Project Report

Improving the understanding and management of skin set and bloom in potatoes

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Preface

This four-year, BPC-funded, project was carried out by researchers at ADAS, SAC, the BPC's Sutton Bridge Experimental Unit and HRI Wellesbourne. It sought to understand the agronomic, physiological and biochemical factors which influence skin adhesion, skin strength, the speed of skin set, and problems associated with poor skin quality, primarily through netting and loss of bloom.

The report is broken down into five sections, covering the following areas of work:

- Manipulation of skin set
- Unsetting of skins
- Effect of micronutrients on skin set
- Factors influencing the occurrence of netting
- Factors influencing skin bloom

The work on netting consisted of one year's trial to evaluate the effects of crop maturity at defoliation, speed of haulm removal and soil moisture availability at haulm destruction on the severity of netting. After the first year, further work on netting was continued with Defra funding ('Blemish diseases of potatoes - physiology and biochemistry of skin set and skin netting' [HP0140]).

Results from this BPC project have shown that with respect to skin set, attention should be given to N application rate, modified by season length, in varieties that are very indeterminate or have a reputation for poor skin set.

Unsetting of skins does not always occur, but when it does, skins can become unset shortly after harvest and continue to be weaker than at harvest for several weeks. The method of haulm destruction did not affect the degree of unsetting observed during the project, however, the soil tuber environment after haulm destruction influenced skin unsetting in two out of the three years studied.

Storage treatments generally had minimal impact on the decline of skin bloom during the project, however, curing did cause changes in skin bloom. Crop duration also influenced skin bloom- longer duration crops tended to have duller skins after prolonged storage. The severity of black dot was also influenced by crop duration, with more black dot developing in longer duration crops. An immediate temperature pull-down following harvest minimised black dot development as well as the rate of skin bloom deterioration.

1. Summary for growers

1.1 Project aims

The objectives were: to improve the understanding, control and maintenance of skin set; to better understand and develop strategies to help maintain skin finish during storage.

1.2 Work undertaken, key findings and conclusions

There were five inter-related agronomy and storage work areas involving experiments by SAC, ADAS and Sutton Bridge Experimental Unit (SBEU).

The work areas were: i) manipulation of skin set; ii) un-setting of skins; iii) effect of micronutrients on skin set; iv) factors influencing occurrence of netting; and v) factors influencing skin bloom. Work on skin netting was done in year 1 of this project, and then taken on as part of a Defra-funded project, led by Warwick HRI (Defra reference number: HP0140).

Skin set

Cara (2001-3) and Nadine (2003-4), grown on a light silt soil in Lincolnshire, were managed to produce differing skin set by manipulating nitrogen (N) nutrition, chitting, haulm destruction method, and planting date. N had no effect in seasons when skins were well set in all treatments but, in two years, skin set was more varied. In these cases, skins were least well set in treatments with greatest N applications. Rainfall, leaching and crop demand influence N availability, so these seasonal effects should be expected.

With Cara, there were effects of N on skin set in 2002 only, when senescence at haulm destruction was about 30%, compared with 55% in 2001 and 46% in 2003. So over-application of N had a negative effect on skin set if the crop was defoliated at early canopy senescence. Often, over-application of N leads to defoliation when the canopy is too green. This suggests that N application should be adjusted in response to anticipated season length. Chitting and planting date did not affect skin set, but did affect canopy senescence, showing that skin set at harvest cannot be predicted solely by senescence at defoliation. There were differences between cultivars in skin set and growers therefore need to take care with N application rates for varieties known to suffer from poor skin set.

A trial was done in 2001 to examine the effect of micronutrients on skin set and skin thickness at harvest. The variety was Cara and the site had high fertility. The micronutrients added were calcium and sulphur, iron, manganese and a commercial balanced micronutrient fertiliser, plus a control. No significant differences between treatments were observed.

Unsetting of tuber skins after harvest has been reported in varieties such as Cara, Nadine, Maris Piper and Hermes. This is distinct from skins not properly set at harvest and was studied in Cara over three years in East Lothian. Skin unsetting was found to occur within two hours after harvest. The effects of several factors were examined, including haulm destruction method, post-harvest tuber environment and handling. The tuber environment (in particular excess moisture pre- and post-haulm

destruction), and small impacts when handling the crop, were shown to exacerbate unsetting.

Netting

An experiment to investigate netting was done on a loamy, medium sand in Nottinghamshire with treatments including chitting, haulm destruction method, and full irrigation or late drought. Earliest netting was recorded 4 weeks after tuber initiation. Seed sprouting or method of haulm destruction had little effect on netting. Related Defra-funded research showed that flailing resulted in less severe netting compared with natural senescence. Netting was not related to tuber size. Field and glasshouse data suggested that water stress, or cycles of stress, led to greater netting severity.

Skin bloom and black dot

Experiments were grown in 2001-2004 on a light silt soil in south Lincolnshire that was suitable for producing tubers with a good skin finish. Field treatment factors included seed maturity, planting date and harvest date and these produced differing skin bloom characteristics. Storage treatments were imposed to study effects of store environment on maintenance of bloom.

Crop duration was shown to affect skin quality: longer duration crops tended to have more black dot and have duller skins (i.e. less bloom) after prolonged storage. An immediate temperature pull-down following harvest consistently minimised black dot development and skin bloom deterioration. Poor skin bloom was shown to result from a loss of integrity of the periderm surface.

1.3 Practical recommendations

To avoid poor skin set, N application should be adjusted in response to variety, available soil N, and anticipated season length (e.g. if planting is delayed because of wet soil conditions).

For reliable skin set, plan to defoliate crops when natural senescence is in progress, and at least 50% of the leaves have started to turn yellow.

Check for changes in skin set after harvest, and handle the crop accordingly.

To minimise netting symptoms, irrigation should be scheduled according to crop demand and soil moisture deficit.

For a good skin finish, harvest the crop as early as possible (but ensuring adequate skin set) and reduce tuber temperatures as quickly as possible after store loading.

Further work is needed to compare the costs (e.g. yield loss) and benefits (higher crop value) of growing for best skin finish.

2. Experimental section

2.1 Introduction

The experimental section is divided into five work areas. These are reported separately below, but key findings from all of these work areas are given in Section 1 of this report.

2.2 Manipulation of skin set

Section authors: Jeremy Wiltshire, ADAS, and Jeff Peters, SBEU.

2.2.1 Introduction

The process of skin-set is influenced by a number of factors, including variety, crop agronomy and method of haulm removal.

Skin strength and set have different components, including the strength of adhesion of the skin to underlying tissues, and the tensile strength of the skin. The adhesion of skin is influenced by cultivar (Bowen, Muir and Dewar, 1996). Varieties also differ in skin thickness even when grown under similar situations, and skin thickness declines after haulm removal. In the above work, Record was found to have the thickest skins, while Pentland Squire and Cara had the thinnest. Skin thickness declined in all cultivars between 3 and 22 days after haulm removal, and in others continued to decline up to 49 days after haulm removal. Skin thickness was shown to be positively related to number of cell layers and thinner skins were associated with a smaller number of cell layers in the periderm. Decline in skin thickness over time was associated with a reduction in the number of cell layers in the periderm.

The work at SAC with the scuff meter demonstrated that skin adhesion strength was poorly related to skin characteristics such as skin thickness, spatial arrangement of cells in the skin or suberin content of cell walls. However, considering extreme treatments, greatest skin adhesion was associated with a thicker periderm, and low adhesion with a thin periderm. Larger differences were evident with the thumb test which better estimates the tensile and shear strength of the periderm and gives a better overall estimate of total skin strength.

Environmental factors can influence skin properties. Skins tend to be thinner and weaker when tubers are developing in cold moist soils during the period of skin set. Superficial periderm cells are thought to be more easily sloughed off at low soil temperatures (Yamaguchi *et al*., 1964). Crops grown in dry soils also tend to have lower numbers of cell layers in the periderm.

Agronomic factors are also thought to have an influence on skin strength. High levels of nitrogen and potash have been associated with thinner and weaker skins, though it is not clear if this is a direct effect or results from delaying crop maturity. Method of haulm destruction has been thought to influence skin set. Rapid separation of haulm from tubers is an important initiator of early skin set.

2.2.2 Materials and methods

Experiments were carried out in the years 2001 to 2004 at Wingland, on a light Lincolnshire silt soil typical of the Holbeach Marsh area. Field plots were managed to produce a range of skin set material by changing treatment factors that included nitrogen nutrition, seed condition, method of haulm destruction, and planting date (Table 1).

TABLE 1. FIELD TREATMENTS.

Year & varieties	Treatment factor	Treatment ID	Treatment
2001 Cara	N nutrition	N1	100 kg/ha
		N2	MAFF RB209 recommendation (160 kg/ha)
	Seed condition	S1	unsprouted
		S2	sprouted
2002 Cara	N nutrition	N1	0 kg/ha
		N2	MAFF RB209 recommendation (80 kg/ha)
		N3	160 kg/ha
	Haulm destruction method	H1	flail
		H2	diquat (split dose)
		H3	flail + glufosinate ammonium
2003 Cara & Nadine	N nutrition	N1	MAFF RB209 recommendation Cara - 165 kg/ha Nadine - 200 kg/ha
		N2	super-optimal Cara - 215 kg/ha Nadine - 260 kg/ha
	Haulm destruction method	H1	diquat (split dose)
		H2	flail + glufosinate ammonium
2004 Nadine	N nutrition	N1	sub-optimal 100 kg/ha
		N2	optimal 160 kg/ha
		N3	super-optimal 1 200 kg/ha
		N4	super-optimal 2 270 kg/ha (maximum RB209 rate)
	Planting date	P1	site practice
		P2	site practice + 23 days

The experiments were of a factorial design, with 4 replicates of each treatment arranged in 4 blocks, with one plot of each treatment in each block.

In 2001 there were two seed storage regimes before planting.

1) Seed for the unsprouted treatment (S1) was stored at 4 °C until 48 hours before planting. Seed temperature was then allowed to rise to ambient temperature before planting.
2) Seed for the sprouted treatment (S2) was managed to allow development of short (approximately 10 mm) sprouts that were compact, firm and dark green. Lighting was used for 12 hours each day and the temperature was adjusted up to a maximum of 11°C as required.

Thermal time was calculated for treatments S1 and S2, using 4°C as the base temperature. The totals were: S1 - 0 day degC; S2 - 150 day degC.

The seed tubers were planted by machine. Row width was 90 cm and seed rates (given in Appendix 1) were representative of best commercial practice for a pre-pack crop.

Planting date was late in 2001 (22 May) because of wet weather, but in 2002 and 2003 planting dates were at typical dates for pre-pack crops (11 April 2002 and 7 April 2003). In 2004 there were planting date treatments, with the intention of achieving typical and late planting dates. However, the first planting date (27 April) was delayed by 2-3 weeks because of wet soil conditions and the second planting date was 23 days later (20 May).

Irrigation, fertilisers and other agrochemicals were applied according to the normal agronomic practice for a farm crop of that variety except for variations necessary to impose treatments (e.g. N application rates). For further details of crop husbandry, plot sizes etc., see Appendix 1.

The times of 50% and full plant emergence were recorded.

For tuber initiation assessment, five sample plants per plot were examined in discard rows that had received the plot treatment. Soil was removed from one side of the potato ridge to expose the root/stolon system around the mother tuber, taking care to expose any stolons below the level of the mother tuber as tuber initiation often occurs on deeper stolons first. Stolons were traced from the mother tuber area to the tip on the exposed ridge side only. The date of initiation was taken as that on which at least two stolon tips on each of five sample plants had produced tubers. After assessment of stolon ends the soil was returned to the ridge so that minimum disturbance was caused to the plant.

Date of canopy closure was recorded as being equivalent to the date when 75% ground cover was achieved using a visual scoring method.

From the start of senescence, foliar senescence was assessed weekly in all plots using a grid method. A quadrat was used which had one dimension equal to the width of the row (0.9 m × 1.0 m), divided into 100 equal sized squares. Three quadrat counts per plot were made at approximately equal intervals along the length of the plot. The quadrat was placed above the crop so that it spanned the row exactly, and the number of squares within the quadrat, which contain more than 50% yellow/brown haulm

were counted. The percentage senescence was then estimated as the percentage of squares with more than 50% yellow/brown haulm.

Plots were defoliated using a tractor-mounted mechanical flail, except where the treatment required a different defoliation method (Table 1). After this operation any remaining stems were severed close to ground level by hand. Each plot was harvested using an elevator digger and the tubers were hand picked from the soil surface and placed into clean, labelled paper sacks. On the day of harvest, the tubers were transported in the paper sacks to SBEU for storage.

Skin set was assessed in the field using a scuffing barrel. Approximately 24 hours after defoliation (2004 only) and approximately 24 hours before harvest (2001-2004), tubers were hand-dug and washed, and 20 tubers, 45-65 mm, were placed in the barrel for 30 revolutions and then assessed for area scuffed in the following categories: 0, <2%, >2%-12.5%, >12.5%-25%, >25%. Median values for each category were used to calculate % area scuffed (Table 2).

TABLE 2. MEDIAN VALUES FOR EACH SCUFFING CATEGORY.

Area scuffed	Median value (mid-point)
0	0
<2%	1
2-12.5%	7.25
12.5%-25%	18.75
> 25%	62.5

Following harvest and delivery to SBEU, plot weights were measured and then the crop was hand graded to remove over- and under-sized tubers. Material was then weighed into labelled trays (to approximately 10 kg/tray). Trays were loaded into a 6 tonne capacity, controlled environment room maintained at a temperature within 1 degC of the incoming crop. Curing commenced from day of intake, at 0.5 degC pull down per day until the final holding condition of 3.5°C was reached, approximately 3 weeks after store loading. Humidity was maintained at 95% relative humidity (RH) during holding.

The intake assessments (each on 25 tubers per plot) were: weight of tubers; % surface area (%SA) and severity of netting; and %SA of silver scurf, black dot, common scab, powdery scab, black scurf and scuffing susceptibility. Subsequent assessments (Appendix 2) were as at intake, except there were no assessments of common scab, powdery scab or black scurf. %SA of skin spot was also assessed after storage.

A further scuffing susceptibility test was carried out 24 h after harvest using a scuffing barrel. Twenty tubers of 45-65 mm size were wetted then placed in a mesh barrel and rotated 30 times. The tubers were then removed and categorised visually into seven divisions depending on the area of skin removed (0, <2%, >2%-5%, >5%-12.5%, >12.5%-25%, >25%-50%, >50%) to allow calculation of mean area scuffed (%) for each treatment.

2.2.3 Results

Effects of nitrogen treatment on crop maturity

In 2001 nitrogen treatment had only a small influence on canopy senescence (Figure 1), and the delayed planting and rainfall after nitrogen application may explain this. Nitrogen was applied approximately five weeks before planting (in anticipation of earlier planting) and there were 72 mm of rainfall between N application and planting. This was followed by a further 50 mm of rain between planting (22 May) and the end of May. Some N may have been lost during this period of wet weather.

In 2002, senescence was most rapid in the zero nitrogen treatment, and slowest in the high nitrogen treatment (Figure 2).

In 2003, time of canopy senescence was similar in all treatments. Foliar senescence at haulm destruction was 5% for Nadine and 46% for Cara (data not presented).

In 2004, for the P1 treatment, senescence was earlier in low N treatments compared with higher N treatments, but the two highest N treatments were similar (Figure 3).

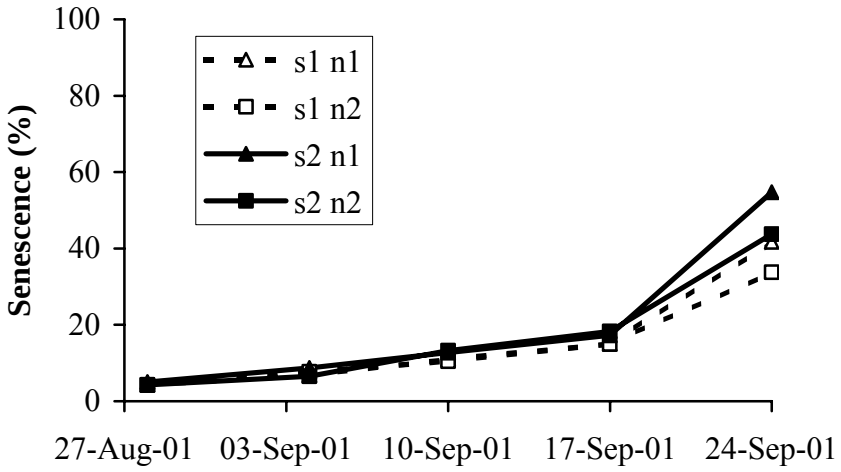


FIGURE 1. FOLIAR SENESCENCE (%), 2001.

s1 - unsprouted; s2 - sprouted; n1 - 100 kg/ha N; n2 - 160 kg/ha N.

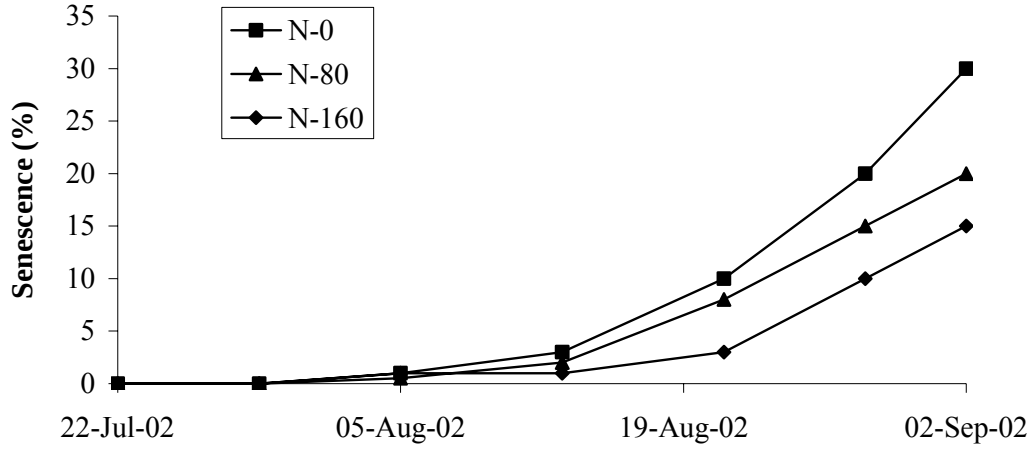


FIGURE 2. FOLIAR SENESCENCE (%), 2002.

N1 - 0 kg/ha N; N2 - 80 kg/ha N; N3 - 160 kg/ha N.

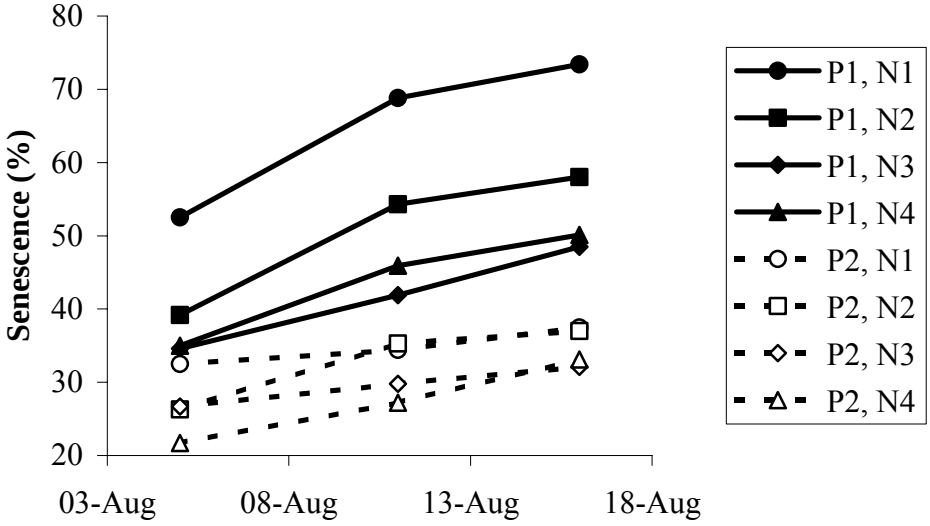


FIGURE 3. FOLIAR SENESCENCE (%), 2004.

For details of treatments see Table 1.

Effects of nitrogen treatment on skin set

In 2001 and 2003, skins were generally well set in all treatments, both 24 h before and 24 h after harvest. In view of the late planting in 2001 (Appendix 1), it appears surprising that skins were generally well set at harvest in all treatments, since Cara is a cultivar which often exhibits poor skin set when the growth period has been short. However, decreased N supply would be expected to improve skin set at harvest, and some N may have been lost during periods of wet weather between N application and planting (72 mm rainfall) and between planting and emergence (50 mm rainfall). In the case of Nadine in 2003, there was a significant effect (P=0.03) of nitrogen application treatment (Table 3), with a decrease in scuffing (better skin set) in the higher nitrogen application treatment 24 h before harvest. However, by commercial

standards skins were well set in all plots, and this effect was not found 24 h after harvest, so this result is not of commercial significance.

In 2002 the highest nitrogen treatment had the poorest skin set, both just before harvest (Table 4) and after harvest (Figure 4).

TABLE 3. THE EFFECT OF NITROGEN TREATMENT ON SKIN SET IN CV. NADINE, 2003.

Treatment	N application	% area scuffed
N1	200 kg/ha	3.87
N2	260 kg/ha	1.57
	SED (9 d.f.)	0.893

TABLE 4. THE EFFECT OF NITROGEN TREATMENT ON SKIN SET IN CV CARA 24 H BEFORE HARVEST IN 2002.

Treatment	N application	% area scuffed
N1	0 kg/ha	1.15
N2	80 kg/ha	0.90
N3	160 kg/ha	2.29
	SED (24 d.f.)	0.387

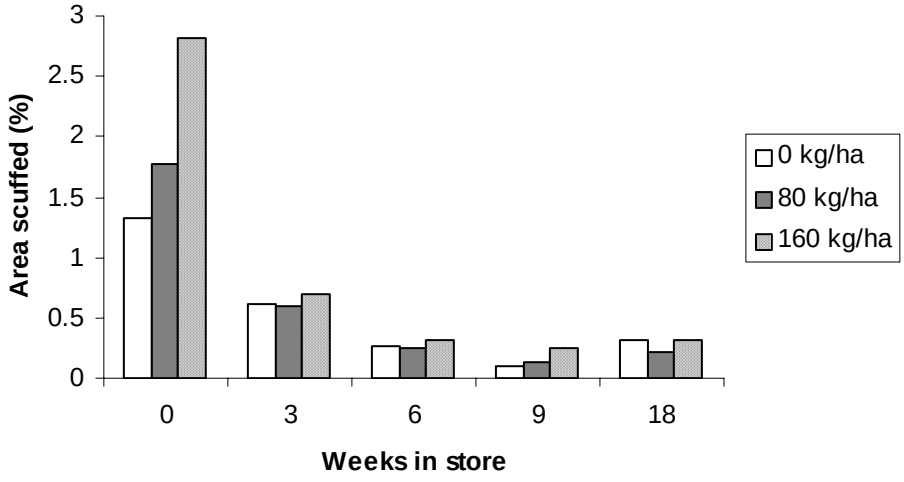


FIGURE 4. EFFECT OF NITROGEN LEVEL ON SCUFFING SUSCEPTIBILITY IN CV CARA OVER AN 18-WEEK STORAGE PERIOD IN 2002.
($SED_{(d.f.=132)}$=0.22.)

In 2004, on the day following defoliation, skins were not set, and there were no significant differences between treatments. At the second scuffing assessment, 24 h before harvest, there were no effects of planting date, and no interaction between planting date and nitrogen treatment. However, there was a significant effect of nitrogen treatment (P=0.002). Mid-range nitrogen treatments (N2 and N3, see Table 1) had skins that were more set (i.e. less scuffing) than treatments N1 (sub-optimal N) and N4 (the highest, super-optimal N treatment) (Figure 5). At store loading, scuffing susceptibility increased with increasing nitrogen application rates ($P<0.05$) (Figure 6). There was no effect of planting date on scuffing susceptibility.

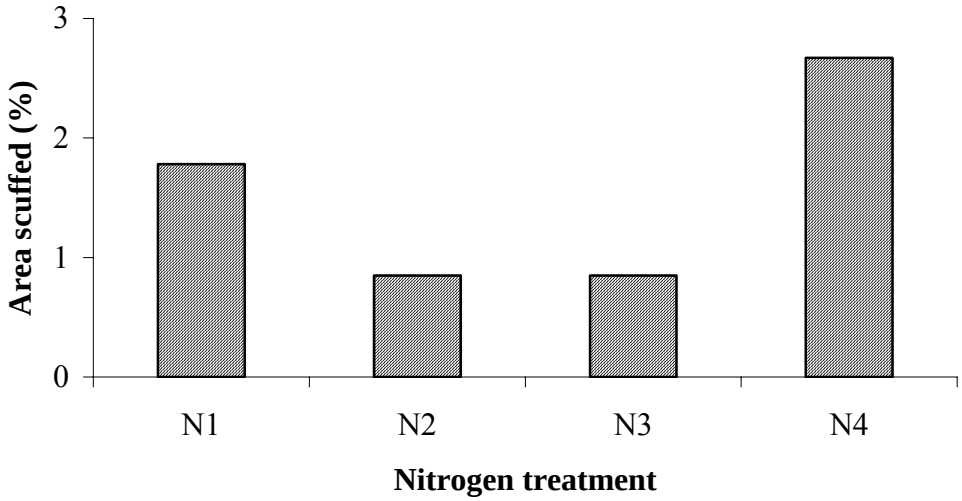


FIGURE 5. AREA SCUFFED (%) FOR NITROGEN TREATMENTS 24 H BEFORE HARVEST IN 2004.
($SED_{(d.f.=21)}$=0.466)

For details of treatments see Table 1.

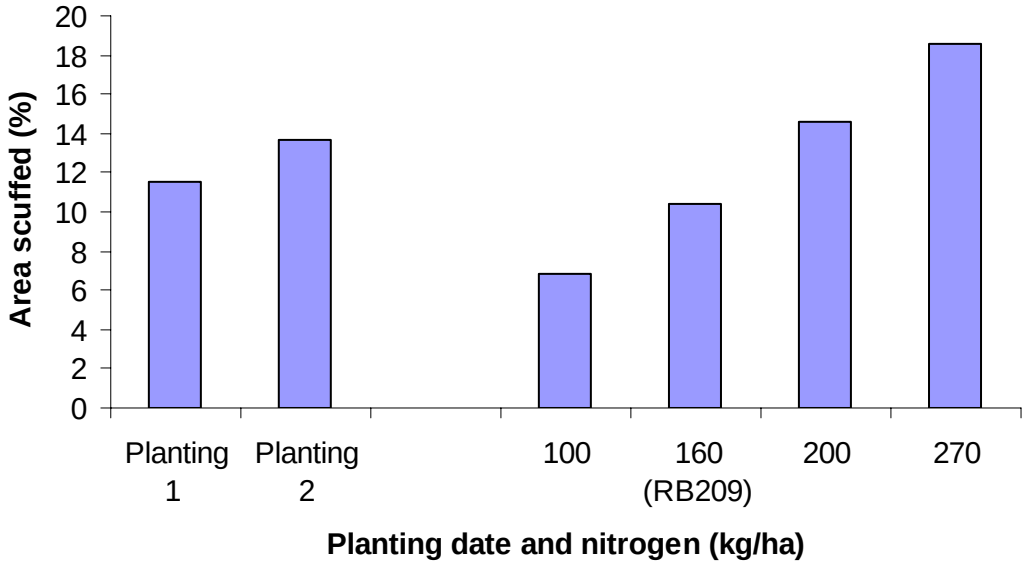


FIGURE 6. SCUFFING SUSCEPTIBILITY (24 HOURS AFTER HARVEST) IN CV NADINE, 2004, UNDER FOUR NITROGEN TREATMENTS AND TWO PLANTING DATES.
(SED planting$_{(d.f.=21)}$=2.90; SED nitrogen$_{(d.f.=21)}$=4.10)

Effects of haulm destruction method on skin set

In 2002, diquate (split dose) increased scuffing susceptibility, when compared with the flail + glufosinate ammonium treatment, but only at store loading (P = 0.005) (Figure 7). There was an interaction between nitrogen and defoliation treatments (P = 0.034), whereby the scuffing susceptibility was greater in those plots that had both the split dose diquat and the high nitrogen treatments. However, this interaction was small compared with the main effects. In 2003 there was no significant effect of defoliation treatment on skin set.

