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Project leaders:	**Gordon R Hanks** **HRI Kirton** **Boston** **Lincs PE20 1NN**
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Project Co-ordinators:	**Roy Willingham and Adrian Jansen**
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PROJECT LEADER AND AUTHOR OF REPORT

G R Hanks BSc, MPhil, MHort, MBPR(Hort), CBiol, MIBiol

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.

....
(signature)

G R Hanks
Horticulture Research International
Kirton
Boston
Lincs PE20 1NN

Date.........................

Report authorised by:

....
(signature)

R L Wood
Site Manager
Horticulture Research International
Kirton
Boston
Lincs PE20 1NN

Date.........................

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PRACTICAL SECTION FOR GROWERS

Objectives and background

There are suggestions that an acidifier should be added to hot-water treatment (HWT) tanks when narcissus bulbs are being treated with thiabendazole fungicide (Storite Clear Liquid). Acidification is said to prevent the loss of thiabendazole. The object of the project was, under practical conditions, to determine the effects of acidifiers on the concentration of thiabendazole in HWT dips and post-lifting bulb sprays, along with any subsequent effects on the performance of the crop.

Summary of results

Bulbs received standard HWT with formalin and Storite, either with:

- No added acidifier (control)
- The addition of a commercial spray acidifier (Croptex Z.I.P.) at a standard rate (2.5 litres per 1000 litres)
- The addition of sodium bisulphate (sodium hydrogen sulphate) at a standard rate (1.38kg per 1000 litres)
- The addition of sodium bisulphate (as the commercial product Briswim Dry Acid) at a range of rates, increasing daily

For each mixture, HWT was carried out over a 5-day period, with three treatments per day. The pH value and thiabendazole concentration were monitored over this period.

The pH values of the HWT dips were as follows:

- In the control the initial pH was 3.9, and the values stayed in the narrow band between 3.9 and 4.2 throughout the 5 days that the tank was used.
- In the treatment where Croptex Z.I.P. was added (at the maximum recommended rate), the initial pH was slightly lower, at 3.5, and increased slowly to 4.1 by the end of the 5 days of the investigation.
- In the treatment where sodium bisulphate was added at a standard rate with a target pH value of about 2.5, the initial pH was 2.3. This was significantly lower than the Croptex Z.I.P treatment. The pH value rose slowly over the 5-day period to reach 3.3 by the conclusion of HWT, despite the daily addition of additional amounts of 'top-up' acidifier.
- In the treatment where an initially low rate of Briswim Dry Acid was added and additional acidifier was added at the start of each day's dipping to increase pH progressively, the initial pH values at the start of each day were 3.4, 2.8, 2.6, 2.5 and 1.9. Over any one day, the pH value of the dip increased by a pH of about 0.5.

At the recommended rate of Storite Clear Liquid (5 litres of product per 1000 litres of dip) and with a concentration of 220 g of active ingredient per litre of the product, the expected thiabendazole concentration in the tank would be 1.1 mg/ml. This concentration was maintained only in the initial samples of dips with sodium bisulphate added, and in many cases the concentrations determined were much lower. The main findings about total thiabendazole concentrations in the tank were:

- In the control tank the initial thiabendazole concentration was 0.746 mg/ml (68% of the expected concentration). Even during the first dip, this concentration fell considerably. By the end of each day's dips, thiabendazole concentrations had fallen to 42, 23, 22, 22 and 24% of the expected level, respectively.

- Where Croptex Z.I.P. had been used, thiabendazole concentrations were higher than in the control tank, but not markedly so. The initial concentration was 0.776 mg/ml (71% of expected), and by the end of each day thiabendazole concentrations had fallen to 59, 36, 35, 31 and 29% of that expected, respectively.
- Where a fixed rate of sodium bisulphate had been added, the target thiabendazole concentration (1.1 mg/ml) was initially achieved. Over the five days of the investigation, concentrations fell relatively slowly. By the end of each day's dips, thiabendazole concentrations had fallen to 81, 50, 62, 78 and 72% of the expected level, respectively.
- Where increasing amounts of sodium bisulphate (as Briswim Dry Acid) had been added daily to decrease the pH value progressively, the target thiabendazole concentration had almost been achieved initially (1.072 mg/ml or 97% of expected). At the end of the first dip, the concentration had fallen modestly, to 83% of the target concentration. The daily addition of further sodium bisulphate failed to restore the initial concentration of thiabendazole, but these were still higher, at the start of each day's dipping, than in other treatments, at 55, 52, 74 and 71% of the expected value for the four days, respectively. By the end of the final dip on day 5, the thiabendazole concentration was 0.875 mg/ml, 80% of the target value, in excess of the concentrations recorded even in the other sodium bisulphate treatment.

The main effects of the acidifier treatments on subsequent crop growth were:

- In the first year of the crop, plots from sodium bisulphate treatments produced fewer flowers than the controls or those treated with Croptex Z.I.P., although there was no effect of varying the amount of sodium bisulphate, over the range tested.
- In the second year of the crop, bulbs treated with Croptex Z.I.P. produced more flowers than controls or those treated with sodium bisulphate. Again, there was no effect of different rates of sodium bisulphate.
- The number of damaged flowers or buds was negligible in all treatments.
- Crop appearance (including foliage height and stem length) was normal in all treatments.
- Compared with the controls, there were no significant effects on the total yield of bulbs (after two years) of using Croptex Z.I.P. or the standard rate of sodium bisulphate. Yields in the 8 – 12 cm grades of bulbs were lower where this sodium bisulphate treatment was used.
- Where different rates of sodium bisulphate were used, the highest rate (lowest pH) resulted in a lower total bulb yield, associated with a lower yield of 12 – 14 cm grade bulbs and a higher number of rotted bulbs at grading time.
- There were no differences in the subsequent incidence of storage rots between controls and plots treated with Croptex Z.I.P. or the standard rate of sodium bisulphate. However, the two highest sodium bisulphate rates resulted in a higher percentage of storage rots than lower rates.

When Croptex Z.I.P. was added to Storite and used as a post-lifting bulb spray, acidification was not substantially increased, and there was no benefit of increased thiabendazole concentrations. In the first year of the crop, plots treated with the acidifier had many more dead flower buds. Compared with the control, there were no effects of the acidifier treatment on flower numbers or other aspects of crop appearance in the second year, nor on bulb yield.

Action points for growers

The following actions are suggested, but bear in mind these procedures have so far been tested in a limited way and only on cv. Golden Harvest, so caution should be exercised:

- Before using sodium bisulphate, a COSHH assessment should be carried out.
- For the HWT of narcissus bulbs with Storite Clear Liquid (thiabendazole), add sodium bisulphate to the tank at a rate of 1.38 kg per 1000 litres of dip (dissolve the bisulphate in the warm dip before adding the Storite). Check the dip pH, which should be 2.5 - 3.0. The *exact* pH is probably not critical, but do not go lower than pH 2.5. Flower number and bulb yield should not be affected above pH 2.5.
- When topping up tanks, add sodium bisulphate at the same rate as before (1.38 kg / 1000 litres water added). Check the dip pH at intervals. It may be necessary to add further sodium bisulphate to maintain the pH at 2.5 – 3.0.
- Keep to standard procedures regarding the handling and storage of bulbs, HWT conditions and the rates of other chemicals added (including using the recommended rates and top-ups for Storite).
- There is no benefit in adding an acidifier to Storite Clear Liquid when used as a post-lifting spray treatment.
- Please note that the UK Pesticides Safety Directorate have confirmed both in 1998 and in 2000 that the use of such acidifiers does not fall to be regulated as either a pesticide or adjuvant under current UK legislation. All statutory conditions for the use of Storite Clear Liquid must be adhered to.
- Sodium bisulphate is currently classified as absent from List 1 and List 2 of the Groundwater Regulations 1999. Changes to this classification may be made in the future.

