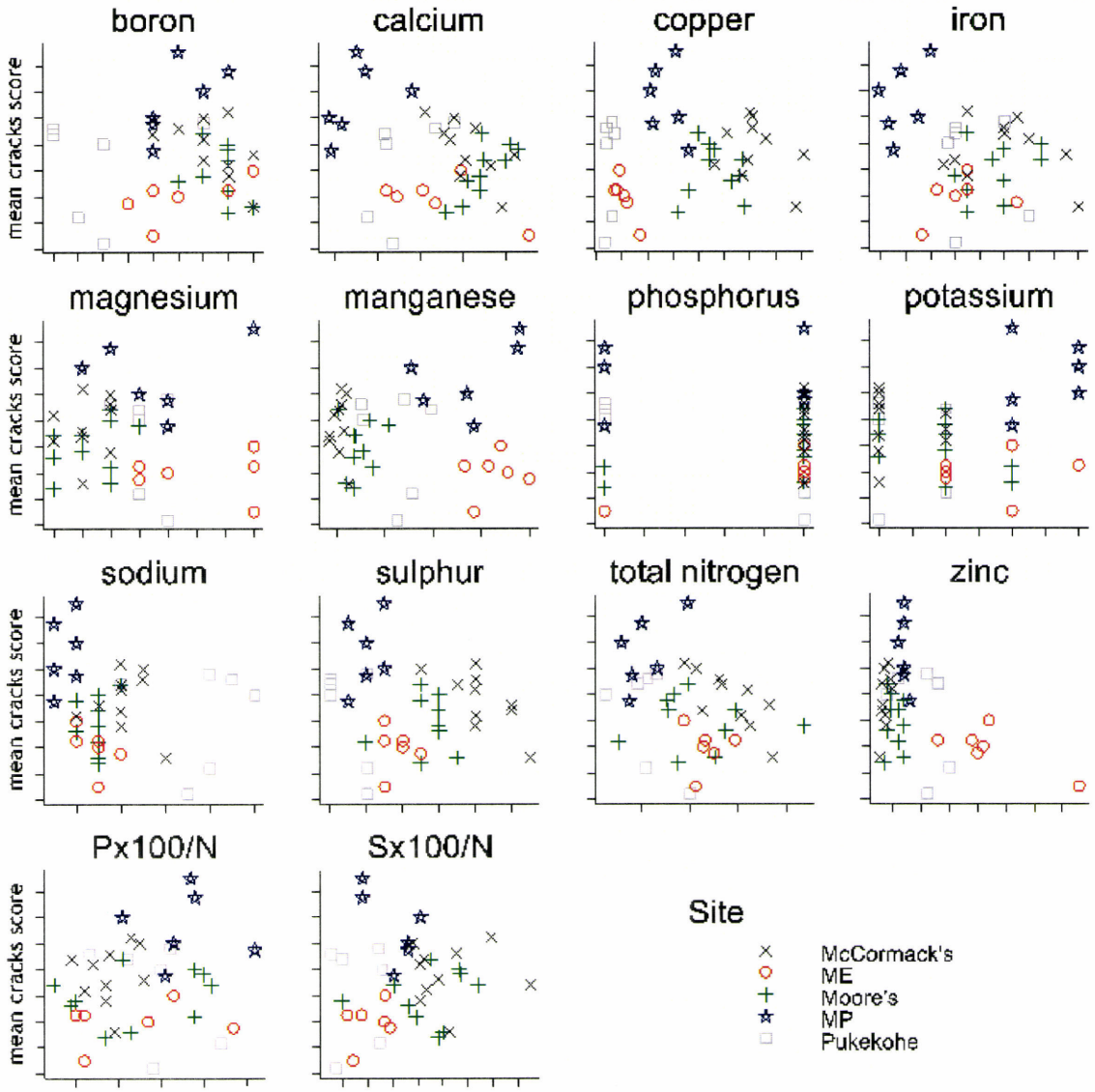

Figure 7: Scatter graphs showing relationships between nutrient levels in skins and the mean skin crack score for onions grown at five different sites: Moore's and McCormack's sites in Hawke's Bay; ELK (ME) and PLK (MP) onions in Matamata; one site in Pukekohe.