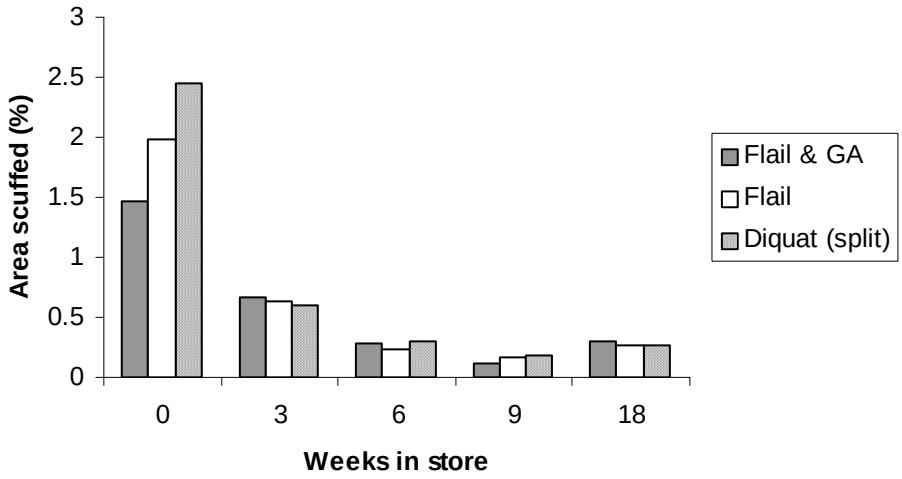


FIGURE 7. EFFECT OF DEFOLIATION TREATMENTS ON SCUFFING SUSCEPTIBILITY IN 2002, OVER AN 18-WEEK STORAGE PERIOD.
(SED$_{(d.f.=132)}$=0.22)

Effects of seed condition and planting date on skin set and crop maturity

There were no effects of seed condition or planting date (2001 and 2004 respectively) on skin set.

Dates of emergence, tuber initiation and canopy closure are given in Table 5 (2001) and Table 6 (2004). In 2001, seed sprouting advanced tuber initiation by one week, and canopy closure by only 4 days. Senescence was more rapid in the sprouted treatment, compared with unsprouted, but the differences were not large (Figure 1). Thus, differences in maturity between sprouted and unsprouted treatments were small, explaining the similarity between treatments in skin set.

In 2004, the differences in growth stage between planting date treatments were larger than the differences in growth stage between seed sprouting treatments in 2001. Late planting delayed tuber initiation by 17 days, and canopy closure by 9 days (Table 6). Senescence was also affected, and was later in late planted treatments (Figure 3). Despite these differences, there were no effects of planting date on skin set.

TABLE 5. EMERGENCE, TUBER INITIATION AND CANOPY CLOSURE IN CV. CARA, 2001. (S1 - unsprouted; S2 – sprouted).

	S1	S2
First emergence	14 June	06 June
50% emergence	18 June	09 June
Full emergence	25 June	14 June
Tuber initiation	26 July	19 July
Canopy closure	13 July	09 July

TABLE 6. EMERGENCE, TUBER INITIATION AND CANOPY CLOSURE IN CV. NADINE, 2004.

	Planting 1	Planting 2
First emergence	30 May	11 June
50% emergence	02 June	14 June
Full emergence	05 June	16 June
Tuber initiation	18 June	05 July
Canopy closure	03 July	12 July

Effects of treatments on tuber yield and quality

In 2001 and 2003, tuber yields were unaffected by treatments. In 2002, tuber yield (Figure 8) was greatest in the N3 treatment (160 kg/ha) and least in the N1 treatment (0 kg/ha) (P<0.001). In 2004, yields were greatest in the P1 treatment (59.8 t/ha), compared with P2 (45.7 t/ha), and treatment N1 had a lower yield (44.9 t/ha) than other N treatments (54.6–56.6 t/ha).

In general, disease levels were extremely low at harvest (generally <1% mean surface area of tuber affected) and remained so for the storage duration. An exception to this was that in 2002, violet root rot severity was increased in the zero nitrogen, flail only treatment (P<0.001) (Figure 9). Also in 2002, tubers in zero nitrogen plots had higher levels of black dot over the 18-week storage period compared with levels on tubers grown in nitrogen amended plots (data not presented, P<0.001).

In 2002, nitrogen nutrition dramatically affected weight loss after storage at 3.5°C for 18 weeks (Table 7). Weight loss was higher in tubers grown in the 0 kg/ha nitrogen plots than those grown in the 80 and 160 kg/ha plots (P<0.001).

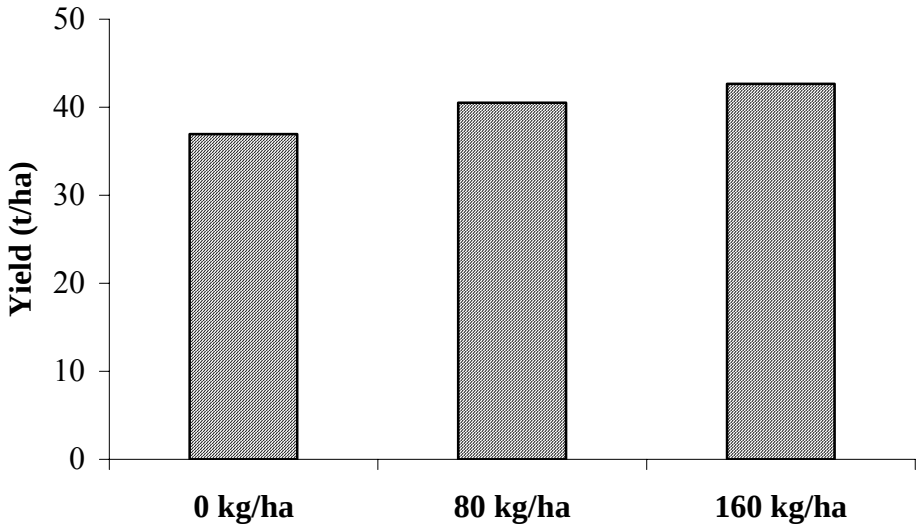


FIGURE 8. MEAN YIELDS FOR NITROGEN TREATMENTS IN 2002 (T/HA). ($SED_{(d.f.=24)}$=1.121)

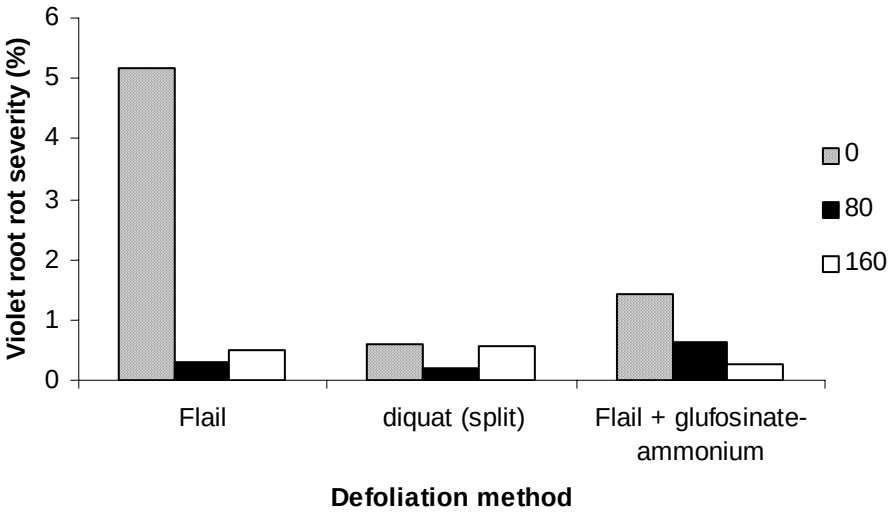


FIGURE 9. VIOLET ROOT ROT SEVERITY IN CV. CARA, 2002 FOR EACH OF THE DEFOLIATION METHODS AND NITROGEN APPLICATION TREATMENTS (0, 80 AND 160 KG/HA) (mean of three sampling occasions), $SED_{(d.f.=78)}$=1.60.

TABLE 7. EFFECT OF NITROGEN NUTRITION AND DEFOLIATION METHOD ON WEIGHT LOSS (%) IN CV CARA AFTER 18 WEEKS STORAGE AT 3.5°C.

Different letters indicate differences between treatment means (for the same treatment factor) at the 95% probability level.

Treatment factor	Treatment	Weight loss (%)
Nitrogen nutrition	0 kg/ha	5.78[b]
	80 kg/ha (RB209)	5.09[a]
	160 kg/ha	4.67[a]
Defoliation method	Flail	5.22[a]
	Flail + GA	5.24[a]
	Diquat (split)	5.07[a]

Tuber surface area affected by netting in 2004 was lower in later planted crop than in earlier planted crop (P<0.001) (Figure 10), but nitrogen application had no influence on the degree of netted surface area.

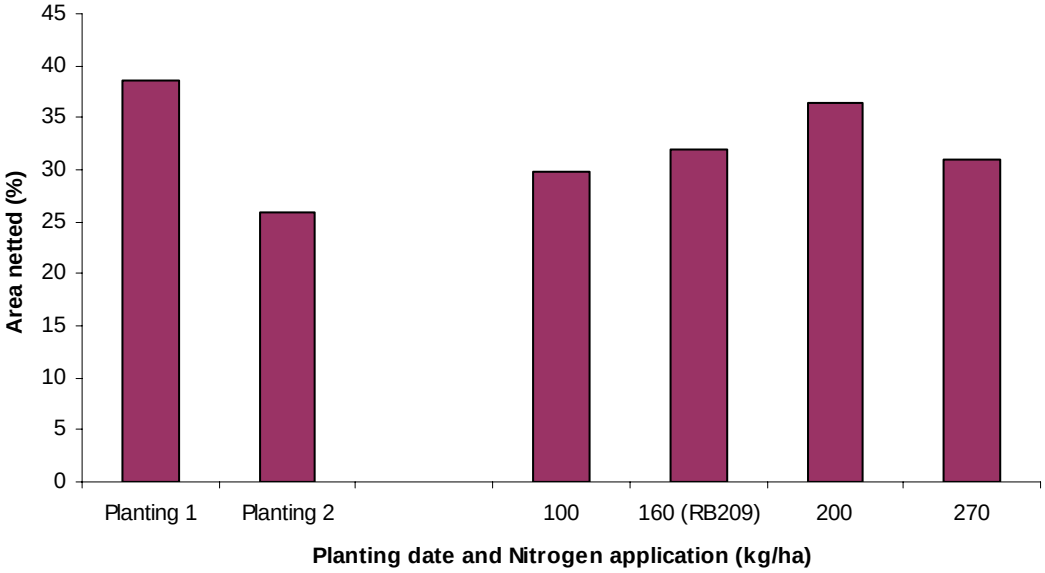


FIGURE 10. NETTING AREA (24 HOURS AFTER HARVEST) IN CV NADINE, 2004, UNDER FOUR NITROGEN TREATMENTS AND TWO PLANTING DATES.
(SED planting$_{(d.f.=21)}$=2.90; SED nitrogen$_{(d.f.=21)}$=4.09).

2.2.4 Discussion

Effects of nitrogen were not consistent between seasons. The main feature of this inconsistency was the absence of a nitrogen effect when skins were well set in all treatments. In the two seasons when skins were less well set at harvest, generally skins were less well set in treatments that had high nitrogen applications, above the optimal application rate for yield.

Environmental and agronomic factors, as well as N application rate, influence availability of N to the crop, so seasonal effects were not unexpected. For example, rainfall, leaching and crop demand (influenced by growth rate, delayed planting, season duration and canopy size) all influence N availability.

Cara was used in three successive seasons, 2001-2003, and effects of nitrogen on skin set were observed in 2002 only, when foliar senescence at defoliation, in the most mature treatment, was about 30%, compared with 55% in 2001 and 46 % in 2003. Over-application of nitrogen has a negative effect on skin set if the crop is defoliated when canopy senescence is in the early stages. The grower needs to recognise that often it is over-application of nitrogen that leads to defoliation when the canopy is too green. It is important that nitrogen application is adjusted in response to anticipated season length, as for example, when planting is delayed because of wet soil conditions.

Seed condition and planting date had no effects on skin set in this work. In 2004, effects of planting date on canopy senescence were of a similar magnitude to effects of nitrogen application treatment. This suggests that skin set at harvest cannot be predicted by the extent of senescence at defoliation. Crop maturity continues to be

poorly defined, and the ability to define and measure crop maturity should be an important target for researchers.

Cultivar effects have not been studied in this work, but there are indications of large differences between cultivars in skin set after defoliation. This is recognised in the industry, and there are many anecdotal reports of poor skin set in crops of Cara and Nadine, the two varieties used in this study. Growers need to avoid over application of nitrogen to varieties prone to poor skin set.

2.2.5 Conclusions

Clearly there are factors which are within the control of potato growers which can be manipulated to improve skin set in potatoes. In particular, attention should be given to nitrogen application rate, modified by season length, in varieties that are very indeterminate, or have a reputation for poor skin set.

2.3 Un-setting of skins

Section author: Fraser Milne, SAC.

2.3.1 Introduction

The objective of this part of the project is to examine the phenomenon of unsetting of tuber skins after harvest that frequently occurs with the variety Cara. It is also reported to occur with several other varieties such as Nadine, Maris Piper and Hermes. The study involved measuring the changes in skin-set and skin proprieties post harvest to try and understand what is changing to make the skins become unset. The project confirmed that unsetting can occur in some crops and subsequently the factors that might influence skins to become unset were examined. The report is presented on a year-by-year basis. The 14 trials carried out are listed below.

Experiments

2001

a) Changes in skin properties in the variety Cara post harvest using two haulm destruction techniques and two storage temperatures.

2002

a) Skin unsetting following harvest.
b) Effects of conditioning on skin unsetting
c) Handling experiment
d) Agronomy factors
e) Effect of haulm destruction pre-treatments on skin set

2003

a) Skin unsetting following harvest
c) Effect of post-harvest environment on skin set.
d) Effect of certain 'additives' on skin set.
e) Temperature cycling and skin set.

2004

a) Skin set as influenced by stage of crop growth and temperature.
b) Influence of crop maturity on skin set altered by chitting and low nitrogen levels.
c) Effects of soil environment on skin set

2.3.2 Materials and methods

Method of skin set assessment

All samples were hand dug and handled gently until processed.

A sample of 20-tubers of 50-65 mm size was placed in the SAC scuffing barrel and then the barrel rotated for a set number of turns. The tubers were then removed and categorised into five groups depending on the area of skin removed. The percentage area scuffed of the sample was calculated using the numbers of tubers in each group by the average area scuffed for each group.

TABLE 8. THE FIVE GROUPS USED FOR SCUFFING ASSESSMENTS.

Area scuffed	Mid point
No scuffing	0
<1%	0.5
1-12.5%	6.75
12.5%-25%	18.75
> 25%	62.5

Guide to interpreting the results.
A crop with not more than 50% of the tubers having up to 1% area scuffed (average pre-pack standards for set skin) would require the sample to have the area scuffed to be less than 0.25%.

2.3.3 Results

2001

Introduction

The aim of the first year of this study was to find out if unsetting existed. It involved measurement of the changes in skin-set and skin proprieties post harvest to understand what was changing to make the skins become unset. Two haulm destruction techniques were used as well as two storage temperatures to identify whether these factors had any effect on the unsetting of the skin.

Trial design

a) Changes in skin properties in the variety Cara post harvest using two haulm destruction techniques and two storage temperatures.

A commercial crop of Cara was subjected to two methods of haulm destruction, and two storage regimes. The two haulm destruction methods used were haulm pulled and desiccation by sulphuric acid (2x application). The storage regimes were ambient temperature, and cold storage at 5^{o}C after one week at ambient after harvest. Assessments were carried out at weekly intervals for 8 weeks after harvest to determine when the "unsetting" phenomenon occurs.

The trial was replicated 4 times with each alternate drill being subjected to a different haulm destruction treatment. Samples were then hand dug and placed in nets with half the sample from each group going to an alternate storage regime.

Assessments

Skin-set (see material and methods)
Skin dry matter
Skin adhesion
Skin tensile properties

Skin dry matter was carried out on 1.5 mm peeler depth of tissue form the middle area of the tubers. Four replicates were taken per treatment. Samples were dried for 48 hours at 90 °C.

Tests of skin tensile strength and adhesion were carried out on excised samples of tissue placed in special fixtures. The breaking strength was determined in a material-testing machine

Abbreviations used in the following graphs.

SA= **S**ulphuric acid / **A**mbient storage
SC= **S**ulphuric acid / **C**old storage
HA= **H**aulm pulled / **A**mbient storage
HC= **H**aulm pulled / **C**old storage

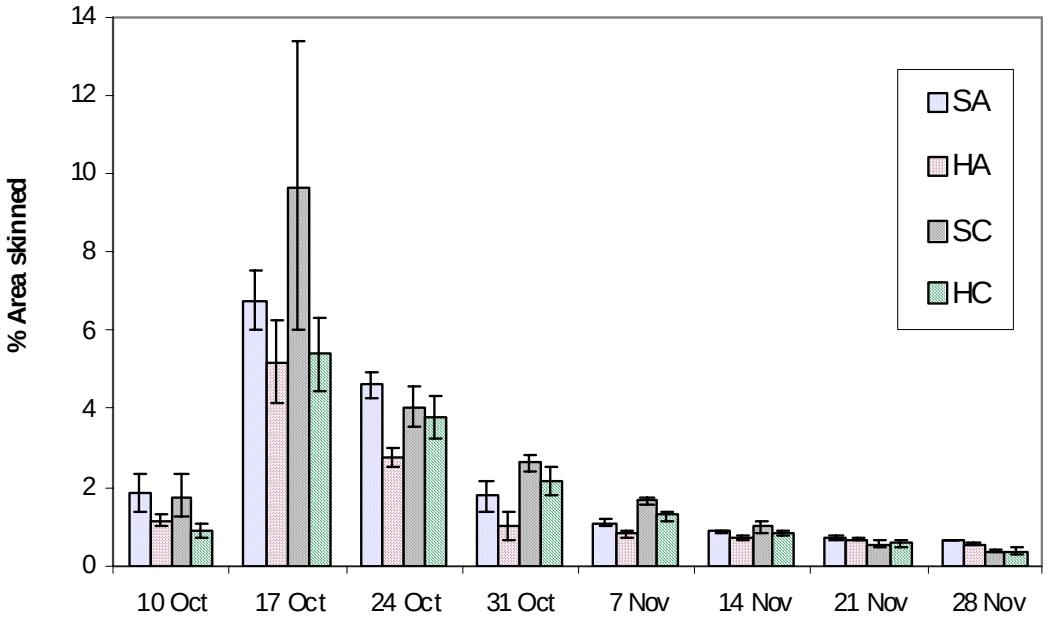


FIGURE 11. CHANGES IN SCUFFING OF CARA POTATOES OVER 8 WEEKS FOR TWO HAULM DESTRUCTION TECHNIQUES AND TWO STORAGE TEMPERATURES.

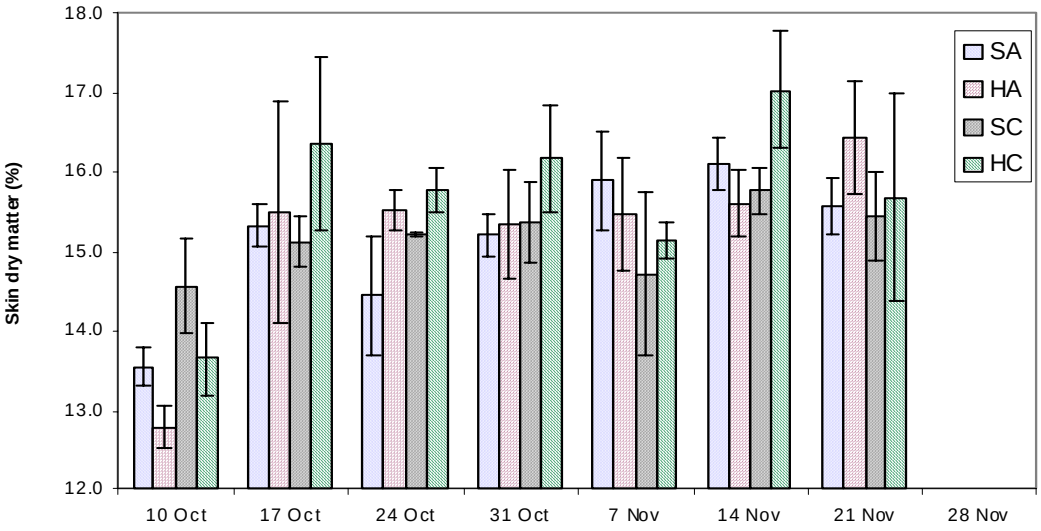


FIGURE 12. CHANGE IN SKIN DRY MATTER (%) OF CARA POTATOES OVER 8 WEEKS FOR AMBIENT AND COLD STORAGE TEMPERATURES.

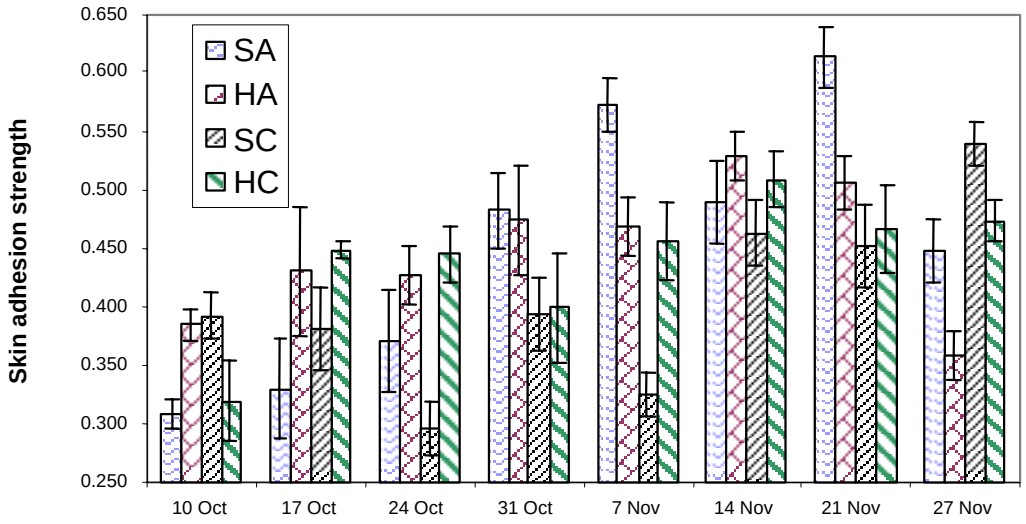


FIGURE 13. CHANGE IN SKIN ADHESION (N/mm^2) OF CARA POTATOES OVER 8 WEEKS FOR TWO HAULM DESTRUCTION TECHNIQUES AND TWO STORAGE TEMPERATURES.

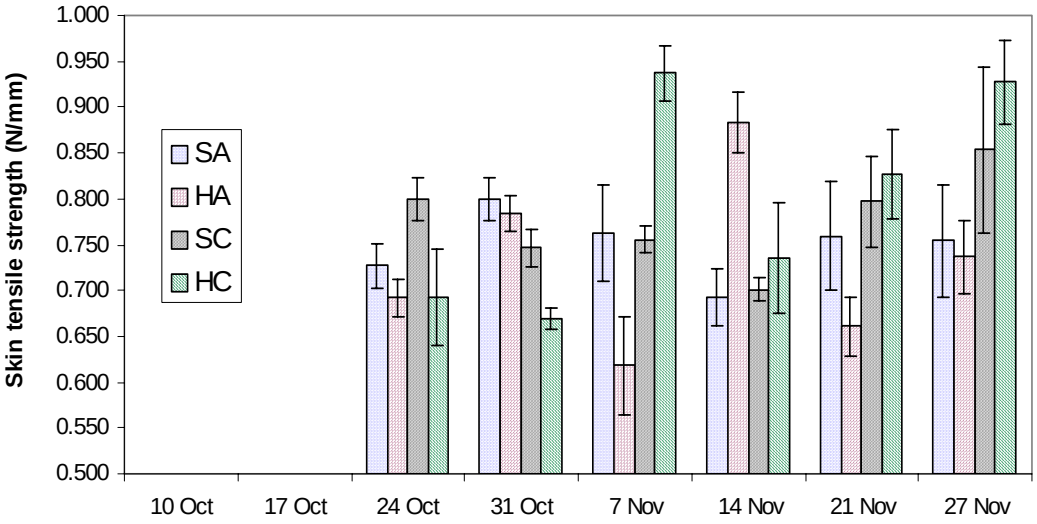


FIGURE 14. CHANGE IN SKIN TENSILE STRENGTH (N/MM) OF CARA POTATOES OVER 8 WEEKS FOR TWO HAULM DESTRUCTION TECHNIQUES AND TWO STORAGE TEMPERATURES.

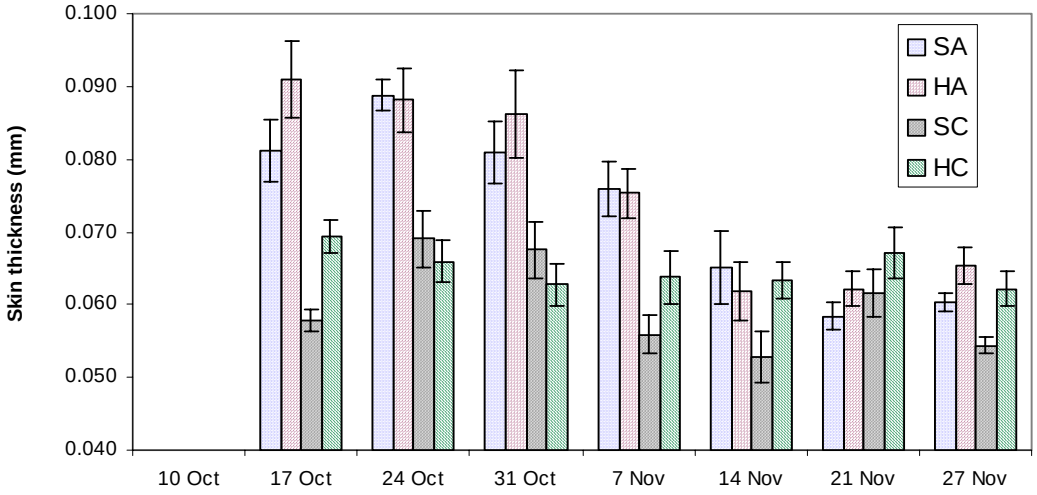


FIGURE 15. CHANGE IN SKIN THICKNESS (MM) OF CARA POTATOES OVER 8 WEEKS FOR TWO HAULM DESTRUCTION TECHNIQUES AND TWO STORAGE TEMPERATURES

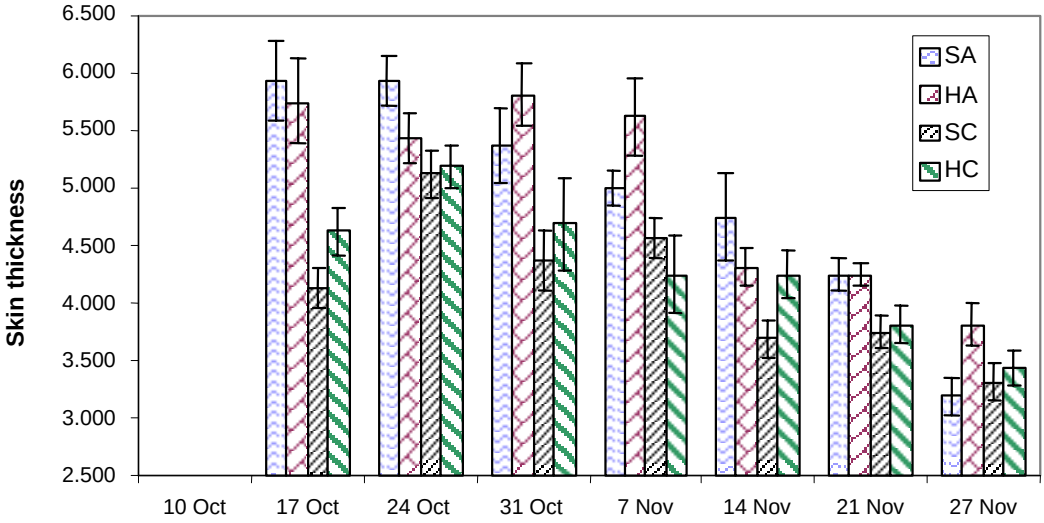


FIGURE 16. CHANGE IN NUMBER OF PERIDERM CELLS OF CARA POTATOES OVER 8 WEEKS FOR TWO HAULM DESTRUCTION TECHNIQUES AND TWO STORAGE TEMPERATURES

Discussion 2001

In the first year of the project we have identified that instead of skins becoming unset 4-6 weeks after lifting as reported by many farmers, the skins can become un-set shortly after harvest, and continue to be weaker than at harvest for several weeks. The method of haulm destruction did show a difference but only in the degree of skin set, the unsetting following a similar pattern. A similar picture emerged with the storage regime with the recovery slightly faster using ambient storage. The skin dry matter did show a rapid change (became drier) after harvest corresponding to the

unsetting of the skin, however it is unlikely that this is the main cause of the skins unsetting as the dry matter then stabilized but the skin set continued to change.

2002

Introduction

Skin set was very poor in this year experiment. We had intended to harvest the crop 3 weeks after haulm desiccation but skin set was so poor that we had to leave the crop for an extra week to get some degree of skin set. Even then skin set was much poorer than in 2001 and in some plots in particular the agronomy trial, skins did not set even after 4 weeks post desiccation.

Trial design

Five experiments were conducted this year as replicated trials.

a) Skin unsetting after harvest
b) Effects of conditioning on skin unsetting
c) Handling experiment
d) Agronomy factors
e) Haulm destruction pre-treatments effects on skin set

- Experiments were conducted at Drem in East Lothian on a silty clay loam soil
- All plots were replicated 4 times
- Fertiliser was 160:150:250 NPK unless stated otherwise
- Crop was planted on 29 April
- Late planted crop was planted on 27 May by hand
- Haulm destruction was by Sulphuric acid unless otherwise stated on 1 September

a) Skin unsetting following harvest.