Practical and financial benefits from study

For the small additional cost of using sodium bisulphate with Storite in HWT tanks, the effectiveness of the fungicide should be enhanced. However, the main practical and financial benefits would come if it is found possible to used a reduced (half or quarter) rate of Storite fungicide where an acidification treatment is used. It is hoped this will be investigated in an extension to this project.

EXPERIMENTAL SECTION

Introduction

Most UK bulb growers would agree that narcissus basal rot is still the main problem facing the industry. Despite extensive trials with fungicides that have led to detailed advice for bulb growers (e.g., see the Final Report on HDC Project BOF 31), serious cases of basal rot are all too common.

The keystone of current recommendations is the use of a thiabendazole fungicide, Storite Clear Liquid. This is most conveniently, and most usually, applied to bulbs by adding the fungicide to the hot-water treatment (HWT) tank.

When daffodil growers still have inconsistent or disappointing control of basal rot, in spite of using Storite in HWT, possible reasons could include:

- The use of a lower-than-recommended rate of fungicide, inadequate circulation in the HWT tank, or not using correct 'top-up' procedures
- The presence of other over-riding factors, such as poor general hygiene or storing bulbs at inappropriate temperatures, attempting to treat bulb stocks in which the growth of pathogen is already too far advanced by the time of HWT, or planting bulbs into heavily infested soil
- The occurrence of thiabendazole-tolerant and (or) particularly aggressive strains of the basal rot fungus
- The loss of active ingredients in the HWT tank, due to precipitation or degradation of the active ingredient, or its absorption by soil and other debris in the tank

The first two of these points can be addressed directly by growers. The third, the study of the variation between different strains of the pathogen, is currently the subject of MAFF-funded research (MAFF project reference HH1024SBU). The final point, however, involving maintaining the concentration of the active ingredient at the proper level in the HWT tank, is addressed in this project.

There is an 'anecdotal' recommendation in the bulbs industry for adding an acidifier to the HWT dip when bulbs are being treated with thiabendazole. This may have originated in the USA with the addition of acidifier to formulations of thiabendazole being used to treat Dutch elm disease. Many pesticides are known to be broken down by alkaline hydrolysis when exposed to water with a pH value greater that 7 (Hortichem leaflet, see Reference list), including benzimidazole (MBC) fungicides such as benomyl and carbendazim. Water authorities aim to keep their mains water at a pH value above 7 (neutral or slightly alkaline). However, thiabendazole, another MBC fungicide, is reported to be "Stable in aqueous solution regardless of pH" (Wood, 1976). It is "Very stable in aqueous suspension and in acidic media" and "Stable to heat and light" (Tomlin, 1997). Thiabendazole is also more soluble in acidic water, and Storite Clear Liquid is itself an acidic formulation containing thiabendazole as the hypophosphite. Thiabendazole has a solubility in water of less than 0.05g per litre at pH values between 5 and 12 (mildly acidic to strongly alkaline), but of 10g per litre at a pH of 2 (strongly acidic) (Tomlin, 1997). The maximum solubility of thiabendazole in water is given by Wood (1976) as 3.84%, occurring at a pH of 2.2 and decreasing at both higher and lower pH values. In hard water areas, therefore, thiabendazole in solution might be lost by precipitation (and possibly some alkaline hydrolysis), in addition to any losses due to absorption on soil and debris in the tank. The presence of scum and deposits on treated bulbs when Storite is being used, especially in the first one or two dips, suggests a loss of fungicide and subsequently depleted concentrations in the dip tanks (personal communications).

While informal advice circulating in the bulbs industry calls for the addition of an acidifier (sodium bisulphate, sodium hydrogen sulphate) to Storite in HWT tanks, the value of the procedure does not appear to have been tested in a critical way. In a single trial carried out at HRI Kirton in the early 1990s, part of a MAFF-funded project, the effects of standard HWT with Storite were compared with using full- and half-rate Storite with an acidifier (1.38 kg sodium bisulphate per 1000 litres) (G.R. Hanks, unpublished data). In this trial, using the acidifier with a healthy bulb stock did not appear to result in any crop damage, while using the acidifier with a diseased stock decreased the amount of bulb rots with both rates of the fungicide. This rate of acidifier was chosen as it would be expected to produce a pH of about 2.5. Rates of use quoted by bulb growers have ranged from 0.5 to 1.2 kg of sodium bisulphate per 1000 litres. The project described in the present report was designed to test thoroughly the effect of adding acidifiers (sodium bisulphate and a commercial product, Croptex Z.I.P.) to Storite for bulb HWT, so that properly authenticated and rational recommendations can be made. An ideal acidifier for the purpose would have some buffering capacity in its own right (buffering capacity is the ability of a buffer solution to resist changes in its pH in response to added alkali or acid). Phosphoric acid would be effective and cheap, although the concentrated acid would be unpleasant to handle. Sodium bisulphate is a convenient powder that acts as sulphuric acid when in solution.

Daffodil bulbs are sometimes treated with thiabendazole applied as a spray between lifting and storage, as an alternative to, or even as well as, treatment in HWT. Although the fungicide solutions are used quickly in spray treatments and spraying is carried out at ambient temperatures, the same considerations about hard water and acidifiers may apply, and some growers add an acidifier to the spray tank; others say this is unnecessary (personal communications). The spray procedure was, therefore, also be checked in the current project. Results from the first stage of the project were described in the earlier annual report, and this final report brings all the results together.

There are good financial reasons for wishing to optimise the use of thiabendazole in bulb growing. Basal rot is probably the main reason for loss of bulb yield and quality in UK-grown daffodil bulbs. With a farm-gate value (FGV) of around £30m *per annum* for the UK production of daffodil dry bulbs and field-cropped cut-flowers, even a modest improvement of about 5 per cent in bulb and flower yields, through better control of basal rot, would increase FGV by between £1m and £2m. In some cases, much greater benefits might be expected. Storite is an expensive pesticide, currently about £105.50 per 5 litres, so treating one tonne of daffodil bulbs in HWT costs about £32 for the regular top-up solution, in addition to the cost of making up the initial dip. If the benefits of using Storite can be more fully realised, for example by the correct use of an acidifier, then the cost of the fungicide would represent 'money well spent'. In the longer term, healthier bulb stocks should mean that Storite would not have to be used every time bulbs are dipped. MAFF-funded research indicated that the frequency and method (dip or spray) of thiabendazole use should reflect the level of basal rot in the individual stock being treated (G.R. Hanks, unpublished data). In time, therefore, there could be savings in fungicide costs as stock health improves. It is also possible that, if proved useful, the use of an acidifier with Storite would allow a reduced-rate Storite treatment to be used, strongly reducing costs. Even if trials were to show that there is no benefit of using an acidifier, then at least this practice could be abandoned and efforts directed elsewhere.

Materials and methods

Plant material

The HRI-Kirton 'basal rot stock' of narcissus cv Golden Harvest was used in both the post-lifting spray and HWT investigation. This is a stock in which a moderate level of basal rot has been maintained for a number of years by omitting the recommended procedures of using a post-lifting fungicide dip, high temperature (35ºC) drying, and treatment with thiabendazole fungicide in HWT.

The bulk of the stock was lifted on 23-24 July 1998, given an immediate post-lifting dip at ambient temperatures for 15 minutes in formaldehyde and non-ionic wetter, dried at 35ºC for 3 days and then further dried and stored under fans at ambient temperatures until HWT. 180, 10 kg lots of bulbs were allocated from these bulbs for use in experimental treatments; each lot was placed in a net bag and labelled randomly for three replicates of each of 60 treatments.

A further ½ tonne of the stock was lifted on 27 July 1998 and used the next day in the post-lifting spray investigation, without any other prior treatments being given other than holding in a bulk bin overnight under ambient conditions.