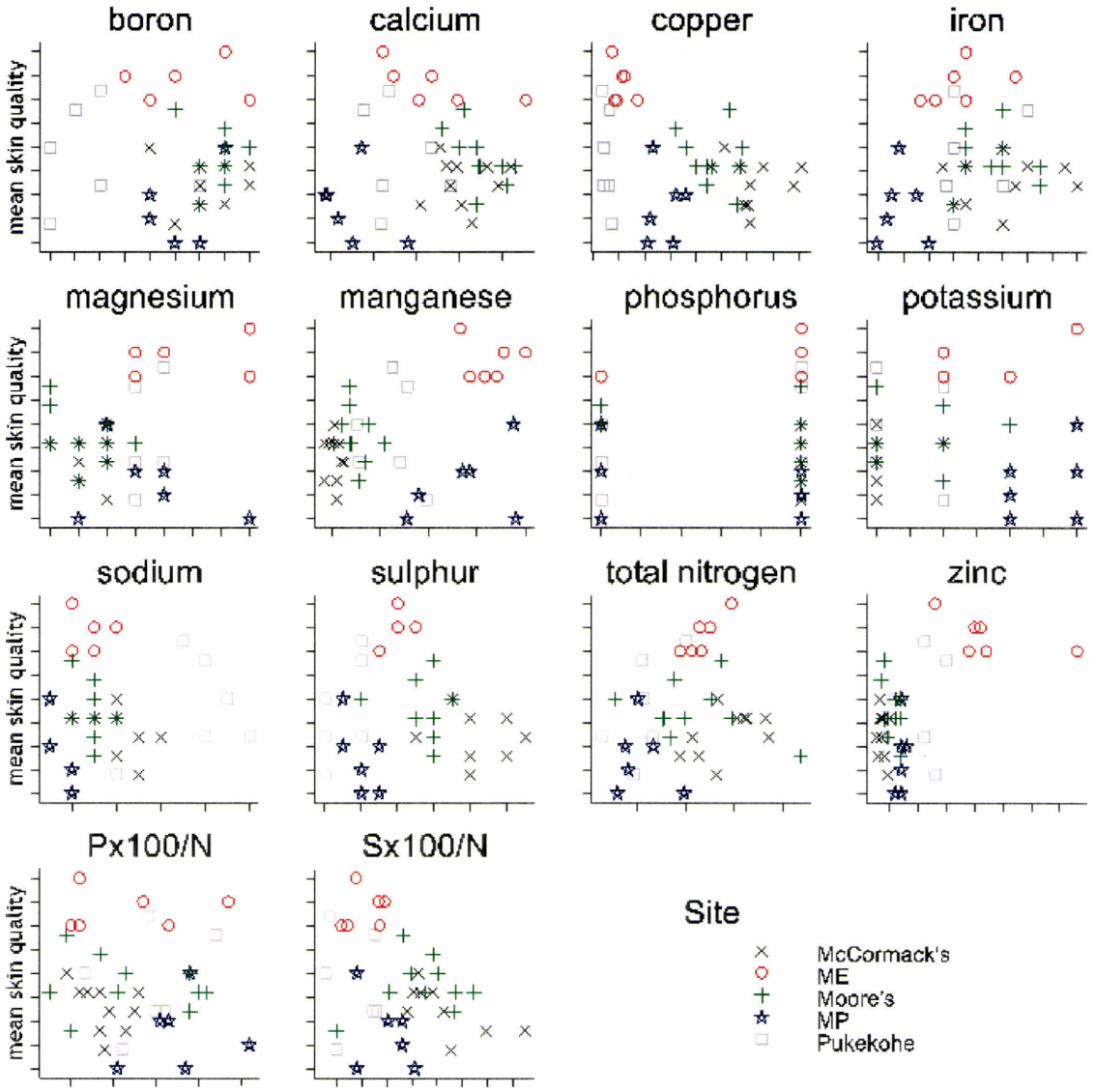

Figure 8: Scatter graphs showing relationships between nutrient levels in skins and the mean skin quality score for onions grown at five different sites: Moore's and McCormack's sites in Hawke's Bay; ELK (ME) and PLK (MP) onions in Matamata; one site in Pukekohe.