This test involved measuring skin-set at shorter time intervals after harvest than the 7-day interval in 2001. The 2,4 and 6 hours after harvest assessments were conducted in the field; the remainder was conducted after storage in an unventilated store at ambient temperature.

One of the tests involved leaving potatoes un-harvested in the field for a further 48 hours before testing, for comparison with the harvested crop to show the effects of the different environment. This was to check that if it was the harvesting of the crop that caused the un-setting and not a natural progression that would occur even if the crop were left in the ground.

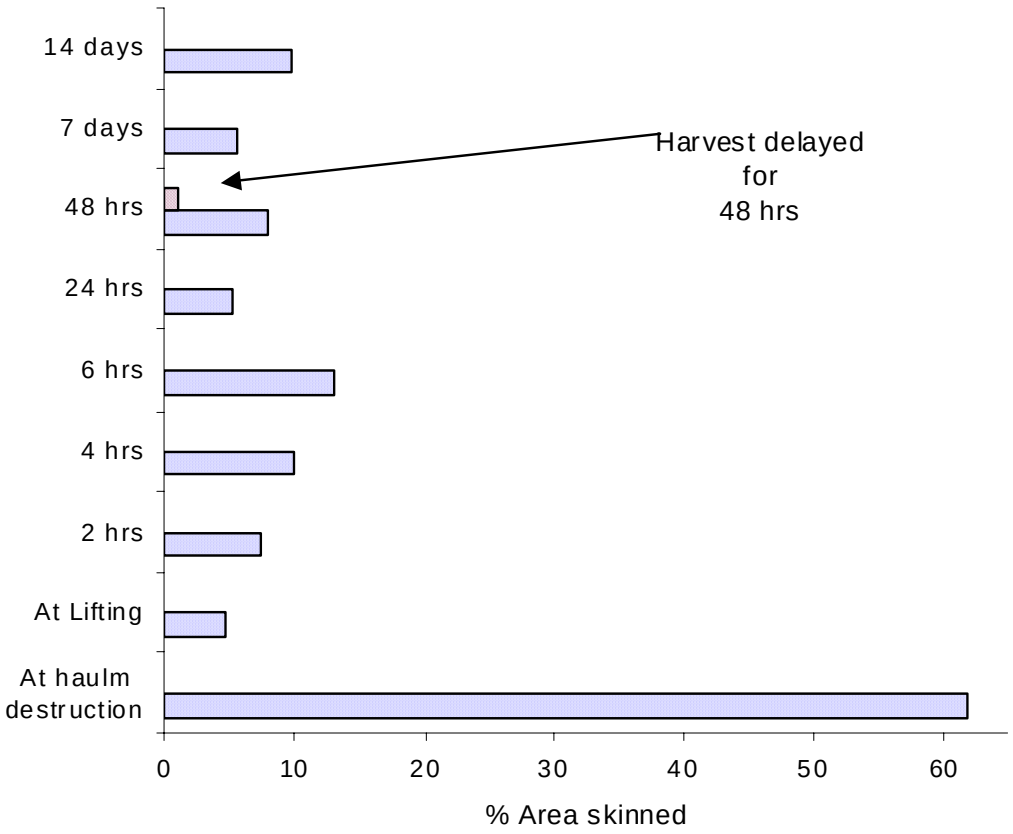


FIGURE 17. SKIN UNSETTING FOLLOWING HARVEST

(Haulm destruction on 01 September, lifted on 28 September).

This experiment showed that skin set started to be lost within 2 hours after lifting and became progressively poorer up to the 6-hour period (Figure 17). 24 hours after harvest skin set had recovered slightly but was still poorer than when first harvested. After 14 days the skin set was still poorer that at harvest.

b) Effects of conditioning on skin unsetting

This experiment was designed to highlight whether the soil / tuber environment and moisture had an effect on skin-set.

Treatments:

- Immediately after haulm destruction (1 Sept.) the crop was dug and reburied (4 Sept.) in the central part of the bed and left until harvest (30 Sept.). It was then assessed at intervals.
- Crop placed immediately after harvesting into damp peat. Assessed for skin set after 6 hours.
- Crop harvested and subjected to constant airflow at ambient temperature before testing at intervals.

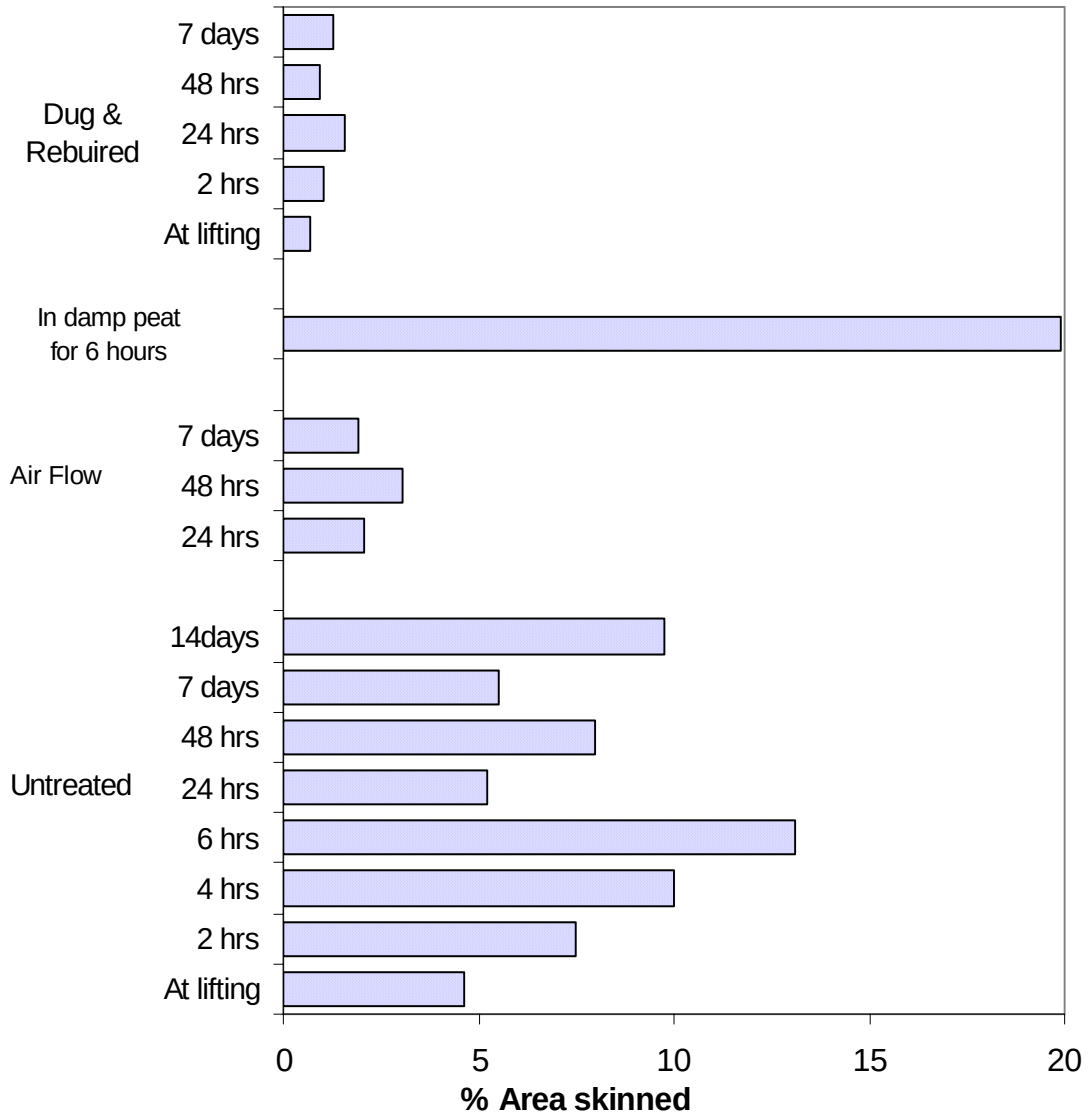


FIGURE 18. EFFECTS OF CONDITIONING ON SKIN UNSETTING.

Digging and re-burying the crop at haulm destruction then leaving the crop for 4 weeks achieved the greatest improvement and best skin set of all the treatments (Figure 18). This suggests that the soil/tuber environment after haulm destruction could be a key to achieving good skin set. Skin unsetting after harvest still occurred but to a lesser degree than with the convention method. Placing tubers in wet peat showed how quickly the skin could be released. After only 6 hours in the damp peat the area that could be scuffed had increased to 19.9%. Forcing air through the crop after harvest did help preserve the skin set better than without air, but caution should be exercised in handling the crop immediately after this treatment, as the skin will be dry and brittle.

c) Handling experiment

The crop was subjected to treatments to identify if unsetting was a post harvest handling problem

Treatments:

- Gentle vibration of tubers for 1 minute, to test for the effects of small impacts on skin adhesion.
- Warming tubers up for 6 hours, to test for temperature rise effect on skin adhesion.
- Damaging tubers by coring, to test if unsetting of the skin was a physiological response to damage.

All reference tubers (untreated) for this experiment were handled very gently and placed in a plastic crate for handling to limit stresses on the skin. Tests were conducted 24 hours after harvest.

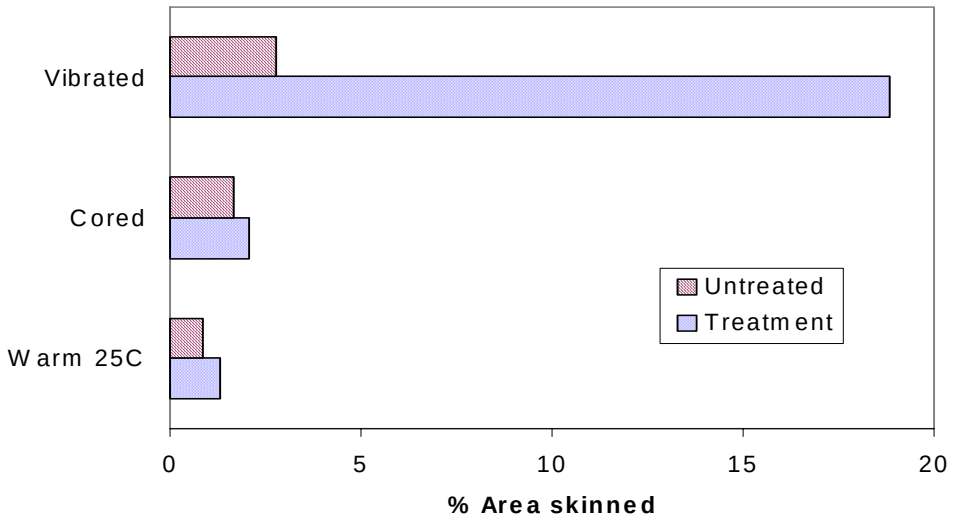


FIGURE 19. EFFECT OF HANDLING ON SKIN SET.

The unsetting of the skin was not found to be the result of a physiological stimulus due to wounding, as damaging the tuber by coring did not cause the skin to be released. Also, an artificial temperature rise to mimic an increase in temperature at lifting did not show any response to temperature change and skin unsetting. However, the test did show that small impacts and strains imparted on the skin would reduce skin set and result in more scuffing.

d) Agronomy Factors

This trial looked at general agronomy and its effect on skin unsetting. Treatments are given in Table 9.

TABLE 9. AGRONOMY FACTORS TREATMENTS.

Treatments	N application	Planting depth	Planting date
Micro-nutrients	160Kg/ha	150 mm cover	Normal
Low N	80kg/ha	150 mm cover	Normal
High N	200kg/ha	150 mm cover	Normal
Late planted	160Kg/ha	150 mm cover	Normal + 3 weeks
Shallow Planted	160Kg/ha	100 mm cover	Normal
Deep planted	160Kg/ha	250mm cover	Normal

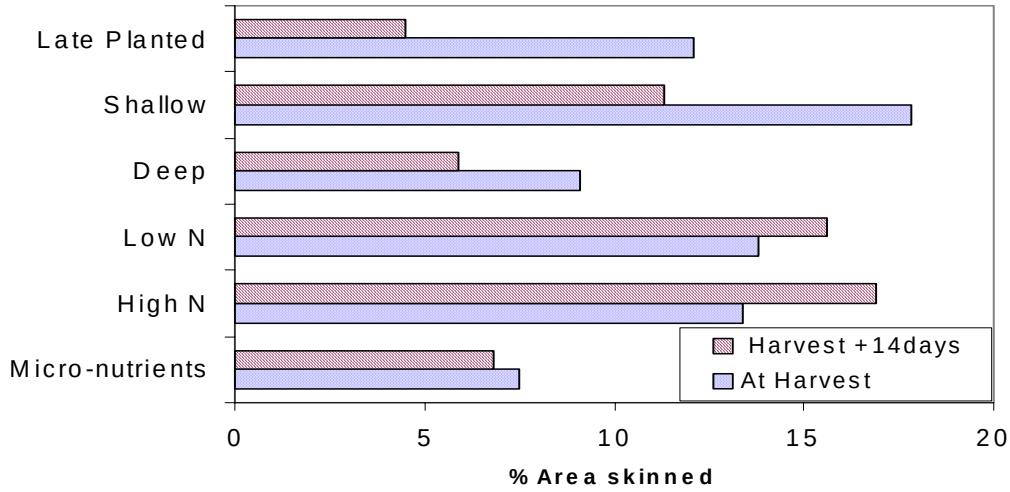


FIGURE 20. AGRONOMY EFFECTS ON SKIN SET.

Skin set had not been achieved in the crop from the area of field were the trial was sited by the time of harvest. Unsetting of the potato skin occurred only in Low N and High N plots.

e) Effect of haulm destruction pre-treatments on skin set

The objective of this experiment was to identify whether a pre-haulm destruction treatment before a conventional chemical desiccation could improve skin set by partially killing the plant before a full kill by acid.

Treatments:

- Sulphuric acid (1 Sep, 7 Sep) 2 applications (reference)
- Flail (20 Aug) then followed by 2x Sulphuric acid at 7 days
- Folded down (20 Aug) followed by 2x Sulphuric acid at 7 days
- Reglone at 2l/ha (20 Aug) followed by 2x Sulphuric acid at 7 days
- Growth balancer (12 Aug) followed by 2x Sulphuric acid at 7 days

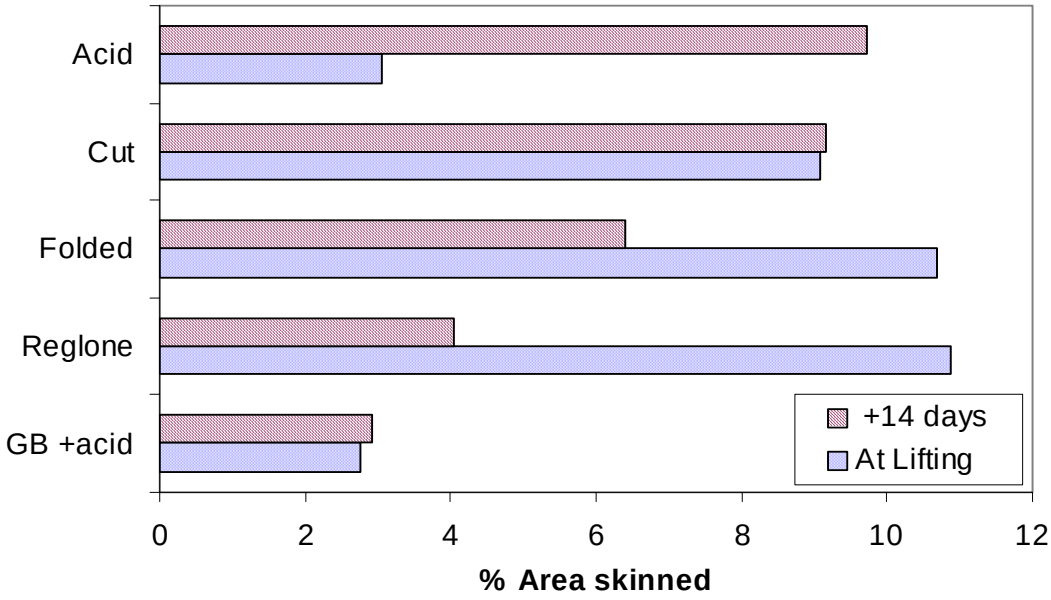


FIGURE 21. EFFECTS OF HAULM DESTRUCTION ON SKIN SET.

The only pre haulm destruction treatment that showed any signs of improving skin set and unsetting was the treatment involving the application of a growth balancer compound (Figure 21). The growth balancer consisted mainly of boric acid and is thought to reduce nitrogen uptake.

The only treatment to show unsetting was the conventional treatment used as a reference. No conclusion or recommendations can be reached, as this was a one-year trial and in a difficult season for skin set in the area of the field where the trial was conducted.

Discussion 2002

The 2001 experiment showed skin unsetting occurring within 7 days of harvest. In 2002, skin set started to be lost after only 2 hours after harvest.

In 2002 there was a large improvement in skin set with the digging and reburying treatment. The placing of tubers in a damp peat was also very interesting confirming the problem of a wet environment.

The handling experiment indicated that even small impacts can affect skin adhesion and that the effect as far as we can tell at present is physical and not a chemical reaction to the impacts.

The agronomy plots showed that with the same general agronomy and same seed stock, skin-set is determined by the soil/environment, as skin set was very poor in these plots compared to the other plots.

2003

Introduction

Most of the 2003 work was done with the variety Cara but some commercial crops of Nadine were also tested. There were a series of five experiments conducted similar to the ones conducted in 2002. The 2003 season was very exceptional in terms of temperature and lack of rain particularly in the late July-August period. In 2003, we had the best skin set in Cara that we have every encountered.

Trial Design

Experiments were conduct at Drem in East Lothian on a sandy silt loam soil.
Fertiliser was 120:120:232 NPK.
Crop was planted on 9 April.
Haulm destruction was by sulphuric acid (unless otherwise stated) on 3 September.
Each test was replicated 4 times.

a) Skin unsetting following harvest

This test involved measuring skin-set at intervals after harvest to identify when unsetting occurs. Additionally in 2003, we examined two methods of haulm destruction. The purpose of this was to examine whether it is the effect of sulphuric acid in actual contact with the tubers that may be causing the skin to unset. Previous work had assumed that the only effect on skin set would be from the haulm destruction method and not the chemical in direct contact with the tubers.

Treatments:

1 Sept	3 Sept	29 Sept
• Flailed	Sulphuric acid 225l/ha	Harvest
• Haulm Pulled		Harvest

Plots sprayed with sulphuric acid were compared to plots that had the haulm-pulled with no acid. On the haulm pulled plots just prior to the application of sulphuric acid the ground was covered with plastic sheet to prevent any acid spray getting on to the plot. This was necessary, as it could not be guaranteed that the spraying of acid would not drift on to the other plots. After the trial was sprayed with acid, the covers were removed from the haulm-pulled plots.

Assessments were carried out immediately on harvesting the crop and then after 4 hrs, 24 hrs, 48 hrs, 7 days, 2, and 4 weeks.

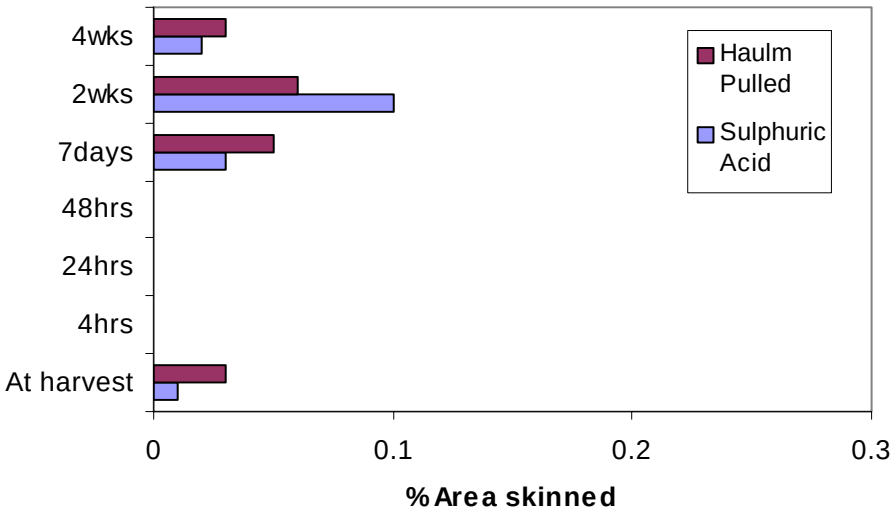


FIGURE 22. SCUFFING INDEX AT INTERVALS OF 4 HRS TO 4 WEEKS AFTER HARVEST, IN CROPS DEFOLIATED BY HAULM PULLING OR APPLICATION OF SULPHURIC ACID.

No major differences in skin set were found between the plots which had sulphuric acid sprayed on to them compared to the crop that had no acid applied and haulm pulled (Figure 22). There was a small amount (particularly in sulphuric acid plots) of unsetting of the skin after 2 weeks.

Previous work in 2002 and 2001 had shown that the skin become markedly less well set soon after harvest. In 2003, this did not happen.

b) Effects of soil environment on skin set and unsetting.

This experiment was designed to highlight whether the soil/ tuber environment and moisture had an effect on skin-set. This was a repeat of a test carried out in 2002, which showed a large improvement in skin set by this process. To the casual observer there may appear to be no difference between the environments. Soil surrounding the tubers in the area where they were grown is usually compacted due to crop enlargement. The soil after reburying is much less compact and more open. The difference is expected to be greatest in wet soils with silt or clay content, which can become sealed due to capping.

Treatments

- Crop dug at haulm destruction and then reburied in the central part of the bed and left until harvesting.
- Untreated, crop left in drill post haulm destruction and harvested at same time as above.

Haulm destruction was carried out on the 3 September. The treatment of digging and reburying was carried out on the 8 September.

The crop was harvested on the 19 Sept and assessed immediately on lifting then after 24 hrs and again at 10 days.

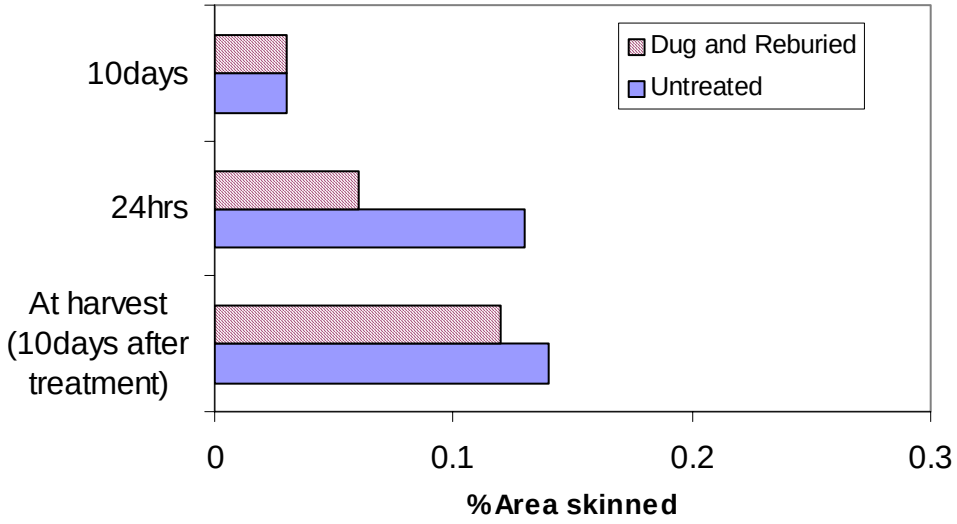


FIGURE 23. SKIN SET FOLLOWING DIGGING AND REBURYING TREATMENT

Digging and reburying the crop at haulm destruction then leaving the crop in the ground until harvest showed very little difference this year in skin set or unsetting compared to conventional system (Figure 23). This year's site had less silt/clay and was much more 'open' structure due to the dry conditions.

c) Effect of post-harvest environment on skin set.

The crop was subjected to various treatments after harvest to identify what factors improved or delayed skin setting or caused the skin to become unset. The aim was to identify the best environment to get skin to set and prevent unsetting occurring. An understanding of this would help us modify conditions in the ground to get better skin set post desiccation

Treatments:

In all treatments the crop was harvested before haulm destruction and held at constant temperature of 18°C, which was close to ambient for this year.

Trial 1

Crop of Cara harvested without haulm destruction on 19 August, placed into the environments below for 10 days then assessed

- Free airflow around tubers 60% RH
- Free airflow around tubers 98% RH
- Tubers placed in saturated vermiculite (to simulate very wet conditions)
- Tubers placed in oven dried vermiculite (to simulate very dry conditions)
- Tubers placed in a sealed plastic bag (to simulate anaerobic conditions)
- Field sample, crop left in the ground with haulm removed.

Trial 2

Crop of Nadine harvested without haulm destruction on the 10 September placed into the environments below for 10 days then assessed:

- Free airflow around tubers 60% RH
- Free airflow around tubers 98% RH

- Tubers placed in saturated vermiculite (to simulate very wet conditions)
- Tubers placed in oven dried vermiculite (to simulate very dry conditions)
- Tubers placed in a sealed plastic bag (to simulate anaerobic conditions)

Trial 3
Crop of Cara harvested on the 25 Aug and subjected to the treatments below for 5 hours then assessed:

- 'Air dry' placed into forced air stream of ambient air for 5 hours
- 'Wet' placed into saturated peat for 5 hours

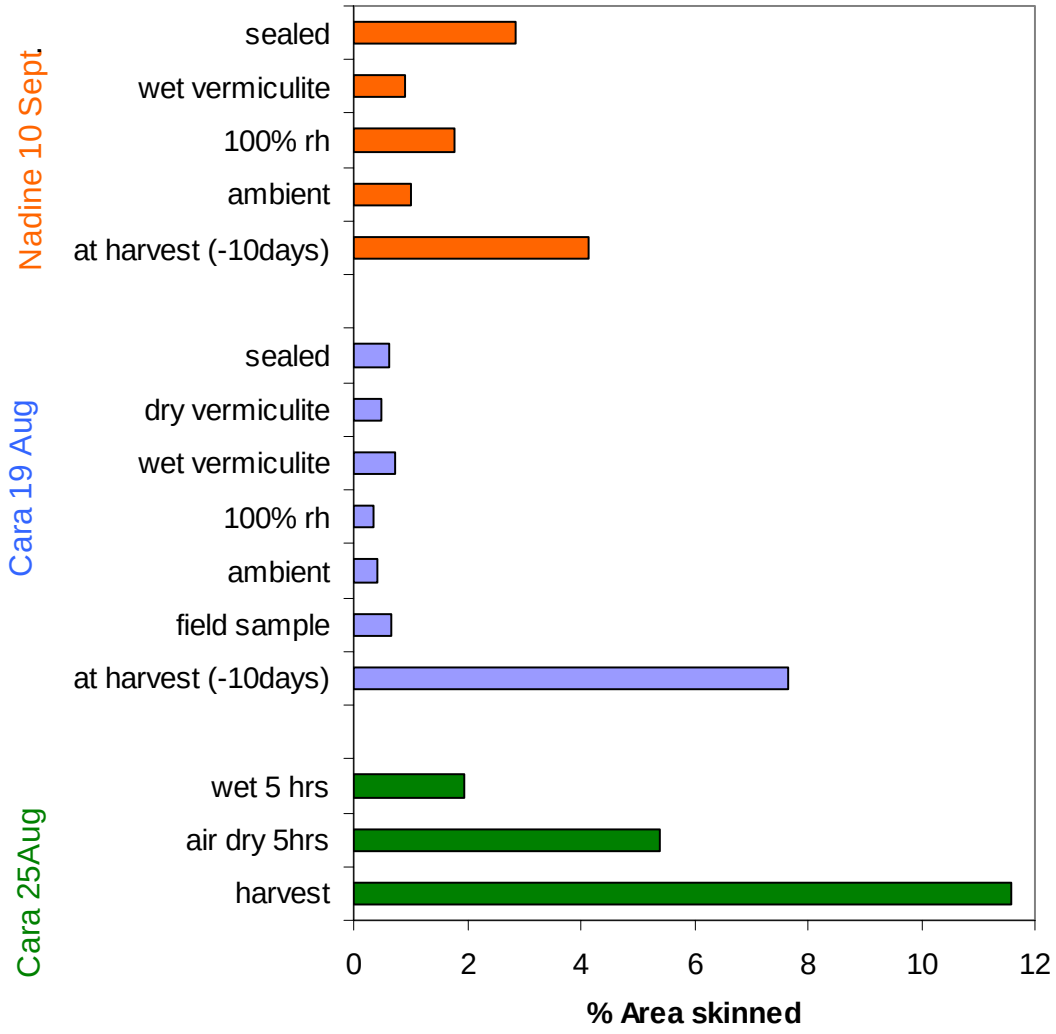


FIGURE 24. POST HARVEST ENVIRONMENT EFFECTS ON SKIN SET.

Trial 1 (Figure 24, Cara 19 Aug) showed that none of the treatments prevented the skin from improving and becoming more set. All treatments produced excellent skin set in 10 days. Even with the field sample skin set was rapid.

