Project title:	Narcissus: The handling of bulb stocks with basal rot
Report:	Final Report (December 2001)
Previous reports:	Year 2 Annual Report (December 2000) Year 1 Annual Report (December 1999)
Project number:	BOF 42
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Location:	Horticulture Research International, Kirton
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Date project commenced:	1 July 1999
Date completion due:	31 December 2001
Keywords:	Narcissus, daffodil, bulb, basal rot, *Fusarium oxysporum* fsp. *narcissi,* HWT, controlled temperature storage, Storite, thiabendazole, prochloraz, large narcissus fly, *Rhizopus*, bulb scale mite

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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PRACTICAL SECTION FOR GROWERS

Background and Objectives

Base rot is probably still the main cause of yield loss in UK-grown daffodil bulbs. In the longer term the solution is likely to be the development of cultivars that are resistant to the disease. In the short-term, the application of fungicides remains a key method of the control of basal rot, but this alone is not always reliably effective and other ways of managing the disease are needed.

Previous R&D has shown that some aspects of bulb handling are important in controlling basal rot, including:

- Immediate post-lifting fungicide treatment
- High-temperature (35ºC) bulb drying
- Continued drying and storage of bulbs at 17 to 18ºC
- Hot-water treatment (HWT) with thiabendazole fungicide and formalin

Although these bulb handling treatments have been tested on an experimental scale and are widely used by growers, neither the individual components nor the combined programme have been critically evaluated using near-commercial scale plots. In this project, three typical disease-susceptible commercial narcissus stocks were used as 'case studies' to test the four procedures, either as individual treatments or in combination. The aim was determine how important each component is likely to be in the overall disease-management programme.

The questions posed included:
- *What was the initial health of the stocks?*
- *How well are bulb rot diseases controlled by the imposed treatments during the drying and storage phases, before planting?*
- *What are the effects of these imposed treatments on crop growth and disease status over a two-year-down growing period?*
- *How do these treatments affect the development of bulb rots during storage?*

Summary of results and conclusions

The project was carried out over 1999-2001 using three commercial bulb stocks obtained from growers in eastern England, two (randomly designated B and C) of the highly base rot-susceptible cultivar 'Golden Harvest', and the third (A) a stock of 'Carlton' which had previously shown a high incidence of base rot.

Six tonnes of each stock 'as lifted' were transported to HRI, Kirton in summer 1999, and each stock was allocated in *ca.* 1 tonne lots to receive one of following six treatments:

Treatment number	*Post-lifting spray*	*First stage drying*	*Second stage drying and storage*	*HWT*
1	Storite	3 days 35°C	17°C	With Storite
2	Storite	Ambient temps	Ambient temps	No Storite
3	None	3 days 35°C	Ambient temps	No Storite
4	None	Ambient temps	17°C	No Storite
5	None	Ambient temps	Ambient temps	With Storite
6	None	Ambient temps	Ambient temps	No Storite

What was the initial health of the stocks?

The health status of the three stocks at receipt from the suppliers was measured by sampling bulbs from each bulk bin and subjecting them to a storage test (storage at 25°C for 8 weeks to elicit any bulb rots). In the storage assessment two stocks, A and C, showed very high levels of bulb rots of 68 and 83%, respectively. Of these rotted bulbs, 97% were typical of bulb rots due to *Fusarium* (basal, neck or whole-bulb rot or mummified bulbs), with the remainder due to soft rot (*Rhizopus*) or large narcissus fly damage. In contrast, stock B had only 4% rots, of which 75% were of the *Fusarium* type. Finding such a high incidence of bulb rots in two of the three stocks was of great concern.

How well are bulb rot diseases controlled by the imposed treatments during the drying and storage phases, before planting?

After the completion of bulb drying in late July, three weeks after lifting, bulbs of the three stocks were examined on the cleaning-grading line, removing and assessing all obviously rotted bulbs. A variable but sometimes high number of rotted bulbs was present. The fewest rotted bulbs were found in stock B, with an average of 12 bulbs per 'half-tonne bin'. In stock A and C the corresponding numbers were 52 and 288, respectively. In stocks A and C most bulbs had rots of the basal or neck rot type, with stock C also having many mummified bulbs, perhaps indicating that many of the bulbs had previously begun to rot whilst in the ground. There was evidence of large narcissus fly damage in all three stocks, and other bulbs with non-specific mechanical damage to the base plates were also present. The presence of soft rot (due to *Rhizopus*) was suspected in some bulbs, and was confirmed by isolation and culturing on an agar medium in small numbers of bulbs from all three stocks. In stock C, the worst affected stock, most rotted bulbs occurred in treatment 3, and least in treatment 4. This indicates that second stage drying and storage at 17°C, rather than ambient temperatures, is a critical phase in the management of this disease. In the case of stocks A and B, too few rotted bulbs were found to assess any treatment differences.

After HWT, following the completion of all experimental treatments, bulbs were once again inspected on the cleaning-grading line. There had been a dramatic increase in the number of rotted bulbs since the previous assessment 4 weeks earlier. The number of obviously rotted

bulbs removed was still greatest in stock C and lowest in stock B, with stocks A and C having bulb rots at a more advanced stage (many whole-bulb rots) than those of stock B (many basal or neck rots). There were large effects due to treatments:

The number of rotted bulbs removed in each treatment combination (per original 750 kg bulbs) varied from:

- 1085-4042 bulbs in stock C
- 318-1708 bulbs in stock A
- Only 9-83 bulbs in stock B

Expressed in terms of the overall loss of bulb weight from receipt, which as well as rotted bulbs includes losses due to drying (around 15-20%) and previous sampling:

- 82-85% of the starting weight remained in the various treatments of stock B
- 60-75% for stock A
- 50-75% for stock C.

In stocks A and C, treatments 1 and 4 gave the best results (fewest bulbs lost), perhaps because these treatments both included a period of controlled temperature drying/storage at 17°C rather that at ambient temperatures. Treatment 1 also included first stage drying at 35°C and a post-lifting Storite application, possibly responsible for a further small improvement in disease control in comparison to treatment 4.

What are the effects of these imposed treatments on crop growth and disease status over a two-year-down growing period?

When crop performance was assessed after the first growing season, the growth of bulbs from stock B remained high in all cases. Growth was poorer and treatment-dependent in stocks A and C. In bulb plots grown-on at Kirton, treatments 1 and 4 exhibited the best growth in stocks A and C. In plots grown-on at the suppliers' farms, bulbs of stock A grew relatively well and uniformly, while the performance of bulbs of stock C was poorer and more affected by treatment. In stock C , treatments 4 and 5 resulted in the worst growth and treatment 6 in the best growth. Hence the benefit of treatment 4, previously noted, was not maintained. Overall, crop performance was better in plots grown-on at the suppliers' farms than at Kirton, perhaps because of the lower planting rates used at the suppliers' farms, which would reduce the spread of disease.

Assessed in the second growing season, the relative vigour of the three stocks was maintained with stock B being the most vigorous, then stock A, then stock C. Treatment effects were mainly evident in the least vigorous stock, stock C, grown at the farm of origin, where losses were highest in treatment 5. Bulb yields (for bulbs grown-on at Kirton and lifted in summer 2001) were acceptable in stock B, where all treatments gave similar yields of sound bulbs (about 100% weight increases). The yields of stocks A and C were extremely poor and usually negative. In both stocks A and B, treatments 1, 2 and 4 produced the best yields.

How do these treatments affect the development of bulb rots during storage?

Storage assessments of bulb rots always showed a higher incidence of rots than when examining bulbs 'on the line'. In a storage assessment conducted at the end of applying the experimental treatments, stocks A and C gave 42-78% rotting with the different treatments.

In

stock B treatment 5 resulted in 26% rotting, whereas in the other five treatments of stock B the level varied from 0 to 11%. Consistent treatment effects were difficult to see, other than that treatments 3, 5 and 6 gave generally high levels of rotting in stocks A and C, while only treatment 5 did so in stock B. In stocks A and C, treatments 2 and 4 gave the better results.

Assessing storage rots after the first and second years' growth, treatment effects were not consistent with the previous results, nor between tests, although there appeared to be specific significant treatment effects in some cases. However, the initial relative health of the three stocks (B>A>C) remained, and bulbs of stocks A and C progressed to a whole-bulb rot faster than stock B. In general, levels of rotting were higher in bulbs grown-on at the suppliers' farms than in those at Kirton.

Action Points for Growers

- Other than when during a brief, first stage drying period at 35°C, narcissus bulbs of disease-susceptible cultivars should be dried and stored at a controlled temperature of 17°C. Combined with good air flows, this will keep bulb rots due to *Fusarium* to a minimum. If 17°C is not available, every effort should be made to keep bulbs at temperatures below 20°C, eg by using ventilation, shading, etc. Using almost any insulated building would be better than leaving bulbs exposed to higher temperatures. Temperatures should be checked inside the mass of bulbs, as these may be warmer than the 'ambient' air in the store.

- A post-lifting application of Storite fungicide should be sprayed onto bulbs of disease-susceptible cultivars immediately after lifting. This is known to give useful protection against *Fusarium* bulb rots under otherwise non-optimal conditions.

- In seriously diseased stocks (say with >5% rotted bulbs), a single cycle of post-lifting Storite application and 17°C storage is likely to reduce, but not eliminate, basal rot. Consistent treatment is needed after each lift until disease levels are reduced to <1%.

- Although not specifically endorsed by the current results, there is no reason (other than saving money) to depart from the usual recommendations of first-stage drying at 35°C and, where basal rot levels are high, of including Storite in the HWT tank.

- The findings from this project have been incorporated in the following **'Fourteen tips for good basal rot management' (see next page)**

The findings from this project have been incorporated in the following

'Fourteen tips for good basal rot management'

1 Leave at least 8 years between narcissus crops. Long rotations between crops help to reduce the levels of basal rot fungus in the field.

2 Avoid sites and treatments that expose bulbs in the soil to high temperatures. The preferred temperature range of the basal rot fungus is 20-30°C. Relatively deep planting also helps keeps bulbs cool in summer.

3 Whenever possible, grow bulbs no longer than two-years-down, although one-year-down growing should be considered for especially valuable stocks.

4 Lift early to minimise the time the bulbs spend in warm soil, but keep foliage and bulb damage to a minimum.

5 Thoroughly clean bulb equipment, stores, etc, with water and suitable disinfectant before use.

6 Do not allow bulbs to stand in the open where they can be exposed to sun and rain.

7 **Either**
Spray bulbs of disease-susceptible cultivars immediately after lifting with Storite (1 litre Storite Clear Liquid in 5 litres per tonne of bulbs). This is known to give useful protection against *Fusarium* bulb rots under otherwise non-optimal conditions.
or
Dip bulbs in formalin (5 litres commercial formalin per 1000 litres dip, + non-ionic wetter) for 15 minutes at ambient temperatures within 1 day of lifting. In severe cases, add Storite (5 litres per 1000 litres dip).

8 **Either**
Dry bulbs promptly below 18°C. Drying should be done using the recommended airflow, air exchange rate and humidity, aiming to surface-dry the bulbs (including necks and base plates) rapidly. This will keep bulb rots due to *Fusarium* to a minimum, at least during the storage period. If 17°C is not available, every effort should be made to keep bulbs at temperatures below 20°C, eg by using ventilation, shading, etc. Temperatures should be checked inside the mass of bulbs, as these may be warmer than the 'ambient' air in the store.
or
Dry bulbs initially at 35°C for 3 days, and then cool rapidly and continue drying at below 18°C.
Note:
In seriously diseased stocks (say with >5% rotted bulbs), consistent cycles of post-lifting Storite application and 17°C storage are required until disease levels are reduced to <1%.

9 Whenever possible, inspect and destroy bulbs that look or feel soft or lightweight or are damaged.

10 Store bulbs at 17°C as this has been shown to be a major factor in inhibiting basal rot. Storage at temperatures much lower than this will delay the plants development.

11 Strictly follow recommendations for pre-soaking and hot-water treatment. Do not pre-soak bulbs suspected of having stem nematode. Dip bulbs in formalin (5 litres commercial formalin per 1000 litres dip) + non-ionic wetter + (if needed) anti-foam preparation. In severe cases, add Storite Clear Liquid (5 litres per 1000 litres dip). Otherwise add another fungicide such as prochloraz.

Bulbs should be dipped at 44.4°C for 3 hours, timed from the moment when the dip temperature remains the target temperature after immersing the bulbs. Where the bulbs have first been 'pre-warmed' to protect flower buds from HWT damage, they are immersed for 3 hours or overnight in a cold dip containing formalin prior to HWT, which is then done at 46°C.

12 Always top-up tanks according to the manufacturer's recommendations, or (if not specified) top-up at the same rate as used originally. In the case of Storite Clear Liquid, see the specific top-up recommendations on the label. Dips can be topped up and re-used many times before disposal but ensure there is not excessive build up of soil and debris.

13 Cool, dry and ventilate bulbs rapidly after dipping, then store at below 18°C until planting.

14 Consider planting in September, in cooling soils.

A number of other potential bulb health problems were raised during the course of this project that growers should take note of.

- Bulbs damaged by the large narcissus fly were common in the stocks investigated. Since this pest is generally considered a problem in the South-West, but not in eastern England, this finding indicates a need for vigilance in checking for narcissus fly in bulbs grown in the east.
- More general mechanical damage of the basal plates was common, suggesting that lifting and other machinery needs to be carefully adjusted to avoid damage. Both mechanical or fly damage will increase the risk of infection of bulbs by *Fusarium*.
- Bulbs affected by soft rot (*Rhizopus*) were also found, indicating a need to avoid periods when bulbs might be kept under warm, damp conditions (eg in the drying store while it is being filled).
- The finding of bulbs with bulb-scale mite further indicates the need for good hygiene in bulb stores. Bulb-scale mites in the bulbs should be killed by standard HWT.

Practical and financial benefits from the study

- Drying and storing bulbs at a controlled 17°C can reduce the incidence and development of bulb rots in storage due to *Fusarium*, compared with storage at even slightly higher summer temperatures (> 20°C). Under UK summer conditions this will require cooling and heating at different times, so, ideally, a high quality CT store would be needed. Starting from scratch, this would involve capital investment of the order of £50K to £100K for a 10 ha bulb enterprise, added to basic bulb drying costs of around £3K *per annum*. However, within the UK bulbs industry the availability of CT storage has increased, with the advent of fewer larger growers, greater capitalisation, and the utilisation of potato stores for narcissus bulbs. Indeed, in many cases the better utilisation of existing facilities might eliminate the need for expensive new storage, and using almost any insulated building would be better than leaving bulbs exposed to natural temperatures. Narcissus bulbs should not routinely be stored below 17°C, as lower temperatures delay internal development.

- As for other aspects, a prompt post-lifting spray application of Storite has been shown to be effective in controlling basal rot, and is increasingly considered good practice: the cost is around £7K *per annum* for the same size enterprise as above, so this should be considered where it is not already being practised. Adding Storite to HWT is more costly, around 2½-times the cost of the post-lifting spray.

- In the present study, stored bulb losses were reduced by up to 15% as a result of a controlled temperature storage (17°C) treatment. With the assumptions that 75% of the UK narcissus area consists of disease-susceptible cultivars, and that one-third of these are heavily affected by *Fusarium* rots, a 15% improvement in marketable yield would represent an additional £67.5K of bulbs annually. This would have to be balanced by the costs of new bulb store facilities, if not already available. This estimate makes no account of improved flower yields.

- 'Physical' methods of controlling bulb diseases (eg by correct bulb drying, storing and handling methods) should offer environmental and customer benefits over treatments that are reliant on pesticide applications.