As the design of the experiment called for the HWT of full bulk bins of bulbs (thereby simulating commercial treatments), another stock of HRI-Kirton narcissus (variety Carlton) was used to provide a supply of full bins in which the 10 kg experimental lots were to be placed and treated. After lifting this stock in the first week of August 1998, it received the usual post-lifting dip (in thiabendazole, formaldehyde and non-ionic wetter) and was dried for three days at 35ºC and then further dried and stored at ambient temperatures under fans until HWT. The standard concentrations of chemicals used were the same as given below.

HWT investigation

All HWT was carried out using ½-tonne bulk bins of bulbs in tanks with a liquid capacity of 2000 litres. Three replicate, weighed 10 kg lots of bulbs in net bags were placed within each full bin of stock bulbs (see above) for HWT.

HWT tanks were run for each of four 'treatments' for 5 days, with three dips per day. Treatments 1 and 2 were started on 10 August 1998, and treatments 3 and 4 a week later on 17 August. On the day before the start of treatments, the tanks were thoroughly cleaned and washed out, filled with the local mains water and brought to temperature. The following standard chemicals were used in all tanks:

- thiabendazole (10 litres of Storite Clear Liquid per 2000 litres)
- formaldehyde (10 litres of commercial formalin per 2000 litres)

- non-ionic wetter (600 ml Activator 90 per 2000 litres)

The four ‘treatments’ consisted of HWT with different acidifier additions:
- No acidifier (control) (treatment 1)
- Croptex Z.I.P. (5 litres per 2000 litres) (treatment 2)
- Sodium bisulphate (2.76 kg per 2000 litres) (treatment 3)
- Briswim Dry Acid (added at an increasing rate each day to give a range of pH values, see below) (treatment 4)

Normally the acidifier was added to the tank before the other chemicals, although, on the first two days of the sodium bisulphate and Briswim Dry Acid treatments, the acidifier was (in error) added at the same time. From the results obtained this clearly did not have an adverse effect on thiabendazole concentrations.

Croptex Z.I.P. (Hortichem Ltd.) is a formulation containing soluble nutrients (zinc, iron and phosphate), spreading agent (3% alkylbenzenesulfonates) and buffering agents or acidifiers (3% citric acid and 12% phosphoric acid), which is used to acidify pesticide sprays. Croptex Z.I.P. is said to be compatible with most pesticides, and would be expected to be effective with thiabendazole (Hortichem Ltd., personal communication). It was used at the higher recommended rate (250 ml per 100 litres).

Sodium bisulphate ($NaHSO_4$, also known as sodium hydrogen sulphate) was purchased as a technical grade chemical. Briswim Dry Acid (Bartletts Water Chemistry, a division of Ellis & Everard (UK) Ltd) is sodium bisulphate marketed as an acidifier for swimming pools, where it is used to prevent effects such as lime scaling or ineffective chlorination. For use in swimming pools, the recommended rate is 1 kg per 100,000 litres, much lower than that in the present study, but the aim in swimming pools is to keep the pH below 7.8 and ideally around 7.5. Preparatory checks on the supplies of sodium bisulphate and Briswim Dry Acid showed that each gave the expected pH value of 2.6 when dissolved in water at a rate of 1.38 kg per 1000 litres. No significant insoluble residues were left when the materials were dissolved in warm water.

In the case of treatment 4, additional amounts of Briswim Dry Acid were added at the start of each day, to produce a range of target pH values:
- Day 1: 0.5 kg Briswim Dry Acid per 2000 litres (pH 5.5)
- Day 2: 0.5 kg Briswim Dry Acid per 2000 litres (total added 1.0 kg) (pH 4.5)
- Day 3: 1.0 kg Briswim Dry Acid per 2000 litres (total added 2.0 kg) (pH 3.5)
- Day 4: 1.0 kg Briswim Dry Acid per 2000 litres (total added 3.0 kg) (pH 2.5)
- Day 5: 7.0 kg Briswim Dry Acid per 2000 litres (total added 10.0 kg) (pH 2.0)

Each HWT dip consisted of a 3 hour period at 44.4ºC, plus an initial period (of about 15 to 20 minutes) to regain the target temperature following loading the tank with bulbs. After each treatment the bins of bulbs were allowed to drain, dried under fans at ambient temperatures and stored at ambient temperatures until planting. When convenient, the 10 kg lots were recovered from the full bins for planting.

At the end of the day’s dips, tanks were topped-up to the original level with water (usually requiring 100 to 150 litres per tank). Immediately before the next day’s dips were started, chemicals were replenished as follows:

- Formaldehyde was added such that the concentration in the top-up volume was equivalent to that originally used (0.5 litres commercial formalin per 100 litres). Additional amounts of top-up formalin were considered, but as the formaldehyde analyses showed a steady concentration (see below) this was considered unnecessary
- Wetter was added such that the concentration in the top-up volume was equivalent to that originally used (30 ml Activator 90 per 100 litres)
- Thiabendazole was added at the recommended rate of 1.5 litres Storite Clear Liquid per tonne of bulbs treated (i.e., 2.25 litres per day)
- Croptex Z.I.P. (treatment 2) was added such that the concentration in the top-up volume was equivalent to that originally used (0.25 litres per 100 litres). In the light of the pH values obtained, additional amounts of top-up were considered unnecessary
- Sodium bisulphate (treatment 3) was added such that the concentration in the top-up volume was equivalent to that originally used (0.138 kg per 100 litres). However, as a rapid loss of acidity was observed, additional amounts were added in an attempt to maintain approximately the required pH (an additional 0.25 kg per tank on days 2 and 3, and 0.5 kg per tank on days 4 and 5)
- Briswim Dry Acid concentration (treatment 4) was increased daily as part of the experimental protocol (see above), in addition to 'top-ups'. Each day's basic top-up amount was related to the previous day's concentration. The additional amounts of top-up were the same as for treatment 3

HWT tank temperatures and circulation were maintained throughout the 5-day periods.

<u>Samples and records taken during HWT</u>

pH value of dips

On the first day of each treatment, the pH value of the tank dip was recorded at the start, and after one and two hours and at the end of the first dip, then at the end of the second and third dips. On subsequent days, the pH value was recorded at the start of dipping and at the end of each dip.

The pH value of the mains water used was also measured initially and each day when topping-up.

Buffering capacity

The buffering capacity of the mains water and of the tank solutions was determined at the start and end of each 5-day run. For treatment 4, buffering capacity was also determined at the start of each day. Sodium hydroxide (0.2N) was added drop-wise to 50 ml samples of water or dips, and the volume needed to raise the pH of the sample by 1.0 pH units was recorded.

Thiabendazole concentration

Samples of dip (each *ca.* 100 ml) were taken for analysis according to the following schedule:

- For treatments 1 to 3:
  - At the start of the first dip (three samples from treatment 1)
  - After 1 and 2 hours in the first dip
  - At the end of the first, second and third dips on the first day (three samples from

treatment 1 after the third dip)
    - At the end of each subsequent day's dips
- For treatment 4 (increasing pH values):
    - At the start and end of the first dip each day
    - At the conclusion of the final dip

Samples were not replicated except as indicated, where additional samples were taken to check the reproducibility of results. All samples were stored in polypropylene bottles, frozen immediately, and kept frozen until analysis, in order to prevent further degradation of the thiabendazole. Analysis was carried out by Agrisearch (Analytical) Ltd using high-performance liquid chromatography (HPLC) with diode array detection; a copy of the analytical report was given in Appendix 2 of the earlier annual report.

Formaldehyde concentration
The formaldehyde concentration of the tank dips was checked at the end of the first, second and third dips on the first day of each treatment, and also at the start and end of each day's dips in all treatments. Formaldehyde concentrations were determined using a standard titration method (see Appendix 1 of the earlier annual report).