Trial 2 (Figure 24, Nadine 10 Sept) was from a commercial crop of Nadine, which was irrigated. It also gave good skin set but the 'sealed' and'100% RH' treatments were slower to set skin than the others.

Trial 3 (Figure 24, Cara 25 Aug) was carried out because in 2002 we had found rapid unsetting of the skin when tubers were placed into saturated peat. Whereas placing the tubers in to a flow of ambient air maintained skin set. On this occasion placing the tubers into wet peat had no effect and skin set progressed better than in forced air.

d) Effect of certain 'additives' on skin set.

This trial examined the effects of certain 'additives' to see if they altered skin set and skin unsetting. It is thought that they may have an effect on the tuber skin. The trace element fertiliser and growth balancer were supplied from New-Trition Ltd. The growth balancer consisted mainly of boric acid and is thought to reduce nitrogen uptake.

Treatments

- Trace element supplement for potatoes applied at planting time;
- 'Growth balancer' applied to the crop 4 weeks (1 August) before haulm destruction;
- Untreated.

Haulm desiccation was by flailing then acid on 3 September, harvested on the 16 September.

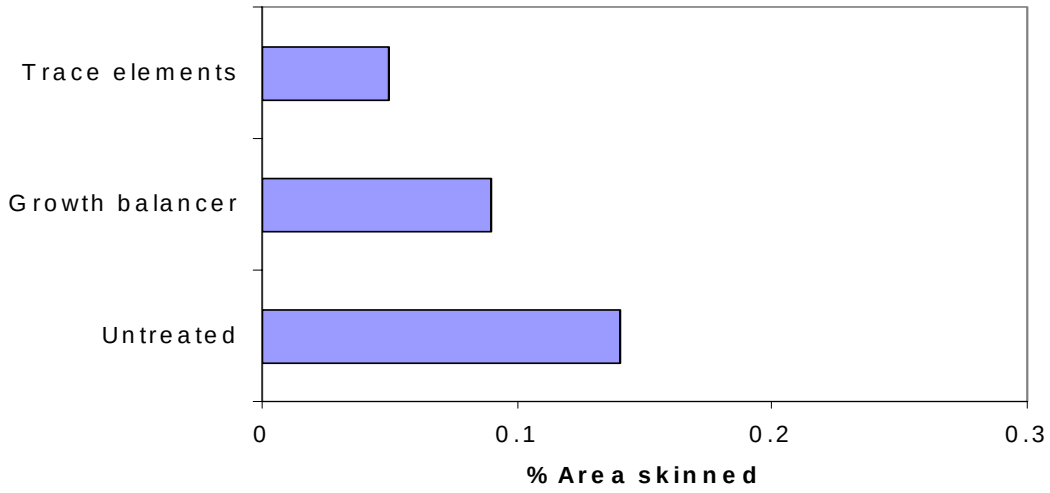


FIGURE 25. THE EFFECT OF CERTAIN ADDITIVES ON TUBER SKIN SET.

On this crop (Figure 25) no difference were found from the application of growth balancer or trace elements to skin set at harvest.

e) Temperature cycling and skin set.

This experiment was undertaken to examine what effect changes in temperature may have on skin set. This could occur in a year with high daytime air temperatures followed by low night temperatures or from taking tubers out of cold soil in to warm air temperatures then cooling for storage. The test were carried out with both Cara and Nadine taken from field immediately after harvest

Treatments:

- Control, kept at constant 15°C;
- Cycled, alternated between 5°C and 15°C over a period of 24 hours.

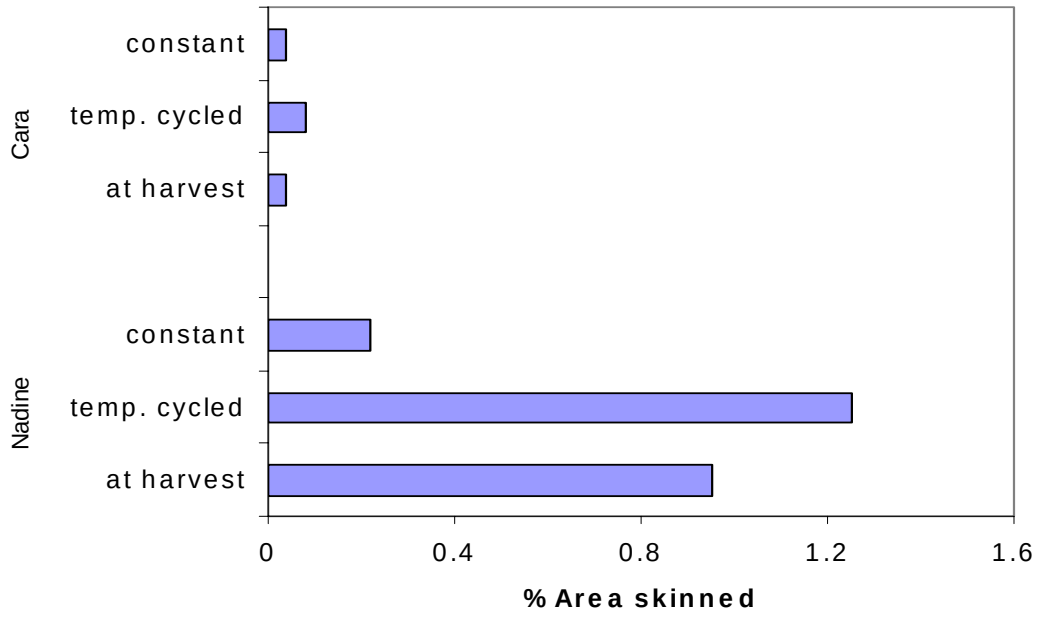


FIGURE 26. TEMPERATURE CYCLING AND SKIN SET.

The sample of Cara used had well set skin and only a very small amount of unsetting was found due to treatment (Figure 26). However in a sample of Nadine in which the skin was not as well set, there was a noticeable difference in skin set with the sample that was subjected to temperature cycling compared to the sample held at constant temperature.

Discussion 2003

The 2003 season was very exceptional in terms of temperature and lack of rain particularly in the late July-August period. The trial was irrigated at tuber initiation and throughout the year up to mid July. Irrigation was withdrawn in mid July in anticipation of the usual seasonal rainfall, unfortunately it failed to occur. As time progressed without rain the possibility of growth cracking increased so irrigation was not resumed. This year we had the best skin set in Cara that we have every encountered. To put it into perspective, the skin set was better this year from the crop with green haulm (growing crop, no haulm destruction) than with samples 4 weeks after haulm destruction in 2002. The down side was that none of the trials exhibited unsetting of the skin apart from the temperature cycling test on Nadine. The fact that the treatments showed no signs of unsetting does give us clues to some of the basics of skin set in potatoes. It would appear that unsetting of the skin does not necessarily always occur, and once initiated nothing will stop it progressing. The question now is, can we identify and manage the key factors and thereby obtain good skin set in any year.

2004

Introduction

The 2004 trial was designed to provide answers to some questions concerning the results of the 2003 trials. This showed that despite the various tests that we carried out we could not get the skins to unset. From this we deduced that either there was an irreversible factor of "initiation" skin set, which can occur before haulm destruction, or that some environmental conditions play a much larger role in achieving skin set than we first appreciated. In 2004 we conducted several experiments to try and separate out these factors. The trial work was carried out with the variety Cara.

Trial Design

Experiments were conduct at Drem in East Lothian on a sandy silt loam soil. Fertiliser was 120:120:232 NPK unless specified otherwise. Crop was planted on 14 April. Haulm destruction was by haulm cutting followed by stem pulling at appropriate dates. Each test was replicated 4 times.

a) Skin set as influenced by stage of crop growth and temperature.

The aim was find out whether there was a difference in the rate of skin set after haulm destruction at two crop maturities. This test involved measuring skin set at 4 and 6 weeks after haulm destruction for the first test and 4 weeks post haulm destruction in the second test. Haulm destruction was by cutting then haulm pulling. The plots were sub-divided in to three, after haulm destruction. Temperature was regarded as the influencing factor in 2003 resulting in good skin set so we also compared the sample with two storage temperatures; above ambient and below ambient.

Treatments following haulm destruction on 27th July and 24th Aug

- Left in field
- Harvested at haulm destruction and held in store at 20°C
- Harvested at haulm destruction and held in store at 10°C

TABLE 10. SKIN SET AS INFLUENCED BY STAGE OF CROP GROWTH AND TEMPERATURE (% AREA SCUFFED).

Haulm destruction 27 July	**23 Aug (+4wk)**	**7 Sept(+6wk)**
Haulm destruction and left in field (avg. 16°C)	2.55%	0.60%
Harvested and put into cold store (10°C)	0.82%	0.04%
Harvested and put into warm store (20°C)	0.00%	0.00%
Haulm destruction 23 Aug	**18 Sept (+4wk)**	
Haulm destruction and left in field (avg. 14°C)	2.75%	
Harvested and put into cold store (10°C)	1.69%	
Harvested and put into warm store (20°C)	0.03%	

Tubers harvested and placed in store at 20°C and at 10°C had much better skin set after 4 weeks from both harvest dates (27/7 and 24/8) than those left in the ground for the same period. The soil had an average temperature of 16°C on the first date and 14°C for the second date.

b) Influence of crop maturity on skin set altered by chitting and low nitrogen levels.

This trial compared skin set at two harvest dates, of crops grown with chitted seed (400day degree advancement) with non-chitted low nitrogen (40kg) compared to non-chitted with 160kg nitrogen. All plots were planted at the same time. The aim of this trial was to see if crop maturity was a factor in the rate of skin set. Chitting should advance maturity at any given active growth period; likewise low nitrogen should cause a shortening of crop life by lack of nutrients. Assessments were made at two dates, 3 and 5 weeks post haulm, destruction to obtain an indication of the rate of skin set.

TABLE 11. TREATMENTS, CROP MATURITY ALTERED BY CHITTING AND N FERTILISER.

Treatment		Nitrogen kg/ha
Normal		120
Chitted	400 day degrees	120
Low N		40

TABLE 12. INFLUENCE OF CROP MATURITY ON SKIN SET, ALTERED BY CHITTING AND LOW NITROGEN LEVELS (% AREA SCUFFED).

(1st test, HD on 2nd Aug. skin-set after 3 and 5 weeks in ground. 2nd test HD on 23 Aug. and tested after 3 and 5 weeks in ground)

Haulm Destruction 2 Aug	25 Aug (HD+3wk)	7 Sept (HD+6wk)
Normal N	11.18%	0.60%
Low N	3.75%	1.02%
Chitted	9.82%	3.41%
Haulm Destruction 23 Aug	13 Sept (HD+3wk)	27 Sept (HD+6wk)
Normal N	2.75%	1.30%
Low N	1.50%	0.43%
Chitted	7.56%	2.35%

In this trial, chitting of Cara did not improve skin set compared to non-chitted seed. In fact skin-set of the chitted seed was poorer than un-chitted. Also, while reducing the amount of nitrogen did improve skin set compared to the control it did not guarantee good strong skin set, and failed to reach the degree of skin set obtained in 2003.

(Note, data for the first test "Normal" nitrogen is suspected to be non-representative, as the first result is high and the second result too low compared to the 2nd test)

c) Effects of soil environment on skin set

This experiment was designed to highlight whether soil/ tuber environment and moisture in contact with the tubers had an effect on skin-set. This was a continuation of a test carried out in previous years, which have shown a large improvement in skin set in 2002 but not in 2003, by this process.

Treatments (effected on 6th Sept.) Assessments made on 21st Sept.

- Crop dug at haulm destruction and then reburied in the central part of bed and left until harvesting.
- Control, crop left in drill post haulm destruction and harvested at same time as above.

TABLE 13. EFFECTS OF SOIL ENVIRONMENT ON SKIN SET (% AREA SCUFFED).

Treatment	Treatment date 6-Sept	21 Sept (HD+2wk)
Haulm destruction Left in situ	22.5%	2.54%
Dug and reburied	22.5%	1.08%

Digging and reburying the crop at haulm destruction then leaving the crop in the ground until harvest showed a small improvement in skin set compared to leaving the crop *in situ* in the drill following haulm destruction. The effect is much smaller than in 2002. No differences were found in 2003.

Discussion 2004

In the first trial, skin set as influenced by crop growth stage and temperature showed that by taking the crop away from its growing environment a difference in skin set was achieved. The differences were not attributable to temperature alone, as samples held at 10^{o}C in store had better skin set than the crop left in the field that had an average temperature over the period of 16^{o}C first date and 14^{o}C for second.

Advancing physiological maturity of the seed by chitting did not appear to improve the prospect of achieving good skin set. This was not what we expected. Perhaps no improvement was found due to Cara being a very indeterminate variety. With a very indeterminate variety, growth will continue in some form until there is a limiting factor of some kind such as temperature, water, sunlight, or nutrients.

2.3.4 Discussion

The trials in 2001 and 2002 identified that in crops where unsetting can occur, instead of skins becoming unset 4-6 weeks after lifting as reported by many farmers, the skins can become unset shortly after harvest (2hrs) and continue to be weaker for several weeks than at harvest time. Haulm destruction method did show a difference but only in the degree of skin set and not in unsetting. Both haulm destruction treatments followed a similar pattern. A similar picture emerged with the storage regime, with recovery slightly faster using ambient storage. The skin dry matter did show a rapid change (became drier) after harvest corresponding to the unsetting of the skin, however it is unlikely that this is the main cause of the skins unsetting as the dry matter then stabilized but the skin set continued to change.

Skin set was very poor in all of the 2002 experiments. We had intended to harvest 3 weeks after haulm desiccation but skin set was so poor that we delayed harvesting until 4 weeks. Even then skin set was much poorer than 2001 and non-existent in some plots such as in the agronomy trial.

The experiments effects of environment on skin unsetting were designed to highlight whether soil/ tuber environment and moisture had an effect on skin-set. Digging and reburying the crop at haulm destruction then leaving the crop for 4 weeks achieved the greatest improvement and best skin set of all the treatments in 2002 (but not in 2003 as it was already set). This suggests that the soil/tuber environment after haulm destruction could be the key to achieving good skin set. Placing tubers in wet peat showed how quickly the skin could be released after only 6 hours in the damp peat, the area scuffed increased to 19.9 %. Blowing air through the crop after harvesting did help preserve the skin set better than without air, but caution should be exercised in handling the crop immediately after this treatment, as the skin will be dry and brittle.

The handling experiments showed that small impacts and strains imparted on the skin would reduce skin set and result in much more scuffing. Unsetting of the skin was not found to be the result of a physiological stimulus due to wounding, as damaging the tuber by coring did not cause the skin to be released. Also an artificial temperature rise to mimic increase in temperature at harvest did not result in any response to temperature change and skin unsetting.

The only pre-haulm destruction treatment that showed a marginal improvement in skin set and unsetting was the treatment involving the application of a growth balancer compound.

The 2003 season was abnormal due to the dry conditions. This resulted in none of experiments showing any signs of skin unsetting. This would suggest that seasonal effects have a much greater effect than any changes to the crop agronomy.

2.3.5 Conclusions

- If the variety is known to have a tendency to unset, then handle as gently and as little as possible and within 2 hours of harvesting as skin set deteriorates progressively from lifting.
- Try to avoid handling the crop after harvest until the skins have become fully set.
- Temperature has an effect on skin set but it is not the only factor contributing to poor skin set in the field.
- The environment around the tuber has a part to play in achieving skin set, though we still do not known exactly why and are therefore unable to manipulate it with confidence. Dry soils as in 2003 season produced a much better skin set than the wetter 2002 season. It is therefore reasonable to assume that wetter soils are more prone to skins unsetting.

2.4 Effect of micronutrients on skin set

Section author: Fraser Milne, SAC.

2.4.1 Introduction

The aim of the project was to examine whether the addition of certain micronutrients has any effect on skin adhesion strength, skin thickness, periderm cell numbers and graded yield. The variety used for the trial was Cara due to its skin set problems.

2.4.2 Materials and methods

Treatments

Control N=120kg/ha P=150 kg/ha K=200 kg/ha
Control + Ca & S
Control + Mn
Control + Fe
Control + Multi-nutrient fertiliser (New –Tritron Potato and Veg mix)

TABLE 14. MICRONUTRIENT APPLICATION RATES.

	kg/ha	% Element
Manganese sulphate	6	23
Ferrous sulphate	30	20
Calcium sulphate (gypsum)	200	
calcium in above		24
sulphur in above		19
Multi-nutrient	50	-

Calcium sulphate and "Multi-nutrient" applied to seedbed
Ferrous sulphate applied as liquid after planting
Manganese sulphate applied to foliage at 19 DAE ~20% foliage cover

Assessments

Carried out 3 weeks after haulm destruction (25 Sept). Haulm destruction by flail and acid (4 Sept)

Skin-set
Graded yield
Periderm thickness (5 samples per rep)

Method of skin set assessment

All samples were hand dug and handled gently until processed.
A sample of 20-tubers of 50-65 mm size was placed in the SAC scuffing barrel and then the barrel rotated for a set number of turns. The tubers were then removed and categorised into groups depending on the area of skin removed.

2.4.3 Results

TABLE 15. SCUFFING RESULTS (% OF SAMPLE).

	Not scuffed	>1% of surface area scuffed
Multi-Nutrient	23.75	33.75
Fe	11.25	57.50
Mn	18.75	37.50
Ca+S	18.75	46.25
Control	18.75	40.00

The addition of Fe resulted in signs of poorer skin set with 57.5 % of the sample having more than 1% scuffing compared to the Multi-Nutrient that had 33.75% of the sample greater than 1% of area scuffed.

TABLE 16. YIELDS BY SIZE GRADE (T/HA).

Treatment	35-45mm	45-65mm	65-75mm	75-85mm	45-85mm	Total
Multi Nutrient	2.49	23.54	10.82	4.50	38.87	41.36
Fe	2.36	21.18	10.10	5.59	35.76	38.12
Mn	2.06	23.04	10.27	3.31	34.64	36.70
Ca+S	2.53	24.60	10.54	3.12	38.27	40.80
Control	2.12	22.23	10.53	2.89	35.65	37.77

TABLE 17. SKIN THICKNESS.

Treatment	Skin Thickness (mm)	Cell Count
Multi Nutrient	0.101	6.45
Fe	0.096	6.16
Mn	0.094	6.56
Ca+S	0.094	6.45
Control	0.095	6.72

The addition of Fe resulted in slightly lower numbers of periderm cells.

2.4.4 Discussion

Work by *McLean et al.* had indicated that the micronutrients used above could increase the number of periderm cells. The aim of this project was to find out if this was the case, and if the increase in periderm cells numbers resulted in improved skin set. Unfortunately neither an increase in periderm cell number or thickness was achieved nor was there any improvement in skin set.

2.4.5 Conclusions

No conclusions can be reached, as this was only a one-year trial on one variety. No significant differences were found, but there were indications of a trend suggesting that balanced micronutrients could help skin set. The trial site was above average fertility, and it would be prudent to repeat the test with the balanced micronutrients fertiliser on a different site and with two potato varieties.

2.5 Factors influencing the occurrence of netting

Section author: David Turley[1] and Jeremy Wiltshire, ADAS.

2.5.1 Introduction

Potato skins can suffer from shallow grooves or breaks in the skin which characteristically form a net like pattern referred to as 'netting'. For premium markets, skins should be free of such blemishes. Symptoms also indicate weak points in the skin, which can be subject to tear and breakage, increasing the risk of disease ingress or loss of quality etc., reducing crop value. Little is known about the factors that influence netting, but netting is likely to be closely related and influenced by environmental factors and physiological factors in the periderm of maturing tubers.

Varieties differ in factors such as skin adhesion and skin thickness (Bowen, Muir and Dewar, 1996). Skin adhesion increases after haulm removal while skin thickness declines (Bowen, Muir and Dewar, 1996). Skin adhesion is affected by tuber maturity, and increases with maturity at the time of assessment (Bowen, Muir and Dewar, 1996). The speed of development of adhesion and changes in periderm thickness are affected by maturity at time of haulm removal and differ between cultivars. The speed or method of haulm removal has a greater effect on skin adhesion when tubers are less mature, and differences diminish as tuber maturity increases (Bowen, Muir and Dewar, 1996).

Skin thickness relates to the number of cell layers in the periderm, and it has been postulated that differences in cell alignment in the periderm (regular (columnar) v irregular (bricking or overlapping)) could influence skin strength and perhaps may influence propensity to netting damage. Netting symptoms have been associated both with cell wall rupture and cell separation at the middle lamella between cell walls.

It is hypothesised that netting is a problem associated with tubers during the period of skin set. Factors which lead to rapid skin set while conditions are still conducive to tuber swelling (i.e. high soil moisture availability, and an intact root system) could increase stress on the maturing periderm causing surface fracture. To test this hypothesis a factorial range of treatments was designed to study the effect of speed of haulm removal, tuber maturity and soil moisture availability at desiccation on subsequent netting of tubers. Haulm destruction methods were designed to facilitate either rapid removal of haulm while leaving an intact root system or a more controlled senescence of haulm and roots together.

The objective of this study was to better understand the factors which influence netting, through evaluation of the effects of crop maturity at defoliation, speed of haulm removal and soil moisture availability at haulm removal on the incidence and severity of netting.

[1] David Turley is now working at the Central Science Laboratory, Sand Hutton, York.

2.5.2 Materials and methods

An experiment was conducted at ADAS Gleadthorpe, near Mansfield, Nottinghamshire, on a loamy medium sand (Cuckney series). Individual plots were irrigated, according to treatment, using a linear irrigator.

Physiological age

Seed of cv Estima (a cultivar susceptible to netting damage) was subject to two temperature regimes during storage to provide tubers of two different physiological ages from dormancy break (Table 18), designed to influence crop maturity at the time of desiccation.

TABLE 18. TREATMENTS.

Physiological age	1. 0 Accumulated day degrees > 4°C at planting (un-chitted) 2. 113 Accumulated day degrees > 4°C at planting (chitted)
Haulm removal	1. Fast – Haulm flailed 2. Slow – Glufosinate Ammonium applied (3l/ha)
Irrigation	1. Full regime throughout (146 mm water) 2. Late droughted – full regime until 14 July then droughted (121 mm water (i.e. last 25 mm withheld)

Haulm removal

Haulm was either removed 'quickly' by flailing, or more slowly by chemical desiccation (Table 18). Haulm was removed from all treatments on 15 August when senescence had started in the crop established with unsprouted seed (average of 18 % and 46% senescence in crops from unsprouted and sprouted seed stocks respectively at the time of haulm removal). Haulm desiccated quickly in the chemically-treated plots. One week after treatment only green stems remained in both haulm removal treatments. Two weeks after treatment, there was no crop green area remaining in either treatment.

Soil moisture at harvest

Two irrigation schedules were instigated. These were designed to minimise the risk of common scab infection during early tuberisation while providing differential soil moisture availability during the period prior to, and during, skin set (Table 18). In the 'late restriction treatment' a differential watering regime was instigated after 14 July when irrigation was stopped. However 48 mm of rain fell between 2 and 12 August. At the time of desiccation, soil moisture deficits were 34.7 and 15.3 mm water respectively in the 'late droughted' and 'full irrigation regime'.

Treatments were arranged in a fully randomised design, with three replicates of each treatment. Individual plot size was 6 rows wide x 9 m long, with the centre two rows reserved for yield assessments. Seed was hand planted on 3 May. The crop was subject to a normal (farm practice) herbicide, fungicide, insecticide, nematicide (PCN control) and fertiliser programme. The crop was harvested on 11 September.

Assessments

The date of emergence of each stock was recorded and the date of tuber initiation and achievement of 75% ground cover was recorded for each seed treatment.

To provide information on when netting began, tubers were sampled on 4 occasions during the season:

1) Tuber initiation + 4 weeks (11 July) (selected plots)
2) Tuber initiation + 6 weeks (24 July) (selected plots)
3) Pre desiccation (14 August) (selected plots)
4) Post harvest (14 September) (all plots)

At timings 1-3, 4 neighbouring plants were removed from defined sampling areas in each plot to provide a minimum of 25 tubers for assessment of netting. At harvest, a random sample of 50 tubers was retained for netting assessments. At harvest the 50 tubers assessed for netting were size graded to see if there was any relationship between tuber size and the incidence of netting damage.

Netting was assessed using modification of a method developed by BPC staff at SBEU. The percentage of tuber surface area affected by netting was categorised into 7 bands delimited on an approximately logarithmic scale to give a median value for % surface area affected by netting for each tuber (Table 19). The average median value was then calculated for each sample.

TABLE 19. RELATIONSHIP OF NETTING SCORES TO TUBER SURFACE AREA AFFECTED.

Netting Score	Area range (%)	Median value
C0	0	0
C1	0.1-2	1
C2	2-5	2.5
C3	5-10	7.5
C4	10-25	17.5
C5	25-50	37.5
C6	50-100	75

In addition an area index score was calculated based on the above categories, designed to produce a weighted index score between 0 and 100. The method adopted was based on that used to assess eyespot disease in cereals. The aim of such indices is to highlight treatments where a proportion of the sample is severely affected, as the method is increasingly weighted towards the more severe categories.

The index was calculated as follows (based on the categories in Table 19), where nC0 is the number of tubers in category C0, nC1 is the number of tubers in category C1, etc.

$$\text{Area index} = \frac{(nC0x0)+(nC1x1)+(nC2x2)+\ldots+(nC6x6)}{6} \times \frac{100}{\text{No of tubers assessed}}$$

The severity of netting was categorised by assessment against a photographic key supplied by SBEU. The categories were S1 = slight, S2 = moderate, S3 = severe. These were used to derive a netting index (as for netting area index described above).

$$\text{Severity index} = \frac{(nS1x1)+(nS2x2)+(nS3x3)}{3} \times \frac{100}{\text{No of tubers assessed}}$$

Total yield was recorded by machine lifting and hand-weighing produce from 2 rows of crop per plot.

Five tubers from each plot within the 50-60 mm size fraction were sent to SAC to determine periderm thickness, the number of cell layers in the periderm and to assess the uniformity of cell alignment. Tubers were sliced and examined microscopically. Using a graduated eyepiece the periderm thickness was measured in units, and converted to millimetres by calibration. Periderm thickness and the number of overlying cells in the periderm were assessed at two points on each of the 5 tubers.

2.5.3 Results

Crop emergence and growth

The sprouted seed emerged very quickly within 18 days of planting. The un-sprouted seed emerged 22 days after planting. The majority of the crop had emerged by 23 May in the sprouted treatment and by 29 May in the un-sprouted treatment, a difference of 6 days. Tuber initiation was achieved by 8 June in the sprouted treatment and 15 June in the un-sprouted treatment. 75% ground cover was achieved 6 days earlier in the sprouted treatment (15 June). The crop from sprouted seed started to senesce on 2 August. Thirteen days later at the time of desiccation, the crop from un-sprouted seed was around 20% senesced while sprouted seed was 50% senesced.

At the start of senescence on 2 August, irrigation treatment had no effect on crop cover. At the time of haulm removal irrigation treatments still had no significant effect on the level of crop senescence, which suggests that the crop was not stressed in the late droughted treatment at the time of desiccation. The soil moisture deficit of 35 mm of water in the late droughted treatment at the time of desiccation would not be considered stressful to potato crops. Rainfall after the end of irrigation in the late-droughted treatment therefore compromised the difference between the two planned irrigation treatments. However, irrigation treatment did have a small significant effect on yield (see yield section), which suggests there was a difference in tuber water uptake between the two irrigation treatments.

Netting symptoms

At the first assessment (4 weeks after tuber initiation) netting symptoms were difficult to detect, but traces of netting symptoms were found (Table 20, Table 21, Table 22). The incidence and proportion of tuber area affected increased in successive weeks until haulm removal, and continued to increase, albeit less severely, in the period between haulm removal and harvest. By harvest, netting symptoms were common in all treatments with most tubers in area category 4 or 5, representing 10-25 and 25-50% of tuber area affected. The effect of seed maturity had a significant effect on

netting only at 6 weeks after tuber initiation, with sprouted seed having more severe netting. No other treatments had a significant effect on netting at the time of harvest.

At the time of desiccation skins were starting to set on tubers. At the time of harvest, skins were set in all treatments.

TABLE 20. NETTING AREA (AVERAGE MEDIAN SCORE) AT EACH DATE OF ASSESSMENT.

Treatment			**Assessment timing/date**			
Seed	Irrigation	Haulm Removal Method	**TI+4 weeks** (11 July)	TI + 6 weeks (24 July)	Haulm removal (14 Aug)	Harvest (14 Sept)
Sprouted	Full	Flail	0.4	1.4	28.6	40.1
		Chemical				38.8
	Restricted	Flail				43.1
		Chemical				37.9
Unsprouted	Full	Flail	0.3	0.6	30.7	41.8
		Chemical				37.8
	Restricted	Flail				43.7
		Chemical				45.6
	means					
	Seed	Sprouted	0.3	1.4	28.6	39.9
		Unsprouted	0.4	0.6	30.7	42.2
	Irrigation	Full				39.6
		Restricted				42.6
	Haulm Destruction	Flail				42.2
		Chemical				40.0
		SEM				
		1. Sprouting	0.09 (ns)	0.40 (*)	3.95 (ns)	1.60 (ns)
		2. Irrigation				1.60 (ns)
		3. Haulm				1.60 (ns)
		1 x 2				2.26 (ns)
		1 x 3				2.26 (ns)
		2 x 3				2.26 (ns)
		1 x 2 x 3				3.19 (ns)

TABLE 21. NETTING AREA INDEX SCORE (0-100) AT EACH DATE OF ASSESSMENT.