Adrian Jansen, HDC Co-ordinator for the project, writes "This major project has highlighted the extent to which basal rot infection can exist in commercial narcissus stocks, and proved that storage of bulbs at 17°C can help reduce its development during the storage period. The results offer the grower a number of options, all of which are straightforward and practical, and not necessarily expensive. All narcissus growers will benefit by implementing the action points."

EXPERIMENTAL SECTION

INTRODUCTION

Base rot is probably still the main cause of yield loss in UK-grown daffodil bulbs. In the longer term, the solution is the development of cultivars that are either resistant to, or considerably less susceptible to, the disease. In the short-term, however, fungicide treatments alone are not reliably effective, and other means of managing the disease are needed. The control of base rot was reviewed in an earlier HDC-funded project, BOF 31[1].

MAFF-funded R&D at Kirton and Rosewarne in the 1980s showed that aspects of bulb handling are important in controlling basal rot, in particular:

- Immediate post-lifting fungicide treatment
- High-temperature (35ºC) bulb drying
- Continued drying and storage of bulbs at 17 to 18ºC
- Hot-water treatment (HWT) with thiabendazole fungicide and formalin

Although the benefits of a bulb handling regime including these components have been tested on an experimental scale (eg, see Hanks, 1996[2]), it does not appear that either the individual components, nor the combined programme, have been critically evaluated at the 'development project' level or using near-commercial scale plots. These bulb-handling techniques are widely used by growers, although rarely as a total package. This could be due to the level of investment needed to implement all the procedures, perhaps, or because of doubts about the translation of results from relatively small-scale research to a commercial farm level. Further, it can be difficult to assess the impact of different procedures at a farm level, because it is usually impractical to split stocks, apply different treatments, and monitor closely the progress of basal rot in the various batches. Bulb farms with basal rot problems can, therefore, find it difficult to manage affected stocks in a cost-effective way.

In this project, three typical disease-susceptible commercial narcissus stocks were used as 'case studies' to test the four procedures of post-lifting fungicide application, 35ºC bulb drying, controlled-temperature storage, and HWT with thiabendazole, either as individual treatments or combined. The bulk of the stocks remained on the suppliers' farms, where they continued to be subject to the usual local crop husbandry, while 6-tonne samples were taken to HRI, Kirton, to receive the treatments outlined above under controlled conditions.

Following treatment at Kirton, stocks were again sub-divided for growing-on, either at the original farm or at Kirton. Over the two years of the project, bulbs were assessed at appropriate stages to answer four questions:

- *What was the initial health of the stocks?*
- *How well are bulb rot diseases controlled by the imposed treatments during the drying and storage phases, before planting?*
- *What are the effects of these imposed treatments on crop growth and disease status over a two-year-down growing period?*
- *How do these treatments affect the development of bulb rots during storage?*

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[1] Linfield, C.A. and Hanks, G.R. (1994). *A review of the control of basal rot and other diseases in narcissus.* Final Report on Project BOF 31, Horticultural Development Council, East Malling.

[2] Hanks, G.R. (1996). Control of *Fusarium oxysporum* f.sp. *narcissi*, the cause of narcissus basal rot, with thiabendazole and other fungicides. *Crop Protection*, **15**, 549-558.

By following crop and disease development in this way, it was hoped to see how typical commercial stocks of cultivars Carlton and Golden Harvest respond to these handling procedures. The findings should enable growers to decide on the relative importance of procedures, such as high-temperature drying or controlled-temperature storage, so that future investments can be planned more effectively. They should highlight the most appropriate action to be taken when growing these popular but disease-susceptible varieties.

MATERIALS AND METHODS

Plant material

In consultation with the HDC Bulbs and Outdoor Flowers Panel and the HDC Project Co-ordinators, three narcissus stocks were identified for use in the project. These were 'typical' commercial stocks from farms in eastern England, two of the disease-susceptible cultivar 'Golden Harvest', and the third a stock of 'Carlton' with a history of basal rot.

Immediately after lifting in late-June or early-July 1999, approximately 6 tonnes of bulbs of each stock, as lifted and untreated except that normal soil and clod removal took place in bringing the bulbs back to the yard, were transported to HRI, Kirton, Lincolnshire in the growers' one-tonne bins. The remainder of the stocks remained on the farm of origin, to be grown-on according to prevailing local practice.

The bulb handling and husbandry practices used in producing these stocks (in 1997-1999), and subsequently in growing the test material at the suppliers' farms (in 1999-2001), were collated and are summarised in Appendix B.

Procedures carried out at Kirton

The scheme used is summarised in Figure 1 (page 11).

The four aspects of bulb handling practice were:
- Post-lifting bulb spray application of thiabendazole fungicide. The 'control' treatment was no post-lifting fungicide treatment.
- High-temperature (35°C for 3 days) first-stage drying. The 'control' treatment was drying at ambient temperatures.
- Second-stage drying and continued bulb storage at 17ºC. The 'control' treatment was drying and storage at ambient temperatures.
- Hot-water treatment (HWT) with thiabendazole fungicide and formalin. The 'control' treatment was HWT with formalin only.

These key treatments were tested on bulbs either (a) as all four treatments used together or (b) as the four individual treatments, while a control group received none of the treatments, as shown in the table below. It was considered impractical to include all combinations of the four treatments, but this scheme would show the relative merits of the whole programme and of its main components.

Treatment number	*Post-lifting spray*	*First stage drying*	*Second stage drying and storage*	*HWT*
1	Storite	3 days 35°C	17°C	With Storite
2	Storite	Ambient temps	Ambient temps	No Storite
3	None	3 days 35°C	Ambient temps	No Storite
4	None	Ambient temps	17°C	No Storite
5	None	Ambient temps	Ambient temps	With Storite
6	None	Ambient temps	Ambient temps	No Storite

On receipt at Kirton, 100 bulbs were sampled at random from each of the 18 one-tonne bins. These samples were placed in clean, lined trays and stored at 25°C for bulb rots to be assessed 8 weeks later. Each of the three bulb stocks was divided amongst 12 sterilised '½-tonne' bulk bins (each actually holding approximately 375kg of bulbs). Two ½-tonne bins of each stock were allocated at random to each of the six treatments. No cleaning or selection took place at this stage.

Bulbs for the post-lifting spray (treatments 1 and 2) were treated on a roller table (table speed *ca.* 10 t/h) with thiabendazole fungicide at the recommended rate (1 litre Storite Clear Liquid plus 4 litres water, per tonne), via two standard hydraulic nozzles operating at 3 bar. This treatment was applied on the day following lifting and transport to Kirton.

Bins for high temperature drying (treatments 1 and 3) were placed on a letter-box drying wall at 35ºC. Bins for drying at ambient temperatures (treatments 2, 4, 5 and 6) had 'fan tops' fitted and were placed in an unheated shed. At this stage, one fan-top was used per stack of two bins, keeping distinct treatments separate. When drying or storing bulbs in bins under fan-tops, polythene film was stapled around the sides of the stack of bins, to ensure that the air flow was directed down through the bins. Storage treatments were started on the day after lifting and transporting to Kirton.

After 3 days, bins for 17ºC storage (treatments 1 and 4) were moved to a controlled-temperature store for continued drying under fan-tops as before, and those for storage at ambient temperatures (treatments 2, 3, 5 and 6) were kept in or moved to the unheated shed, under fan-tops. Drying and storage temperatures in the bins were logged hourly.

Twenty days after the start of drying (at 35ºC or ambient temperatures), when the bulbs were considered dried to commercial standards, all bulbs were passed along a cleaning/grading line to remove any remaining soil. All obviously rotted bulbs were removed by hand and assessed for type of rot immediately. The sound bulbs were replaced in the same bins as before and returned to the required conditions (17˚C or ambient) with fan-tops. From this point one fan-top was used per stack of nine bins.

Over the period 23-25 August, all bulbs were given standard HWT for 3 hours at 44.4ºC with commercial formalin (5 litres per 1000 litres) and non-ionic wetter (300 ml Activator 90 per 1000 litres). For treatments 1 and 5, thiabendazole fungicide was added to the dip (5 litres Storite Clear Liquid per 1000 litres). Following HWT, bins were ventilated on a letter-box drying wall at ambient temperatures overnight.

The following day, bulbs were passed along a cleaning-grading line. Random, 100-bulb samples were taken at the start of the line from each treatment for the assessment of rots in a storage test, as described above. On the line, all obviously rotted bulbs were removed by hand and assessed for type of rot immediately. The weights of sound bulbs remaining were recorded as they were accumulated in nets containing 25 kg at the end of the line. Bulbs were allocated for planting at Kirton or at the suppliers' farms, and were stored at ambient temperatures until planting.

Because of the considerable and unexpected losses due to bulb rots, and the variation in amounts of sound bulbs between stocks and treatments, the size of field plots originally planned (made up of 3 x 150kg replicates for each treatment) was modified. Apart from stock B (where 300kg quantities of bulbs were available for all treatments), uneven sized plots were used (in preference to reducing plot size to that possible with the lowest yielding treatment).

For stock B, 300kg bulbs were returned for planting at the supplier's farm, and 300kg were allocated, in three replicate lots of 100kg each, for planting in a replicated field trial at Kirton. For stocks A and C, 250kg bulbs of each treatment were returned for planting at the suppliers' farms. The remaining bulbs in each treatment were divided into three equal replicate lots for planting in a replicated field trial at Kirton. For stock A, the weight of each replicate was 110, 83, 75, 104, 67 and 76kg for treatments 1 to 6, respectively. For stock C, it was 103, 55, 48, 97, 46 and 42kg, respectively.

The dates of the main operations in 1999 are shown in the following table:

Stock	*Lift and transport to Kirton*	*Spray and 1st stage drying*	*2nd stage drying and storage*	*Inspect*	*HWT*	*Return to growers*	*Plant at Kirton*	*Plant at growers*
A	05 July	06 July	09 July	26 July	25 Aug	26 Aug	7 Sep	7 Sept
B	29 June	30 June	03 July	19 July	23 Aug	25 Aug	7 Sep	25 Aug
C	05 July	06 July	09 July	26 July	24 Aug	26 Aug	7 Sep	28 Aug

Bulbs grown-on at suppliers' farms

Bulbs for re-planting at the suppliers' farms were placed in the original bins in which they had been supplied by the growers, and were despatched from Kirton on 25 or 26 August 1999. The bins were first rinsed out with a pressure washer then sprayed with disinfectant (1 part 'Jet 5' to 125 parts water), using a coarse spray to ensure that all surfaces were thoroughly wetted. Each treatment was planted in labelled rows, adjacent to the bulb stocks from which they were taken, and grown using the regular local practices (see Appendix B). The length of each planted row was recorded. Planting in ridges at 0.90m centres, the average planting densities used were 12, 19 and 18 t/ha for farms A, B and C, respectively, lower than the rate used at Kirton (20 t/ha). For planting dates, see the table above.

Bulbs grown-on at Kirton

Bulbs for planting at Kirton were planted on 7 September 1999. The length of ridge used for each treatment was proportional to the weight of bulbs planted, maintaining a planting density of 20 t/ha in ridges at 0.76m centres (1.52kg bulbs per 1m run of ridge). Following the usual procedures for planting bulb trials at Kirton, the trials area was ridged out, the position of plots was marked in the furrows, the bulbs were placed evenly in the plots by hand, and the bulbs were covered by splitting-back the ridges. Each plot was three ridges wide and up to 23m long. The trial was arranged in a randomised block design, with three replicate blocks. A separate area was used for each stock, and each area had spare bulbs of that stock planted on either side as guards. The husbandry of these bulbs followed the usual HRI Kirton protocols. After taking and analysing soil samples, fertilisers were applied according to MAFF recommendations (in this case sulphate of potash was applied and cultivated in pre-planting, and nitrate of ammonium was top-dressed shortly before shoot emergence). Herbicide applications were diquat + paraquat in autumn, cyanazine pre-crop-emergence, chlorpropham + linuron at early crop emergence, and isoxaben + metazachlor post-flowering, in both years. A fungicide spray programme was applied, using three sprays between emergence and flowering in each year (iprodione, chlorothalonil + non-ionic wetter, vinclozolin), and two sprays post-flowering in the first year only (mancozeb + benomyl, chlorothalonil + non-ionic wetter). All pesticides were applied according to manufacturers' recommendations or Off- Label Approvals.

Bulb samples for rot assessments in 2000

In early October 2000, samples of bulbs were lifted by hand from all treatments and plantings. In the case of bulbs planted at Kirton, sufficient length of ridge was lifted to provide 50-bulb samples for each replicate plot. For bulbs re-planted at the suppliers' farms, sufficient length of ridge was lifted to provide 100-bulb samples for each treatment. The length of ridge lifted in each case was recorded, and the proportion of each plot used was calculated to provide an estimate of 'relative bulb loss' for the treatment. Bulbs were stored and rots assessed.

Flower and bulb yields and rot assessment in 2001

At Kirton, flower yields were recorded for each plot in spring 2001. The plots were lifted at the end of the second growing season on 5 July 2001. Bulbs were surface-dried under fans at ambient temperature, and passed down a cleaning-inspection line. At the start of the line, before any other bulbs had been removed, 100 bulbs per plot were sampled at random for the assessment of storage rots. Subsequently, all rotted bulbs were removed and assessed immediately for rot type, and the yield of sound bulbs was recorded.

Three samples of *ca*. 100 bulbs each were lifted by hand from each treatment at the suppliers' farms on 3 July 2001 (stock A) and 5 July (stocks B and C), along with 100-bulb samples of the original (non-experimental) stocks. The length of ridge lifted in each case was again recorded and used as an estimate of 'relative bulb loss' for the treatment. Samples were taken to Kirton to assess storage rots.