Dip temperature
Tank temperatures were logged throughout the treatments.

<u>Post-lifting spray investigation</u>

On 28 July 1998 bulbs, freshly lifted the previous day and otherwise untreated, were treated on a roller table with a spray application of thiabendazole, using standard hydraulic nozzles. There were two separate runs:

- Using thiabendazole only, with no other chemicals added. The rate used was 1 litre Storite Clear Liquid, diluted to 5 litres with local mains water, per tonne of bulbs.
- Using thiabendazole (as above) but with Croptex Z.I.P. acidifier added first at a rate of 12.5 ml per 5 litres.

The two spray mixtures were made up fresh at the start of the day and were kept agitated at intervals over an 8-hour working period. However, as there was no requirement for continuous bulb treatment, the sprays were used and bulbs passed down the line only to obtain samples of treated bulbs at the start and after 2, 4, 6 and 8 hours for either treatment. Non-replicated samples of solutions (*ca.* 25ml) were taken for thiabendazole analysis from each spray tank initially and then at the same intervals as bulbs were treated. These samples were stored and analysed as described for the main investigation (see above). The pH values of the solutions were determined at the same times. All treatments were at ambient temperatures.

For each 'treatment', 40 kg bulbs (plus an allowance for spares) were treated. Each *ca.* 40 kg lot was collected as four approximately equal 'replicates' (sub-samples). After spray treatment the bulbs received standard treatments consisting of 3 days' drying at 35ºC, further drying and storage under fans at ambient temperatures, standard HWT with formaldehyde and non-ionic wetter, and surface-drying and storage until planting at ambient temperatures. As convenient, the weight of each 'replicate' was adjusted to 10 kg ready for planting.

Planting and cultural practices

Bulbs for both the HWT and post-lifting spray investigations were planted in the field on 8 September 1998. Following the usual procedures for planting field trials at Kirton, the trials areas was ridged out (ridges at 0.76 m centres) and the position of plots marked in the furrows using fibre-glass canes. The bulbs were placed evenly in the plots by hand and covered by splitting-back the ridges. Each plot consisted of a single length of ridge 6.6 m long, giving a planting rate of about 20 t/ha.

In addition to these experimental plots, the first bin of stock bulbs from the HWT experiment for treatments 1, 2 and 3, and the first bin of each day's dipping from treatment 4, were planted by machine in pairs of labelled rows in the field at a density of 20 t/ha.

The husbandry of the bulbs followed standard two-year-down commercial practices for the area. Fertilisers were applied according to analysis and MAFF recommendations (potash in the base pre-planting, nitrogen as a top dressing pre-emergence). Weed control was by dormant season diquat + paraquat, pre-emergence cyanazine and post-emergence chlorpropham + linuron, all used according to standard recommendations. Crops received a fungicide spray programme, with five sprays in the first year (iprodione, chlorothalonil, vinclozolin, mancozeb + benomyl, chlorothalonil) and three in the second year (iprodione, chlorothalonil, vinclozolin). Flowers were not cropped.

Bulbs were harvested on 19 July 2000 (HWT investigation) and 20 July 2000 (spray investigation) by elevation to the surface with a single-row bulb lifter, then picking bulbs by hand into standard bulb trays. Immediately prior to lifting the bulbs were defoliated by mechanical flailing. Bulbs were dried using fans at ambient temperatures, then cleaned and split by hand ready for recording yields.

Crop records

The appearance of all experimental plots was checked at shoot emergence, flowering and early senescence for any abnormalities. In the first and second years the number of flowers was counted in each experimental plot, along with the number of any flower abnormalities (e.g., shrivelled buds or 'starry' flowers) in each. In the second flowering season only, stem and foliage lengths were measured for ten central plants of each plot. The stock plantings were used for general observations and a photographic record only. After bulb lifting, bulbs were graded and the weight in each grade (<8, 8-10, … 16-18 and >18 cm circumference) was recorded following the removal of any obviously rotted bulbs, the weight of which was noted separately. Sound bulbs of 10-12 and 12-14 cm grades were mixed and replaced in trays and stored in a shed at ambient temperatures for the assessment of storage rots.

Bulb rot assessments

In mid-November 2000, 100 bulbs from each plot were bisected lengthwise and examined for rots. Bulbs and rots were classified into typical base rot, neck rot (*Fusarium*- or *Penicillium*-type), whole-bulb rot (where the start of the rot could not be identified) or mummified (completely rotted and desiccated) bulbs.

Experimental design and statistical analysis

For each experiment a randomised block design was used, with 60 treatments (four acidifier treatments x 15 dips) and three blocks for the HWT investigation, and 10 treatments (two acidifier treatments x five times) and four blocks for the spray investigation. Guard bulbs were planted round the edges of each trial. The data were subjected to the analysis of variance as appropriate. The initial planting weight was used as a co-variate, but as the co-variate effect was found to be non-significant, the unadjusted data are presented in Results. The main experiment was arranged to (a) compare the use of no acidifier, Croptex Z.I.P. and a standard rate of sodium bisulphate, and (b) to compare the effects of increasing the sodium bisulphate rate; as this resulted in a non-balanced design, data for the two parts of the experiment were analysed separately.

Results

HWT investigation

pH values of dips

The pH values of the HWT dips are given in Table 1 and Figure 1. These showed:

- In the control (no acidifier added) the initial pH was 3.9, and the values stayed in the narrow band between 3.9 and 4.2 throughout the 5 days that the tank was used.
- In treatment 2, where the commercial acidifier Croptex Z.I.P. was added at the maximum recommended rate, the initial pH was slightly lower, at 3.5, and increased slowly to 4.1 by the end of the 5 days of the investigation.
- In treatment 3, where sodium bisulphate was added at a moderate rate with a target pH value of about 2.5, the initial pH was 2.3, significantly lower than the Croptex Z.I.P treatment. The pH value rose slowly over the 5 day period to reach 3.3 by the conclusion of HWT, despite the addition of additional amounts of acidifier (see Materials and methods).
- In treatment 4, where an initially low rate of Briswim Dry Acid was added and additional acidifier was added at the start of each day's dipping to create a range of increasing pH values, the initial pH values at the start of each day were 3.4, 2.8, 2.6, 2.5 and 1.9, respectively. Over any one day, the pH value of the dip increased by a pH of about 0.5.

Table 1. pH values of HWT dips

Sample time			pH value of dips in four treatments			
Day no.	Dip no. and stage	Time from start (hours)	Control	Croptex Z.I.P.	$NaHSO_4$	$NaHSO_4$ (incr. rate)
1	1 (start)	0	3.9	3.5	2.3	3.4
1	1 (after 1 hour)	1	4.0	3.6	2.5	3.6
1	1 (after 2 hours)	2	3.9	3.6	2.5	3.6
1	1 (end)	3	3.9	3.6	2.5	3.5
1	2 (end)	7	4.1	3.7	2.8	3.7
1	3 (end)	11	4.2	3.8	3.0	3.8
2	1 (start)	24	4.1	3.8	2.9	2.8
2	1 (end)	27	4.2	3.8	3.1	3.2
2	2 (end)	31	4.2	3.8	3.2	3.4
2	3 (end)	35	4.2	3.9	3.3	3.5
3	1 (start)	48	4.2	3.9	3.0	2.6
3	1 (end)	51	4.2	3.9	3.2	2.8
3	2 (end)	55	4.2	3.9	3.3	3.0
3	3 (end)	59	4.1	3.9	3.4	3.2
4	1 (start)	72	4.2	4.0	3.1	2.5
4	1 (end)	75	4.1	3.9	3.1	2.6
4	2 (end)	79	4.1	4.0	3.2	2.8
4	3 (end)	83	4.2	4.0	3.3	3.0
5	1 (start)	96	4.2	4.1	2.9	1.9
5	1 (end)	99	4.1	4.1	3.0	1.9
5	2 (end)	103	4.2	4.1	3.2	2.1
5	3 (end)	107	4.2	4.1	3.3	2.2

pH of water supply

The pH values of the water supply used to fill and top-up the HWT tanks each day are shown in Table 2. On the first day of the investigation a pH value of 7.3 was recorded; thereafter, the pH varied between 7.6 and 7.8. One possible explanation of the initially lower value would be the presence of 'stale' water in the system following a period of disuse.