Treatment			Assessment timing/date			
Seed	Irrigation	Haulm Removal	**TI + 4 weeks** (11 July)	TI + 6 weeks (24 July)	Haulm removal (14 Aug)	Harvest (14 Sept)
Sprouted	Full	Flail	5.7	10.2	64.5	76.9
		Chemical				75.2
	Restricted	Flail				78.6
		Chemical				73.2
Unsprouted	Full	Flail	4.7	6.0	66.0	77.1
		Chemical				73.8
	Restricted	Flail				75.7
		Chemical				80.1
	means					
	Seed	Sprouted	5.7	10.2	64.5	76.0
		Unsprouted	4.7	6.0	66.0	76.7
	Irrigation	Full				75.7
		Restricted				76.9
	Haulm destruction	Flail				77.1
		Chemical				75.6
		SEM				
		1. Sprouting	1.30 (ns)	0.68 (*)	4.51 (ns)	1.70 (ns)
		2. Irrigation				1.70 (ns)
		3. Haulm				1.70(ns)
		1 x 2				2.40 (ns)
		1 x 3				2.40 (ns)
		2 x 3				2.40 (ns)
		1 x 2 x 3				3.40 (ns)

TABLE 22. NETTING SEVERITY INDEX (0-100) AT EACH DATE OF ASSESSMENT.

Treatment			Assessment timing/date			
Seed	Irrigation	Haulm Removal	**TI + 4 weeks** (11 July)	TI + 6 weeks (24 July)	Haulm removal (14 Aug)	Harvest (14 Sept)
Sprouted	Full	Flail	18.2	19.5	79.6	88.2
		Chemical				86.2
	Restricted	Flail				89.3
		Chemical				84.0
Unsprouted	Full	Flail	12.9	15.6	81.1	85.8
		Chemical				84.2
	Restricted	Flail				84.4
		Chemical				85.8
means						
	Seed	Sprouted	18.2	19.5	79.6	86.9
		Unsprouted	12.9	15.6	81.1	85.1
	Irrigation	Full				86.1
		Restricted				85.9
	Haulm destruction	Flail				86.9
		Chemical				85.1
		SEM				
		1. Sprouting	3.93 (ns)	0.55 (*)	3.00 (ns)	1.56 (ns)
		2. Irrigation				1.56 (ns)
		3. Haulm				1.56 (ns)
		1 x 2				2.20 (ns)
		1 x 3				2.20 (ns)
		2 x 3				2.20 (ns)
		1 x 2 x 3				3.12 (ns)

Periderm morphology

In the 120 tubers assessed by SAC, 95% of the tubers examined demonstrated a regular columnar cell arrangement. 23% of the tubers demonstrated netting symptoms, and a further 19% had a 'flaky' skin surface (where the horizontal cell wall was detached from the neighbouring periderm cell, but remained attached at one edge to the next cell in the periderm). An irregular cell arrangement was more commonly associated with netting damage (3 cases) or collapsed cells in the periderm (2 cases) than a smooth skin finish (1 case). Irregular cell arrangement or collapsed cells in the periderm showed no common association with the treatments applied.

The measures of periderm thickness and number of cell layers in the periderm in this study (Table 23) are consistent with data reported by Bowen *et al*. 1996 for cv Estima. There were no main treatment effects on either periderm thickness or the number of cell layers in the periderm. However there was an interaction between irrigation and

haulm destruction treatments on these parameters, though effects were small and inconsistent.

TABLE 23. MORPHOLOGY OF THE PERIDERM - SKIN THICKNESS (MM) AND NUMBER OF CELL LAYERS IN PERIDERM.

Treatment			Periderm thickness (mm)	Number of cell layers in periderm
Seed	Irrigation	Haulm Removal		
Sprouted	Full	Flail	0.128	7.5
		Chemical	0.145	8.7
	Restricted	Flail	0.146	8.6
		Chemical	0.135	8.1
Unsprouted	Full	Flail	0.141	8.6
		Chemical	0.146	8.3
	Restricted	Flail	0.142	8.8
		Chemical	0.142	8.0
means				
	Seed	Sprouted	0.138	8.2
		Unsprouted	0.143	8.4
	Irrigation	Full	0.140	8.4
		Restricted	0.141	8.2
	Haulm destruction	Flail	0.139	8.3
		Chemical	0.142	8.4
		SEM		
		1. Sprouting	0.0027 (ns)	0.18 (ns)
		2. Irrigation	0.0027 (ns)	0.18 (ns)
		3. Haulm	0.0027 (ns)	0.18 (ns)
		1 x 2	0.0037 (ns)	0.25 (ns)
		1 x 3	0.0037 (ns)	0.25 (ns)
		2 x 3	0.0037 (*)	0.25 (*)
		1 x 2 x 3	0.0053 (ns)	0.35 (ns)

Yield

Yields averaged 69 t/ha, which was typical for the site and season. Seed sprouting and irrigation treatments significantly increased yields (Table 24).

TABLE 24. TOTAL YIELD (T/HA).

Treatment			Yield (t/ha)
Seed	Irrigation	Haulm Removal	
Sprouted	Full	Flail	74.1
		Chemical	75.7
	Restricted	Flail	73.9
		Chemical	69.9
Unsprouted	Full	Flail	65.3
		Chemical	67.6
	Restricted	Flail	63.0
		Chemical	65.9
means			
	Seed	Sprouted	73.4
		Unsprouted	65.4
	Irrigation	Full	70.7
		Restricted	68.2
	Haulm destruction	Flail	69.1
		Chemical	69.8
		SEM	
		1. Sprouting	0.67 (***)
		2. Irrigation	0.67 (*)
		3. Haulm	0.67 (ns)
		1 x 2	0.95 (ns)
		1 x 3	0.95 (ns)
		2 x 3	0.95 (ns)
		1 x 2 x 3	1.34 (ns)

2.5.4 Discussion

Netting appears to occur very early in the life of the crop, from soon after tuber initiation, and continues to develop in the crop up until harvest, though at a slower rate at later stages. However, netting was difficult to identify at early assessment dates, and further work would be valuable to confirm this finding. In particular it would be useful to assess netting more frequently to allow the progress of symptom development to be followed with more confidence. The wide range of treatments applied at the end of the growing season failed to have a significant influence on the incidence of netting. This was despite the fact that there appeared to be some late tuber growth during the differential irrigation period when skins were starting to set. In hindsight it is possible that the assessment methodology adopted was not sensitive enough to pick up potentially subtle differences attributable to treatment. In further work effort will need to be put into defining much tighter scales of assessment to avoid masking of any treatment effects.

Although available data was very limited, there was a suggestion that irregular cell arrangements were more commonly associated with skin problems such as netting and collapsed cells in the periderm, but this requires more extensive research. However, netting was also more commonly observed where periderm cells were organised in a regular pattern.

To examine the influences that agronomic practices can have on netting, treatments need to be extended and linked to the state of skin set. In this study the crop was starting to set skins at the time of desiccation. Moving desiccation forward and having a sequence of desiccation dates could help indicate what effect crop maturity, and therefore skin set, at the time of haulm removal has on subsequent netting development where water is either limited or freely available at and after haulm removal. Varying water availability may also be a factor which affects netting if fluctuations in tuber turgor are promoted which stress the periderm during the period of skin set.

After the first year of this project, the work on netting continued with Defra funding (Defra reference number: HP0140). It was shown that netting commenced six weeks after tuber initiation (in an irrigated crop), and continued to develop until two weeks before harvest. Defoliation by flailing resulted in less severe netting compared with natural senescence. Netting was not related to tuber size. A study using a hydroponic growing system in a glasshouse showed that netting was more severe after cycles of water deficit. Field and glasshouse data suggested that water stress, or cycles of stress and return of water, lead to greater netting severity. However, data from a field experiment in which the soil microenvironment across a potato ridge was recorded and related to netting suggested that the relationship was not as straightforward as this. Netting was reduced with proximity of the tuber to the ridge surface, where it is more likely to experience water deficit and temperature fluctuations. This was found in one season only, and it would be useful to repeat the experiment. Measurements of the mechanical properties of tuber skin showed that netting was correlated with reduced strength. After droughting, skins were also less elastic.

2.5.5 Conclusions

Symptoms of netting can occur very early in the life of a tuber. Method of haulm disposal, when working effectively, appears to have little effect on the incidence of netting.

There does not appear to be a clear relationship between the incidence of netting and cell arrangement in the periderm.

Better methods of assessing netting need to be developed for detailed experimental work.

Effects of combined agronomic treatments on netting may be more easily identified when working with immature crops where skins on tubers have not started to set, as found in studies of potato skin adhesion.

2.6 Factors influencing skin bloom

Section authors: Jeff Peters, SBEU, and Jeremy Wiltshire, ADAS.

2.6.1 Introduction

The dominance of washed and packed potatoes within the fresh market means that producing and maintaining tubers with a good visual appearance is vital for securing premium returns in this sector. In GB alone, it is estimated that the value of the fresh sector is worth around £834 million per annum (Anon, 2005[a]). As a consequence of this, causes of rejections or downgrades – for example poor skin bloom or high levels of a blemish disease, such as black dot – are important and costly concerns for the industry.

A previous BPC-funded study identified an optical technique that provided an objective measure of skin bloom (Gray *et al.*, 2003). The bloom (sometimes also called shine or lustre) is measured as the specular (i.e. direct or mirror-like) component of optical reflection from the potato skin surface. The diffuse component of reflected light provides the colour information. A small hand-held optical meter ('bloom meter') was developed at SAC for the BPC, to objectively assess small areas on a tuber surface and grade them according to a pre-defined scale that related to the bloom of the potato. The scale rates the bloom on a scale of 1 (good) to 5 (poor). Examples of a difference in bloom are shown in Figure 27.

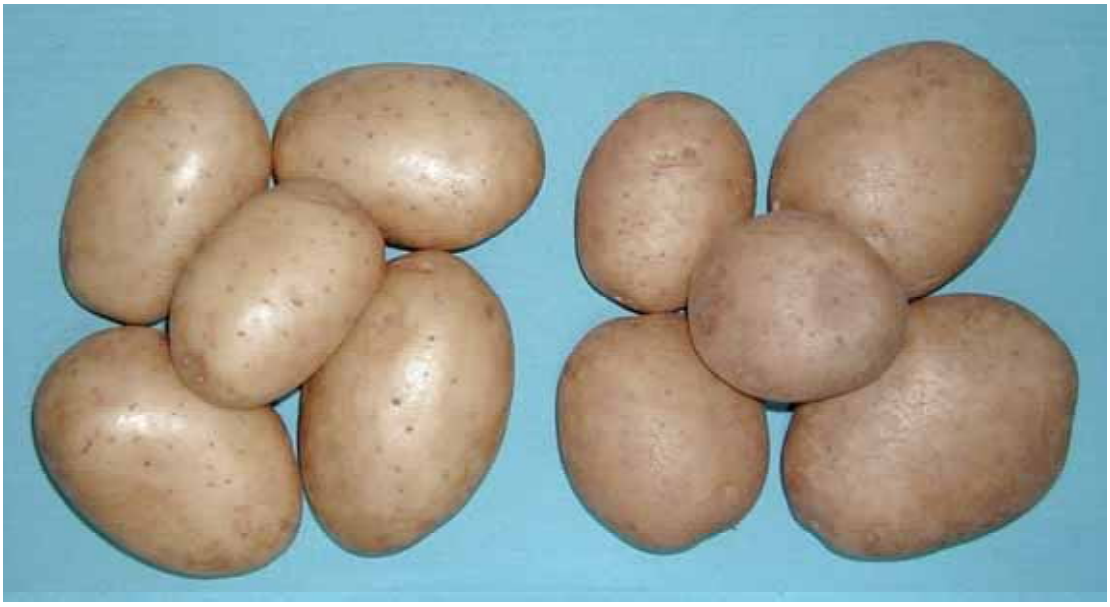


FIGURE 27. DIFFERING LEVELS OF BLOOM IN CV. ESTIMA: BLOOM SCORES OF 2 (LEFT) AND 4 (RIGHT).

A trial was conducted at SBEU and this established that the meter readings correlated well with those of a skilled visual assessor. The bloom meter was used in this study to help model the pattern of bloom deterioration during storage.

Black dot, caused by the fungus *Colletotrichum coccodes*, has become a particularly important blemish disease because of the limited control options (Lees & Hilton,

2003). Current control practices are aimed at minimising soil-borne infection, including the use of azoxystrobin (Hilton *et al.*, 2005), harvesting the crops as early as possible (Hide *et al*., 1994) and dry curing during the early stages of storage (Mawson & Cunnington, 1995). There are no fungicides currently available in the UK for the direct control of black dot on ware and seed tubers.

The objective of this study was to better understand the factors that influence skin quality (bloom), through evaluation of the effects of crop duration and storage conditions (humidity, temperature, ventilation rates and curing). In addition, the work attempted to integrate the effects of agronomy and storage on black dot development.

2.6.2 Materials and methods

Field design and assessments

Experiments were conducted over four seasons from 2001/2 to 2004/5. Field plots were grown at Wingland, south Lincolnshire on a light silt soil typical of the Holbeach Marsh area. Field treatments included seed condition, planting date and harvest date whilst storage treatments were imposed to study the effects of store environment on maintenance of bloom. The treatments are given in Table 25.

The field experiments were of a factorial design, with 4 replicates of each treatment arranged in 4 blocks, with one plot of each treatment in each block. Plot size (harvest area) was 4 rows (3.6 m) by 12 m in 2001, and 9 rows (8.1 m) by 11 m in 2002–2004.

The seed tubers were planted by machine. Row width was 90 cm and seed rates (given in Appendix 3) were representative of best commercial practice for a pre-pack crop. Irrigation, fertilisers and other agrochemicals were applied according to the normal agronomic practice for a farm crop. Further details of crop husbandry are given in Appendix 3.

The dates of 50% and full plant emergence were recorded. Within each block, one plot of each planting date treatment was selected at random for assessment of date of tuber initiation. Five sample plants per plot were examined in discard rows that had received the plot treatment. Soil was removed from one side of the potato ridge to expose the root/stolon system around the mother tuber, taking care to expose any stolons below the level of the mother tuber as tuber initiation often occurs on deeper stolons first. Stolons were traced from the mother tuber area to the tip on the exposed ridge side only. The date of initiation was taken as that on which at least two stolon tips on each of five sample plants had produced tubers. After assessment of stolon ends the soil was returned to the ridge so that minimum disturbance was caused to the plant.

TABLE 25. TREATMENTS FOR SKIN BLOOM EXPERIMENTS.

Year & varieties	Treatment factor	Treatment ID	Treatment detail
2001 Desiree and Estima	Seed condition	S1	unsprouted
		S2	sprouted
	Harvest date	H1	early-defoliated at first observation of senescence in treatment S2 and harvested two weeks later
		H2	late- target dates of haulm destruction and harvest 4 weeks later than H1
	Humidity in store	high RH	storage at 3.5°C; 98% RH
		low RH	storage at 3.5°C; ambient RH (*c.* 85-90%)
2002 Desiree and Estima	Harvest date	H1	early-defoliate at first observation of senescence in either variety and harvest three weeks later
		H2	late- target date of haulm destruction three weeks later than H1; harvest at least two weeks later, when skins have set
	Storage	2.5C -S	storage at 2.5°C; no sprout suppression
		4.0C -S	storage at 4.0°C; no sprout suppression
		4.0C +S	storage at 4.0°C; sprout suppression (CIPC, two applications)
2003 Desiree and Estima	Harvest date	H1	early-defoliate at first observation of senescence in either variety and harvest three weeks later
		H2	late- target date of haulm destruction three weeks later than H1; harvest at least two weeks later, when skins have set
	Storage	normal vent	storage at 3.5°C; ventilation rate during pull down = 0.02 $m^3/s/t$
		high vent	storage at 3.5°C; ventilation rate during pull down = 0.06 $m^3/s/t$
2004 Estima	Planting date	P1	site practice
		P2	site practice + 23 days
	Harvest date	H1	early-(defoliate at first observation of senescence and harvest three weeks later)
		H2	late- (target date of defoliation three weeks later than H1; harvest three weeks after defoliation, when skins have set.)
	Storage	immediate pull-down	storage at 3.5°C; immediate 0.5°C/day pull-down from 12°C
		cure	storage at 3.5°C; cure at 12°C for 14 days followed by 0.5°C/day pull-down

Planting date was late in 2001 (22 May) because of wet weather, but in 2002 and 2003 planting dates were at typical dates for pre-pack crops (11 April 2002 and 7 April 2003). In 2004 there were planting date treatments, with the intention of achieving typical and late planting dates. However, the first planting date (27 April) was delayed by 2-3 weeks because of wet soil conditions and the second planting date was 23 days later (20 May).

Date of canopy closure was recorded as being equivalent to the date when 75% ground cover was achieved using a visual scoring method.

From the start of senescence, foliar necrosis was assessed weekly in all plots using a grid method. A quadrat was used which had one dimension equal to the width of the row (0.9 m × 1.0 m), divided into 100 equal sized squares. Three quadrat counts per plot were made at approximately equal intervals along the length of the plot. The quadrat was placed above the crop so that it spanned the row exactly, and the number of squares within the quadrat that contained more than 50% yellow/brown haulm were counted. Senescence was then estimated as the percentage of squares with more than 50% yellow/brown haulm.

Plots were defoliated using a tractor-mounted mechanical flail. After this operation any remaining stems were severed close to ground level by hand. Each plot was harvested using an elevator digger and the tubers were hand-picked from the soil surface and placed into clean, labelled paper sacks for transport to SBEU. Dates of haulm destruction and harvest are given in Appendix 3.

Storage treatments

Tubers were delivered to SBEU on the day of harvest, where plot weights were measured and material was hand graded to remove any tubers under 35 mm and over 85 mm prior to storage.

In 2001, tubers were weighed into labelled trays (approximately 10 kg per tray), which were loaded into the controlled environment room at ambient temperature (15.0°C; crop temperature was 15.1°C at harvest 1 and 14.5°C at harvest 2). Curing commenced, from day of intake, at 0.5°C pull down/day until the final holding temperature of 3.5°C (at 98% RH, using ultrasonic humidification, and ambient RH for the two storage treatments) was reached approximately 3 weeks after store loading. Storage humidity data are presented in Figure 28.

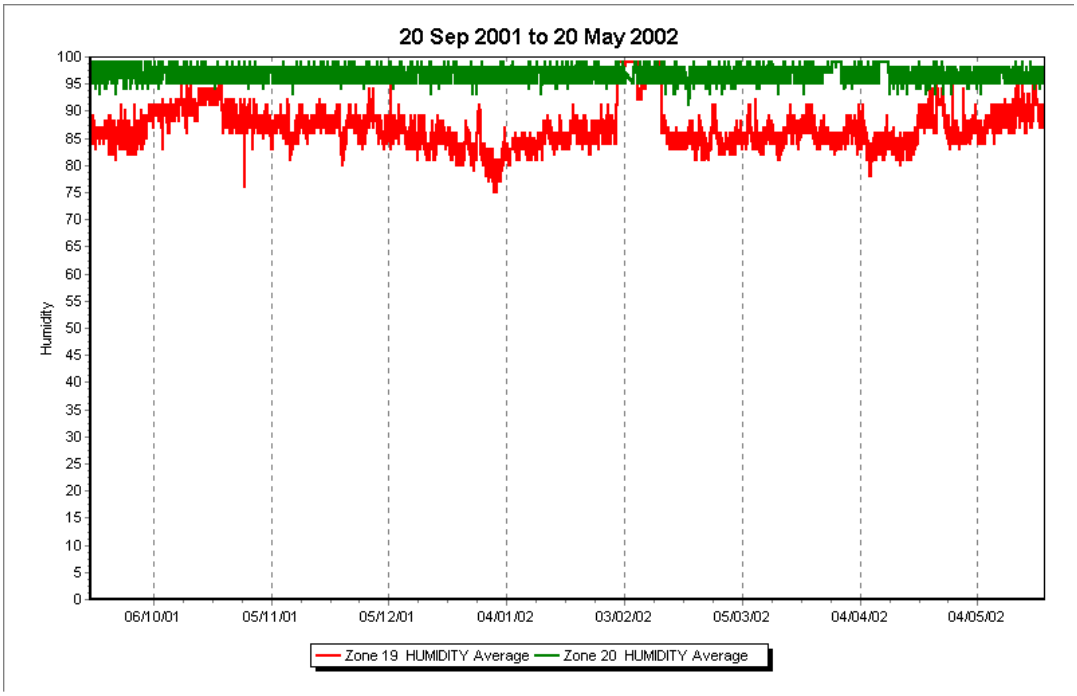


FIGURE 28. RELATIVE HUMIDITY (%) IN EXPERIMENTAL STORES FOR THE CROP HARVESTED IN 2001.

The upper line represents the humidity in the store set to maintain 98% RH. The lower line represents the humidity in the ambient store.

In 2002, tubers were weighed into labelled trays (approximately 20 kg per tray), which were loaded into the controlled environment room at ambient temperature (18.0°C for harvest 1, crop temperature was 18.7°C; and 15°C for harvest 2, crop temperature was 16.0°C). Cooling commenced, from day of intake, at 0.5 degC pull down per day until the final holding temperature of 2.5°C or 4.0°C was reached approximately 3 weeks after store loading. Once the desired holding temperature was achieved, the relative humidity of the stores were maintained at 95% RH for the duration of the storage term using ultrasonic humidification. The sprout suppressant, *MSS CIPC 50 M* (Whyte Agrochemicals Ltd, Huddersfield, HD7 5QE), was applied according to label recommendations. *MSS CIPC 50 M* is a methanol-based formulation containing 500 g CIPC per litre. Applications were made on 10 October 2002 and 10 January 2003 using a Swingfog SN-50 thermal fogging machine (Allman Sprayers Ltd, Chichester, West Sussex, UK). Stores remained switched off for a period of 24 hours following CIPC application. The corresponding 4°C store, where no CIPC was applied, was also switched off for the same duration to minimise temperature differences between treatments.

For storage in 2003, tubers were weighed into labelled, netted bags (*c.* 10 kg per net). The experimental design consisted of a split-plot arrangement whereby the two curing treatments (ventilated at 0.02 or 0.06 m^3/s/tonne during the pull-down period) were the main plot treatments, each replicated twice (i.e. carried out using 4 stores). Six nets for each field treatment/block combination were placed within the top third of buffer tubers (a commercially grown crop, cv. Estima) in 1 tonne boxes. The nets were then covered with additional buffer crop until boxes were nearly full. Filled boxes were loaded into 12-tonne capacity experimental stores at ambient temperature

(16.1°C for harvest 1; crop temperature was 16.1°C; and 16.0°C for harvest 2; crop temperature was 15.1°C) as shown in Figure 29. Curing commenced, from day of intake, at 0.5 degC pull down per day until the final holding temperature of 3.5°C (at 95% RH) was reached.

In 2004, tubers were weighed into labelled trays (*c.* 10 kg per tray), which were loaded into a controlled environment room at 12.0°C (harvest 1 crop temperature was 18.5°C; and harvest 2 crop temperature was 15.0°C). Two storage treatments were imposed:

1) immediate temperature pull-down commenced, from day of intake, at 0.5 degC per day until the final holding temperature (3.5°C) was reached approximately 3 weeks after store loading;
2) alternatively, the crop temperature was held at 12.0°C for 14 days before temperature pull-down commenced.

The stores were maintained at 95% relative humidity (RH) throughout the post-curing storage period. The experimental design consisted of a split-plot arrangement with the two curing treatments (immediate pull-down or pull-down after 14 days) as the main plot treatments, each replicated twice (i.e. carried out using 4 stores). Six trays for each field treatment/block combination were placed in a randomised block design within each store.

Sprout control

The sprout suppressant, MSS CIPC 50 M (Whyte Agrochemicals Ltd, Huddersfield, HD7 5QE), was applied according to label recommendations. Applications were made as required using a Swingfog SN-50 thermal fogging machine (Allman Sprayers Ltd, Chichester, West Sussex, UK). Stores remained switched off for a period of 24 hours following CIPC application.

Tuber quality assessments

The intake assessments (each on 25 tubers per plot) were: bloom; weight of tubers; % surface area (%SA) and severity of netting; and %SA of silver scurf, black dot, skin spot, common scab, powdery scab and black scurf, and area of skin scuffed. Samples (each with 25-tubers per block/treatment combination) were removed from the experimental stores at intervals throughout the 31-39 week storage periods (detailed in Appendix 4) and assessed for skin bloom. Visual assessments of surface area affected by blemish diseases were also recorded. Assessments were as at intake except there was no evaluation of common scab, powdery scab, black scurf or scuffed area.

Tubers for bloom assessment were washed in a barrel washer (Peter Cox Marketing Ltd, UK) for 2 minutes and air-dried overnight.

A hand-held device, the SAC/BPC bloom meter (Figure 30), was used to measure skin bloom, i.e. the amount of specular light reflected off an area of skin under test (approximately 10 mm^2 of flat surface).

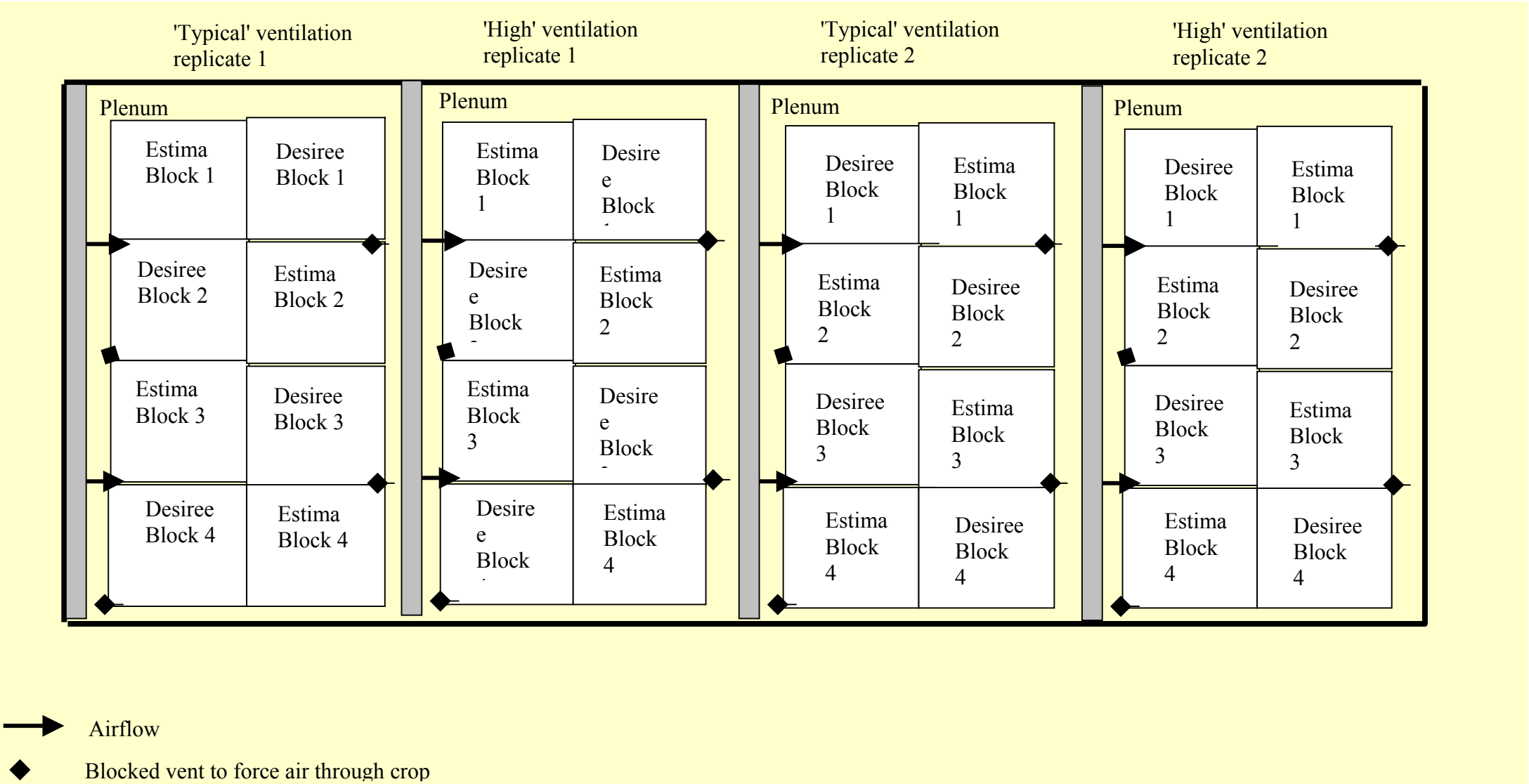


FIGURE 29. EXPERIMENTAL DESIGN OF STORAGE COMPONENT OF 2003-04 TRIAL

Showing layout of samples within 1 tonne boxes in experimental stores. Blocks 1 to 4 refer to the blocking structure in the field.