Bulb rot assessments

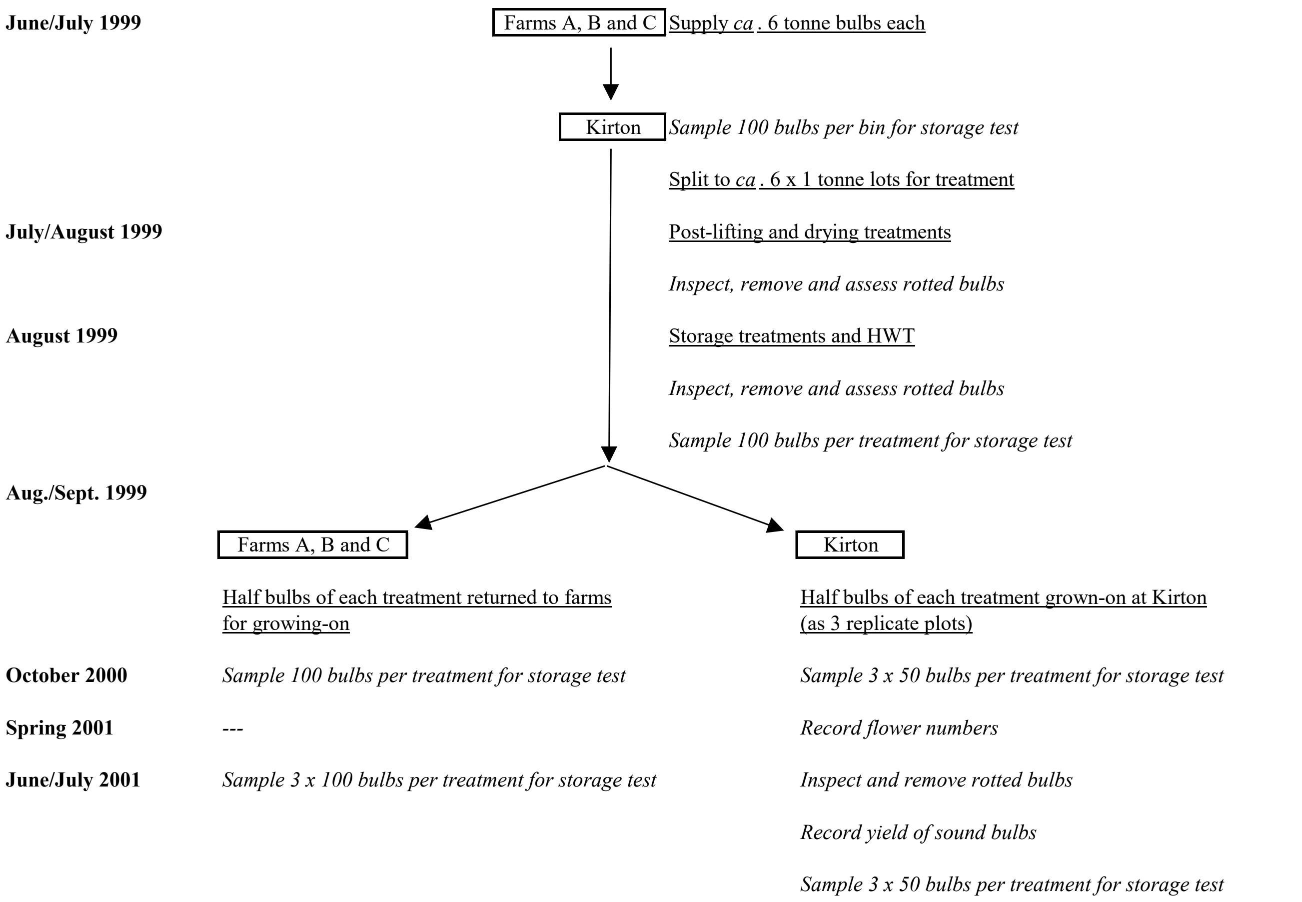
Bulbs were assessed for rots, either immediately after sampling ('on-line assessments') or after a storage period of 8 weeks at 25˚C ('storage assessments'). Other than when bulbs had rotted completely, they were bisected lengthwise to determine the type of rots. Bulbs and rots were classified into typical base rot, neck rot or whole-bulb rot (where the start of the rot could not be identified), soft rots, mummified (completely rotted and desiccated) bulbs, bulbs damaged by narcissus flies, and other damage.

In the case of bulbs removed from the line after bulb drying in 1999, typical rotted bulbs were examined by John Carder (Plant Pathology and Microbiology Department, HRI, Wellesbourne). Cultures were made in order to identify the fungi present.

Statistical analysis

Because of the gross effects of stocks and treatments and the large size of 'samples', no formal statistical analysis was carried out on the data gathered in 1999, and in the tables of results, where appropriate, standard deviations (SD) are given alongside means. True replication was impractical for bulb plots grown at the suppliers' farms. Other, replicated data were subjected to the analysis of variance as appropriate.

Figure 1. Summary of treatments and *samples*



RESULTS AND DISCUSSION

The results will be described according to the four questions set out in the Introduction, viz:

- *What was the initial health of the stocks?*
- *How well are bulb rot diseases controlled by the imposed treatments during the drying and storage phases, before planting?*
- *What are the effects of these imposed treatments on crop growth and disease status over a two-year-down growing period?*
- *How do these treatments affect the development of bulb rots during storage?*

The main findings are illustrated graphically in this section, but in all cases more detailed tables of results may be found in Appendix A.

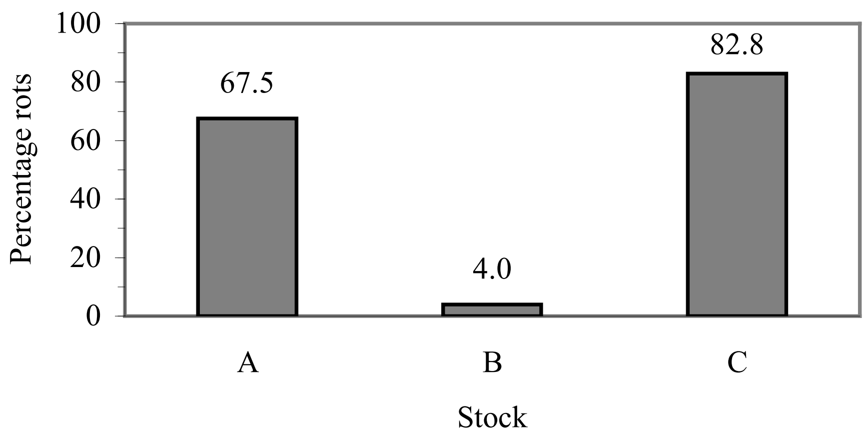
Note that 'storage assessments' refer to bulb assessments made after an 8-week period of storage at 25°C, while 'on-line assessments' refer to bulb assessments made directly after the removal of bulbs from the inspection line. Unless otherwise stated, results refer to bulbs grown-on at Kirton.

What was the initial health of the stocks?

To establish the health of the three stocks as received in July 1999, a storage assessment was carried out on a sample of bulbs from each bin. Bulbs were sampled at receipt and stored for 8 weeks at 25ºC, as described in Materials and Methods. The storage test is designed to allow the detection of any latent bulb rotting: *Fusarium oxysporum*, the cause of basal rot and probably most neck rots, grows quickly at this temperature.

The results are shown in Figure 2 (and see Appendix Table 2). Stocks A and C had high total numbers of rotted bulbs, 67.5 and 82.8%, respectively. Of these, >97% were typical of *Fusarium*-type rots (basal, neck or whole-bulb rots and mummified bulbs), while the remainder were soft rots (*Rhizopus*) or the result of large narcissus fly damage. Stock B had a total of only 4.0% rots, of which 75% were basal, neck or whole-bulb rots.

Figure 2. Storage test of bulbs as received (all rot types combined)



These initial assessments plainly indicated the importance of *Fusarium*-rots for the UK narcissus industry. While the stocks had indeed been selected to provide at least a *reasonable* incidence of bulb rots, the very high level of latent infection shown by the storage test in two of the three stocks, presented a revealing and worrying picture! This type of development of bulb rot can happen after apparently healthy bulbs have been sold, with serious repercussions for the grower. It can be difficult to establish whether the infection was present at the point of sale, or had developed later as a result of inappropriate storage conditions. Nevertheless, from an experimental point of view, the three stocks were well chosen for this type of work: they contrast with the many previous basal rot trials where the incidence of disease has been below the limits of detection!

How well are bulb rot diseases controlled by the imposed treatments during the drying and storage phases, before planting?

Soon after receipt of the bulbs, it was apparent that two of the three stocks had seriously high levels of bulb rotting. It was clear that (unplanned) assessments and removal of affected bulbs would be needed more than once during the application of treatments, in order to prevent complete loss of most or all of the bulbs in the worse affected stocks.

A. On-line assessments at the conclusion of bulb drying treatments

In July 1999, an initial assessment was made of the rotted bulbs removed on the inspection line, after drying was complete but before further storage and HWT. This identified variable numbers and types of rotted and damaged bulbs present in all three stocks.

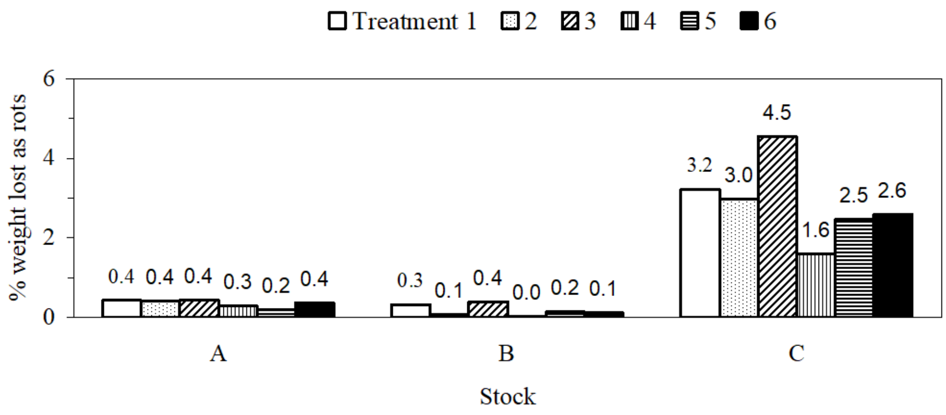
Stock B contained the highest percentage of sound, healthy bulbs. The overall number of unacceptable bulbs across all treatments was only 12 bulbs (0.19kg) per ½-tonne bin, and most of these were soft, grey and completely rotted with a musty smell suggesting the presence of *Rhizopus*. This stock also contained a few bulbs with obvious internal damage due to narcissus fly larvae (larvae of small narcissus flies were seen, but none of the large narcissus fly). In addition, many bulbs had physically damaged base plates, which could be due to a variety of causes. Except for treatment 4, where there were few rotted bulbs and no fully rotted ones, samples were examined and fungi isolated by John Carder at HRI, Wellesbourne. *Rhizopus* was identified in many cultures, and *Penicillium* and bulb scale mites were also recorded. This was the first indication of the usefulness of treatment 4 (see later).

In stock A, many more unacceptable bulbs were found, with a mean (across all treatments) of 52 bulbs (1.33kg) per ½-tonne bin. Most had distinct basal or neck rot or were mummified. Very few bulbs were completely rotted, but these were soft and similar to those in stock B suspected of having *Rhizopus*. Many bulbs had obvious internal narcissus fly damage, and many more had physically damaged base plates. Cultures from typical soft-rotted bulbs again revealed that *Rhizopus* was present on several samples.

Stock C had the largest number of unacceptable bulbs: the mean across all treatments was 288 bulbs (10.91kg) per ½-tonne bin. Like stock A, these consisted mainly of basal and neck rot and mummified bulbs. Some bulbs had narcissus fly damage (larvae of large and small narcissus flies were seen), and there was some physical damage of the base plates. Although no bulbs were seen that were fully rotted by soft rot, samples of bulbs with base and neck rots were examined, and *Rhizopus* was confirmed in cultures of three of the 35 bulbs so tested.

The overall losses were relatively small at this stage, except in stock C. Results are summarised in Figure 3 as the percentage weight of bulbs removed at this stage due to rotting. In stock C, bulbs of treatment 4 had the least bulb rot, while those in treatment 3 had most. Fully detailed results are given in Appendix Table 3.

Figure 3. Percentage weight removed as rotted bulbs after drying



The overall health of the three bulb stocks – if representative of the industry in general – raises a number of concerns, besides the self-evident one of high rates of *Fusarium* rots. *Rhizopus* soft rots were found in all three stocks, even in stock B, by far the healthiest of the stocks. Bulb losses due to *Rhizopus* are usually connected with bulbs that have been stored warm and damp, so this implies less-than-ideal bulb handling and storage at some stage. There were many instances of damage to the basal plates of bulbs, again, in all three stocks, and to an extent that should give concern about the facilitated entry of pests and pathogens into the bulbs and damage to root initials. In some cases damage appeared to be associated with invasion by the larvae of the large narcissus fly, and in others cases was apparently due to non-specified mechanical damage. As all three stocks originated in the east of England, this finding suggests that growers should perhaps be more aware of the possibility of large narcissus fly damage in this region. At HRI Kirton, where quantities of narcissus bulbs have regularly been bisected in autumn to record bulb rots in trials, fly larvae and their damage has been incidentally recorded, at a low level of say 1-2%, for several years. The frequent incidence of other damage to the basal plates, apparently mechanical, may be the result of poor adjustment of bulb lifting and cleaning machinery. Larvae of small narcissus flies attack only already damaged bulbs. The (albeit low) incidence of bulb scale mite should be noted as a further possible cause of concern.

Although at an early stage of the project, it was interesting to note that treatment 3, which resulted in most rotting in stock C, included 35°C drying but no initial Storite spray treatment. Treatments 1 and 3 resulted in highest weights of rotted bulbs in all three stocks. Perhaps 35°C drying, i.e. a higher 'incubation' temperature, hastened rotting, so that these rotted bulbs were more obvious at the time that the inspection was made. Treatment 4 appeared to have some advantage in managing bulb rots, although the reason for this was not clear at this stage. However, treatment 4 probably resulted in the removal of least weight in stocks B and C (and second least in A) because having no 35°C drying and then storage at 17°C would hold back the progress of rots, preventing these bulbs being spotted and removed.

B. On-line assessments after completion of HWT and other treatments

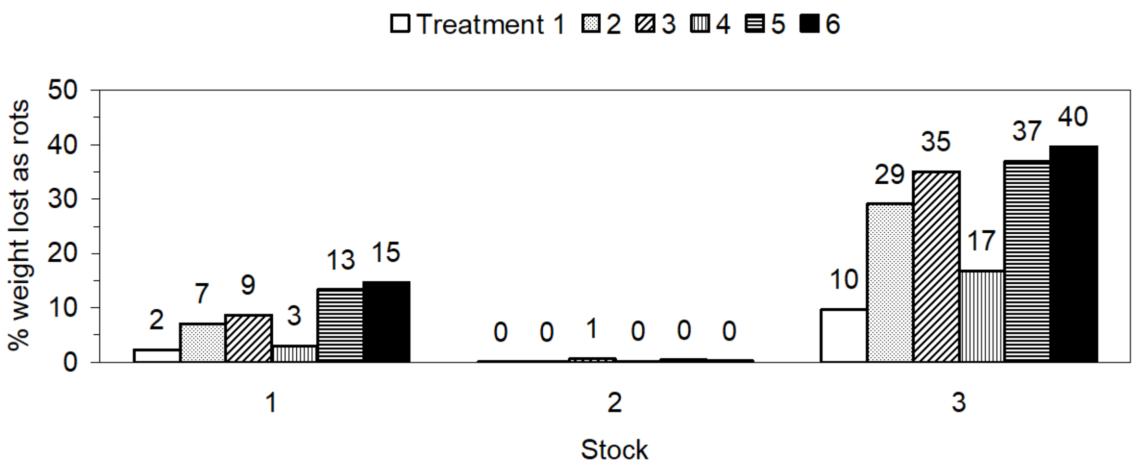
In August 1999, when all the experimental treatments had been completed, all bulbs were again passed along a cleaning-grading line and inspected, removing obviously rotted bulbs.

As for the previous inspection, most rotted bulbs were found in stock C and least in stock B (Appendix Table 4). In stock C, the numbers of rotted bulbs removed (per original lot of 750kg bulbs) for the various treatments varied from 1085 to 4042 (between 10 and 40% of the weight remaining after HWT). For stock A the figures were from 318 to 1708 (between 2 and 15% of the weight after HWT), and for stock B just 9 to 83 (in all cases <1% of the weight after HWT).

In stocks A and C, the numbers of rots in the different treatments was 6 > 5 > 3 > 2 > 4 > 1. In the worst case over 248kg of rotted bulbs was rejected at this stage per treatment (40% of the weight after HWT), and, in the best, only 0.4kg (0.06% of the weight after HWT).

The overall percentage loss in weight due to rotting bulbs removed is shown in Figure 4. This shows that losses had increased dramatically in stocks A and C since the inspection only four weeks before. In these stocks there were clear treatment effects, treatments 1 and 4 being most beneficial. For stocks A and C, the majority of affected bulbs had progressed to whole-bulb rots, whereas in stock B there were about equal numbers of bulbs with whole-bulb rot or with rots clearly associated with base or neck. For detailed results, see Appendix Table 4.