5 Discussion

Foliar Ca application can be a routine management tool in onion production. However, our results obtained from five onion paddocks indicate that foliar Ca applications do not increase yield or result in improved skin quality of onions. Foliar Ca applications did not result in improved skin Ca concentration, indicating that there was little uptake of applied Ca by onion

leaves. These results suggest that the use of foliar Ca sprays to improve skin quality cannot be recommended.

Skin quality did, however, vary between sites. A first hypothesis that this variation in skin quality was due to variation in nutrient levels in the crop was not proven (Figures 6-8), suggesting that skin quality variation between sites is caused by other factors. Other research has indicated that cultivar is a more important determinant of skin quality than nitrogen or irrigation application (Hole et al. 2002). We are unable to comment on the effect of cultivar as we used ELK at all but one site.

The leaf tagging at the two Hawke's Bay sites showed that leaves 5-9 formed the onion skins, with leaf 7 forming the bulk of the skins, and leaves 8-9 the bulk of the innermost skins. Growth characteristics of these leaves were not related to subsequent skin physical characteristics such as weight, area or thickness. If factors influencing the growth of the leaves (and hence the bulb), such as nutrients or irrigation, are to affect skin quality, a relationship between leaf growth and skin quality would be expected. The lack of such a relationship suggests that nutrients or irrigation did not affect skin quality in our trial. Climate is another factor that may contribute to variation in skin quality, but was outside the scope of the present project. We concluded from our study that 2006 was a year of good onion skin quality. However, we have to recognise that our onions were given gentle handling, with no machine harvesting, no truck transport and no exposure to a grading and packing line.

One part of the leaf that has not been studied is the basal part – the white fleshy part of the leaf that can eventually become the skin. Its size and ability to expand as bulb diameters increase are probably key components of skin quality, but they have not been studied directly. Before we are able to manage skin quality, we need to understand how the basal component of the leaf changes over time as influenced by nutrients or climate.

Measuring skin quality is not easy. There is no simple measure of quality and the larger the sample the better. From our study we believe that the most useful measures of skin quality are:

- Dry skin number;
- Skin cracking score;
- Skin adhesion score for first adhering skin layer.

These measures could be tested during commercial handling and storage by periodic sampling from the same bin or bag. Another useful observation that should be checked commercially is to carefully examine onions around the basal plate during storage to look for and to count remnants of shed (lost) skins. Lost skins imply that there is less protection for the onion during the remaining storage period.

One of the goals of improving onion skin quality is to make the crop more resistant to thrips infestations. Thrips numbers after 5 weeks in storage were higher than expected from the Hawke's Bay site, as the counts had been much lower just after harvest. The good-quality onions from this site did not appear to be able to stop thrips infestation. The thrips infestation pattern did match the belief that onions harvested and going into storage early in the season are prone to a buildup of thrips in storage. This is probably related to

the warmer temperatures favoured by thrips. There is also a belief that ELK are more susceptible to thrips than PLK. An in-depth study of onion qualities (skin and neck) using a thrips-infested line from topfall through to the end of the first month in storage could help link thrips infestation levels to onion skin quality. More needs to be known about the trigger for thrips to move from leaves into the bulb during curing, e.g. do bulbs removed from the field at lifting harbour any thrips (eggs, nymphs or adults)? The study would need to be done when the temperatures are warm and the thrips population active.