Table 2. pH values of water supply

Date	Mains pH value
10 August	7.3
11 August	7.8
12 August	7.8
13 August	7.8
14 August	7.8
17 August	7.8
18 August	7.8
19 August	7.7
20 August	7.8
21 August	7.6

Buffering capacity of dips

The buffering capacity of dips was measured at the start and end of each 5-day run for each of the four treatments, and results are given in Table 3. This illustrates that the buffer capacity of the dip was progressively increased by adding Croptex Z.I.P. or by increasing concentrations of sodium bisulphate.

Table 3. Buffer capacity of HWT dips

Sample time			Buffer capacity (ml)*			
Day no.	Dip no. and stage	Time from start (hours)	Control	Croptex Z.I.P.	$NaHSO_4$	$NaHSO_4$ (incr. rate)
1	1 (start)	0	0.5	1.0	1.7	0.7
2	1 (start)	24	-	-	-	0.8
3	1 (start)	48	-	-	-	1.0
4	1 (start)	72	-	-	-	1.3
5	1 (start)	96	-	-	-	6.3
5	3 (end)	107	0.6	0.8	1.2	4.2

* see text for details

Thiabendazole concentration

The concentrations of total thiabendazole circulating in the tanks are given in Table 4 and Figures 2 and 3. At the recommended rate of Storite Clear Liquid (5 litres of product per 1000 litres of dip) and with a concentration of 220 g of active ingredient per litre of the product, the expected initial thiabendazole concentration would be 1.1 mg/ml. This concentration was achieved only in the initial samples of dips with sodium bisulphate added, and in many cases the concentrations determined were much lower. The main findings were:

- In the control tank (with no added acidifier) the initial thiabendazole concentration was 0.746 mg/ml (68% of the expected concentration). Even during the first dip, this concentration fell considerably. By the end of each day's dips, thiabendazole concentrations had fallen to 42, 23, 22, 22 and 24% of the expected level, respectively.
- Where Croptex Z.I.P. had been used, thiabendazole concentrations were higher than in the control tank, but not markedly so. The initial concentration was 0.776 mg/ml (71% of expected), and by the end of each day thiabendazole concentrations had fallen to 59, 36, 35, 31 and 29% of that expected, respectively.
- Where a fixed rate of sodium bisulphate had been added, the target thiabendazole concentration (1.1 mg/ml) was initially achieved. Over the five days of the investigation, concentrations fell relatively slowly. By the end of each day's dips, thiabendazole concentrations had fallen to 81, 50, 62, 78 and 72% of the expected level, respectively.
- Where increasing amounts of sodium bisulphate (as Briswim Dry Acid) had been added daily to decrease the pH value progressively, the target thiabendazole concentration had almost been achieved initially (1.072 mg/ml or 97% of expected, probably well within the limits of experimental error). At the end of the first dip, the concentration had fallen modestly, to 83% of the target concentration. The daily addition of further sodium bisulphate failed to restore the initial concentration of thiabendazole, but these were still higher, at the start of each day's dipping, than in other treatments at 55, 52, 74 and 71% of the expected

value for the four days, respectively. By the end of the final dip on day 5, the thiabendazole concentration was 0.875 mg/ml, 80% of the target value, in excess of the concentrations recorded even in the other sodium bisulphate treatment.

Table 4. Total thiabendazole concentration in HWT dips

Sample time			Thiabendazole concentration (mg/ml)			
Day no.	Dip no. and stage	Time from start (hours)	Control	Croptex Z.I.P.	$NaHSO_4$	$NaHSO_4$ (incr. rate)
1	1 (start)	0	0.746	0.776	1.108	1.072
1	1 (after 1 hour)	1	0.389	0.764	0.889	-
1	1 (after 2 hours)	2	0.367	0.798	0.902	-
1	1 (end)	3	0.696	0.850	0.428	0.909
1	2 (end)	7	0.427	0.441	0.705	-
1	3 (end)	11	0.459	0.646	0.894	-
2	1 (start)	24	-	-	-	0.605
2	1 (end)	27	-	-	-	0.504
2	3 (end)	35	0.250	0.396	0.550	-
3	1 (start)	48	-	-	-	0.569
3	1 (end)	51	-	-	-	0.984
3	3 (end)	59	0.246	0.390	0.677	-
4	1 (start)	72	-	-	-	0.810
4	1 (end)	75	-	-	-	0.738
4	3 (end)	83	0.247	0.338	0.862	-
5	1 (start)	96	-	-	-	0.778
5	1 (end)	99	-	-	-	0.845
5	3 (end)	107	0.261	0.323	0.791	0.875

Figure 1. The effect of acidifiers on the pH of HWT Storite dips

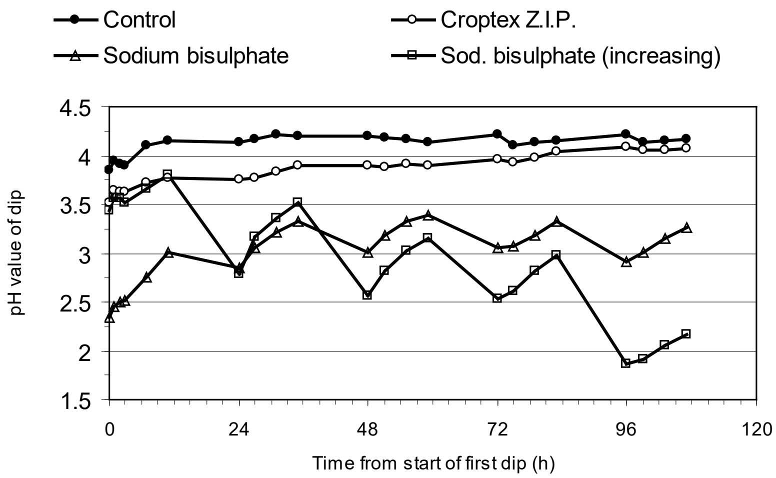


Figure 2. The effect of acidifier on thiabendazole concentrations in HWT

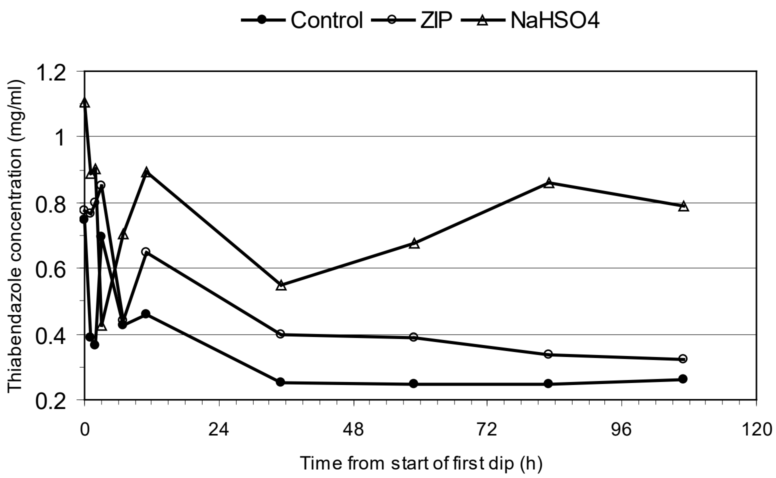
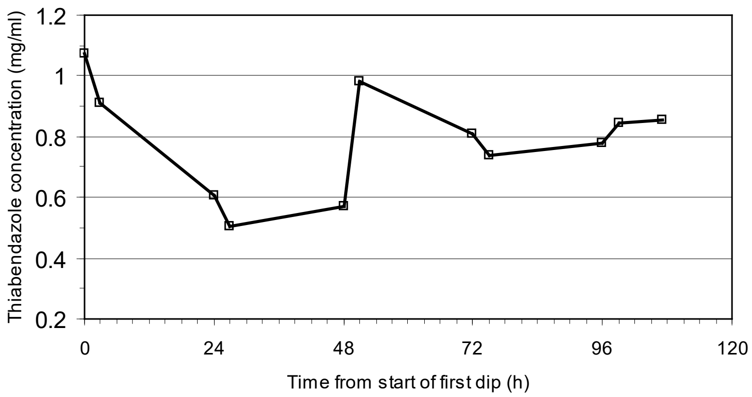