Figure 4. Weight of rotted bulbs removed after completion of treatments

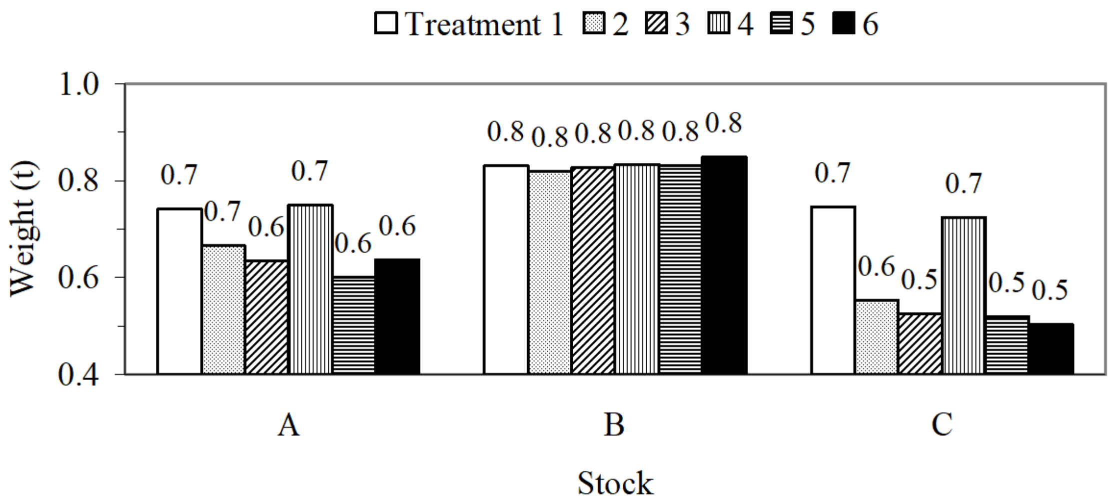


Each treatment started with a weight of 'as lifted' bulbs of approximately 750kg. The weight of sound bulbs remaining after the completion of treatments is shown in Figure 5, with figures adjusted to a 'per tonne' basis. Note that the weight losses include not only those due to the removal of rotted and damaged bulbs, but also those due to drying, bulb cleaning and the removal of samples for storage assessments. Hence, this is not an exact statement of yields, nevertheless the figures may be useful in estimating likely yields from different treatments and from stocks with different amounts of bulb rots.

The weight of sound bulbs of stock B varied between 614 and 637 kg (per 750 kg treated) for the six treatments (82-85% of the starting weight). In stock A, between 451 and 562 kg remained (60-75%), and in stock C, between 378 and 560 kg (50-75%). In stocks A and C, the yield of bulbs for treatments 1 and 4 (72-75% of initial weight) were higher than yields for the other four treatments (50-67%), an effect particularly evident in stock C where, otherwise, yields were very low.

For stocks A and C, treatments 1 and 4 gave the highest yields and the smallest amount of rotted bulbs. It can be assumed that, by this stage, the inclusion of Storite in the HWT dip would be unlikely to have had any effect on the numbers of rotted bulbs. Both of these treatments had in common a period of storage at 17ºC, and so this is the element most likely to have resulted in the reduction in weight of visibly rotted bulbs at this inspection. It is known that incubation at 17ºC of bulbs that have been artificially inoculated with *Fusarium* will result in slower rate of rotting than those incubated at 20 or 25ºC[1]. At this time ambient temperatures were higher than average (see temperature data below).

Figure 5. Weight of marketable bulbs remaining (adjusted to per tonne treated)



1 J.H. Carder, personal communication.

What are the effects of these imposed treatments on crop growth and disease status over a two-year-down growing period?

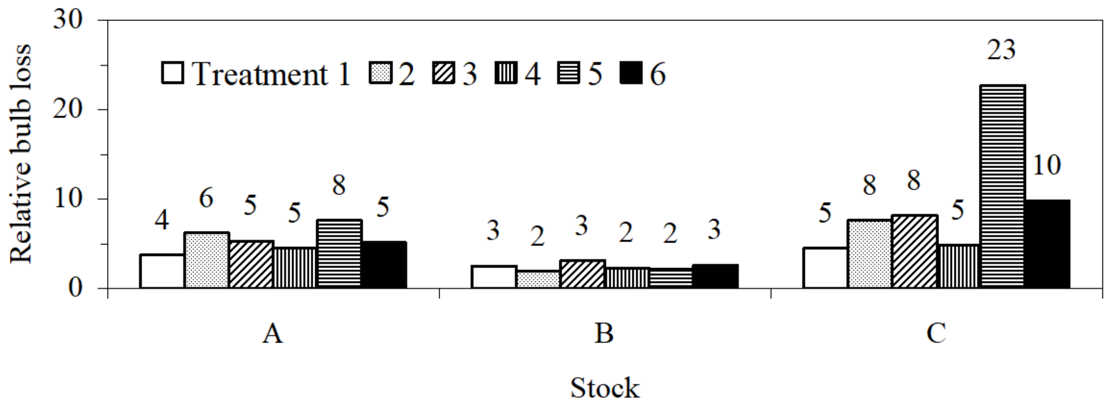
A. Growth in first crop year (1999-2000)

In the first growing year, crop appearance was generally satisfactory, although there were the expected differences in vigour between stocks. After the end of the first growing season, samples of 50 bulbs were recovered from each plot for storage assessments (for results of the storage test, see later section). The length of ridge lifted to provide this number of bulbs could be converted to a percentage of the total plot length, providing a rough estimate of 'relative bulb loss' for the different treatments.

The figures for the bulbs planted at Kirton are shown in Table 6 (Appendix Table 6). Statistical analysis showed that stock, treatment and the interaction between them all had significant effects on crop performance. As expected, bulb losses were highest in stock C and lowest in stock B. In the worst affected stock, C, losses were lower in treatments 1 and 4 than in other treatments, and a similar trend was seen in stock A. These results confirmed the earlier findings of benefits from treatments 1 and 4. In stock B losses were low, and there were no clear differences between the six treatments. In stock C losses were very high in treatment 5.

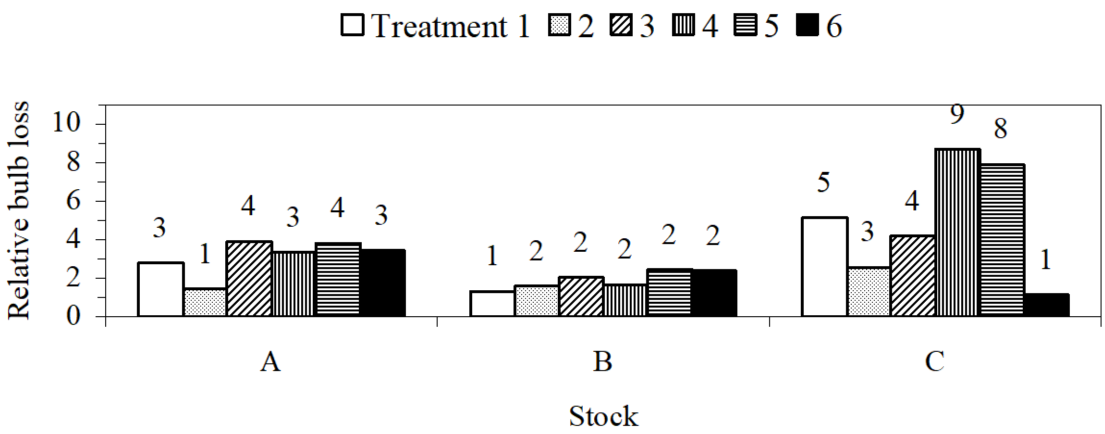
Treatments 1 and 4 shared a second stage drying and storage period at a controlled 17°C rather than ambient temperatures, presumably the reason for better performance. In treatment 5, which appeared to increase rotting, both phases of bulb drying had been at ambient (rather than controlled) temperatures, although if this alone were the reason similar results would have been expected from treatment 6.

Figure 6. 'Relative bulb loss' (see text) during the first crop year



The comparable figures for the bulbs grown-on at the suppliers' farms are shown in Figure 7 (Appendix Table 7). Overall, the relative bulb losses appeared lower in these bulbs than in those grown-on at Kirton, perhaps due to the lower planting densities used at the suppliers' farms (especially for stock A, where the planting density used was 12 t/ha). There were no clear treatment effects in the better stocks, A and B. In stock C, higher losses were seen in both treatment 4 and 5, contradicting other results already described.

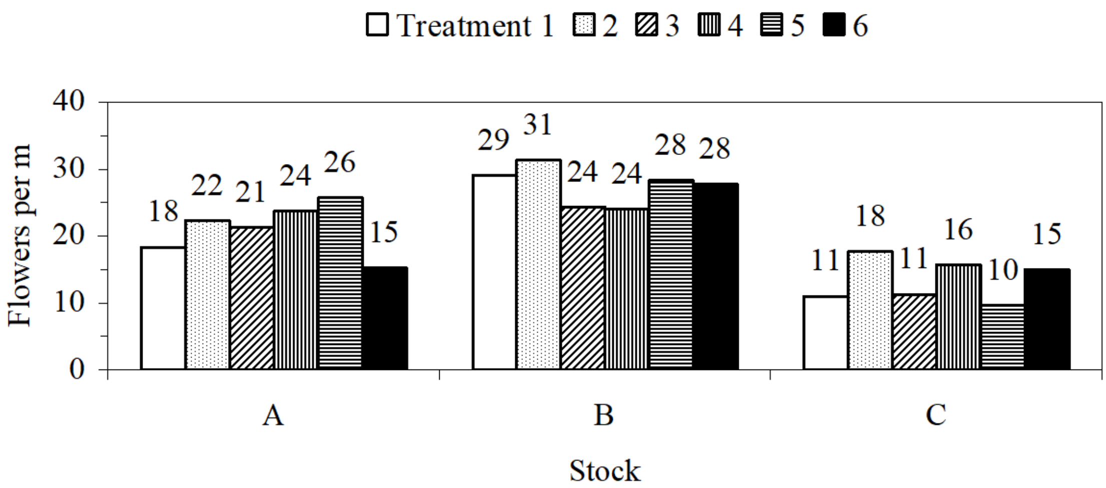
Figure 7. 'Relative bulb loss' (see text) during the first crop year - *bulbs at suppliers' farms*



B. Crop growth in second year (2000-2001)

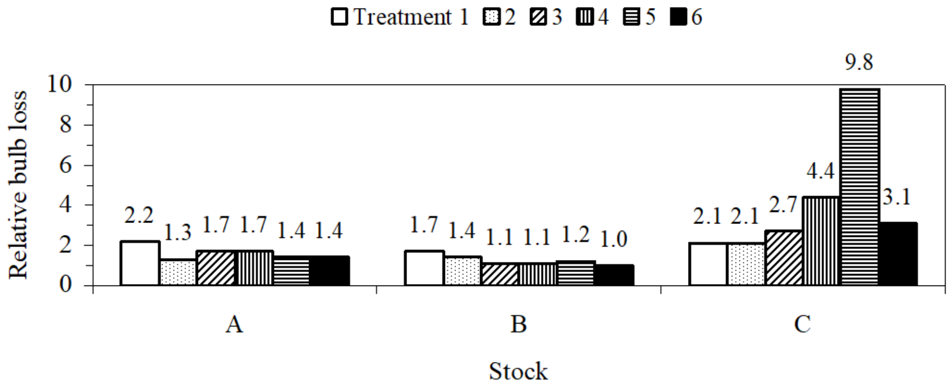
The relative flower yields of the stocks and treatments are shown in Figure 8 (Appendix Table 8). As expected, stock B had the highest vigour, and stock C the lowest. The statistical analysis showed that there were significant effects due to stock, but the huge amount of variation here swamped any disclosure of treatment effects or interactions. There was no obvious consistency in treatment effects, either between stocks or with earlier results.

Figure 8. Flower yields in second crop year



For bulbs grown at the suppliers' farms, relative bulb loss was again estimated as the proportion of the plot dug to recover bulb samples for storage tests (Figure 9, Appendix Table 9). There were significant effects of stock, treatment and of the stock x treatment interaction on relative bulb loss. As expected, losses were highest in stock C and lowest in stock B. Differences between treatments were small for stocks A and B, where percentages varied only between 1.0 and 2.2. However, in stock C treatment effects were expressed strongly, with treatments 3, 4, 5 and 6 having greater losses (9.8 for treatment 5).

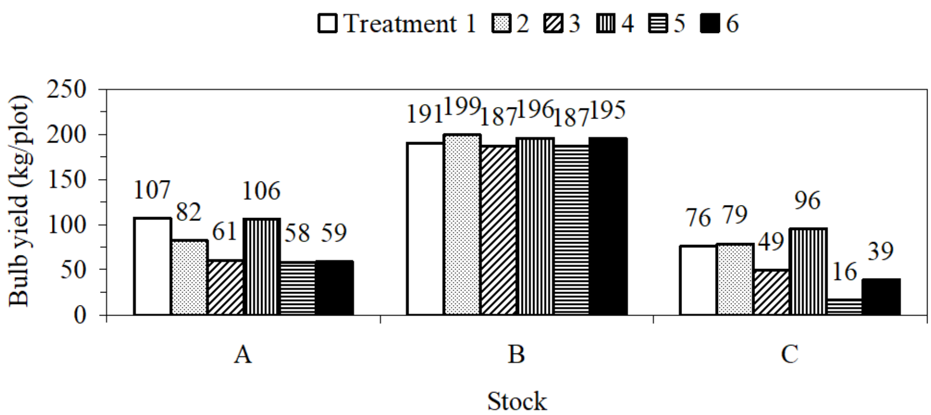
Figure 9. 'Relative bulb loss' (see text) during the second crop year - *bulbs grown at suppliers' farms*



C. Bulb yields after 2 years

The actual marketable lift of bulbs from each plot (after the removal of rotted bulbs) is shown in Figure 10 (Appendix Table 10). As different weights of bulbs were planted for different stocks and treatments, this does not purport to be an accurate picture of crop growth, but it does represent the cumulative effects of treatments since receipt of the bulbs at Kirton. Consistently high yields were seen in all treatments of stock B, varying only between 187 and 199 kg/plot. In stock A, treatments 1 and 4 gave the highest yields, and in stock C, treatments 1, 2 and 4. This confirms the beneficial effects of treatments 1 and 4, previously seen, although, on this basis, treatment 2 (involving storage at ambient temperatures) would have been expected to give poor results.

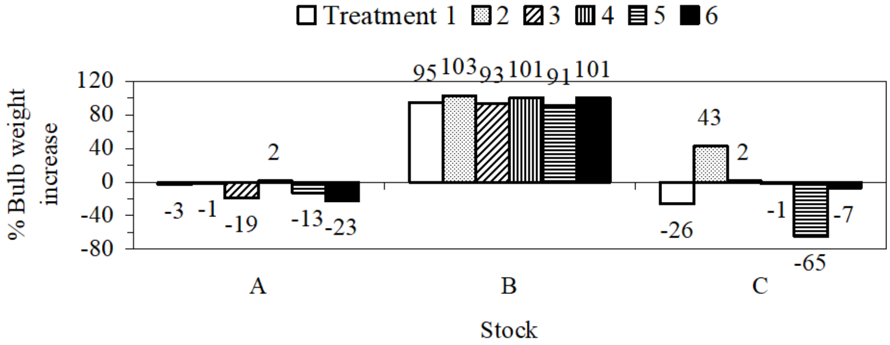
Figure 10. Yield of marketable bulbs



Bulb yields are also shown as the percentage bulb weight increase, after the removal of rotted bulbs (Figure 11, Appendix Table 11). The percentage bulb weight increase was calculated as: (weight increase / weight planted) x 100. Stock B gave acceptable weight increases, whereas very small increases, or even weight losses, were found for the treatments of stocks A and C.