FIGURE 30. BPC/SAC BLOOM METER.

Integer values from 1 (bright, shiny skin) to 5 (dull, matt skin) were obtained. Care was taken to avoid areas that were affected by netting, eyes and obvious blemishes. Multiple readings were taken across the surface of each tuber in order to obtain a value that was representative of the sample. In the first year of this study, each tuber was graded into six size categories (<40mm length, 40-50mm, 50-60mm, 60-70mm, 70-80mm, and >80mm) in order to determine whether size and skin bloom were correlated.

Ultrastructure of skin

Samples of Estima and Desiree tubers showing good (i.e. bright and shiny) and bad (i.e. dull) skin bloom were sent to Warwick HRI in order to carry out investigations of the tuber skin's ultrastructure using scanning electron microscopy.

Statistical analysis

Statistical analyses were carried out using Genstat statistical software (VSN International Ltd, Hemel Hempstead, Herts. HP1 1ES). Where skewed values were detected, analyses were performed on square root-transformed data. Models (either logistic or exponential) were fitted to skin bloom and black dot data in order to obtain parameter estimates. Generalized linear models (on square root transformed parameter estimates, if required) were used to calculate the treatment effects on bloom.

2.6.3 Results

Agronomic factors

Dates of emergence, tuber initiation and canopy closure are given in Appendix 5. Senescence was more rapid in Estima than Desiree, and for both cultivars in 2001, more rapid in the sprouted treatment compared with unsprouted, but the differences were not large (Figure 31).

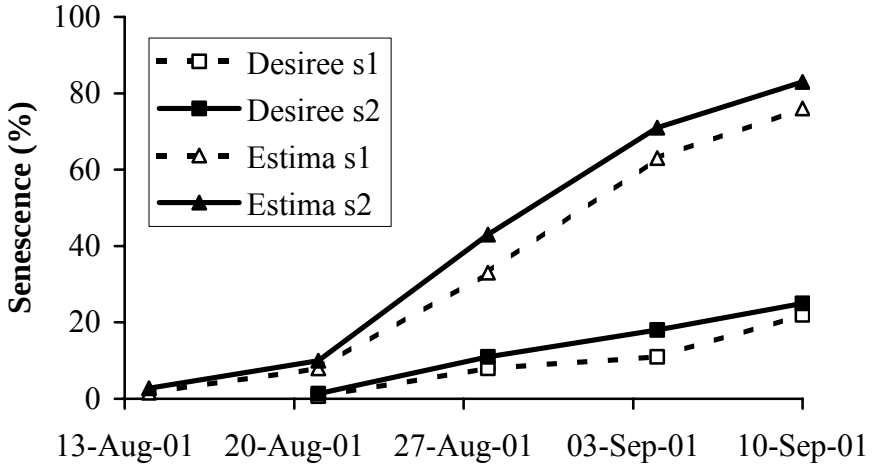
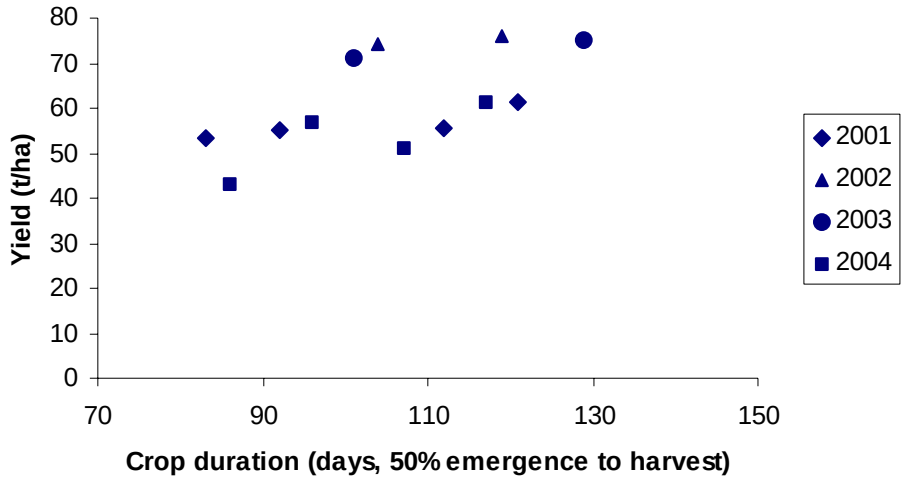


FIGURE 31. FOLIAR SENESCENCE, 2001. S1 - UNSPROUTED; S2 - SPROUTED.

Yield

For both Desiree and Estima, yield increased with crop duration (Figure 32). The increase was generally linear but the r^2 value was low (only 32% of the variance was accounted for). Seasonal differences (i.e. soil temperature, rainfall etc.) probably accounted for much of the variability.

A.



B.

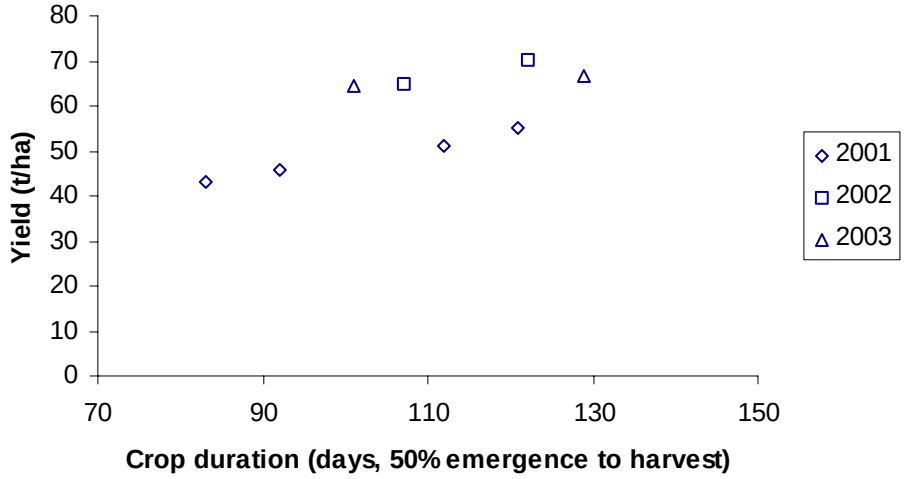


FIGURE 32. YIELD (T/HA) OF CVS A. ESTIMA; AND B. DESIREE IN FIELD EXPERIMENTS CARRIED OUT DURING 2001-2004.

Weight loss

At the end of the 2001 to 2004 storage seasons, weight loss was approximately 4–5%. During the 2001-02 season, weight losses of tubers that had been stored at 3.5°C for 35 weeks, at either 98% RH or ambient RH, were compared. The weight losses of Desiree and Estima tubers were not significantly different, so weight loss data were averaged across varieties (Table 26). Store RH of 98% dramatically reduced weight loss compared with no RH control (P<0.001). During the 2002-03 season, weight losses of tubers that had been stored at 2.5°C and 4.0°C for 35 to 37 weeks were compared (Table 27). The weight loss of Desiree tubers was lower than for Estima tubers (P<0.001). Despite a greater weight loss at 2.5°C compared with 4.0°C (P=0.034), the differences were small and not of commercial importance. There was no difference in weight loss between early- and late-lifted tubers (despite the early harvested tubers having a storage period that was two weeks longer than later lifted

tubers). Humidity and temperature during storage were the only treatments to affect weight loss.

TABLE 26. EFFECTS OF STORE HUMIDITY AND HARVEST DATE ON WEIGHT LOSS (%) DURING THE 2001-02 SEASON.

Treatment	Weight loss (%)
Storage @ RH 98%	4.4[a]
Storage @ ambient RH	5.1[b]
S1 (unsprouted)	5.1[a]
S2 (sprouted)	5.3[a]
Harvest 1 (11/09/01)	5.2[a]
Harvest 2 (10/10/01)	5.2[a]
	Significance levels
Storage RH	<0.001
Seed sprouting	0.141
Harvest date	0.837

Different letters after weight loss values represent significant differences at $P<0.05$.

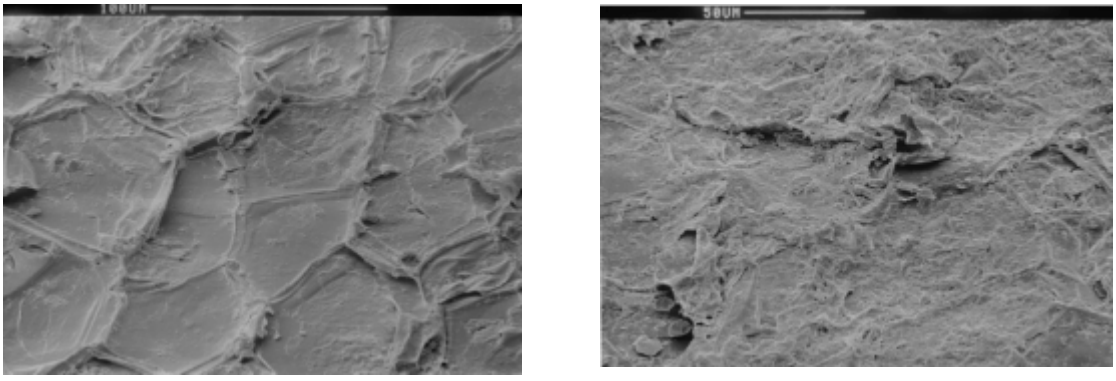
TABLE 27. EFFECTS OF STORAGE TEMPERATURE AND HARVEST DATE ON WEIGHT LOSS (%) IN ESTIMA AND DESIREE DURING THE 2002-03 STORAGE SEASON.

Treatment	Weight loss (%)
Storage @ 2.5°C -CIPC	4.54[b]
Storage @ 4.0°C +CIPC	4.30[a]
Storage @ 4.0°C -CIPC	4.25[a]
Desiree	4.10[a]
Estima	4.63[b]
Harvest 1 (37 week storage)	4.28[a]
Harvest 2 (35 week storage)	4.44[a]
	Significance levels
Storage treatment	0.034
Variety	<0.001
Harvest date/duration	0.094

Different letters after weight loss values represent significant differences at $P<0.05$.

Skin bloom

Scanning electron micrographs, taken by Warwick HRI, of the skins from tubers with a range of bloom values revealed that areas on tubers with bloom values of 2 (i.e. bright and shiny) had a smooth skin surface. Whereas, areas on tubers with bloom values of 5 (i.e. dull) had a rough skin surface (Figure 33). In 2001, a generalised linear model was used to test the correlation between bloom data (for Estima) and tuber size. The correlation was small and not significant (P=0.522).



A. B.

Micrographs courtesy J. Andrews, Warwick HRI.

FIGURE 33. MICROGRAPHS SHOWING MAGNIFIED DETAIL OF AREA ON TUBERS

A) bloom values of 2 (i.e. bright and shiny); and B) bloom values of 5 (i.e. dull).

During the four years of study, logistic and asymptotic models have adequately described the change in bloom over approximately 35 weeks of storage (at 2.5°C, 3.5°C and 4.0°C). Figure 34 shows an example of the way that skin bloom deteriorates (data from the 2001-02 crops). The cultivar Estima had consistently lower bloom scores compared with Desiree (P<0.001). However, it is not clear whether this was due to variation in skin bloom *per se* or a consequence of the difference in skin colour between cultivars.

Figure 35 shows the pattern of lower asymptote (obtained from logistic or exponential curves fitted to bloom data) in cv. Estima. This is the point at which the curve flattens out following the decline in bloom during storage (i.e. poorest bloom score). There was a general lowering of this value with increasing crop duration (P=0.023) but seasonal variation had the greatest influence on final skin bloom values (P<0.001).

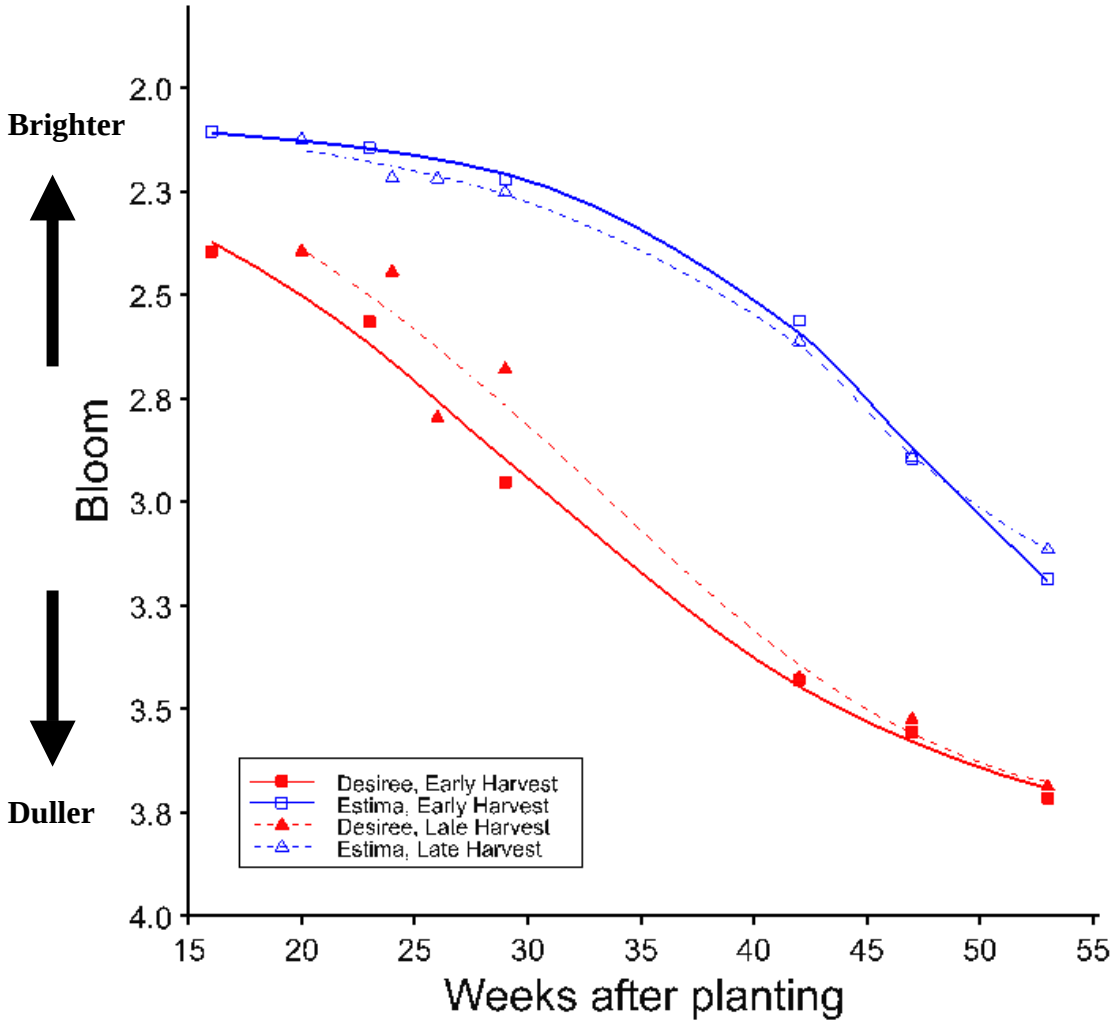


FIGURE 34. PATTERN OF BLOOM DETERIORATION IN DESIREE AND ESTIMA TUBERS STORED AT 4°C.

Unbroken lines represent early harvest treatments, and broken lines represent late harvest treatments. A bloom value of 3 or less is acceptable for pre-pack standards. The variance accounted for was 98.5%. $LSD_{(P=0.05)}$=0.12.

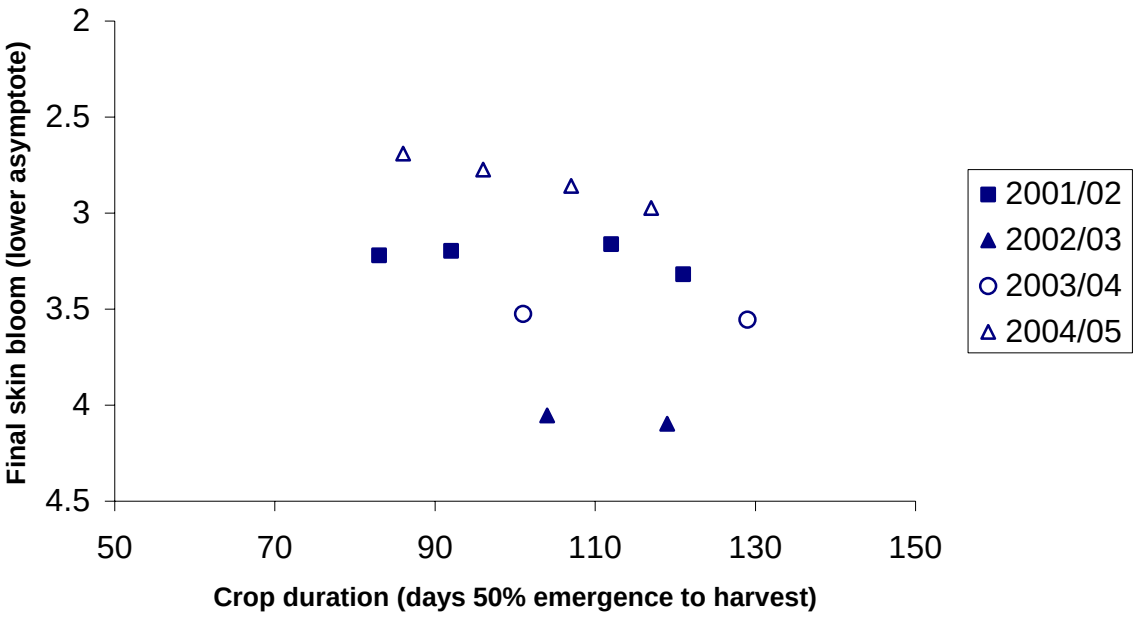
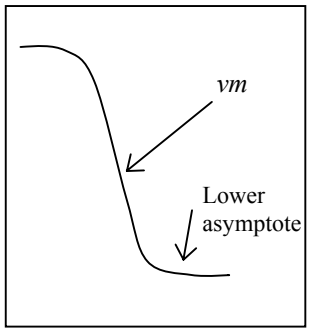


FIGURE 35. FINAL SKIN BLOOM (LOWER ASYMPTOTE) IN CV. ESTIMA, PLOTTED AGAINST CROP DURATION.



An analysis of the points of inflexion (*vm*, or time taken to reach the mid-bloom value, see inset) and lower asymptote (final skin bloom) was used to identify how bloom was altered by crop duration (measured in days from 50% emergence to harvest) and storage treatments (Table 28, A-D). Crop duration had a large influence on skin bloom in Estima but not in Desiree. During the 2004-05 season, in Estima, the skin bloom in older crops took longer to deteriorate (i.e. the point of inflexion increased with crop age; *P*=0.012). Skin quality also became poorer (i.e. there was a corresponding increase in the lower asymptote) but this difference of approximately 0.2 bloom value units was not significant (*P*=0.174) (Figure 36). During the 2001-02 season, the skin bloom in Estima tubers deteriorated earlier in older crops (P=0.009) but the level to which bloom declined was largely not affected by crop duration (*P*=0.073).

TABLE 28. COMPARISONS OF THE EFFECTS ON SKIN BLOOM OF STORAGE TREATMENTS (FOR APPROXIMATELY 35 WEEKS) AND CROP DURATIONS.

Summary results from GLM of logistic (†and exponential) models. Each value represents a significance level for a mid-bloom value (*vm*, the points of inflexion), and a final bloom value (lower asymptotes for logistic and asymptotic models) when fitted to the skin bloom data.

A. Storage treatment effects in cv Estima

Year	Storage treatment	**Time to mid bloom value *(vm)***	Final bloom value (lower asymptote)
2001-02	Humidity	0.798	0.973
2002-03	Temperature/CIPC	0.733	0.576
2003-04	Ventilation rate	-†	0.824†
2004-05	Curing	**0.047**	0.669

B. Crop duration effects in cv Estima

Year	Crop duration (days, 50% emergence to harvest)	*vm*	Asymptote
2001-02	83, 92, 112, 121	**0.009**	0.073
2002-03	104, 119	0.788	0.835
2003-04	101, 129	-†	0.612†
2004-05	86, 96, 107, 117	**0.002**	**<0.001**

C. Storage treatment effects in cv Desiree

Year	Storage treatment	*vm*	Asymptote
2001-02	Humidity	0.837	**0.016**
2002-03	Temperature/CIPC	0.732	0.854
2003-04	Ventilation rate	-†	0.571

D. Crop duration effects in cv Desiree

Year	Crop duration (days, 50% emergence to harvest)	*vm*	Asymptote
2001-02	83, 92, 112, 121	0.326	0.346
2002-03	107, 122	***0.054***	0.617
2003-04	101, 129	-†	0.317

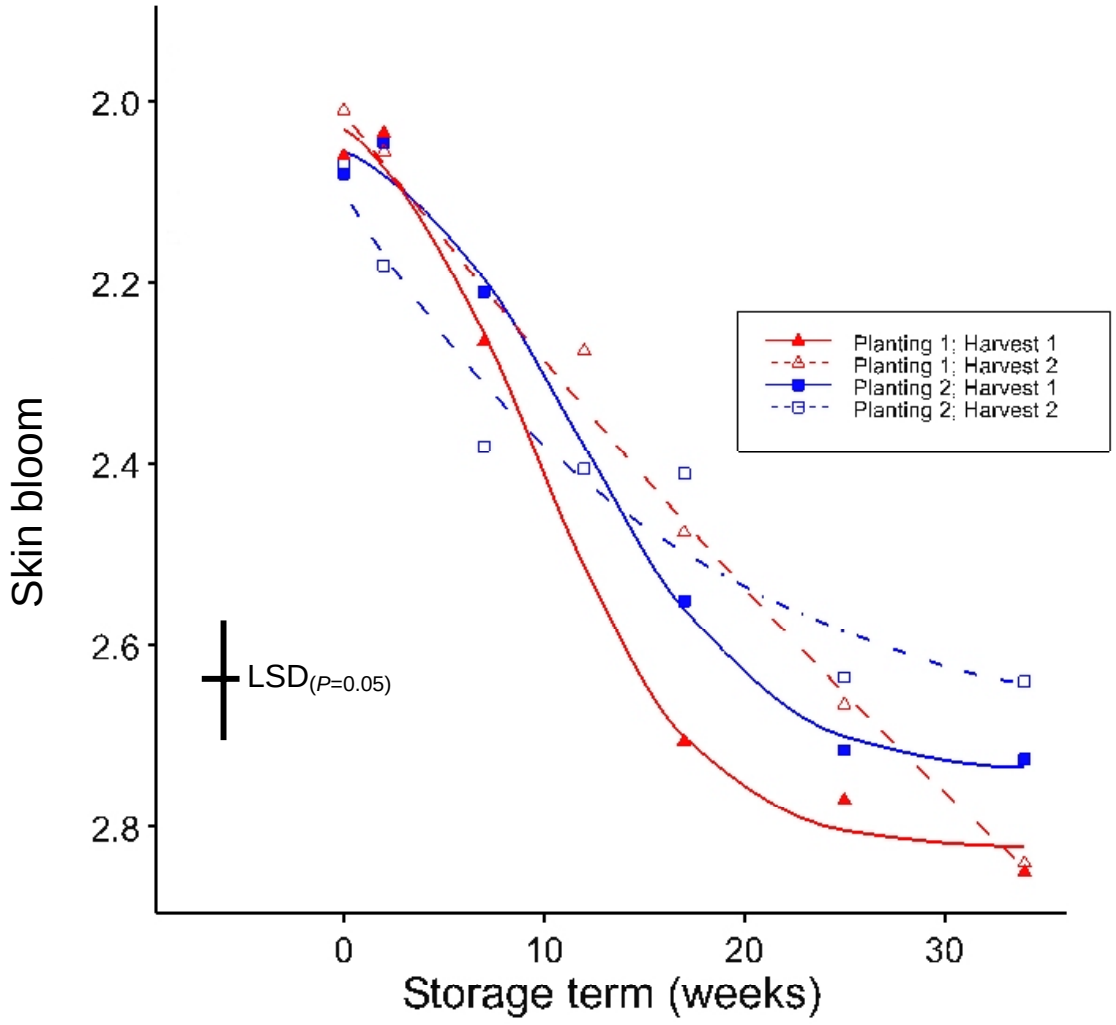
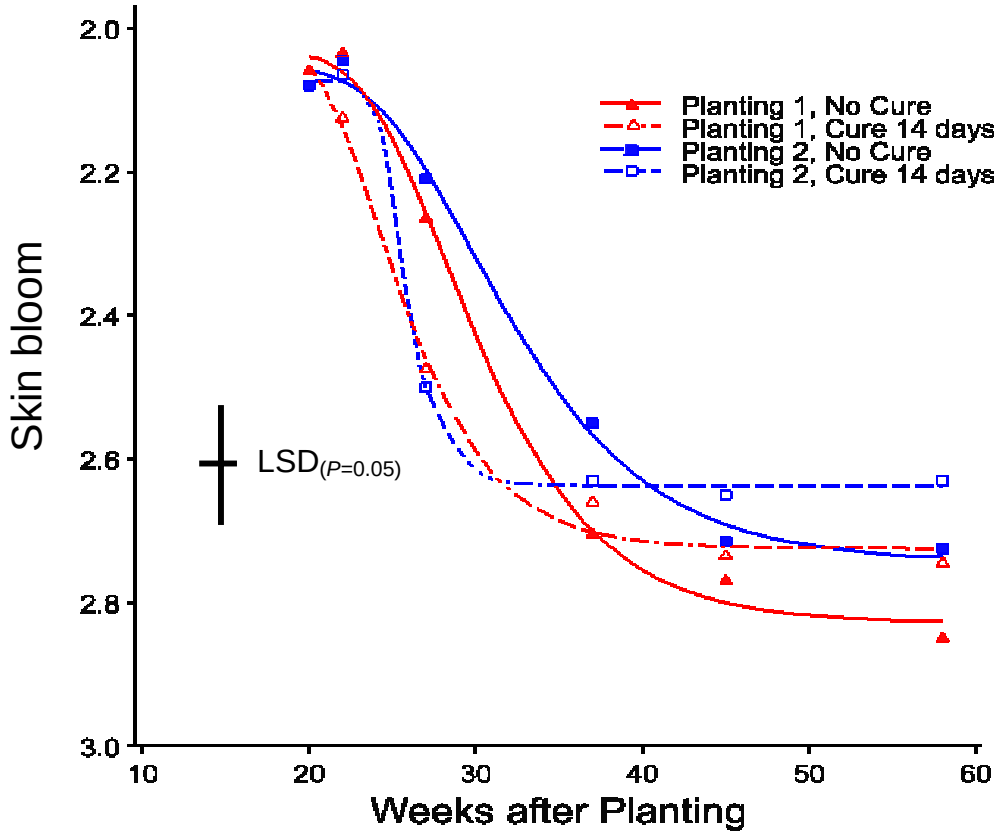


FIGURE 36. THE EFFECT OF CROP DURATION ON DETERIORATION OF SKIN BLOOM DURING STORAGE.

The horizontal and vertical bars represent the least significant difference (*P*=0.05) across both vectors.

Storage treatments generally had minimal impact on the decline of skin bloom. Temperature and CIPC (at 2.5°C compared with 4.0°C) and ventilation rates did not affect skin bloom deterioration. In Desiree, humidity had a small effect, whereby 98% RH resulted in brighter skins than tubers stored at ambient RH (*P*=0.016) at the end of storage. Humidity did not affect bloom deterioration in Estima (*P*=0.973).

Curing did affect changes in skin bloom. In the early harvested tubers (crop durations of 83 and 92 days), a 14 day curing period at 12°C was followed by a decline in bloom, on average, 18 days sooner than in tubers that had not been cured (pulled-down immediately after store loading) (*P*=0.047) (Figure 37).



(NB: Horizontal and vertical bars represent the least significant difference (P=0.05) across both vectors)

FIGURE 37. THE DETERIORATION OF SKIN BLOOM DURING STORAGE IN EARLY HARVESTED TUBERS.

Area affected by netting

During the 2004-05 season, later planting and harvest resulted in more netting on Estima tubers (P<0.001) (Table 29). There was no interaction between planting and harvest dates.

TABLE 29. EFFECT OF HARVEST DATE ON NETTED AREA (%) IN ESTIMA.

Treatment	Netted area (%)	Significance level
Planting 1	29.3	<0.001
Planting 2	49.0	
Harvest 1	31.4	<0.001
Harvest 2	46.9	

Blemish disease levels

Disease severity at intake was generally too low (<1% mean surface area) to analyse. However, black dot levels were sufficiently high in all seasons to allow comparison between treatments. In general, black dot increased asymptotically from harvest to the end of the storage duration (30-38 weeks).