6 Conclusions and recommendations

- We conclude from our study that application of foliar Ca does not give clear benefits in improved onion skin quality. We do not recommend use of foliar Ca applications to improve the yield and/or skin quality of onions.
- Skin quality did change during storage. It also varied between sites but we did not find an indication of the likely cause of this variation.
- We measured low to moderate thrips numbers on onions at the start of storage. There did not seem to be a link between thrips infestation and use of foliar Ca nor between thrips infestation and onion skin quality.
- We measured a wide range of onion skin qualities during storage and, although none are quick and simple, we believe some could be used in future studies to assess skin quality in research and possibly in commerce. We recommend a focus on nutritional and climatic factors affecting the growth and expansion of the basal part of the leaf that goes on to become the onion skin.
- We believe that an in-depth study linking thrips population and onion skin and neck properties could help decide whether there are crop management strategies between lifting and harvest that could reduce thrips numbers in storage.
- From our study we believe that the most useful measures of skin quality are dry skin number, skin cracking score, and skin adhesion score (for the first adhering skin layer). In addition to these measures, we believe an assessment of shed (lost) skins (around the basal plate) and neck quality (length and tightness) could be useful additional quality measures.

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8 References

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Appendices

Appendix I Field layout of Ca trial, Hawke's Bay

SFF Onion skin trial (Mark Apatu's paddocks on Tannery Rd, Meanee)

Site 1: Moores

Treat 1: Control
Treat 2: Ca Spray

Plot size: 1 bed wide, 10m long, each plot separated by 1 bed of onions
Note: 5 plants marked in middle of plots 5 & 6

Guard	Guard	1	control	3	Ca	5	control	7	Ca	9	control	Guard	Guard	2	Ca	4	control	6	Ca	8	control	10	Ca	Guard	Guard

Tannery rd — track — drain

Site 2: McCormacks

Treat 1: Control
Treat 2: Ca Spray

Plot size: 1 bed wide, 10m long,
each plot separated by 1 bed of onions
Note: 5 plants marked in middle of plots 5 & 6

Guard	Guard	1	control	3	Ca	5	control	7	Ca	9	control	Guard	Guard	2	Ca	4	control	6	Ca	8	control	10	Ca	Guard	Guard

track — drain

Site 1 — track

site 2

Appendix II Ca treatment details for Site 1 (Moore's). Prepared by Peak Research, Havelock North.

	Application 1	Application 2	Application 3	Application	Application 5	Application 6	Application 7	Application 8
Date and Time	6/10/05	13/10/05	20/10/05	26/10/05	4/11/05	10/11/05	19/11/05	24/11/05
	8.40	9.30	7.15	17.00	6.30	17.00	10.00	18.00
Treatments	2	2	2	2	2	2	2	2
Crop Stage	4 leaf	4/5 leaf	5/6 leaf	5/6 leaf	6 leaf	7/8 leaf	8/9 leaf	9 leaf
Crop –wet/moist/dry	dry	dry	dry	dry	dry	dry	Dry	Dry
Weather – fine/cloudy	fine	cloudy	cloudy	fine	fine	fine	fine	fine
Temp °C	12	17	14	19	16	23	24	16
Humidity %	68	65	58	52	62	52	45	48
Wind m/s & Direction	0.0-0.5 NW	0.0-0.5 NW	0.0	0.0-1.0 W	0.0	0.0-1.0 W	0.0-0.5NE	0.5-1.5SW
Application equipment	Echo	Echo	Echo	Echo	Echo	Echo	Echo	Echo
Nozzle type	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002
Pressure kpa	300	300	300	300	300	300	300	300
Water Rate /ha Actual	300	300	300	300	300	300	300	300

Appendix III Ca treatment details for Site 2 (McCormack's). Prepared by Peak Research, Havelock North.