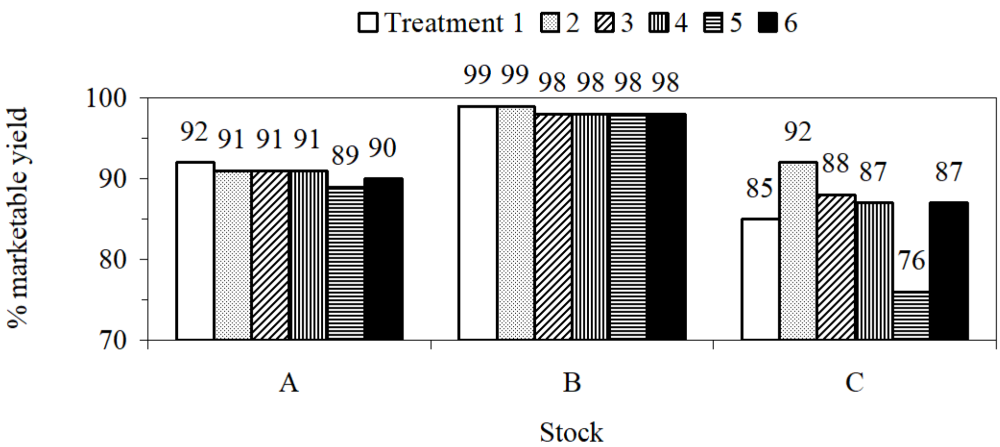
Analysis of the data for percentage weight increase showed that both stock and treatment had significant effects on growth, and the interaction between the two factors was also significant. Stock B gave the best and most consistent growth, with only 91 – 103% increases. Stock A achieved virtually zero increase in treatments 1, 2 and 4, and large weight losses in treatments 3, 5 and 6. In stock C the results were more variable, with a 43% weight increase using treatment 2 but considerable weight losses in treatments 1 and, especially, 5.

Figure 11. Percentage bulb weight increase (marketable bulbs)



The percentage (by weight) of sound bulbs in the lift are shown in Figure 12 (Appendix Tables 12). For all six treatments in stock B, sound bulbs accounted for 98-99% of the lift. In stock A results were also uniform, but less good (89-92% sound bulbs). In contrast, stock C gave more variable results, with 76% sound bulbs in treatment 5 and 85-92% sound bulbs in the other five treatments.

Figure 12. Percentage of marketable bulbs in lift



How do these treatments affect the development of bulb rots during storage ?

As well as carrying out a bulb storage test on the bulbs as received, to establish initial disease levels, storage tests were carried out at intervals over the two-year project to follow the health of the stocks and the effects of treatments.

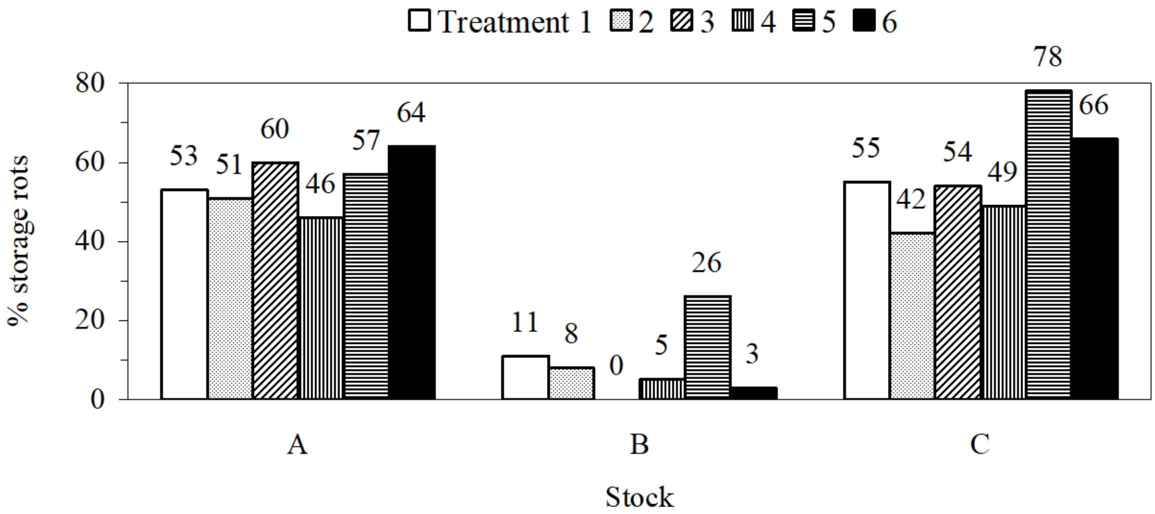
A. Storage assessment of bulbs after completion of treatments

In August 1999 bulbs were sampled at the completion of treatments. The incidence of storage rots is shown in Figure 13 (Appendix Table 13).

Storage increased losses due to rotting in almost all treatments of all stocks, compared with the expectations following rot assessment on-line carried out at the same time (see above). This is inevitable since some of the bulbs examined on-line would have been infected but the rot would not have been sufficiently advanced for the bulb to be removed as rotted. However, after eight weeks storage at 25ºC most of these bulbs would have rotted completely. It was also found that, in storage assessments, treatment and stock effects were reduced. Rots in stock A increased to levels similar to those in stock C. However, the high percentage of rots in stocks A and C, previously seen in stored samples of bulbs 'as received' (Figure 2), was still evident in all treatments, with total rots of 42-78%. In bulbs of stock B, the percentage rot was 11% or lower, except for treatment 5 (26%) (treatment 5 also gave very high rots (78%) in stock C). Most of the bulb rot observed at this stage had progressed to a whole-bulb rot. No bulb damage due to narcissus fly was observed, probably due to the overwhelming effect of fungal rots.

The generally high levels of rotting in bulbs of treatment 5 (in all stocks) and treatments 3 and 6 (in stocks A and C) may be related, as suggested previously, to storage of the bulbs at ambient temperatures rather than 17°C (without the benefits of post-lifting Storite as in treatment 2). The previously demonstrated benefits of treatments 1 and 4, however, were not evident in this assessment.

Figure 13. Storage rots after completion of HWT and other treatments

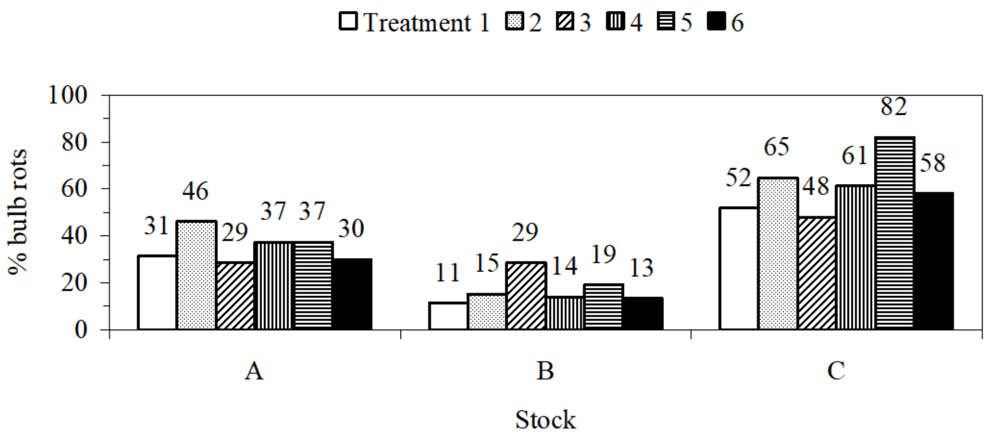


B. Storage assessment of bulbs after one year's growth

The storage assessment of bulbs after one year's growth at Kirton are given in Figure 14 (Appendix Table 14). The combined percentage of bulb rots in all categories showed significant differences due to stock, treatment and the interaction between the two, although the stock effect was the overwhelming one. Stock C remained the most heavily infested stock, and stock B the least. When compared to the values obtained after HWT in 1999 (Table 13), stock A showed an overall reduction in rots across all treatments, stock B an overall increase (except treatment 5) and stock C, little change.

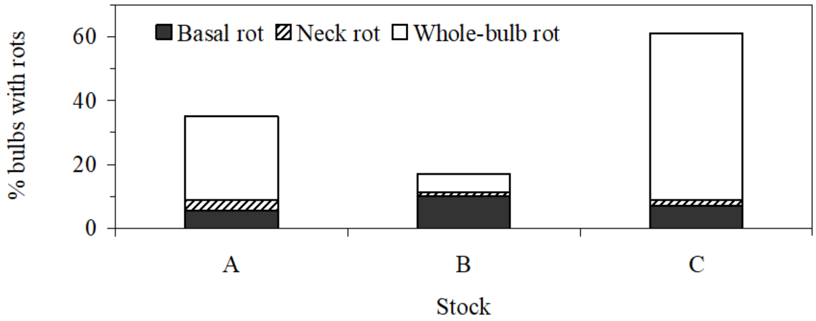
The previous pattern of lowest rots occurring in treatments 1 and 4 was not maintained. In stocks A and C, the highest amounts of rotting were found in treatments 2, 4 and 5, but in treatment 3 in the case of stock B. Hence there was no common factor linking treatments that performed poorly.

Figure 14. Storage rots in bulbs sampled after first crop year



There were no statistically significant effects, due either to treatment or the stock x treatment interaction, on the percentage of bulbs in specific rot categories in these samples. However, there were marked differences due to stock (Figure 15, Appendix Table 15). Combining all types of fungal rots, 61% of bulbs were affected in stock C and 35% in stock A, but only 17% in stock B. In stocks A and C a much greater proportion of bulbs had progressed to a whole-bulb rot.

Figure 15. Proportion of rot types in storage assessment after one year's growth at Kirton

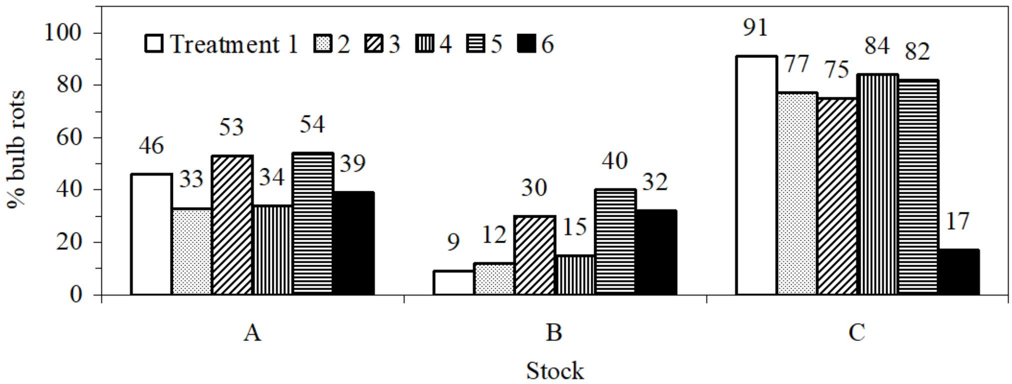


The percentage of bulbs with rots in storage assessments, from samples recovered from plantings at the suppliers' farms, are shown in Figure 16 (Appendix Table 16).

These figures confirmed the relative incidence of bulb rots between the three stocks (C>A>B), as seen in the results for the plantings at Kirton. Stock C again had the largest proportion of bulbs where rots had progressed to a 'whole-bulb rot' stage. In general, the percentage of rotted bulbs was higher in bulbs grown at the suppliers' farms than at Kirton. Whereas there were still many rotted bulbs in all treatments of stocks A and C, treatment effects now also emerged in stock B.

The pattern of rotted bulbs between the six treatments was not consistent with some previous results (eg, the better results seen with treatments 1 and 4). In stock A, treatments 2 and 4 gave the lowest incidence of rotting bulbs, while in stock B treatments 1, 2 and 4 performed well. However, in stock C treatment 6 gave an unexpectedly good result, and, as this value has been verified, some explanation is necessary. It was this treatment-stock combination, grown at the suppliers' farms, that had previously shown a very low 'relative bulb loss' (see Figure 7), but this good result did not persist in subsequent assessments (see Figures 9 and 19). Possibly this variation simply reflects a non-uniform distribution of infected bulbs and soil-borne fungi, with a chance concentration of diseased bulbs at the site of bulb sampling in the first crop year at the supplier's farm.

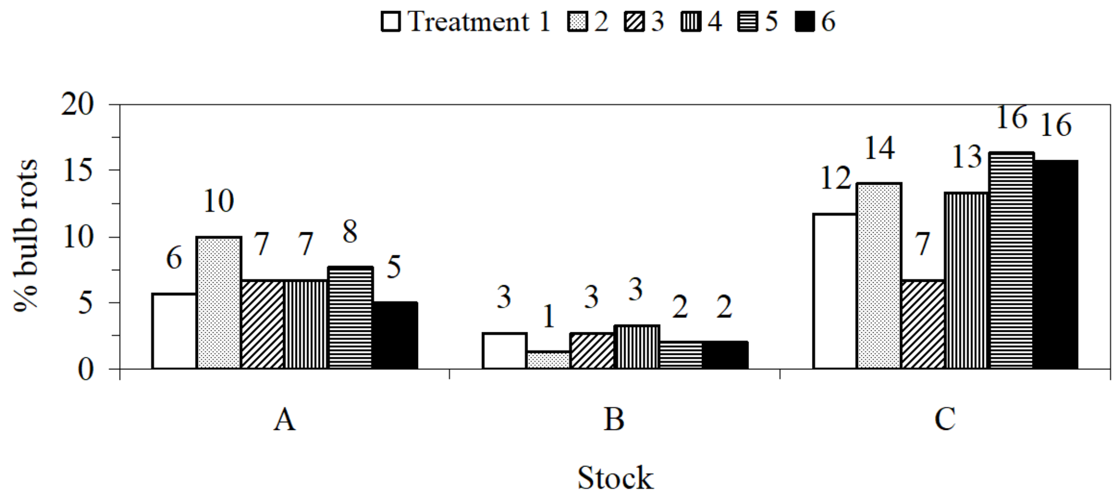
Figure 16. Storage rots in bulbs sampled after first crop year - *bulbs grown at suppliers' farms*



C. Storage assessments after bulb lifting

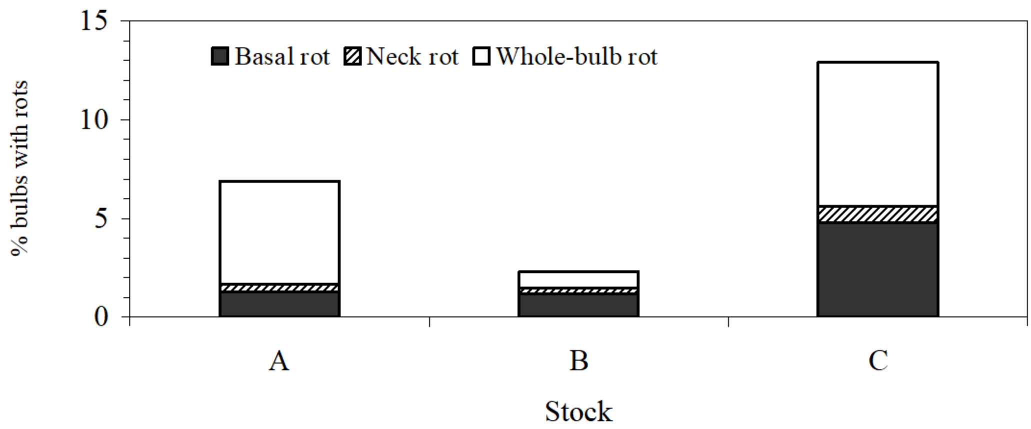
Storage assessments on bulbs grown for two years then lifted are shown in Figure 17 (Appendix Table 17). As in the case for flower yields, plot differences were dominated by effects due to stocks. The incidence of storage rots was only 1-3% in stock B, rising to 5-10% in stock A and 7-16% in stock C. In the poorest stock, C, storage rots were lower in treatment 3 than in any other treatment.