Figure 3. The effect of daily increasing rate of sodium bisulphate on thiabendazole concentrations in HWT



These results refer to the total concentration of thiabendazole in dips, that is, that in solution plus that in suspension; this is considered a reasonable expression of the 'available' thiabendazole in the tanks, as it is supposed that solid fungicide particles lodging on bulbs will be effective as well as thiabendazole in solution. As a check of the ratio of dissolved to total thiabendazole in the dips, dissolved thiabendazole was also determined in six samples, and the results are shown in Table 5. These measurements showed that about 90% of the total thiabendazole was present as the dissolved material. Differences in this ratio between the start and end of dips, and between the treatments, showed no clear trends. Some white deposit, presumably fungicide, was seen on the floor of all tanks when they were emptied.

Table 5. Concentration of total and dissolved thiabendazole in HWT dips

Sample details				Thiabendazole concentration (mg/ml)		
Day no.	Dip no. and stage	Time from start (hours)	Treatment	Dissolved	Total	Percentage dissolved
1	1 (start)	0	Control	0.903	0.943	95.8
1	1 (start)	0	$NaHS0_4$	1.029	1.108	92.9
1	1 (start)	0	$NaHS0_4$ incr.	0.945	1.072	88.2
5	3 (end)	107	Control	0.227	0.261	87.0
5	3 (end)	107	$NaHS0_4$	0.666	0.791	83.4
5	3 (end)	107	$NaHS0_4$ incr.	0.782	0.875	89.4

Formaldehyde concentration

Formaldehyde was determined regularly throughout the investigation (Table 6). The standard rate of commercial formalin added to HWT tanks should produce a concentration of 0.20% w/v of active ingredient (formaldehyde), although previous checks with the same supply of formalin had typically given concentrations of about 0.18% w/v. In the investigation, the concentrations found varied slightly, between 0.17 and 0.19%, in line with previous experience, but there were virtually no changes over the 5-day periods within a tank. This indicated that the formalin top-up procedures were adequate and that there were no adverse interactions with the different acidifiers.

Table 6. Formaldehyde concentrations in HWT dips

Sample time			Formaldehyde concentration (%)			
Day no.	Dip no. and stage	Time from start (hours)	Control	Croptex Z.I.P.	$NaHSO_4$	$NaHSO_4$ (incr. rate)
1	1 (start)	0	0.18	0.17	0.19	0.19
1	1 (end)	3	0.17	0.17	0.19	0.19
1	2 (end)	7	0.18	0.17	0.19	0.19
1	3 (end)	11	0.17	0.17	0.19	0.18
2	1 (start)	24	0.17	0.17	0.18	0.18
2	3 (end)	35	0.17	0.17	0.18	0.19
3	1 (start)	48	0.17	0.17	0.19	0.19
3	3 (end)	59	0.17	0.17	0.19	0.19
4	1 (start)	72	0.17	0.17	0.19	0.19
4	3 (end)	83	0.17	0.17	0.19	0.19
5	1 (start)	96	0.17	0.17	0.19	0.19
5	3 (end)	107	0.17	0.17	0.19	0.19

Temperature
HWT temperatures were recorded and remained in tolerance (±0.5°C) throughout the treatments.

Crop growth and flower yield – year 1
Crop appearance appeared vigorous and normal in all experimental plots, and in the stock plantings, throughout the first year's growth. There were, however, significant treatment effects in the number of flowers produced. The analysis of the three main treatments (no acidifier, Croptex Z.I.P. and standard rate of sodium bisulphate) showed that most flowers were produced in Z.I.P.-treated bulbs, and least in those that had received dips with sodium bisulphate (Table 8). The difference between flower numbers in the Z.I.P. treatment and the control was not statistically significant, although the difference between the control and sodium bisulphate treatment was. In the analysis of treatments with an increasing rate of Briswim Dry Acid, there was no statistically significant effect of changing pH, but a significant effect of dip number, with more flowers produced from plots treated in the second dip of each day (Table 9). In both analyses there were a just-significant interactions between acidifier treatment and dip number, but this appeared to reflect random variations in results over the course of dip treatments.

Table 8. Effect of three acidifier treatments and dip number (1-15) on flower and bulb yield

	Flowers / plot		Bulb yield (kg / plot)		
	Year 1	Year 2	8-10cm grade	10-12 cm grade	All grades
Acidifier					
None	185.2	213.7	1.457	3.612	17.02
Z.I.P.	188.4	230.0	1.463	3.576	17.45
Sodium bisulphate	170.3	211.3	1.289	3.349	16.85
SED (88 df)	2.65	4.11	0.0465	0.0917	0.324
Dip number					
1	182.7	218.7	1.450	3.954	17.59
2	181.9	222.7	1.584	3.515	17.42
3	177.4	219.7	1.300	3.282	17.06
4	188.4	217.9	1.358	3.773	17.26
5	178.0	208.6	1.343	3.662	17.02
6	182.2	225.9	1.573	3.761	17.28
7	173.2	218.1	1.321	3.434	16.78
8	176.3	213.6	1.544	3.448	16.72
9	172.6	205.4	1.272	3.159	15.86
10	186.8	221.0	1.437	3.256	16.82
11	188.0	229.8	1.249	3.681	18.17
12	183.9	218.4	1.272	3.220	17.20
13	181.2	217.9	1.528	3.424	16.90
14	188.9	216.6	1.317	3.569	17.70
15	177.7	220.6	1.497	3.548	16.81
SED (88 df)	5.93	9.20	0.1801	0.3550	0.724
Significance					
Acidifier	***	***	***	*	NS
Dip number	NS	NS	**	**	NS
Interaction	*	NS	NS	NS	NS

Table 9. Effect of five pH levels and dip number (1-3) on flower and bulb yield and storage rots

	Flowers / plot		Bulb yield (kg / plot)			% rots in storage test
	Year 1	Year 2	12-14 cm grade	All sound grades	Bulbs rotted at grading	
pH of dip						
3.4	170.1	212.6	4.487	16.96	0.415	5.8
2.8	171.9	207.6	4.376	17.23	0.683	7.1
2.6	171.6	208.4	4.439	17.37	0.649	7.8
2.5	167.7	203.6	4.342	16.53	0.752	10.3
1.9	169.3	193.9	3.741	15.11	1.040	12.4
SED (28 df)	4.51	8.57	0.2488	0.612	0.1560	2.03
Dip number						
1	168.2	200.2	4.219	16.46	0.803	9.1
2	177.1	208.5	4.487	17.12	0.641	7.3
3	165.0	206.9	4.125	16.35	0.680	9.7
SED (28 df)	3.50	6.64	0.1927	0.474	0.1208	1.57
Significance						
Acidifier	NS	NS	*	**	**	*
Dip number	**	NS	NS	NS	NS	NS
Interaction	*	NS	NS	NS	NS	NS

Crop growth and flower yield – year 2

Crop appearance was again normal throughout. As in the first year, the number of flowers produced (for the three main treatments) was highest where Z.I.P. had been used and lowest where sodium bisulphate had been used, the greater flower numbers in the Z.I.P. treatment being significantly higher than the control in this case (Table 8). For the Briswim treatments, there were no significant differences in the number of flowers produced in from different pH treatments (Table 9). In both analyses, there were no effects of dip number and no interactions between acidifier treatment and dip number.