	Application 1	Application 2	Application 3	Application 4	Application 5	Application 6	Application 7	Application 8
Date and Time	6/10/05	13/10/05	20/10/05	26/10/05	4/11/05	10/11/05	19/11/05	24/11/05
	9.00	9.45	7.30	17.15	7.00	17.15	10.15	18.15
Treatments	2	2	2	2	2	2	2	2
Crop Stage	4 leaf	4/5 leaf	5/6 leaf	5/6 leaf	6 leaf	7/8 leaf	8/9 leaf	9 leaf
Crop –wet/moist/dry	dry	dry	dry	dry	Dry	dry	Dry	Dry
Weather – fine/cloudy	fine	cloudy	cloudy	fine	fine	fine	fine	fine
Temp °C	12	17	14	19	16	23	24	16
Humidity %	68	65	58	52	62	52	45	48
Wind m/s & Direction	0.0-0.5 NW	0.0-0.5 NW	0.0	0.0-1.0 W	0.0	0.0-1.0 W	0.0-0.5NE	0.5-1.5SW
Application equipment	Echo	Echo	Echo	Echo	Echo	Echo	Echo	Echo
Nozzle type	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002	4 X 11002
Pressure kpa	300	300	300	300	300	300	300	300
Water Rate /ha Actual	300	300	300	300	300	300	300	300

Appendix IV Leaf nutrient contents for Hawke's Bay onions sampled prior to Ca treatment application (3 leaf stage) and averaged for each site.

	total nitrogen % w/w	phosphorus % w/w	potassium % w/w	sulphur % w/w	Ca % w/w	magnesium % w/w	sodium % w/w	iron mg/kg	manganese mg/kg	copper mg/kg	zinc mg/kg	boron mg/kg
Moore's												
	5.6	0.38	3.5	0.78	0.87	0.13	0.03	89	19	7.2	24	14
McCormack's												
	5.6	0.38	3.5	0.84	0.94	0.14	0.03	112	16	7.8	21	15

Appendix V Ca treatment details for Pukekohe ELK crop.

Application Number	1	2	3	4	5	6	7	8
Date	04.10.05	12.10.05	19.10.05	24.10.05	31.10.05	07.11.05	15.11.05	23.11.05
Interval (days)	-	8	7	5	7	7	8	8
Growth Stage	3-4 leaf to 200mm	3-4 leaf to 250mm	5-6 leaf to 300mm	5-6 leaf to 400mm	6-7 leaf	8+ leaf	neck swell	9-10 leaf
Foliage (wet/dry)	dry	dry	damp	wet	dry	dry	damp	dry
Air Temperature (°C)	20.1-20.9	18.6-20.3	17.4-20.4	14.5-15.3	14.4-32.9	19.6-22.9	10.9-18.4	20.0-21.9
Relative Humidity (%)	41-48	45-63	46-60	59-71	21-63	42-59	51-75	31-43
Soil Temperature (°C)	18.9	17.2	16.9	12.7	20.7	21.3	14.9	20.8
Soil Moisture	moist	moist	moist	moist	dry	dry	moist/wet	moist/dry
Wind (km/hr)	SW 5-8	0	E 3-5	0	0	SW 2-4	0	SW 3-5
Cloud Cover (%)	80	20	90	0	20	100	0	0
Additives	MZ	MZ	MZ	Acrobat MZ	Acrobat MZ	Acrobat MZ	MZ	MZ

Post Stopit timings with MZ + Ascend on 30.11.05, 08.12.05, 15.12.05 and 24.12.05.

Appendix VI Ca treatment details for Matamata ELK crop.

Stopit applied at 5 L/ha in 500 L/ha of water on 14/10/05, 19/10/05, 27/10/05, 3/11/05, 10/11/05, 17/11/05, 24/11/05, 2/12/05, 8/12/05, 15/12/05, 22/12/05 and 28/12/05, a total of 12 applications.

Appendix VII Ca treatment details for Matamata PLK crop.

Stopit applied at 5 L/ha in 500 L/ha of water on 16/11/05, 24/11/05, 2/12/05, 9/12/05, 15/12/05, 22/12/05, 29/12/05, 6/01/06, 12/01/06, 20/01/06, 29/01/06 and 2/02/06, a total of 12 applications.

Appendix VIII Skin adhesion results for Skin 1 for commercial sites (means of 15 onions).

Site	Ca	Time (weeks) 3	5	10	15	20	Mean
Matamata, ELK	Control		2.0	1.4	1.3	1.3	1.5
	Ca		1.6	1.6	1.3	1.6	1.6
Matamata, PLK	Control		1.9	1.7	1.5	1.5	1.7
	Ca		2.1	1.5	1.7	1.6	1.7
Pukekohe, ELK	Control	1.3	1.3	1.3	1.4	1.5	1.4
	Ca	1.5	1.4	1.3	1.5	1.4	1.4

Appendix IX Skin adhesion results for Skin 2 for commercial sites (means of 15 onions).