Figure 17. Storage rots in bulbs sampled after lifting



There were no statistically significant effects, due either to treatment or the stock x treatment interaction, on the percentage of bulbs in specific rot categories in these samples. There were, however, marked differences due to stock (Figure 18, Appendix Table 18). In stocks A and C most affected bulbs had progressed to a whole-bulb rot.

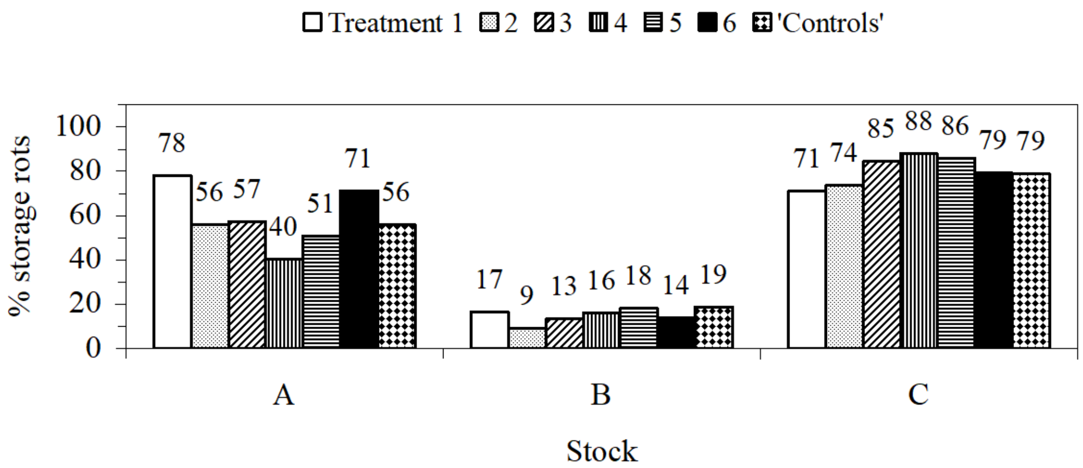
Figure 18. Proportion of rot types in storage assessment after one year's growth at Kirton



Comparable data for bulbs grown at the suppliers' farms are shown in Figure 19 (Appendix Table 19). There were the usual major differences due to stocks, the good results with stock B being maintained. Storage rots in bulbs from all three growers' farms were much higher for all three stocks than the corresponding values for the Kirton-grown plots, possibly reflecting some difference in handling methods. Treatment effects were, overall, not significant, varying from 9-18 for stock B and 71-88 for stock C, but there was a significant interaction between the two factors resulting from treatment differences with stock A. For this stock the percentage rotted bulbs varied from 40% for treatment 4 to 78% for treatment 1. Samples were also taken of the original bulb stocks, retained at the suppliers' farms throughout. In storage tests, these 'controls' had 56, 19 and 79% fungal rots for stocks A, B and C, respectively, broadly in line with the average for the various treatments.

In stock A, 3.4% of bulbs in the storage assessment showed damage due to large narcissus fly larvae, while in the other two stocks the percentage was 1% or less.

Figure 19. Storage losses due to fungal rots after lifting in second year - *bulbs grown at suppliers' farms*



Correlations between rot assessments

It would be useful to know whether different types of bulb rot or growth assessments were correlated, for example, whether the results from pre-planting storage assessments related to results from the storage assessments of field samples or to the percentage of lifted bulbs marketable. Regression (trend-line) analysis was therefore carried out on the data given in the previous sections.

The percentage of bulb weight lost as rots after the completion of HWT treatment was positively correlated with the bulb weight lost at the end of drying treatments ($R^2 = 0.67$)[1].

The percentage of bulb weight lost as rots at the end of drying treatments was:

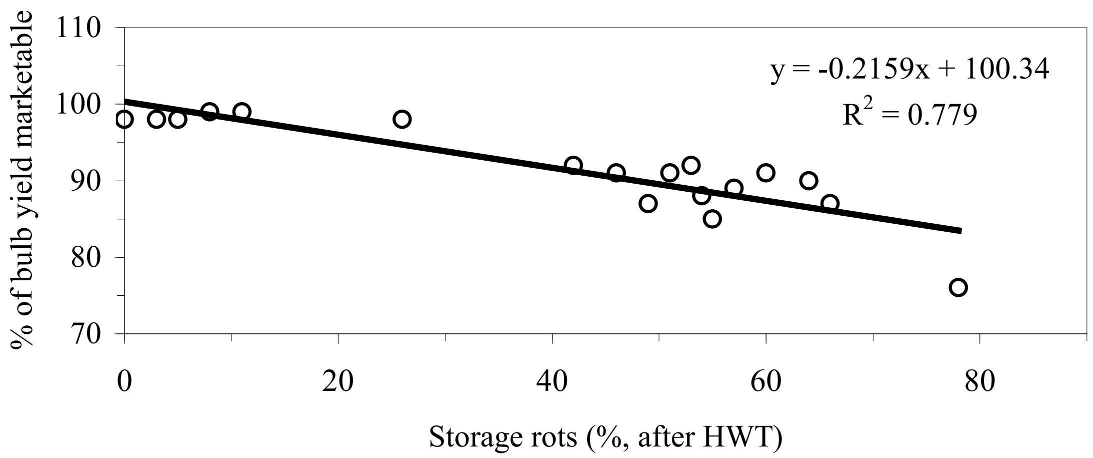
- Negatively correlated with flower yield in the second crop year ($R^2 = 0.58$)
- Negatively correlated with bulb yield ($R^2 = 0.59$) and percentage of lifted bulbs marketable after lifting ($R^2 = 0.56$)
- Not strongly correlated with relative bulb losses in years 1 or 2 ($R^2 < 0.50$)

The percentage of storage rots from pre-planting samples was:

- Not strongly correlated with the percentage of storage rots in samples taken after one and two years of growth ($R^2 < 0.50$)
- Negatively correlated with the percentage of bulbs marketable after lifting ($R^2 = 0.78$) (Figure 20)

The results already presented showed that some bulb-handling treatments (such as second stage drying and then storage at 17ºC) have a major effect on the numbers of visibly rotted bulbs detectable on-line after HWT. These further analyses showed that the eventual bulb yields and disease status are largely, but not entirely, dependent on stock health at planting.

Figure 20. Storage rots after HWT (x) and % marketable yield after lifting (y)



[1] As the value of the regression coefficient, R^2, approaches 1.0, the two sets of data are more closely correlated.

Temperature records and bulb rots

Temperatures recorded by probes placed with the bulbs in bulk bins during their time on the drying wall are shown in Figure 21. This shows that the mean temperatures achieved were close to the target (35°C). Temperature records during 17°C storage also showed that the target temperature was achieved, within acceptable limits (Figure 22).

Figure 21. Temperatures in bins on drying wall

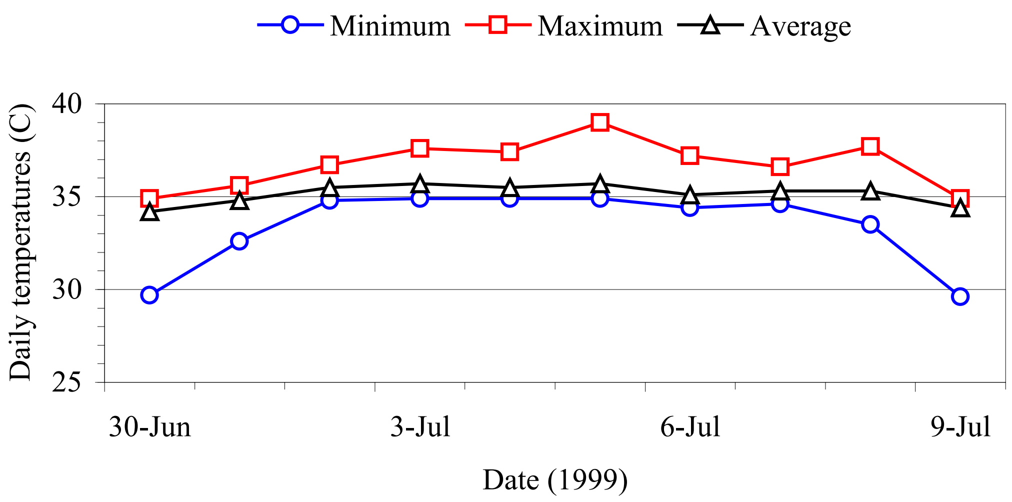
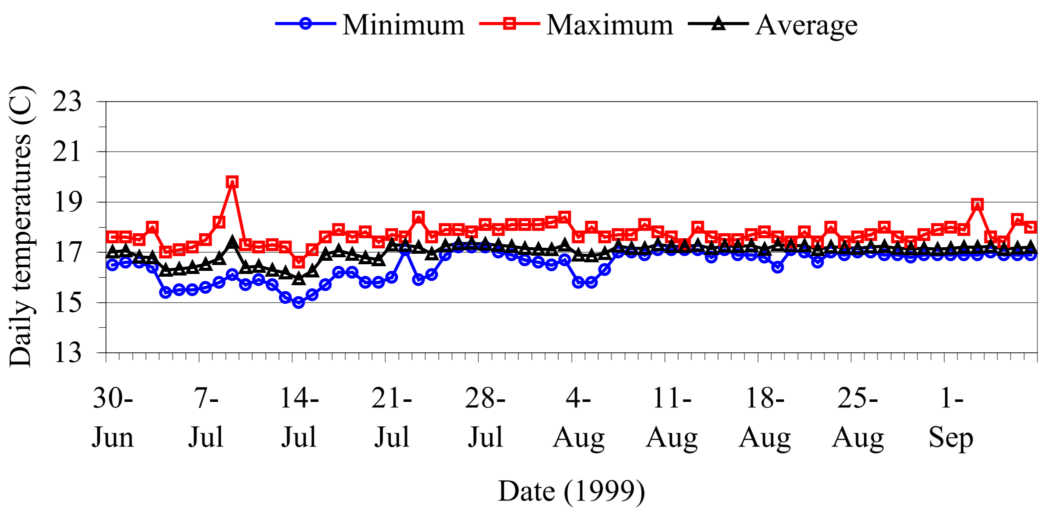
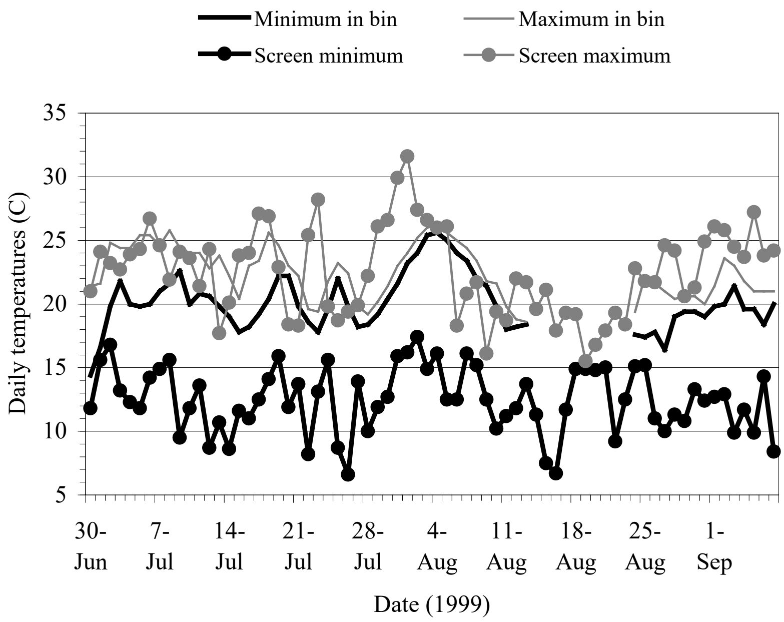


Figure 22. Temperatures in 17C store



Daily minimum and maximum temperatures recorded in bins of bulbs during drying and storage at 'ambient temperatures' (in a well ventilated, unheated shed) are shown in Figure 23. For most of the time, bin temperatures fluctuated between about 18 and 25°C. Screen temperatures from the nearby Kirton meteorological Station are also shown in Figure 23, and showed that temperatures inside the bins were considerably warmer than temperatures recorded outside. This meant that the experimental comparison of 'ambient' and 17°C storage treatments was well justified in this case, probably accounting for a large part of the treatment effects on bulb rots and crop performance. Due to insulating effects, the temperature fluctuations recorded in the bins lagged behind changes in outdoor temperatures by a few days.

Figure 23. Temperatures in bins held at ambient temperatures and screen temperatures



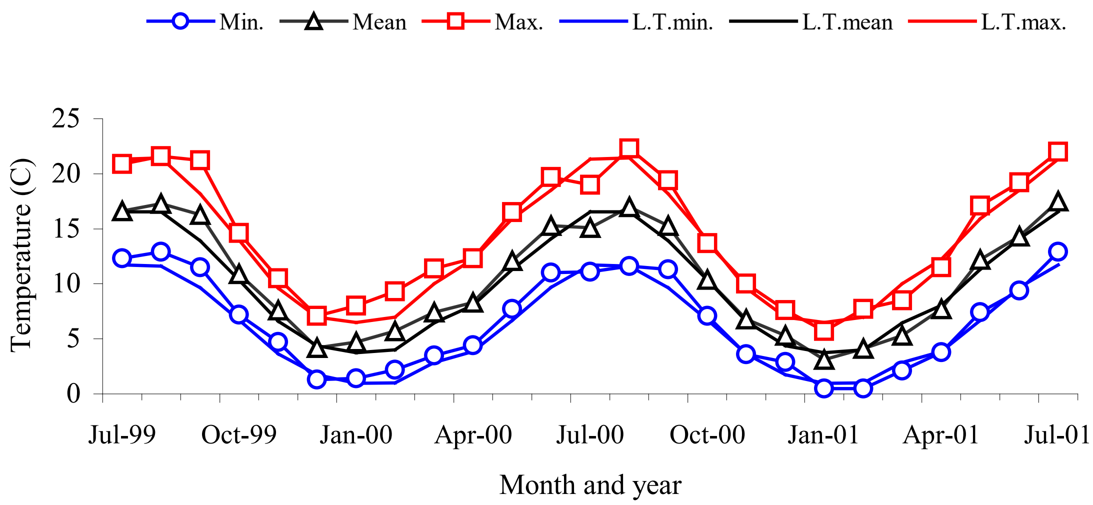
The 1999 and long-term (30 year) mean screen temperatures for the June to September 1999 period, for the Kirton meteorological site, are given in Table 1. Temperatures in June were similar to the long-term average, but those in July and August were 1-2°C higher than expected. September temperatures were considerably higher (2-3°C) than the long-term values. These higher than average temperatures would have been amplified within the bulb bins (Figure 22).

Table 1. Mean daily temperatures for June to September at Kirton

	Daily minima (°C)			Daily mean (°C)			Daily maxima (°C)		
	Long-term	1999	*Excess of 1999 over long-term*	Long-term	1999	*Excess of 1999 over long-term*	Long-term	1999	*Excess of 1999 over long-term*
June	9.5	9.3	*-0.2*	13.9	13.9	*0*	18.5	18.5	*0*
July	11.4	12.3	*0.9*	16.2	17.6	*1.4*	21.2	22.9	*1.7*
Aug.	11.1	12.9	*1.8*	16.1	17.3	*1.2*	20.9	21.6	*0.7*
Sep.	9.4	11.5	*2.1*	13.6	16.3	*2.7*	18.0	21.2	*3.2*

Monthly temperature data for the 2-year duration of the project are shown in Figure 24. Mean daily minimum, mean and maximum figures for the whole period were only slightly higher than the long-term averages. However, the warmer than expected temperatures in late-summer 1999, when the experiment was being set up, can clearly be seen in the figure, giving added weight to the 'ambient v. 17°C' comparison.