The quality of flowers was examined carefully when they were fully open. Only small numbers of dead buds (where the buds within the spathe are desiccated), small 'starry' flowers and flowers with damaged trumpets were found, and no statistically significant effects of treatments could be discerned at these low levels. In the three main treatments the overall mean numbers of flowers per plot with these defects were 0.04, 0.10 and 0, respectively, and for the Briswim treatments, 0.07, 0.20 and 0.02.

Mean foliage and stem lengths were also analysed. No significant effects due to treatments were found.

Bulb yield

Among the three main treatments there were no significant effects on the total yield of sound bulbs lifted. The overall mean of percentage weight increase from planting was 73%. In most cases there were also no significant effects on the yield of bulbs in individual grades, but effects due to acidifier and dip number were significant in the 8-10 and 10-12 cm grades (Table 8). In both cases these grades yielded less where sodium sulphate had been used, while the apparently significant effect of dip number seemed probably due to random variations over the course of dip treatments. The amount of bulbs with rots at grading was small (overall, 0.80 kg per plot), and there were no significant effects of treatments.

The analysis for Briswim treatments showed a significant effect of pH on the total yield of sound bulbs, with lower yields in the two lowest pH treatments (Table 9). The mean of the percentage weight increases from planting for the five treatments, in order of decreasing pH, were 72, 72, 75, 66 and 51%. For yields in individual grades, only 12-14 cm grade bulbs were significantly affected by treatments, with a smaller yield where the lowest pH had been used. There were no effects of dip number on bulb yields. The amount of bulbs with rots at grading was significantly affected by pH, with means, in order of decreasing pH, of 0.42, 0.68, 0.65, 0.72 and 1.04 kg per plot (Table 9).

Storage assessments

For the three main treatments there were no significant effects of treatments (acidifier or dip number) on the incidence of bulb rots in storage. The overall percentages for the different types of rot were: base rot, 4.2%; neck rot, 4.4%; and whole-bulb rot, 1.4%, a combined total for all types of rot of 10.0%. At these relatively high percentages, it would be expected that any significant effects would be detected by the statistical analysis.

For the Briswim treatments the overall percentages of rot types in storage were: base rot, 4.6%; neck rot, 3.5%; and whole-bulb rot, 0.7%, and no significant differences were indicated. However, when all types of rot were combined there was a significant effect of pH (Table 9). In order of decreasing pH, the percentage of bulb rots was 5.8, 7.1, 7.8, 10.3 and 12.4%.

Post-lifting spray investigation

pH values of sprays

The pH of the two Storite sprays (with and without added acidifier) ranged from 1.74 to 1.82 over the 8-hour period of the investigation, a range probably well within the limits of error of the pH meter. After standing overnight the pH values of the two solutions were 1.71 (with acidifier) and 1.77 (without acidifier). The pH value of the mains water used for making up the solutions was 7.28. There was no obvious 'scum' or precipitate in either spray tank.

Thiabendazole concentration

The concentrations of thiabendazole in the spray tank are shown in Table 10. At the recommended rate of Storite Clear Liquid (1 litre of product per 5 litres of spray) and with a concentration of 220 g of active ingredient per litre of the product, the expected initial thiabendazole concentration would be 44 mg/ml. Approximately this concentration was achieved in all samples, the range of values being from 42.5 to 52.7 mg/ml. There were no consistent effects over the 8 hours of the investigation, and no consistent difference between the control solution and the solution to which acidifier had been added.

Table 10. Total thiabendazole concentration in spray tanks

Time from start (hours)	Thiabendazole concentration (mg/ml)	
	Control	Croptex Z.I.P.
0	42.53	46.04
2	43.08	42.74
4	52.73	48.13
6	44.33	43.70
8	43.73	43.01

Crop growth and flower yield – year 1

There were significant effects of using Croptex Z.I.P. on flower viability in the first year of the crop (Table 11), although the total number of flowers (viable flowers plus dead buds) was not affected. Using the acidifier significantly increased the proportion of dead buds. Apart from this, crop appearance was normal.

Table 11. Effect acidifier and spray number (1-5) on flower and bulb yield and storage rots

	Dead buds / plot	Flowers / plot		Bulb yield (kg / plot)		% rots in storage test	
	Year 1	Year 1	Year 2	10-16 cm grades	All grades	Neck rot	All rot types
Acidifier							
None	37.0	127.4	198.6	11.67	15.64	4.9	19.8
Croptex Z.I.P.	56.6	107.4	203.3	12.08	16.07	7.3	21.2
SED (27 df)	3.67	4.90	7.80	0.382	0.551	0.97	2.27
Spray number							
1	49.1	115.6	191.0	10.34	14.12	6.5	25.8
2	35.4	112.9	181.4	10.33	13.67	6.9	24.6
3	50.7	112.0	195.1	11.29	15.37	7.1	20.9
4	53.1	115.7	211.9	13.45	17.57	4.6	16.6
5	45.6	130.9	225.4	13.98	18.55	5.4	14.7
SED (27 df)	5.80	7.74	12.33	0.604	0.871	1.53	3.60
Significance							
Acidifier	***	***	NS	NS	NS	*	NS
Spray number	*	NS	*	***	***	NS	*
Interaction	NS	NS	NS	**	NS	NS	NS

Crop growth and flower yield – year 2

Crop appearance was normal, and there were no significant effects of using Croptex Z.I.P. on the number of flowers (Table 11) or on foliage or stem length. Virtually no damaged flowers were seen in either case. There were small but statistically significant effects of spray number on the number of flowers (more being produced with later treatments; Table 11) and on stem length (the effect was irregular with no clear trends).

Bulb yield

There were no significant effects of using Croptex Z.I.P. on total bulb yield or bulb yields in individual grades. However, there were significant effects of spray number on the total yield of bulbs, and on the yield of bulbs in the 10-12, 12-14 and 14-16 cm grades (the saleable grades) (Table 11), accompanied by some weak but significant interactions between acidifier treatment and spray number. Bulb yields were higher with later spray treatments.

Storage assessments

The overall percentages for the different types of rot were: base rot, 7.1%; neck rot, 6.1%; whole-bulb rot, 7.3%; and mummified bulbs, 0.13%, a combined total for all types of rot of 20.5%. The only statistically significant effect on individual types of rot was on neck rot, where there were more bulbs affected when Croptex Z.I.P. had been used (Table 11). There were no effects of acidification on the overall total of bulbs with rots, but the incidence of bulb rots decreased significantly with later spray treatments (Table 11).

Discussion

The pH value of standard HWT dips (comprising Storite Clear Liquid, commercial formalin and wetter) remained very close to 4.0 throughout the 5-day period of the investigation. Adding the higher recommended rate of a commercial spray acidifier, Croptex Z.I.P., reduced the pH of the dip only slightly, by no more than 0.5 pH units. In both the 'control' and 'Z.I.P.' tanks the concentration of thiabendazole was initially lower than expected, then fell rapidly over the first few hours of dipping, continuing to fall more slowly thereafter. Thiabendazole concentrations were consistently somewhat higher with Z.I.P. acidifier than without acidifier; even so, the concentration had fallen to less than half of the expected level within one working day in the case of the control, and within two working days in the case of the 'Z.I.P.' treatment.