Site	Ca	Time (weeks) 3	5	10	15	20	Mean
Matamata, ELK	Control		2.9	2.4	2.0	2.2	2.3
	Ca		2.7	2.7	2.2	2.8	2.6
Matamata, PLK	Control		3	2.8	2.3	2.8	2.7
	Ca		2.9	2.4	2.7	2.7	2.7
Pukekohe, ELK	Control	2.5	2.2	2.2	2.6	2.6	2.4
	Ca	2.9	2.9	2.1	2.6	2.5	2.6

Appendix X Leaf nutrient analysis results from commercial sites.

	Date	total nitrogen % w/w	phosphorous % w/w	potassium % w/w	sulphur % w/w	Ca % w/w	magnesium % w/w	sodium % w/w	iron mg/kg	manganese mg/kg	copper mg/kg	zinc mg/kg	boron mg/kg
Matamata ELK													
Seedling (pre-Ca)	30/09/05	4.9	0.44	5.2	0.75	1.27	0.20	0.07	627	120	56	10	16
Leaf (no Ca)	06/12/05	2.5	0.25	2.1	0.58	0.72	0.14	0.01	38	85	20	4	16
Leaf (Ca)	06/12/05	2.4	0.29	2.1	0.60	0.67	0.14	0.02	46	80	23	5	19
Matamata PLK													
Seedling (pre-Ca)	19/11/05	3.5	0.34	4.2	0.66	1.32	0.22	0.02	98	130	30	8	18
Leaf (no Ca)			No Samples										
Leaf (Ca)			No Samples										
Pukekohe ELK													
Seedling pre-Ca (no Ca)	5/10/05	5.42	0.38	3.4	0.8	1.17	0.18	0.05	58	15	8	20	17
Seedling pre-Ca (Ca)	5/10/05	5.75	0.47	4.1	0.92	1.34	0.20	0.06	60	25	26	25	17
Leaf (no Ca)	7/12/05	2.74	0.22	1.80	0.59	0.85	0.13	0.06	8	48	7	28	16
Leaf (Ca)	7/12/05	3.09	0.31	2.00	0.66	0.76	0.14	0.05	10	40	5	29	24

Appendix XI Bulb and skin nutrient analysis results from commercial sites.

	Date	Skin total N (ppm)	Bulb NO3-N (ppm)	S (ppm)	P (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Se (ppm)	Mo (ppm)	NO3 (ppm)	Co (ppm)
Matamata ELK																		
Skin (no Ca)	27/2/06	4.1		440	310	200	146	50	2695	38	0.68	0.79	0.1	1.1	3.4	0.06		0.01
Skin (Ca)	27/2/06	4.2		480	270	180	137	60	2685	41	1.1	0.95	0.11	1.7	1.6	0.06		0.01
Bulb (no Ca)	10/3/06		217	848	377	334.3	258.6	29.1	5916	1.82	1.48	1.25	0.89	5.9		0.03	217.4	
Bulb (Ca)	10/3/06		250	714	345	244.5	240.3	21.7	5680	1.82	1.06	1.05	1.09	5.0		0.02	249.7	
Matamata PLK																		
Skin (no Ca)	27/2/06	4.7		310	320	180	145	60	2740	21	0.8	0.86	0.1	1.7	1.5	0.1		0.01
Skin (Ca)	27/2/06	4.3		520	330	190	131	50	2570	37	1.9	1.5	0.1	1.8	2.8	0.33		0.02
Bulb (no Ca)	10/3/06		271	718	387	299.8	249.6	25.9	4060	1.8	1.11	1.1	0.75	4.0		0.02	271.4	
Bulb (Ca)	10/3/06		250	663	352	244	220.6	26.4	5327	1.38	1.35	0.99	1.1	6.0		0.03	249.7	