Figure 24. Mean daily minimum, mean and maximum screen temperature, 1999-2001 (with long-term means (1981-2000) indicated by L.T.)



GENERAL DISCUSSION

Health status of bulb stocks

The bulb stocks used for this project were selected on the basis of being cultivars susceptible to basal rot and (or) stocks with a history of basal rot problems. As such, they lived up to expectations, and, if anything, the levels of *Fusarium*-type bulb rots were rather too high (in two of the three stocks) for comfortable experimentation! In all assessments made during this project, stock B was consistently the most healthy, and stock C the least so. One practical effect of this, shown by statistical analysis, was that the overwhelming variation contributed by stock may in some cases have masked smaller differences due to treatment or to the stock x treatment interaction. Treatment effects were easily discerned in the two highly diseased stocks (A and C), whereas in stock B the low disease levels made the detection of treatment effects less likely. Bulb rots in stocks A and C not only had higher incidences of basal rot, but rots were further advanced when the assessments were made. This might be because 'successful' treatments merely delayed the development of *Fusarium*-type rots, but did not cure them. Another possible explanation might be the presence of relatively virulent strains of the pathogen in stocks A and C. Variations in the virulence of isolates of *Fusarium oxysporum* f.sp. *narcissi* is the subject of on-going DEFRA-funded research by John Carder at HRI Wellesbourne.

Of further concern was the incidence of other problems and types of damage. Some bulbs with soft rot were seen, and the soft-rot fungus *Rhizopus* was isolated in some bulbs from all three stocks; the occurrence of soft-rot would usually imply a period of inappropriate (warm and damp) bulb storage. Large narcissus fly damage was seen in all stocks, as was a more general mechanical damage to the basal plates, possibly caused by earlier narcissus fly or other damage and poorly adjusted lifting or other bulb-handling machinery. The large narcissus fly is not generally considered to be a pest of bulb crops in eastern England. Lower incidences of bulb scale mites (which can attack healthy bulbs) and of small narcissus flies (which attack only damaged bulbs) were also seen. These observations are a clear warning that a closer watch should be kept on narcissus flies, mechanical damage, soft-rot, and bulb scale mites in narcissus crops grown in the east of England.

Control of Fusarium-*type bulb rots during the bulb-handling phase*

The examination of bulbs twice between lifting and re-planting - after drying and again after HWT – demonstrated the speed with which *Fusarium*-type bulb rotting can occur during the bulb-handling phase. By the end of bulb drying, approximately 20 days after lifting, weight losses (due to the removal of rotted bulbs) amounted to 2-5% in the worst affected stock (stock C). By the time HWT had been completed, 4 weeks later, the percentage of bulb weight lost due to the further removal of rotted bulbs had risen. The losses were 10-40% for the different treatments of stock C, and 2-15% for the different treatments of stock A. In the healthiest stock, B, these losses were consistently <1%. Bulb rots at this stage are crucial for producers, as bulbs may appear rot-free on inspection, yet may be rejected by the customer a few weeks later as rots develop. It has not been clearly established that the application of thiabendazole fungicide is curative of *Fusarium* rots in narcissus bulbs, or whether it merely causes a delay in the development of rotting[1]. Planting infected bulbs will inevitably lead to an increase of *Fusarium* in the soil. It has been shown previously[2] that even with less than 10% infected bulbs in a

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[1] J.H.Carder, personal communication.

[2] Price, D. (1977). Some pathological aspects of narcissus basal rot, caused by *Fusarium oxysporum* f. sp. *narcissi*.

planting stock, this would translate to one infected bulb per metre of ridge, and healthy bulbs can become infected by a diseased bulb over 70cm distant. Surprisingly, relatively little is known about the sources and timing of basal rot infection.

While it was impossible to discern any effects of the imposed treatments against the low background level of bulb rots in stock B, some treatment effects were clearly seen in the more diseased stocks (A and C). Assessed after HWT and subsequent drying, treatments 1 and 4 showed clear advantages in terms of reduced numbers and weights of visibly rotted bulbs identified and removed from the line. No other treatment resulted in such a clear response. When storage rots were assessed some eight weeks later, the benefits of these two treatments was much less apparent, implying a delay in the progress of rots by these two treatments, rather than a prevention or cure. While treatment 1 included both a post-lifting Storite fungicide bulb spray *and* high-temperature drying, treatment 4 included neither of these; the two treatments, however, shared bulb storage at a controlled 17°C rather than at ambient temperatures. Temperature records confirmed that the outdoor summer temperatures at the relevant time were higher than average, and (despite correct ventilation) bulb temperatures were even higher in the bulk bins. The average 'ambient' bulb storage temperature in this period was around 22°C, well into the temperature range (20-30°C) that favours growth of *Fusarium oxysporum*, the basal rot pathogen. This implies that controlled temperature (CT) bulb storage at 17°C is likely to be more effective in reducing post-HWT losses due to basal rot than either a post-lifting fungicide spray or using 'high-temperature' (35°C) drying. In practical terms, using CT storage reduced bulb weight losses (due to bulb rots) from lifting until just after HWT from 40-50% to 30% in affected stocks.

Persistence of disease control during the two-year field phase

Once bulbs have been re-planted in the field it is likely that many other factors will interact with those applied during bulb handling (such as planting density, inoculum levels and nitrogen concentrations). The beneficial effects of reduced bulb losses seen as an apparent consequence of applying treatments 1 and 4 to the diseased stocks (A and C), were still apparent in the estimate of first-year 'relative bulb loss' made for bulbs grown-on at Kirton. In contrast, for bulbs grown-on at the suppliers' farms when assessed at the end of both first and second crop years, no such benefits could be demonstrated. Indeed, with the most diseased stock, C, the most consistent effect observed with bulbs grown at both locations was that treatment 5 increased bulb losses. This is explained by the fact that this treatment contained the highest proportion of infected bulbs at planting as evidenced by the storage rot assessment value of 78% (Table 13). This stock-treatment combination also resulted in the largest percentage yield loss at lifting, 54% (Table 11).

While bulbs of stock B gave consistent and acceptable (though hardly spectacular) weight increases in all six treatments, most treatments resulted in a net *loss* of bulb weight in the other two stocks. In stock A, treatments 1, 2 and 4 gave a zero weight increase from planting, whereas the other treatments resulted in a loss of weight (see Figures 10-12). Thus, the advantages of treatments 1 and 4, suggested as due to the use of 17°C storage, were evident, and it is suggested that the inclusion of a post-lifting thiabendazole spray in treatment 2, also beneficial, might compensate for the lack of CT storage in this case. Treatment 2 resulted in a small percentage weight increase in stock C. None of the treatments applied to stocks A or C came close to

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achieving acceptable percentage yield increases. The benefits of low numbers of infected bulbs in stock B were evident in every assessment made on this stock, regardless of treatment, over the two years of the experiment. However, even stock B, when grown on the supplier's farm, showed percentage bulb rots in the final storage assessment of between 9 and 18%.

Bulb storage tests are useful for eliciting the maximum likely expression of *Fusarium* and other bulb rots, providing a check of bulb quality. Perhaps a less advanced rot at planting can be tolerated by the bulb which will survive and multiply over a two year period, hence it was not surprising that no clear benefits were seen, in storage tests, as a consequence of using treatments 1 or 4. However, as found in other cases (see above), treatment 5 gave very high levels of bulb rots with the most diseased stock, stock C.

Associations between variables

Correlation analysis was used to determine whether there was any association between the variables measured. There were strong associations between the proportion of bulbs lost as rots after completion of HWT with that after the completion of drying treatments. The percentage of bulb weight lost as rots at the end of bulb treatments was also strongly associated with flower and bulb yield and the proportion of marketable bulbs in the lift. The proportion of marketable bulbs in the lift was also strongly associated with storage rots in samples taken at planting. Hence, the eventual bulb yields and disease status are largely, but not entirely, dependent on bulb health at planting.

Choice of bulb handling techniques

For easy reference, the six treatments are repeated here:

Treatment number	*Post-lifting spray*	*First stage drying*	*Second stage drying and storage*	*HWT*
1	Storite	3 days 35°C	17°C	With Storite
2	Storite	Ambient temps	Ambient temps	No Storite
3	None	3 days 35°C	Ambient temps	No Storite
4	None	Ambient temps	17°C	No Storite
5	None	Ambient temps	Ambient temps	With Storite
6	None	Ambient temps	Ambient temps	No Storite

The aim of the project was to determine which of several aspects of bulb handling are the more important in reducing the impact of *Fusarium*-type bulb rots. Although not all the variables measured or stocks used behaved in exactly the same ways in respect to the six treatments, nevertheless two features emerged from an overview of the analyses:

- The best results (lower rots in planting stocks, higher marketable yields) were obtained in bulbs which had received treatment 4 (or, to a less consistent extent, treatments 1 and 2)
- Poor results (higher rots, lower marketable yields) were often found where treatment 5 had been used**.**

Treatments 1 and 4 had different post-lifting spray treatments (Storite spray or no spray), different first-stage drying temperatures (35°C or ambient, respectively), and different HWT treatments (Storite or no Storite), but they both had second stage drying and storage at a controlled 17°C, rather than at ambient temperature. In practice, the ambient temperature around the bulbs was about 22°C, a temperature known to favour the development of basal rot, a result of warmer-than-average summer temperatures in 1999 and the insulating effects of bulb storage in bulk. It was concluded that any significant periods of second stage drying and bulb storage should aim to keep narcissus bulbs at 17°C, and that this treatment was likely to have a more significant effect in reducing bulb rots than using a Storite spray post-lifting, drying bulbs at 35°C, or including Storite in the HWT tank. The less consistently beneficial effect of treatment 2, involving bulb storage at ambient temperatures, presumably resulted from the post-lifting application of Storite, a treatment known, from earlier work, to compensate to some extent for subsequent poor bulb handling[1].

Of the aspects of bulb handling evaluated in this project, the most effective for the management of basal rot was carrying out second stage bulb drying and storage at 17°C. Under UK summer conditions this will require cooling and heating at different times, so, ideally, a high quality CT store would be needed. Starting from scratch, this would involve capital investment of the order of £50k to £100k for a 10 ha bulb enterprise, added to basic bulb drying costs of around £3k *per annum*. However, within the UK bulbs industry the availability of CT storage has increased, with the advent of fewer larger growers, greater capitalisation, and the utilisation of potato stores for narcissus bulbs. Indeed, in many cases the better utilisation of existing facilities might eliminate the need for expensive new storage, and using almost any insulated building would be better than leaving bulbs exposed to natural temperatures. Narcissus bulbs should not routinely be stored below 17°C, as lower temperatures delay internal development. As for other aspects, a prompt post-lifting spray application of Storite has been shown to be effective in controlling basal rot, and is increasingly considered good practice: the cost is around £7k *per annum* for the same size enterprise as above, so this should be considered where it is not already being practised. Adding Storite to HWT is more costly, around 2½-times the cost of the post-lifting spray.

Other aspects of basal rot control

Like roguing, the careful inspection of narcissus bulbs on the cleaning-grading line and the disposal of damaged and soft bulbs, is always recommended but often restricted owing to labour costs. The original intention in this project protocol was to subject the stocks to a good, commercial standard of inspection on the line, but the high proportion of affected bulbs in two of the three stocks used required this to be done to a high standard to safeguard the experiment. At present no automated methods of bulb quality assessment are available, but this approach is of considerable interest. As it has been strongly argued that measures used to 'control' basal rot may merely slow its development[2], the efficient removal of inoculum may be more important than the procedures tested in this project.

The development of basal rot is highly temperature-dependent, so it is expected that a reduction of a few degrees centigrade in the main storage period of narcissus bulbs would reduce the apparent levels of basal rot, as indeed shown here. Increasingly, narcissus bulbs are subjected to higher temperatures, such as high-temperature drying (a potential problem in the warm-up and cool-down phases), warm storage (before HWT), higher HWT temperatures, bulk handling (retaining heat), early planting (into relatively warm soil), and display in warm garden centres, in addition to the possible effects of global warming. It is possible that these factors have, together,

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[1] Linfield, C.A. and Hanks, G.R. (1994). *A review of the control of basal rot and other diseases in narcissus.* Final Report on Project BOF 31, Horticultural Development Council, East Malling.

[2] J.H. Carder, personal communication.

contributed to current raised levels of bulb rots. It may be possible to develop a model of basal rot development that would explain these effects and lead to better handling procedures.

In the longer term, disease-resistant trumpet and long-cup cultivars of narcissus will be developed, but at present Golden Harvest and Carlton continue to be the most widely grown varieties - in the UK – because the vigour and quality of their bulbs and flowers are very high. Although some UK growers are phasing out these cultivars, it is likely that they will remain important for some years to come. Also, there have been instances of a relatively resistant cultivar, St Keverne, to succumbing to basal rot. The 1970's generation of 'Rosewarne' disease-resistant cultivars is not yet widely available, and is in the hands of a relatively few growers. With careful attention to disease management recommendations, however, the other excellent properties of Golden Harvest and Carlton can still make them worthwhile crops.

ACKNOWLEDGEMENTS

The author thanks the staff of HRI Kirton, especially Linda Withers, Pippa Hughes and Rod Asher, for carefully carrying out this work; John Carder (HRI, Wellesbourne) for advice and for examining bulbs; Adrian Jansen (Lingarden Ltd.) for arranging supplies of bulbs for the project; and the staff of the three co-operating bulb firms for their help throughout. I am also indebted to John for his thorough critique of, and interest in, this project.

APPENDIX A

Tables of full results

Table 2[1]. Percentage bulb rots in stored, initial sample. Values are means of six, 100-bulb samples, with SD in parenthesis

Stock	Percentage of sample with rot types						
	Base	Neck	Whole bulb	Mummified bulbs	Soft rot	Narcissus fly	All rots
A	55 (8.4)	1 (0.9)	10 (2.8)	0	1 (0.8)	1 (1.0)	68 (8.6)
B	2 (2.1)	0	1 (0.9)	0	1 (0.8)	1 (0.8)	4 (2.3)
C	47(12.9)	1 (0.5)	33 (8.2)	1 (1.6)	1 (1.2)	0	83 (8.9)

Table 3. Numbers and total weight of rotted bulbs removed per bin (containing *ca.* 375 kg) after drying. Values are means of two bins with SD in parenthesis

Stock	Treatment	Number of bulbs per bin with rot types					Total of all rots	
		Base rot	Neck rot	Whole rot	Mummified bulbs	Narcissus fly	Number per bin	Weight (kg) per bin
A	1	16 (2.8)	7 (4.2)	2 (0.7)	27 (0)	10 (3.5)	61 (1.4)	1.62 (0.051)
A	2	19 (0.7)	8 (7.1)	1 (0.7)	30 (2.8)	6 (2.1)	63 (7.8)	1.52 (0.465)
A	3[1]	20 (7.8)	4 (2.1)	1 (0)	29(17.0)	12 (7.8)	65(34.6)	1.64 (0.946)
A	4	11 (1.4)	1 (0)	1 (0.7)	11 (8.5)	6 (1.4)	30 (4.9)	1.09 (0.201)
A	5	6 (0)	4 (0)	0	22 (5.7)	5 (2.1)	37 (3.5)	0.76 (0.014)
A	6	13 (1.4)	6 (0)	1 (0.7)	34 (1.4)	4 (1.4)	58 (2.1)	1.37 (0.082)
B	1	1 (0.7)	1 (0)	16 (7.1)	0	2 (0.7)	19 (7.1)	1.23 (0.298)
B	2	0	0	4 (0)	0	1 (0.7)	5 (0.7)	0.25 (0.035)
B	3	0	1 (0.7)	21 (4.2)	0	1 (0.7)	22 (5.7)	1.49 (0.354)
B	4	2 (1.4)	1 (0.7)	0	0	1 (0.7)	3 (1.4)	0.14 (0.018)
B	5	3 (2.8)	3 (3.5)	5 (2.1)	0	2 (0.7)	12 (0.7)	0.55 (0.283)
B	6	3 (0.7)	0	6 (4.9)	3 (3.5)	3 (2.1)	13 (4.2)	0.46 (0.212)
C	1	166 (23.3)	16 (6.4)	0	75 (20.5)	11 (0.7)	266(36.8)	12.13 (1.667)
C	2	196 (7.1)	15 (7.8)	0	89 (18.4)	23 (1.4)	323(34.6)	11.18 (1.106)
C	3	237 (7.8)	21 (9.2)	0	107 (16.3)	20 (4.9)	383 (4.2)	17.04 (4.241)
C	4	103 (21.2)	23 (3.5)	0	90 (40.3)	21 (3.5)	236(54.4)	6.04 (0.792)
C	5	128 (20.5)	16 (4.2)	0	93 (14.8)	15(10.6)	251(50.2)	9.28 (1.182)
C	6	126 (0.7)	28(12.7)	0	101 (34.6)	17 (0.7)	271(47.4)	9.76 (0.631)

[1] The high values of the standard deviations (SD) in treatment 3 of stock A were due to particularly high levels of rotting in one of the two bins.