Effect of storage humidity on black dot development

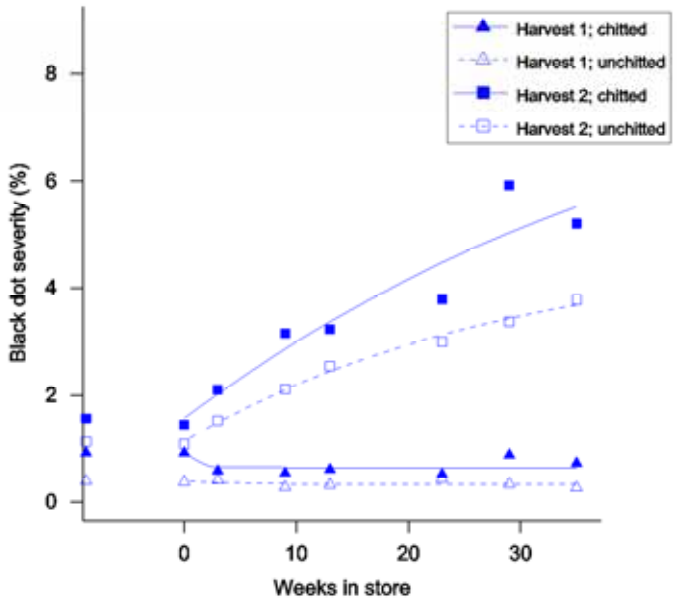
During the 2001-02 season, black dot development, during a 35-week storage period, either increased in a negative exponential pattern or did not increase. Whether the disease increased depended on the length of growing season. There were large interactions between harvest and variety, and harvest and seed; therefore, separate analyses of the slopes were done for each variety and harvest combination. Nevertheless, harvest date and seed age had by far the largest effect on black dot levels. Black dot severity did not increase, over a 35-week storage period, on tubers that had been harvested early (Figure 38). However, in plots where tubers had been harvested late, black dot increases were consistent with a negative exponential model or 'asymptotic regression' (Equation 1). In other words, the rate of increase in disease severity decreased with storage duration. The model was a reasonable fit, accounting for 83.7% and 91.0% of the variation in disease levels in Desiree and Estima tubers respectively. An accumulated analysis of variance on the regression models showed that black dot levels were higher in daughter tubers from sprouted seed compared with levels in daughter tubers from unsprouted seed ($P<0.001$ and $P=0.002$ in Desiree and Estima respectively; Table 30). Black dot severity in later harvested tubers was not affected by storage humidity ($P=0.418$ for Desiree; $P=0.633$ for Estima).

$$y = \alpha + \beta\rho^{x} \qquad (1)$$

Where α, is the upper asymptote; β, is the range of curve between the value $x=0$ and the asymptote; and ρ, is the rate of exponential increase.

TABLE 30. ACCUMULATED ANALYSIS OF VARIANCE ON BLACK DOT REGRESSION MODELS.

Variety	Harvest	Seed treatment	Asymptote	Significance level
Desiree	October	Sprouted	7.125	<0.001
Desiree	October	Unsprouted	4.074	
Estima	October	Sprouted	9.359	0.002
Estima	October	Unsprouted	4.740	



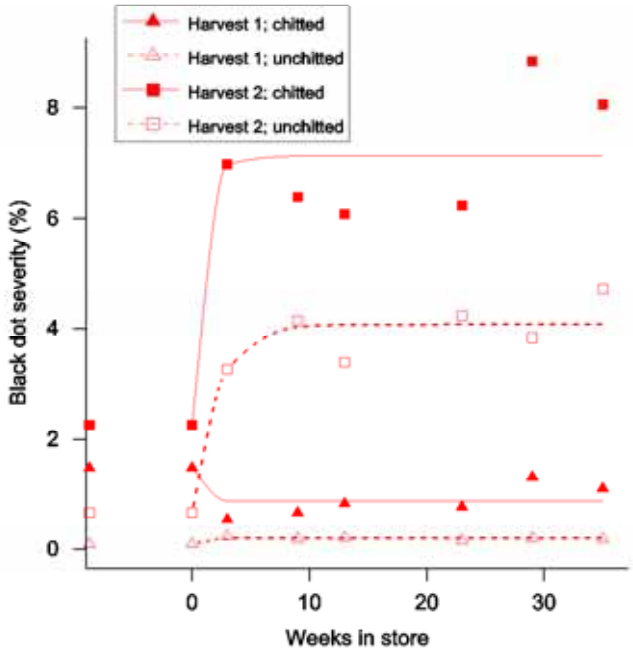


FIGURE 38. BLACK DOT SEVERITY ON A) ESTIMA AND B) DESIREE TUBERS DURING A 35-WEEK STORAGE PERIOD AT 4°C.

$LSD_{(P=0.05)}$=1.09.

Effect of storage temperature on black dot development

During the 2002-03 season, black dot development, during a 35 to 38 week storage period, increased in an exponential, negative exponential pattern or did not increase. Whether the disease increased depended on the length of growing season. There were large interactions between harvest and variety, therefore, separate analyses of the slopes were done for each variety. Nevertheless, harvest date had by far the largest effect on black dot levels. Black dot severity did not increase, over a 35-38 week storage period, on tubers that had been harvested in early September and stored at 2.5°C (Figure 39). However, in plots where tubers had been harvested two weeks later, black dot increases were consistent with a negative exponential model or 'asymptotic regression' (Estima); or an exponential model (Desiree). The model was a reasonable fit, accounting for 64.2% and 82.8% of the variation in disease levels in Desiree and Estima tubers respectively. An analysis of variance on square-root-transformed, black dot severity data, showed that for cv Estima, black dot levels were lower in early-lifted tubers compared with late-lifted tubers. There was a marginal improvement in black dot levels where the tubers were stored at 2.5°C compared with tubers stored at 4.0°C[2] (P=0.058). In cv Desiree, early lifted tubers had lower levels of black dot compared with tubers lifted approximately 2 weeks later (P<0.001). Storage temperature did not influence black dot levels in Desiree (P=0.127).

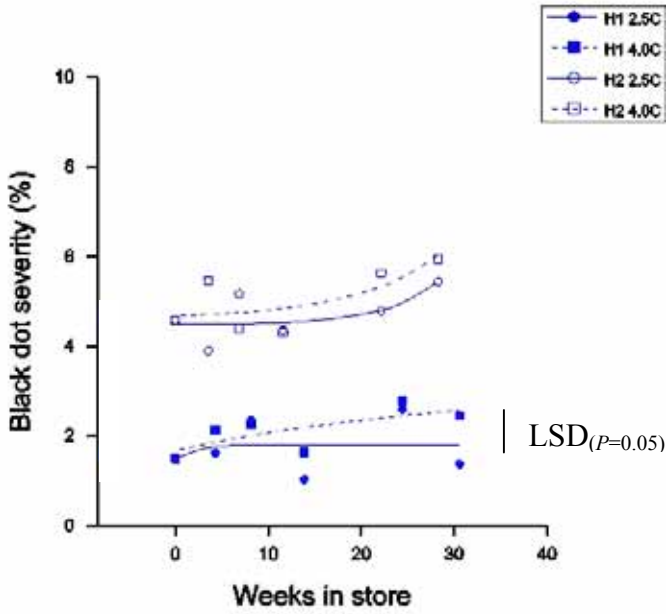
Effect of ventilation rates on black dot

During the 2003-04 season, with the exception of Desiree tubers that had been late lifted and cured using high ventilation rate, black dot severity did not increase over the 39-week storage period (Figure 40). It was not possible to fit an exponential model to the data. Therefore, analysis of the data was performed using ANOVA for repeated measurements. Harvest date had a large effect on black dot severity, for both Estima and Desiree tubers (P<0.001). Later lifted tubers had more black dot developing than early lifted tubers.

The ventilation rate at curing had no effect on black dot severity for Estima (P=613). However, there was a significant interaction between time and ventilation rate on black dot development for Desiree tubers (P=0.030). Figure 40b shows that up to 10 weeks after loading, tubers that had been ventilated at a rate of 0.06 m^3/s/tonne had lower black dot severity than crop that had been cured using a ventilation rate of 0.02 m^3/s/tonne (i.e. normal ventilation). The differences in black dot levels, at either ventilation rate during curing, were not different after a 10-week storage period.

[2] For the purposes of the analysis, CIPC and non-CIPC treatments were combined. This was justified on the grounds that no CIPC treatment effects were detected by ANOVA.

A)



B)

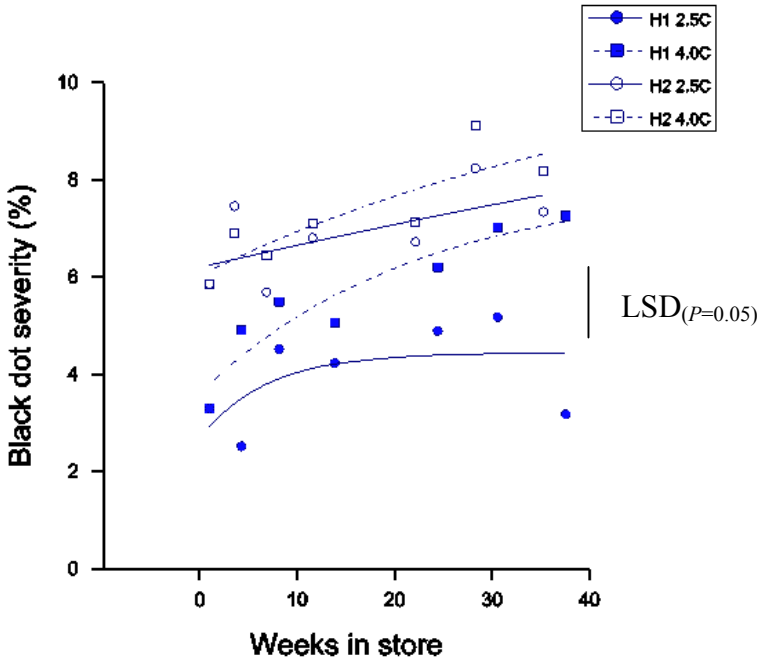


FIGURE 39. BLACK DOT SEVERITY ON A) DESIREE AND B) ESTIMA TUBERS DURING A 35 TO 38 WEEK STORAGE PERIOD AT 2.5°C AND 4.0°C.
$LSD_{(P=0.05)}$=1.10 (Desiree) and 1.68 (Estima).

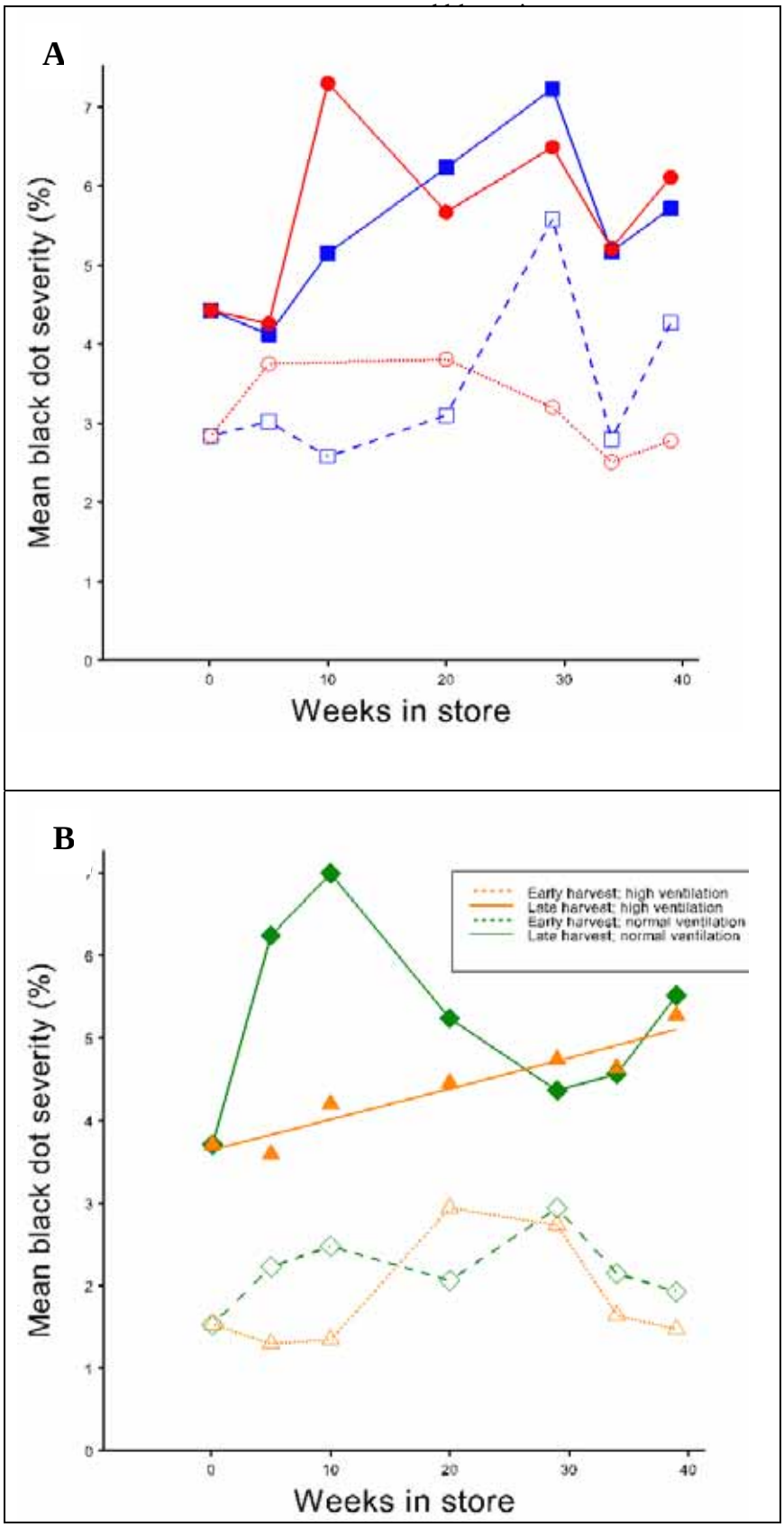


FIGURE 40. PATTERN OF BLACK DOT SEVERITY ON TUBERS STORED AT 3.5°C.

A. Estima (○, H1+high vent; ●, H2+high vent; □, H1+high vent; ■, H2+normal vent) and B. Desiree (□, H1+high vent; ▲, H2+high vent; □, H1+high vent; □, H2+normal vent). $LSD_{(P=0.05)}$ (black dot) =1.56 (Estima) and 1.70 (Desiree).

Effect of curing regime on black dot

During the 2004-05 storage season, black dot severity increased in a negative exponential manner in long duration crop (117 days from 50% emergence to lifting) or did not increase in short duration crops (82 days from 50% emergence to lifting) (Figure 41). Black dot severity was reduced by immediately cooling the crop by 0.5 degC per day from store loading when compared with disease levels in crop that had been cured at 12°C for 14 days prior to cooling (P=0.062). The effects of immediate pull-down were greater where black dot levels were high (i.e. in the long duration crop).

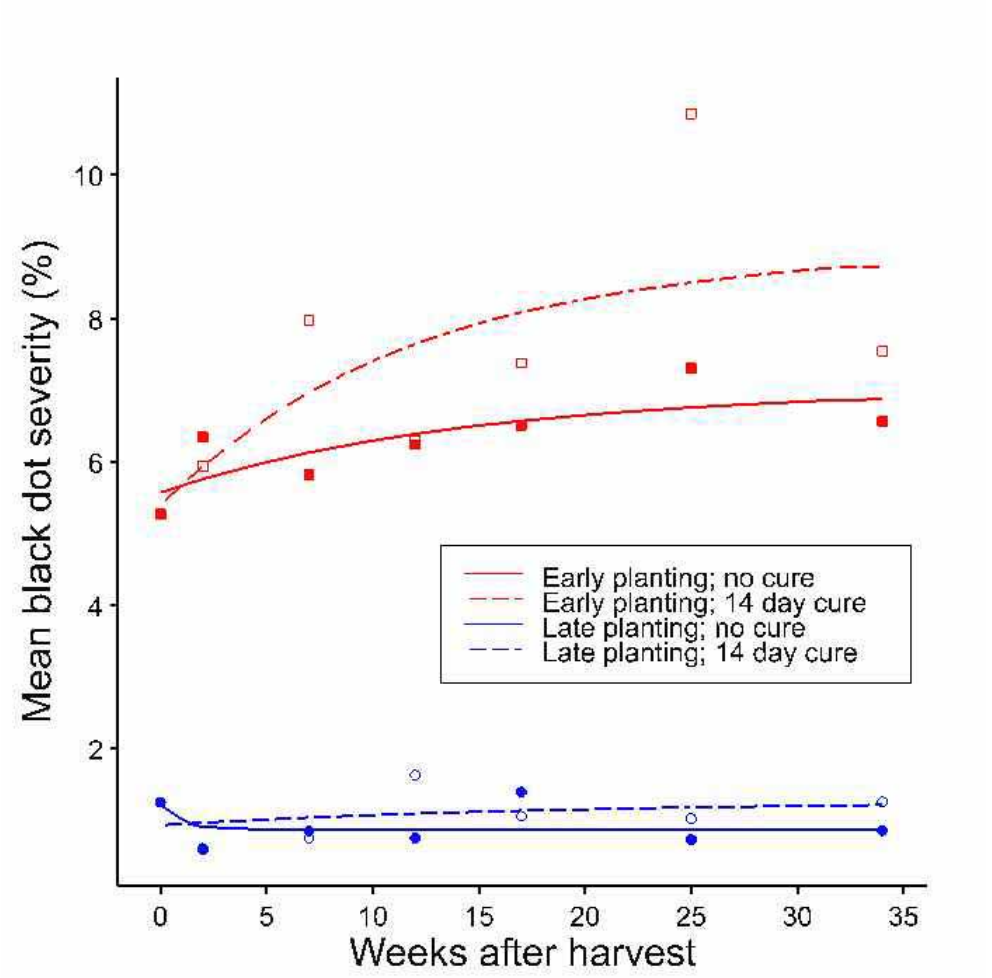


FIGURE 41. BLACK DOT SEVERITY PLOTTED AGAINST STORAGE DURATION.

Curves labelled 'early planting' are for long duration crop and those labelled 'late planting' are for short duration crop. $LSD_{(P=0.05)}$=1.20.

Effect of crop duration on black dot levels at harvest

The mean severity of black dot on tubers of cv. Estima was correlated with crop duration (days, 50% emergence to harvest) (Figure 42). The regressions were highly significant (P=0.001) and 80.3% of the variance was accounted for. The slope of the regression varied between seasons. Black dot levels at the end of the 2001-growing season were low; but were considerably higher in the 2002, 2003 and 2004 seasons (P=0.002).

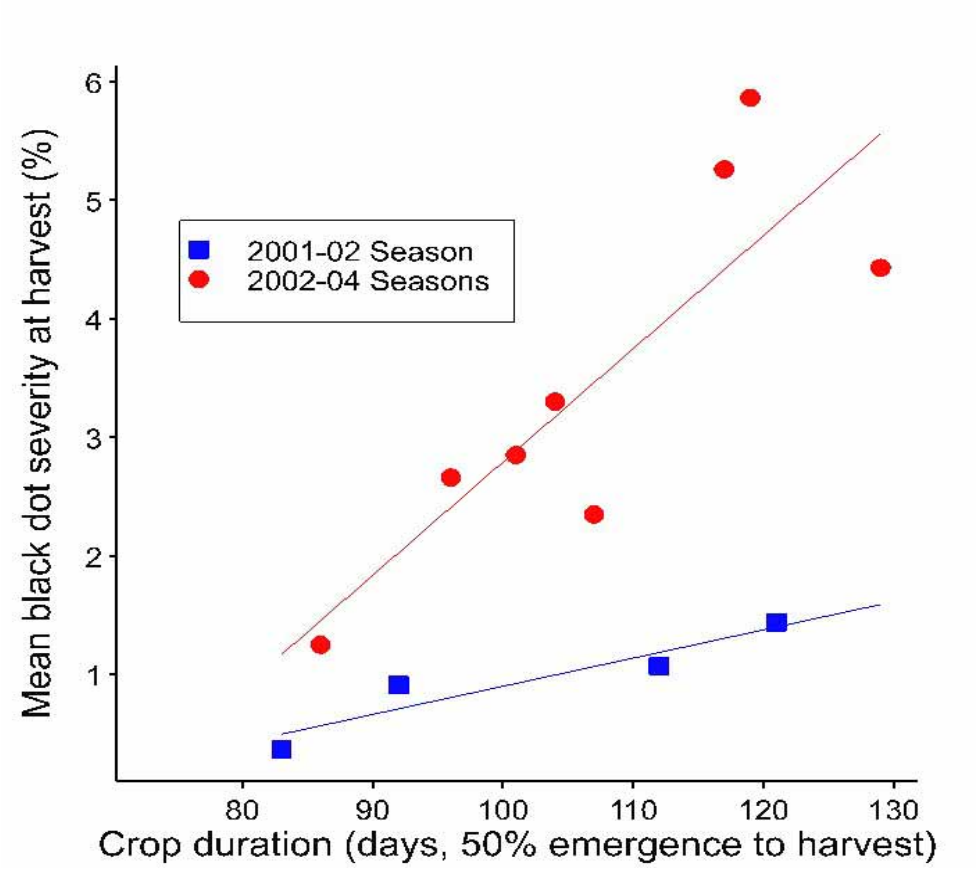


FIGURE 42. BLACK DOT SEVERITY (AT HARVEST) PLOTTED AGAINST CROP DURATION.

The regressions were significant (P=0.001; r^2=0.803).

2.6.4 Discussion

Skin bloom

Ultrastructure work carried out in collaboration with Warwick HRI confirmed that skin bloom is related to the degree of smoothness of the skin surface (Anon, 2005). This information was used to narrow the selection of storage treatments to those that are likely to affect the surface integrity of tuber skins (i.e. ventilation rates during the curing and pull-down period and humidity during storage). Further investigations by Warwick, HRI researchers (Anon, 2005[b]) showed that the phellum cells within the periderm collapsed during storage (Figure 43). This collapse occurred sometime during the 14-day curing period at 12°C (John Andrews, Pers Comm). The loss of periderm integrity caused a roughening of the skin surface resulting in poor bloom.

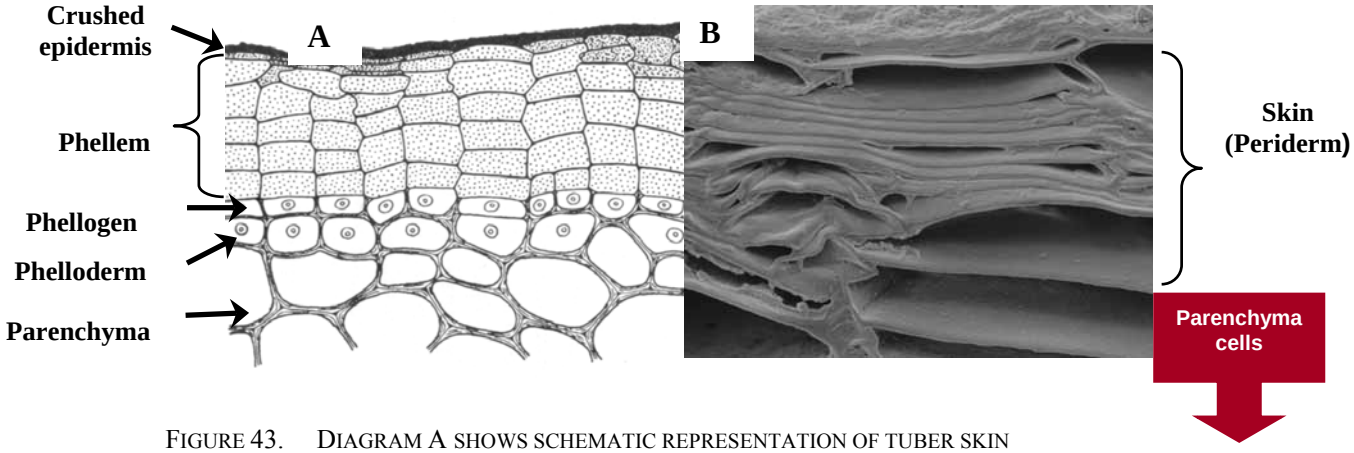


FIGURE 43. DIAGRAM A SHOWS SCHEMATIC REPRESENTATION OF TUBER SKIN

(Periderm, comprising phellum, phellogen and phelloderm) (Esau, 1953). Micrograph B shows collapse of phellum cells during curing, courtesy J Andrews, Warwick HRI.

Skin bloom was not correlated with tuber size ruling out any likelihood of confounding the effects of crop duration on bloom with its effect on tuber size.

The pattern of bloom deterioration in Estima and Desiree tubers followed that of either a logistic (sigmoidal) or exponential (asymptotic) decline. Bloom data in later lifted, or more physiologically mature, crops, whilst broadly following an exponential or logistic decline, showed larger variability than less physiologically mature crops. This suggests that early lifted crops have a more uniform skin bloom than later lifted crops. Uniformity of appearance is an important factor in determining packing acceptability and might be more important that absolute levels of bloom.

Storage treatments generally had minimal impact on the decline of skin bloom. Temperature and CIPC, and ventilation fan speeds did not affect either the inflexion or asymptote of models fitted to skin bloom data. In Desiree, humidity had a marginally significant effect, whereby 98% RH was correlated with skin bloom asymptotes that were lower (i.e. brighter skins) than when tubers were stored at 90% RH. Humidity did not affect bloom deterioration in Estima. However, in the early harvested Estima tubers (83 and 92 days from 50% emergence to harvest), a 14 day curing period at 12°C caused bloom to deteriorate on average 18 days sooner than for tubers that had been cooled immediately following store loading. This suggests that tuber skin integrity might be susceptible to water loss (exacerbated by high temperatures) during the early stages of skin curing.

The range of crop durations (86 to 117 days) enabled us to investigate the effects of crop age on skin quality. In general, the final bloom, or lower asymptote, values increased with crop duration. The lower asymptote in tubers from plots that had a crop duration of 117 days, was a hypothetical 3.9, compared with less than 3.0 for crops of shorter duration. However, the effect of crop duration on the rate of decline in skin bloom was less predictable. Any difference in the inflexion, or time taken to reach 50% of the difference in bloom, was offset by the difference in harvest date. During the 2001-02 season, where seed maturity was investigated, the decline in

bloom in cv Estima was slower for shorter duration crops than in those of longer duration. Also, during 2004-05, where planting date was investigated, in early lifted Estima, skin bloom deteriorated earlier in early-planted crop. Conversely, the bloom in later harvested crops deteriorated slower than earlier lifter crop. This suggests that, in terms of skin bloom, tuber skins in older crops may or may not deteriorate as quickly as those of younger crops, but have the most potential for decline after prolonged storage (i.e. beyond 35 weeks).

Other (unpublished) work carried out by the report authors has shown that washing tubers in a commercial drum washer for between 5 and 10 minutes can improve bloom by between 1.0 and 1.5 bloom units. This shows that adverse effects of crop agronomy and storage can be reversed by washing. However, effects on disease (e.g. soft rots), of abrasion following a lengthy washing process, were not investigated.

Netting

Netting was affected by harvest and planting date, where tubers from late planted and harvested plots had a greater surface area of netting than those in earlier planted and harvested plots. Interestingly, there was no correlation between netted area and crop duration. This suggests that netting is a function of environmental conditions (i.e. temperature, moisture and/or light) at key stages of skin development, rather than being directly associated with crop maturity. Netting has consistently been lower in the early harvested plots in earlier years of this study. However, it should be noted that in Nadine, 2004, netting was lower in tubers from later planted plots.

Black dot

Relatively immature crops produced tubers with initially negligible levels of black dot and levels remained so for the duration of the storage period. Conversely, more mature crops produced tubers with initially low levels of black dot at store loading but disease levels then increased exponentially. The pattern was consistent in both Estima and Desiree in most years of the study. In addition, tubers grown from sprouted seed had higher levels of black dot compared with those produced from unsprouted seed. An exponential (also known as an asymptotic) regression typically describes the progress of monocyclic diseases. This strongly suggests that black dot develops from the expansion of lesions that exist at harvest, or that latent infections below the skin surface form black dot lesions during storage.

During the 2003-04 storage season, black dot levels did not increase over the 39-week storage period, with the exception of late harvested Desiree tubers followed by high ventilation rates during curing. This contrasts with the findings of this study from other seasons, when black dot severity increased over a 35-week period in later lifted tubers. It is likely that effective curing and pull-down regimes in the positively ventilated stores during this season, was sufficient to minimise the post-harvest development of black dot.

Data taken from the 2001 to 2004 crops showed that the severity of black dot (and incidence of outgrades due to the disease) was correlated with crop duration (days from 50% emergence to harvest). The reduction of black dot severity at harvest also translated into reduced disease levels throughout storage. Further control of black dot could be achieved by immediately cooling the crop by 0.5 degC per day compared with curing at 12°C for 14 days prior to cooling.

Weight loss

Surprisingly, a lower storage temperature (2.5°C) resulted in higher tuber weight loss, compared with that in CIPC-treated and non-treated tubers stored at 4.0°C. One explanation might be that the experimental store refrigeration system caused differences in crop humidity. At lower storage temperatures, the fridge coil draws more moisture out of the storage atmosphere than at warmer temperatures. An electronically controlled humidifier unit is installed in all the stores in order to maintain RH at the desired level (in this case, 95%). However, this might not be efficient enough to offset differences in RH within the crop due to differences in fridge run times. Alternatively, stress respiration at, or below, 2.5°C might cause increased water loss in tubers compared with tubers stored above 2.5°C.