[1] Note that Appendix Tables are numbered to correspond with the numbers of Figures in the main text.

Table 4. Numbers and total weight of rotted bulbs removed per two bins (containing *ca.* 750 kg bulbs originally) after completion of HWT and other treatments

Stock	Treatment	Number of bulbs with rot types					Total of all rots		Weight of sound bulbs (kg)
		Base rot	Neck rot	Whole rot	Mummified bulbs	Narcissus fly	Number	Weight (kg)	
A	1	0	13	280	19	6	318	13.3	556
A	2	0	0	783	0	16	799	38.4	500
A	3	0	56	878	0	0	934	45.3	476
A	4	0	16	375	8	8	408	17.5	562
A	5	0	30	1468	0	0	1498	69.6	451
A	6	0	68	1640	0	0	1708	82.1	478
B	1	3	0	5	0	1	9	0.4	623
B	2	7	0	2	0	1	10	0.6	614
B	3	21	39	12	10	1	83	4.3	620
B	4	8	4	4	0	2	18	0.8	625
B	5	11	7	27	2	2	49	2.5	624
B	6	9	2	16	1	2	30	1.5	637
C	1	0	0	1063	0	22	1085	59.9	560
C	2	0	0	2735	0	56	2791	170.3	415
C	3	0	69	3326	0	69	3465	212.5	394
C	4	0	91	2129	0	45	2265	109.9	543
C	5	0	0	3752	0	0	3752	228.6	390
C	6	0	0	3961	0	81	4042	248.3	378

Table 6. Relative bulb loss after one year (see text) (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	3.7	2.5	4.5	3.6
2	6.2	1.9	7.6	5.3
3	5.3	3.1	8.1	5.5
4	4.5	2.3	4.8	3.9
5	7.6	2.2	22.7	10.8
6	5.1	2.6	9.8	5.8
Mean across six treatments	5.4	2.4	9.6	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	0.81
Treatments	*** (P<0.001)	1.14
Stock x treatment	*** (P<0.001)	1.98

Table 7. Relative bulb loss after one year (see text) – *bulbs grown-on at suppliers' farms* (non-replicated samples of 100 bulbs each)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	2.8	1.3	5.1	3.1
2	1.4	1.6	2.6	1.9
3	3.9	2.0	4.2	3.4
4	3.4	1.7	8.7	4.6
5	3.8	2.4	7.9	4.7
6	3.4	2.4	1.1	2.3
Mean across six treatments	3.1	1.9	4.9	

Table 8. Flower yield in second year of crop growth (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	18.3	29.0	11.0	19.4
2	22.3	31.3	17.7	23.8
3	21.3	24.3	11.3	19.0
4	23.7	24.0	15.7	21.1
5	25.7	28.3	9.7	21.2
6	15.3	27.7	15.0	19.3
Mean across six treatments	21.1	27.4	13.4	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	1.88
Treatments	NS (P=0.480)	2.66
Stock x treatment	NS (P=0.426)	4.60

Table 9. Relative bulb loss after two years (see text) – *bulbs grown at suppliers' farms* (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	2.2	1.7	2.1	2.0
2	1.3	1.4	2.1	1.6
3	1.7	1.1	2.7	1.9
4	1.7	1.1	4.4	2.4
5	1.4	1.2	9.8	4.1
6	1.4	1.0	3.1	1.8
Mean across six treatments	1.6	1.2	4.0	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	0.21
Treatments	*** (P<0.001)	0.30
Stock x treatment	*** (P<0.001)	0.51

Table 10. Yield (kg lifted per plot) of marketable bulbs after 2 years (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	107.0	190.5	76.3	124.6
2	82.0	199.3	78.7	120.0
3	60.7	187.4	48.9	99.0
4	105.7	195.9	95.6	132.4
5	58.4	186.9	16.2	87.1
6	58.8	195.4	38.9	97.7
Mean across six treatments	78.8	192.6	59.1	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	2.67
Treatments	*** (P<0.001)	3.78
Stock x treatment	*** (P<0.001)	6.55

Table 11. Percentage bulb weight increase over 2 years (based on marketable bulbs only and adjusted to compensate for bulb samples recovered in year 1) (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	1.0	95.3	-22.5	24.6
2	5.3	103.2	55.1	54.5
3	-14.6	93.4	11.0	30.0
4	6.4	100.5	3.5	36.8
5	-5.8	91.2	-53.8	10.5
6	-18.5	100.6	2.6	28.3
Mean across six treatments	-4.3	97.4	-0.7	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	3.65
Treatments	*** (P<0.001)	5.17
Stock x treatment	*** (P<0.001)	8.95

Table 12. Percentage (by weight) of marketable bulbs in lift (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	92	99	85	92
2	91	99	92	94
3	91	98	88	93
4	91	98	87	92
5	89	98	76	88
6	90	98	87	92
Mean across six treatments	91	99	86	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	0.9
Treatments	*** (P<0.001)	1.2

Stock x treatment	** (P0.001)	2.2

Table 13. Percentage bulb rots in stored samples after the completion of treatment. Values determined from 100-bulb samples

Stock	Treatment	Percentage of bulbs with rot types				All rots (%)
		Base rot	Neck rot	Whole rot	Mummified bulbs	
A	1	9	0	44	0	53
A	2	4	0	47	0	51
A	3	4	0	56	0	60
A	4	8	0	38	0	46
A	5	2	0	55	0	57
A	6	4	0	60	0	64
B	1	2	0	9	0	11
B	2	0	0	8	0	8
B	3	0	0	0	0	0
B	4	0	0	5	0	5
B	5	6	0	20	0	26
B	6	1	0	2	0	3
C	1	3	0	52	0	55
C	2	1	0	41	0	42
C	3	0	0	54	0	54
C	4	2	2	45	0	49
C	5	1	0	73	4	78
C	6	0	0	66	0	66

Table 14. Percentage bulb rots, in all categories combined, for storage assessment of bulbs after one year's growth (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	31.3	11.3	52.0	31.6
2	46.0	15.3	64.7	42.0
3	28.7	28.7	48.0	35.1
4	37.3	14.0	61.3	37.9
5	37.3	19.3	82.0	46.2
6	30.0	13.3	58.0	33.8
Mean across six treatments	35.1	17.0	61.0	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	2.91
Treatments	* (P=0.011)	4.12
Stock x treatment	* (P=0.017)	7.14

Table 15. Percentage bulb rots in categories for storage assessment of bulbs after one year's growth (figures are marginal means for effects of stock)

Rot category	Stock			Mean across three stocks	Significance	SED (34 df)
	A	B	C			
Basal rot	5.7	10.1	7.0	7.6	** (P=0.005)	1.29
Neck rot	3.1	1.3	2.0	2.2	* (P=0.024)	0.62
Whole-bulb rot	26.3	5.6	52.0	28.0	*** (P<0.001)	2.58
Total of above	35.1	17.0	61.0	37.7	*** (P<0.001)	2.91

Table 16. Percentage bulb rots, in all categories combined, for storage assessment of bulbs *(planted at suppliers' farms)* after one year's growth (non-replicated samples)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	46	9	91	49
2	33	12	77	41
3	53	30	75	53
4	34	15	84	44
5	54	40	82	59
6	39	32	17	29
Mean across six treatments	43	23	71	

Table 17. Percentage bulb rots, in all categories combined, for storage assessment of bulbs after lifting (means of three replicates)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	5.7	2.7	11.7	6.7
2	10.0	1.3	14.0	8.4
3	6.7	2.7	6.7	5.3
4	6.7	3.3	13.3	7.8
5	7.7	2.0	16.3	8.7
6	5.0	2.0	15.7	7.6
Mean across six treatments	6.9	2.3	12.9	

	Significance	SED (34 df)
Stocks	*** (P<0.001)	1.26
Treatments	NS (P=0.453)	1.78
Stock x treatment	NS (P=0.341)	3.09

Table 18. Percentage bulb rots in categories for storage assessment of bulbs after lifting (figures are marginal means for effects of stock)

Rot category	Stock			Mean across three stocks	Significance	SED (34 df)
	A	B	C			
Basal rot	1.3	1.2	4.8	2.4	***(P=<0.001)	0.76
Neck rot	0.4	0.3	0.8	0.5	NS (P=0.107)	0.22
Whole-bulb rot	5.2	0.8	7.3	4.5	*** (P<0.001)	0.91
Total of above	6.9	2.3	12.9	7.4	*** (P<0.001)	1.26

Table 19. Percentage bulb rots, in all fungal rot categories combined, for storage assessment of bulbs after lifting – *bulbs grown at suppliers' farms* (means of three replicate samples)

Treatment	Stock			Mean across three stocks
	A	B	C	
1	78.3	16.7	71.1	55.3
2	56.2	9.2	73.6	46.3
3	57.4	13.3	84.6	51.8
4	40.4	16.1	87.9	48.1
5	50.9	18.3	86.0	51.7
6	71.3	14.2	79.3	54.9
Mean across six treatments	59.1	14.6	80.4	
	Significance	SED (34 df)		
Stocks	*** (P<0.001)	2.74		
Treatments	NS (P=0.156)	3.88		
Stock x treatment	*** (P<0.001)	6.71		

APPENDIX B

Previous history of bulb stocks and details of bulb husbandry at suppliers' farms

	Stock A	*Stock B*	*Stock C*
Cultivar	Carlton	Golden Harvest	Golden Harvest
Previous crop 1996-97	Red beet	Vining peas	Wheat
Bulb treatment in 1997			
Post-lifting spray into store or dip	Storite Clear spray	Storite Clear spray	No
Sprayer type or dip conditions	'Team' sprayer	'Team' sprayer	n.a.
First stage drying temperature	35°C	35°C	Ambient
Second stage drying and storage temperature	18°C	Ambient	Ambient
Handling system	Loose bulk	Loose bulk	Loose bulk
Pre-warming	18°C	18°C	No
Pre-soaking	No	No	No
Sterilising (HWT) conditions	Standard	Standard	Standard
HWT chemicals	Storite Clear	Storite Clear	Storite Clear
Planting date	August 1997	August 1997	August 1997
Spray programme 1997-1998			
Herbicides (and number of applications)	MSS CIPC 40 (1), MSS Linuron 50 (1), Touchdown (1)	Fortrol (1), Gramoxone (1), Canter (2)	n.a.
Fungicides (and number of applications)	Penncozeb WDG + Clinger (3), Penncozeb WDG (1), Benlate (1), Ronilan FL (1), Bravo (2), Rovral Flo (1)	Dithane DF + Ronilan FL + Carbendazim FL (4), Rovral Flo (2)	n.a.
Other chemicals (and number of applications)	Manganese sulphate (5), acid (1)	None	n.a.
Spray programme 1998-1999			
Herbicides (and number of applications)	PDQ + Enhance (2), Fortrol (1), Glyphos (1)	Glyfos (1), Shield (2), Fortrol (2), Gramoxone (1)	Fortrol + PDQ + Enhance (1)
Fungicides (and number of applications)	Dithane Dry Flowable (3), Rover 500 (1), Benlate (3), Stefes Mancozeb DF (1), Mycoguard (1), Dithane 945 (1)	Dithane DF + Ronilan FL + Carbendazim FL (4)	Ronilan (2)
Other chemicals (and number of applications)	Liquid manganese (1), manganese sulphate (4), acid (1)	None	None
Bulb treatments in 1999 for bulbs sent to Kirton			
Foliage removal	Acid	Flailing	Flailing
Interval between foliage removal and lifting	10 days	None	2 days
Lifting date	5 July 1999	29 June 1999	5 July 1999
Lifting machinery	One-stage unmanned	One-stage unmanned	One-stage unmanned

Handling system	Boxes	Loose bulk	Loose bulk
Treatment other than clod removal	None	None	None
Despatch of 6 t bulbs to Kirton	5 July 1999	29 June 1999	5 July 1999
Bulb treatments in 1999 for bulbs retained on farm			
Treatments before drying	Clod removal etc. in yard	Clod removal etc. in yard	Clod removal etc. in yard
Post-lifting spray into store or dip	Storite Clear spray	Storite Clear spray	No
Sprayer type or dip conditions	'Team' sprayer	'Team' sprayer	n.a.
Blow bulbs at ambient until store loaded	Yes	Yes	Yes
Tonnage into store	60 t/day	40 t/day	60-70 t/day
First stage drying temperature	35°C (3 days)	35°C	Ambient
Second stage drying and storage temperature	18°C (7 days)	Ambient	Ambient
Handling during drying	Bulk on-floor	Bulk on-floor	Bulk on-floor
Cleaning/grading etc	Spirals and pre-grading	Star rollers, barrel riddle, dust extraction, grader	Star rollers, coils, barrel riddle, grader
Further storage	In bins, ambient	In bins, 18°C, drying wall	In bins, ambient
Pre-warming	18°C	18°C	No
Pre-soaking	No	No	No
Sterilising (HWT) conditions	Standard	Standard	Standard
HWT chemicals	Storite Clear	Storite Clear	Storite Clear
Post-HWT drying	Drying wall	Drying wall	24 h ventilation
Planting date	7 September 1999	26 August 1999	28 August 1999
For bulbs returned after treatment at Kirton			
Any other pre-plant treatment	No	No	No
Planting date	7 September 1999	25 August 1999	28 August 1999
Other special factors			
	None	None	None
Spray programme 1999-2000			
Herbicides (and number of applications)	Glyphosate (1), Fortrol (1), Butisan S (1), Flexidor 125 (1), Scorpion (1)	Glyphosate + Li-700, Fortrol (2), PDQ	n.a.
Fungicides (and number of applications)	Clortosip (3), Amistar (3), Chlorothalonil (1), Bravo (1)	Dithane DF , Ronilan Fl (3), Carbendazim (3), Karamate DF (2), Tariff, Storite Clear	n.a.
Other chemicals (and number of applications)	Acid (1)	n.a.	n.a.
Spray programme 2000-2001			
Herbicides (and number of applications)	PDQ (1), Cyanazine (1)	Glyphosate, Fortrol (2)	n.a.

Fungicides (and number of applications)	Ronilan FL (1), Stefes Mancozeb DF (1), Benlate (1), Bravo (2), Amistar (2), Folicur (1), Storite Clear Liquid (1)	Ronilan FL (2), Amistar (2), Karamate DF, Carbendazim (2), Micene DF, Rovral Flo, Landmark	n.a.
Other chemicals (and number of applications)	Acid (1)	n.a.	n.a.