2.6.5 Conclusions

Crop duration was shown to directly affect skin quality: longer duration crops tended to have more black dot and have duller skins after prolonged storage.

The early development of black dot was reduced in stores where crops were cured with a ventilation rate of 0.06 m^3/s/tonne compared with crops cured at 0.02 m^3/s/tonne.

An immediate temperature pull-down following harvest minimised black dot development and skin bloom deterioration.

3. Further Work

This study was designed to improve the understanding, control and maintenance of skin quality (including skin set, netting and bloom). Some strategies for improving and maintaining skin quality were identified. The financial implications of implementing these improvement strategies were outside the scope of the study. Future work should centre on a cost/benefit analysis of the recommendations given in this report.

4. References

Anon (2005[a]). BPC Retail Report, Issue 24, August 2005. British Potato Council, Oxford.

Anon (2005[b]). The physiology and biochemistry of skin set and skin netting in potatoes. Research report to Defra (Project code HP0140).

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Lees AK & Hilton AJ (2003). Black dot (*Colletotrichum coccodes*): an increasingly important disease of potato. *Plant Pathology*, **52**, 3-12

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McLean J.G., Sparks W.C., Binkleym A.M., The Effects of Certain Minor Elements on Yield Size and Skin Thickness of Potato Tubers. Scientific paper No176, American Society for Horticultural Research.

5. Achievement of project milestones and objectives

These have been met.

6. Summary of technology transfer and project deliverables

- Trial details and results presented to SAC potato advisors. (4 Dec 2001).
- Telephone enquires from two farmers to SAC, with relevance to the project (2002).
- Presentation to "SAC Potato study group", which includes representatives from BPC, potato processors, supermarket agronomists, packers, seed merchants, farmers, and machinery manufactures. (6 Dec 2001).
- Informal discussions throughout project with host grower and agronomist for skin set and bloom studies.
- Presentation and discussion session on diseases affecting pre-pack potatoes with delegates on BPC Store Managers' Course 28 February 2002.
- Manned Poster Displays at BPC Sutton Bridge storage event 1 May 2002.
- Storage disease seminar at BPC Sutton Bridge storage event 1 May 2002.
- Presentation of 2001 and 2002 results to farmers at an SAC, SACAPP meeting Bush Estate 16 Dec 2002.
- Presentation of 2001 & 2002 results to farmers at an SAC, SACAPP meeting St Boswells 12 Dec 2002.
- Supplied results to Paul Coleman for presentation to Greenvale agronomist 10 Dec 2002.
- Presentation of 2001 & 2002 results to farmers at an SAC, SACAPP meeting Finavon Forfar 25 Nov 2002.
- Presentation to "SAC Potato study group", which includes representatives from BPC, potato processors, supermarket agronomists, packers, seed merchants, farmers, and machinery manufactures. 27 Nov 2002.
- Manned Poster Display at BPC Sutton Bridge storage event 1 May 2002.
- Storage disease seminar at BPC Sutton Bridge storage event 1 May 2002.
- Presentation of 2001 results to growers of Irish Potato Marketing seed Elgin 22 February 2002.
- Presentation of 2001 results to growers of Irish Potato Marketing seed Dundee 21 February 2002.
- Bruising and skin set, SACAPP Annual meeting, Huntingtower Hotel, Perth, 22 Jan 2003.
- BPC Spring Workshop, (3 sessions) Bruising and skin set, Harper Adams, Newport, 12 Feb 2003.
- BPC Spring Workshop, (3 sessions) Bruising and skin set, CSC, Cross Keys Hotel, Kelso, 19 Feb 2003.
- BPC Spring Workshop, (3 sessions) Bruising and skin set, Peterborough, 20 Feb 2003.

- BPC Spring Workshop, (3 sessions) Bruising and skin set, CSL, York. 24 Feb 2003.
- BPC Spring Workshop, (3 sessions) Bruising and skin set, McDiarmid Park, Perth, 25 Feb 2003.
- Presentation to "SAC Potato study group", which includes representatives from BPC, potato processors, supermarket agronomists, packers, seed merchants, farmers, and machinery manufactures. 26 Nov 2003 Bush estate.
- Poster Display at BP2003, Newark, 3-4 September 2003.
- Black dot epidemiology and management. Grower guide, 3-4 Sept 2003.
- BPC QC Workshop to grower group. Skin bloom and set, SBEU, 11 Sept 2003.
- Presentation of skin set and bloom results to date at "BPC Storage Discussion Group", SBEU, 6 Nov 2003.
- Presentation of Skin Bloom project black dot results at NIAB Potato Agronomy Group meeting, Cambridge, 4 Dec 2003.
- Presentation of black dot results from skin bloom work at BPC/QV Potato Conference 2004, Peterborough, 11 Feb 2004.
- Presentation of black dot and bloom results at the BPC Potato Storage Event, SBEU, 20 May 2004.
- Meeting with Richard Napier, John Andrews Warwick HRI, 21st April 2004.
- Display, on BPC stand at 'Roots 2004', Thorpe Constantine, 21st & 22nd April.
- Poster, on BPC stand at BPC 'Potato Storage 2004', Sutton Bridge, 20th May.
- Poster display at EAPR Pathology Section Meeting, Lille, 12-15 July 2004.
- Presentation to SAC potato specialists 6th Dec 2004 at SAC, Edinburgh.
- Presentation to "SAC Potato Study Group", which includes representatives from BPC, potato processors, supermarket agronomists, packers, seed merchants, farmers, and machinery manufactures. 7th Dec 2004, SAC, Edinburgh.
- Article on potato bloom in Potato Storage International, December 2004.
- Oral presentation given at the 1st. International Potato Storage Convention. PEI, Canada. June 21-24, 2005.
- Oral presentation given at the 16th Triennial Conference of the European Association for Potato Research, July 17 to 22, 2005, Bilbao, Spain.

Appendix 1. Manipulation of skin set

Crop husbandry 2001.

Soil analysis	pH 8.3		
Index	P: 3, K: 2, Mg: 2		
Previous cropping	2000	Wheat	
	1999	Wheat	
Fertiliser	17.04.01	Nitrogen	100 kg/ha (overall)
	18.04.01	Nitrogen	60 kg/ha (N2 plots)
	17.04.01	Potash	300 kg/ha
	17.04.01	Phosphate	300 kg/ha
Nematicide	12.05.01	Temik 10G	33.5 kg/ha
Seed	Variety	Cara	
	Certification	Elite1, 35-55 mm	
	Tuber count	714 /50 kg	
Planting date	22.05.01		
Plot size (harvest area)	4 rows (3.6 m) by 6 m		
Seed rate and spacing	3.15 t ha^{-1}, 25 cm		
Fungicicides	16.06.01	Dithane	1.7 kg/ha
	04.07.01	Ripost	2.5 kg/ha
	11.07.01	Dithane	1.7 kg/ha
	20.07.01	Invader	2.0 kg/ha
	30.07.01	Curzate	2.0 kg/ha
	06.08.01	Invader	2.0 kg/ha
	13.08.01	Curzate	2.0 kg/ha
	21.08.01	Invader	2.0 kg/ha
	28.08.01	Curzate	2.0 kg/ha
	04.09.01	Invader +	2.0 kg/ha
		Shirlan	200 ml/ha
	20.09.01	Curzate +	2.0 kg/ha
		Shirlan	200 ml/ha
Insecticides	11.07.01	Patriot	1.25 l/ha
		Plenum	0.6 kg/ha
Herbicide	03.06.01	Lexone	0.75 kg/ha
Trace elements	Man	11.07.01	5.0 kg/ha
	Sulph, 32 %	30.07.01	5.0 kg/ha
		13.08.01	5.0 kg/ha
Haulm destruction date	26.09.01		
Harvest date	10.10.01		

Soil analysis	pH 7.9		
Index	P: 2, K: 2, Mg: 2		
Previous cropping	2001	Wheat	
	2000	Wheat	
Fertiliser	04.04.02	Nitrogen (N1)	0 kg/ha
		Nitrogen (N2)	80 kg/ha
		Nitrogen (N3)	160 kg/ha
		Potash	300 kg/ha.
		Phosphate	180 kg/ha
Nematicide	10.04.02	Temik 10G	33.5 kg/ha
Seed	Variety	Cara	
	Certification	E1, 35-45 mm	
	Tuber count	1000/50 kg	
Planting date	11.04.02		
Plot size (harvest area)	2 rows (3.6 m) by 5.5 m		
Seed rate and spacing	2.66 t ha^{-1}, 21 cm		
Fungicicides	05.06.02	Shirlan	300 ml/ha
	12.06.02	Curzate	2.0 kg/ha
	20.06.02	Shirlan	300 ml/ha
	28.06.02	Curzate	2.0 kg/ha
	05.07.02	Invader	2.0 kg/ha
	12.07.02	Curzate	2.0 kg/ha
	22.07.02	Curzate	2.0 kg/ha
	31.07.02	Curzate	2.0 kg/ha
	08.08.02	Invader	2.0 kg/ha
	15.08.02	Curzate	2.0 kg/ha
		Shirlan	300 ml/ha
	22.08.02	Curzate	2.0 kg/ha
		Shirlan	300 ml/ha
	29.08.02	Curzate	2.0 kg/ha
		Farmatin	400 ml/ha
Herbicide	10.05.02	**Linuron**	3.5 l/ha
	22.04.02	Lexone	0.75 kg/ha
Trace elements	Man	12.06.02	5.0 kg/ha
	Sulph, 32 %	28.06.02	5.0 kg/ha
Haulm destruction date	02.09.02	H1	Flail
		H2	Diquat (1 l/ha)
		H3	Flail, Glufosinate-ammonium (3 l/ha)
	06.09.02	H2	Diquat (3 l/ha)
Harvest date	18.09.02		

Soil analysis		pH 7.9		
	Index	P: 3, K: 3, Mg: 2		
Previous cropping		2002	Wheat	
		2001	Wheat	
Fertiliser	Cara	11.03.03	Nitrogen (N1)	165 kg/ha
			Nitrogen (N2)	165 kg/ha
			Potash	275 kg/ha.
			Phosphate	200 kg/ha
		27.03.03	Nitrogen (N2)	50 kg/ha
	Nadine	11.03.03	Nitrogen (N1)	165 kg/ha
			Nitrogen (N2)	165 kg/ha
			Potash	275 kg/ha.
			Phosphate	200 kg/ha
		20.03.03	Nitrogen (N1)	35 kg/ha
			Nitrogen (N2)	35 kg/ha
		27.03.03	Nitrogen (N2)	60 kg/ha
Nematicide		07.04.03	Nemathorin 10G	30 kg/ha.
Seed	Variety	Cara	Nadine	
	Certification	E1/EEC2, 35-45 mm	Elite1 /EEC2 35-55 mm	
	Tuber count	746/50 kg	746/50 kg	
Planting date		07.04.03		
Plot size (harvest area)		2 rows (3.6 m) by 5.5 m		
Seed rate and spacing		Cara: 3.09 t ha^{-1}, 24 cm		
		Nadine: 2.20 t ha^{-1}, 34 cm		
Fungicicides		28.05.03	Shirlan	300 ml/ha
		04.06.03	Shirlan	300 ml/ha
		11.06.03	Shirlan	300 ml/ha
		18.06.03	Shirlan	300 ml/ha
		25.06.03	Invader	2.0 kg/ha
		02.07.03	Curzate	2.0 kg/ha
		09.07.03	Invader	2.0 kg/ha
		16.07.03	Curzate	2.0 kg/ha
		23.07.03	Invader	2.0 kg/ha
		30.07.03	Curzate	2.0 kg/ha
		06.08.03	Invader	2.0 kg/ha
		13.08.03	Curzate	2.0 kg/ha
		20.08.03	Ranman Twin	A=0.2 l/ha, B=0.15 l/ha
Herbicide		07.05.03	Linuron	3.5 l/ha
		30.04.03	Lexone	0.5 kg/ha
Trace elements		18.06.03	$MnSO_4$ (32%)	5.0 kg/ha
		09.07.03	$MnSO_4$ (32%)	5.0 kg/ha
Haulm destruction date		06.08.03	D1	Diquat (1 l/ha)
		06.08.03	D2	Flailed (leaving 15-20 cm stem), Glufosinate-ammonium (3 l/ha)
		11.08.03	D1	Diquat (3 l/ha)
Harvest date	Nadine	27.08.03		
	Cara	17.09.03		

Soil analysis		pH 7.75		
	Index	P: 5, K: 1, Mg: 2		
Previous cropping		2003	Winter wheat	
		2002	Sugar beet	
Fertiliser		01.04.04	Nitrogen (N1)	100 kg/ha
			Nitrogen (N2)	160 kg/ha
			Nitrogen (N3)	200 kg/ha
			Nitrogen (N4)	270 kg/ha
			Phosphorous	350 kg/ha
			Potassium	150 kg/ha
Nematicide		24.04.04	Nemathorin 10G	30 kg/ha
Seed	Variety	Nadine		
	Certification	Elite1/EEC2 35-55 mm		
	Tuber count	582/50 kg		
	Spacing	37 cm		
	Planting date 1	27.04.04		
	Planting date 2	20.05.04		
Plot size (harvest area)		2 rows (3.6 m) by 6.5 m		
Seed rate and spacing		2.58 t ha^{-1}, 37 cm		
	Fungicides	04.06.04	Dithane	2.0 kg/ha
			Shirlan	150 ml/ha
		11.06.04	Dithane	2.0 kg/ha
			Shirlan	300 ml/ha
		21.06.04	Curzate	2.0 kg/ha
		28.06.04	Invader	2.0 kg/ha
		05.07.04	Invader	2.0 kg/ha
		14.07.04	Curzate	2.0 kg/ha
		21.07.04	Invader	2.0 kg/ha
		28.07.04	Curzate	2.0 kg/ha
		05.08.04	Invader	2.0 kg/ha
		13.08.04	Curzate	2.0 kg/ha
		22.08.04	Invader	2.0 kg/ha
			Shirlan	300 ml/ha
		30.08.04	Curzate	2.0 kg/ha
			Shirlan	300 ml/ha
	Herbicide	15.05.04	PDQ	3.0 l/ha
		25.05.04	Linuron	3.5 l/ha
	Trace elements	21.06.04	$MnSO_4$ (32%)	5.0 kg/ha
		28.06.04	$MnSO_4$ (32%)	5.0 kg/ha
		21.07.04	$MnSO_4$ (32%)	5.0 kg/ha
	Haulm destruction	16.08.04	Flail	
	Harvest date	07.09.04		

Appendix 2. Manipulation of Skin set, Assessment schedule

Storage assessment schedule for the 2001-02 season.

	Assessment date/weeks in store						
	Intake	End of curing	6 weeks	12 weeks	20 weeks	26 weeks	33 weeks
Planned	12/10/01	03/11/01	26/11/01	07/01/02	04/03/02	14/04/02	03/06/02
Actual	-	03/11/01[1]	27/11/01	08/01/02	06/03/02	15/04/02	03/06/02

[1] Delay in assessing intake samples was due to unplanned delays in harvest dates which resulted in intake material from 4 studies (including 'manipulation of skin set' and 'skin bloom' studies) arriving within 1 week of each other.

Storage assessment schedule for the 2002-03 season.

	Assessment date/Weeks in storage				
	Intake	3 weeks	6 weeks	9 weeks	18 weeks
Planned	19/09/02	09/10/02	30/10/02	20/11/02	27/1/03
Actual	19/09/02	11/10/02	28/10/02	18/11/02	28/1/03

Storage assessment schedule for the 2003-04 season.

A) Cara

	Assessment date/ Weeks in storage				
	Intake	4 weeks	7 weeks	10 weeks	18 weeks
Planned	27/08/03	25/09/03	16/10/03	07/11/03	05/01/04
Actual	27/08/03	08/10/03	19/11/02	10/12/03	06/01/04

B) Nadine

	Assessment date/ Weeks in storage				
	Intake	3 weeks	6 weeks	9 weeks	18 weeks
Planned	17/09/03	09/10/03	30/10/03	20/11/03	22/01/04
Actual	17/09/03	20/10/03	10/11/03	24/11/03	26/01/04

Storage assessment schedule for the 2004-05 season

	Assessment date/ Weeks in storage				
	Intake	3 weeks	6 weeks	9 weeks	18 weeks
Planned	07/09/04	29/09/04	18/10/04	08/11/04	10/01/05
Actual	09/09/04	26/09/04	20/10/04	08/11/04	11/01/05

Appendix 3. Factors influencing skin bloom, crop husbandry

Crop husbandry, 2001.

Soil analysis		pH 8.3			
Index		P: 3, K: 2, Mg: 2			
Previous cropping		2000	Wheat		
		1999	Wheat		
Fertiliser	Estima	17.04.01	Nitrogen		220 kg/ha
	Desiree	17.04.01	Nitrogen		210 kg/ha
	Estima and Desiree	17.04.01	Potash		376 kg/ha
		17.04.01	Phosphate		376 kg/ha
Nematicide		12.05.01	Temik 10G		33.5 kg/ha
Seed	Estima	Certification	Elite1, 35-55 mm		
		Tuber count	793 /50 kg		
	Desiree	Certification	Elite1, 35-55 mm		
		Tuber count	575 /50 kg		
Planting date		22.05.01			
Seed rate and spacing		Estima	3.17 t ha^{-1}, 22 cm		
		Desiree	3.40 t ha^{-1}, 28 cm		
Fungicides		16.06.01	Dithane		1.7 kg/ha
		04.07.01	Ripost		2.5 kg/ha
		11.07.01	Dithane		1.7 kg/ha
		20.07.01	Invader		2.0 kg/ha
		30.07.01	Curzate		2.0 kg/ha
		06.08.01	Invader		2.0 kg/ha
		13.08.01	Curzate		2.0 kg/ha
		21.08.01	Invader		2.0 kg/ha
		28.08.01	Curzate		2.0 kg/ha
		04.09.01	Invader	+	2.0 kg/ha
			Shirlan		200 ml/ha
		20.09.01	Curzate	+	2.0 kg/ha
			Shirlan		200 ml/ha
Insecticides		11.07.01	Patriot		1.25 l/ha
			Plenum		0.6 kg/ha
Herbicide		03.06.01	Lexone		0.75 kg/ha
Trace elements		Man	11.07.01		5.0 kg/ha
		Sulph, 32 %	30.07.01		5.0 kg/ha
			13.08.01		5.0 kg/ha
Haulm destruction dates		28.08.01			
		10.09.01			
Harvest dates		11.09.01			
		10.10.01			

Crop husbandry, 2002.

Soil analysis		pH 7.9		
	Index	P: 2, K: 2, Mg: 2		
Previous cropping		2001	Wheat	
		2000	Wheat	
Fertiliser	Estima	20.03.02	Nitrogen	220 kg/ha
	Desiree	20.03.02	Nitrogen	165 kg/ha
	Estima and Desiree	20.03.02	Potash	350 kg/ha
		20.03.02	Phosphate	240 kg/ha
Nematicide		10.04.02	Temik 10G	33.5 kg/ha
Seed	Estima	Certification	E1, 35-55 mm	
		Tuber count	581/50 kg	
	Desiree	Certification	SE1, 35-55 mm	
		Tuber count	575/50 kg	
	Planting date	11.04.02		
	Seed rate and spacing	Estima	3.30 t ha^{-1}, 29 cm	
		Desiree	3.40 t ha^{-1}, 28 cm	
	Fungicides	05.06.02	Shirlan	300 ml/ha
		12.06.02	Curzate	2.0 kg/ha
		20.06.02	Shirlan	300 ml/ha
		28.06.02	Curzate	2.0 kg/ha
		05.07.02	Invader	2.0 kg/ha
		12.07.02	Curzate	2.0 kg/ha
		22.07.02	Curzate	2.0 kg/ha
		31.07.02	Curzate	2.0 kg/ha
		08.08.02	Invader	2.0 kg/ha
		15.08.02	Curzate	2.0 kg/ha
			Shirlan	300 ml/ha
		22.08.02	Curzate	2.0 kg/ha
			Shirlan	300 ml/ha
		29.08.02	Curzate	2.0 kg/ha
			Farmatin	400 ml/ha
	Herbicide	10.05.02	Linuron	3.5 l/ha
		22.04.02	Lexone	0.75 kg/ha
	Trace elements	Man	12.06.02	5.0 kg/ha
		Sulph, 32 %	28.06.02	5.0 kg/ha
	Haulm destruction dates	13.08.02	H1	
		02.09.02	H2	
	Harvest dates	03.09.02	H1	
		18.09.02	H2	

Crop husbandry, 2003.

Soil analysis		pH 7.9		
	Index	P: 3, K: 3, Mg: 2		
Previous cropping		2002	Wheat	
		2001	Wheat	
Fertiliser	Estima	11.03.03	Nitrogen	165 kg/ha
		20.03.03	Nitrogen	90 kg/ha
	Desiree	20.03.03	Nitrogen	165 kg/ha
	Estima and Desiree	11.03.03	Potash	275 kg/ha
		11.03.03	Phosphate	200 kg/ha
Nematicide		07.04.03	Nemathorin 10G	30 kg/ha
Seed	Estima	Certification	AA/EEC3, 35-45 mm	
		Tuber count	676/50 kg	
	Desiree	Certification	E2/EEC2, 35-45 mm	
		Tuber count	926/50 kg	
	Planting date	07.04.03		
	Seed rate and spacing	Estima	3.09 t ha^{-1}, 27 cm	
		Desiree	2.77 t ha^{-1}, 22 cm	
	Fungicides	28.05.03	Shirlan	300 ml/ha
		04.06.03	Shirlan	300 ml/ha
		11.06.03	Shirlan	300 ml/ha
		18.06.03	Shirlan	300 ml/ha
		25.06.03	Invader	2.0 kg/ha
		02.07.03	Curzate	2.0 kg/ha
		09.07.03	Invader	2.0 kg/ha
		16.07.03	Curzate	2.0 kg/ha
		23.07.03	Invader	2.0 kg/ha
		30.07.03	Curzate	2.0 kg/ha
		06.08.03	Invader	2.0 kg/ha
		13.08.03	Curzate	2.0 kg/ha
		20.08.03	Ranman Twin	A=0.2 l/ha, B=0.15 l/ha
	Herbicide	07.05.03	Linuron	3.5 l/ha
		30.04.03	Lexone	0.5 kg/ha
	Trace elements	18.06.03	$MnSO_4$ (32%)	5.0 kg/ha
		09.07.03	$MnSO_4$ (32%)	5.0 kg/ha
Haulm destruction dates		H1	06.08.03	
		H2	26.08.03	
	Harvest dates	H1	27.08.03	
		H2	25.09.03	

Crop husbandry, 2004.

Soil analysis		pH 7.75		
	Index	P: 5, K: 1, Mg: 2		
Previous cropping		2003	Winter wheat	
		2002	Sugar beet	
Fertiliser		01.04.04	Nitrogen	215 kg/ha
			Phosphorous	350 kg/ha
			Potassium	150 kg/ha
Nematicide		24.04.04	Nemathorin 10G	30 kg/ha
Seed	Variety	Estima		
	Certification	AA/EEC3 35-45 mm		
	Tuber count	1000/50 kg		
	Spacing	20 cm		
	Planting date 1	27.04.04		
	Planting date 2	20.05.04		
	Seed rate and spacing	2.97 t ha^{-1}, 20 cm		
	Fungicides	04.06.04	Dithane	2.0 kg/ha
			Shirlan	150 ml/ha
		11.06.04	Dithane	2.0 kg/ha
			Shirlan	300 ml/ha
		21.06.04	Curzate	2.0 kg/ha
		28.06.04	Invader	2.0 kg/ha
		05.07.04	Invader	2.0 kg/ha
		14.07.04	Curzate	2.0 kg/ha
		21.07.04	Invader	2.0 kg/ha
		28.07.04	Curzate	2.0 kg/ha
		05.08.04	Invader	2.0 kg/ha
		13.08.04	Curzate	2.0 kg/ha
		22.08.04	Invader	2.0 kg/ha
			Shirlan	300 ml/ha
		30.08.04	Curzate	2.0 kg/ha
			Shirlan	300 ml/ha
	Herbicide	15.05.04	PDQ	3.0 l/ha
		25.05.04	Linuron	3.5 l/ha
	Trace elements	21.06.04	$MnSO_4$ (32%)	5.0 kg/ha
		28.06.04	$MnSO_4$ (32%)	5.0 kg/ha
		21.07.04	$MnSO_4$ (32%)	5.0 kg/ha
	Haulm destruction, H1	16.08.04	Flail	
	Haulm destruction, H2	06.09.04	Flail	
	Harvest date, H1	07.09.04		
	Harvest date, H2	28.09.04		

Appendix 4. Factors influencing skin bloom, Assessment schedule

Schedule 2001-02 season.

	Assessment date/ Weeks in storage						
Storage term H1	Intake	4 weeks	7 weeks	13 weeks	24 weeks	29 weeks	35 weeks
Storage term H2	Intake	3 weeks	6 weeks	9 weeks	18 weeks	25 weeks	31 weeks
Planned, H1	11/09/01	02/10/01	30/10/01	11/12/01	19/02/02	02/04/02	15/05/02
Actual, H1	12/09/01	8/10/01	29/10/01	10/12/01	27/02/02	03/04/02	15/05/02
Planned, H2	10/10/01	06/11/01	20/11/01	11/12/01	19/02/02	02/04/02	16/05/02
Actual, H2	11/10/01	5/11/01	20/11/01	10/12/01	27/02/02	03/04/02	16/05/02

Schedule 2002-03 season.

	Assessment date/ Weeks in storage						
Storage term H1	Intake	4 weeks	7 weeks	14 weeks	24 weeks	31 weeks	38 weeks
Storage term H2	Intake	4 weeks	7 weeks	12 weeks	22 weeks	28 weeks	35 weeks
Planned, H1	03/09/02	04/10/02	28/10/02	09/12/02	10/02/03	31/03/03	19/05/03
Actual, H1	03/09/02	03/10/02	31/10/02	10/12/02	24/02/03	07/04/03	27/05/03
Planned, H2	18/09/02	14/10/02	04/11/02	09/12/02	10/02/03	31/03/03	19/05/03
Actual, H2	19/09/02	14/10/02	07/11/02	10/12/02	24/02/03	07/04/03	27/05/03

Schedule 2003-04 season.

	Assessment date/ Weeks in storage						
	Intake	5 weeks	10 weeks	20 weeks	30 weeks	34 weeks	39 weeks
Planned, H1	27/08/03	01/10/03	05/11/03	14/01/04	24/03/04	28/04/04	02/06/04
Actual, H1	27/08/03	02/10/03	05/11/03	14/01/04	23/03/04	26/04/04	01/06/04
Planned, H2	24/09/03	29/10/03	03/12/03	11/02/04	21/04/04	26/05/04	30/06/04
Actual, H2	24/09/03	27/10/03	01/12/03	10/02/04	19/04/04	25/05/04	29/06/04

Schedule 2004-05 season.

	Assessment date/ Weeks in storage						
	Intake	2 weeks	7 weeks	12 weeks	17 weeks	25 weeks	34 weeks
Planned, H1	07/09/04	22/09/04	27/10/04	30/11/04	04/01/05	02/03/05	10/05/05
Actual, H1	08/09/04	22/09/04	27/10/04	01/12/04	04/01/05	01/03/05	04/05/05
Planned, H2	29/09/04	12/10/04	16/11/04	21/12/04	25/01/05	22/03/05	02/06/05
Actual, H2	29/09/04	1310/04	17/11/04	20/12/04	25/01/05	22/03/05	23/05/05

Appendix 5. Factors influencing skin bloom, emergence, Tuber initiation and canopy closure

Season 2001-02

Emergence	S2	06.06.01	First emergence
	S2	09.06.01	50% emergence
	S2	14.06.01	Full emergence
	S1	14.06.01	First emergence
	S1	18.06.01	50% emergence
	S1	25.06.01	Full emergence

Tuber initiation	Estima	S2	02.07.01
	Estima	S1	05.07.01
	Desiree	S2	12.07.01
	Desiree	S1	19.07.01
Canopy closure	Estima	S2	05.07.01
	Estima	S1	09.07.01
	Desiree	S2	08.07.01
	Desiree	S1	12.07.01

Season 2002-03

Emergence	Estima	16.05.02	First emergence
	Estima	19.05.02	50% emergence
	Estima	22.05.02	Full emergence
	Desiree	14.05.02	First emergence
	Desiree	16.05.02	50% emergence
	Desiree	20.05.02	Full emergence
Tuber initiation	Estima	07.06.02	
	Desiree	07.06.02	
Canopy closure	Estima	07.06.02	
	Desiree	07.06.02	

Season 2003-04

Emergence	Estima	14.05.03	First emergence
	Estima	16.05.03	50% emergence
	Estima	20.05.03	Full emergence
	Desiree	12.05.03	First emergence
	Desiree	16.05.03	50% emergence
	Desiree	20.05.03	Full emergence
Tuber initiation	Estima	02.06.03	
	Desiree	03.06.03	
Canopy closure	Estima	07.06.03	
	Desiree	07.06.03	

Season 2004-05

	Planting 1	Planting 2
First emergence	29.05.04	09.06.04
50% emergence	01.06.04	11.06.04
Full emergence	04.06.04	14.06.04
Tuber initiation	18.06.04	05.07.04
Canopy closure	01.07.04	10.07.04