The addition of substantial quantities of sodium bisulphate (either as the technical grade chemical or as Briswim Dry Acid), lowered pH values and increased thiabendazole concentrations significantly. Used at a rate of 1.38 kg per 1000 litres, a rate derived from previous usage, the starting pH value of the dip was 2.5, about 1.5 pH units lower than the control. Thereafter, the pH value of the dip drifted upwards by approaching 0.5 pH units during the working day, and replacing the acidifier daily (by 'topping-up' plus adding an additional 0.125 or 0.250 kg per 1000 litres) succeeded in keeping the pH between 3.0 and 3.5. In general terms, these procedures maintained a thiabendazole concentration around 0.6 to 0.8 mg/ml (compared to the 'target' of 1.1 mg/ml), much greater than in the control or the 'Z.I.P.' treatment. Adding Briswim Dry Acid in increasing amounts produced pH values of about 3.4, 2.8, 2.6, 2.5 and 1.9 at the start of the successive days of the investigation. With lower pH values, thiabendazole concentrations were correspondingly higher.

These thiabendazole analyses measured total thiabendazole in the tank dip, and additional measurements showed that most of this – about 90% - was in solution rather than in suspension. The project did not seek to determine the amount of thiabendazole in the debris settling out at the bottom of the HWT tanks (or trapped in foam), but it is assumed that much is lost in this way. Some will also be lost by absorption by soil particles and into structures such as wooden bins. The thiabendazole concentrations in or on the treated bulbs were not measured in this study. It is possible that, in HWT tanks with inadequate circulation, significant quantities of fungicide could be lost in the debris. For the present study, top-loading tanks were used, and the situation may be different in front-loading tanks, where solutions are pumped to a slave tank between dips. However, in the present case poor tank circulation does not appear to have been a significant factor: the tanks used in the second week of the project (for treatments 3 and 4, where high concentrations of active ingredient were found) were the same tanks as used in the first week (for treatments 1 and 2, where low concentrations were found). On the other hand, it is likely that a highly acidic pH keeps the thiabendazole in solution and therefore reduces settling-out on the bottom of the tank. Some of the initial large fluctuations observed in thiabendazole concentration in the tanks near the beginning of the study may have been due to the disturbance of settled material during loading and unloading bulbs from the tank.

These findings suggest there may be merit in adding an acidifier such as sodium bisulphate to HWT tanks, so it is necessary to take into account any effect of acidification on subsequent crop growth. In general, there were few significant differences between crop performance in controls and bulbs treated with sodium bisulphate at a standard rate to achieve a dip pH of about 2.5. In the first crop year bulbs treated with sodium bisulphate yielded some 8% fewer flowers than the controls. In the second crop year, however, there were no detrimental effects of using a standard rate of the acidifier on flower numbers, floral disorders, foliage height or stem length, and crop appearance was normal. The overall bulb yield (after two years) was also not significantly different between the control and the standard sodium bisulphate treatment, although there was a small re-distribution of yield between grades (with relatively less yield in the 8 – 12 cm grades when the acidifier was used). The amount of rotted bulbs removed at grading, and the incidence of bulb rots in a storage test, were also unaffected by acidifier treatment. Therefore, apart from the reduction in flower numbers in the first year, adding sodium bisulphate at a standard rate appears to be safe. Tests of other rates of sodium bisulphate, however, showed that it is necessary to avoid excessively high rates (very low pH values). Compared with the standard rate, increasing the addition of sodium bisulphate did not significantly increase the loss of flowers in the first or second years, but bulb growth was affected. The highest rate of sodium bisulphate tested (giving a dip pH of about 1.9) reduced total bulb yields by about 13%, compared with the middle rate (pH about 2.6). This yield reduction was associated with lower yields of bulbs of 12 –14 cm grade and more rotted bulbs (both at grading and in the storage test). The mechanisms responsible for changes in bulb grade-out and increased rotting are not known, but presumably could be due to the pH changes or directly due to the acidifier.

In contrast to the standard sodium bisulphate treatment, using Croptex Z.I.P. as a dip acidifier resulted in more flowers than the control in both years (significantly so in the second year). Because of the multi-purpose nature of Z.I.P. – a buffering agent, acidifier, wetter and nutrient source – it would be interesting to determine whether this effect was a genuine one. However, when Croptex Z.I.P. was used to acidify a post-lifting Storite bulb spray, more dead buds were produced in the next year, although there were no other adverse effects. The thiabendazole environment in bulb sprays is quite different to that in HWT, as is the stage of development of the crop. In the case of sprays the thiabendazole concentration is 40-times higher, and the flower initials will be at a more sensitive stage.

There are anecdotal reports that adding Croptex 'Z.I.P.' to bulb sprays interferes with the determination of formaldehyde levels. However, none of the acidifier treatments tested here resulted in changes of formaldehyde concentrations from the values expected.

In the course of these investigations some significant differences were found in the performance of bulb plots from the different dips of a series. Some random variation would be expected over a succession of batches, but there appeared to be a distinct time-course of crop responses to the time of treatment in the spray investigation, despite there being no significant effects due to presence or absence of an acidifier. Over the 8-hour period of the spray tests, batches treated later in the day subsequently produced greater bulb yields. There is no obvious explanation for this result, and it may simply be an artefact of the experiment, such as the surface-drying of bulbs during the day of treatment, leading to the greater absorption of Storite solution by the relatively drier bulbs treated later in the day. If so, this would point to the importance of practical factors such as the condition of the bulbs when treated by post-lifting fungicide sprays. This result is unlikely to be relevant to HWT.

The dramatic loss of thiabendazole found under standard HWT conditions in the present study raises serious doubts about the cost-effectiveness of Storite Clear use in bulb HWT. It possibly illustrates a rather naïve approach to what happens once a pesticide has been dispensed! A standard rate of sodium bisulphate (1.38 kg per 1000 litres) clearly had beneficial effects on maintaining thiabendazole levels in HWT dips, without adverse effects on the crop (except first year flower numbers). Many growers are apparently already adding sodium bisulphate to HWT tanks, and, on the basis of the current results, this seems reasonable. The method cannot be recommended until further experience has been gained, including testing other cultivars, and so it should remain a treatment to be carried out at the grower's risk. It is a relatively cheap treatment. In this experimental work a 2000 litre tank was used, treating 7½ tonnes of bulbs over a 5-day period, and approximately 4.8 kg of sodium bisulphate was used (0.64 kg per tonne bulbs). The current price of sodium bisulphate is £18.50 per 25 kg, equivalent to £0.47 per tonne bulbs. There appear to be no advantage in using Briswim Dry Acid, which is more expensive (about £30.00 per 25 kg). Croptex Z.I.P. costs about £9.00 per litre. (VAT not included in these prices.)

The legal position on using sodium bisulphate in bulb dips needs to be considered. In response to an enquiry from the HDC, the Pesticides Safety Directorate (PSD) wrote (16 September 1998) "The use of such acidifiers does not fall to be regulated as either a pesticide or adjuvant under current UK pesticide legislation. Use of acidifiers as described in your letter is legal as long as all the statutory conditions of use of the appropriate pesticide product are not infringed". This view was confirmed by PSD in late-2000 to Tim Briercliffe, ADAS, enquiring on behalf of the HDC. Further enquiries were made by Tim Briercliffe in relation to the Groundwater Regulations 1998 and the Health and Safety Executive (HSE). On the former, the Environment Agency wrote: "… I have considered sodium bisulphate with respect to classification under the Groundwater Directive. It does not appear to fall within the categories identified under either List 1 or List 2. The provisional classification is therefore that it does not fall within List 1 or List 2 under this Directive. This is however a provisional classification. All classifications made here at the National Centre are circulated to a steering group for comment and in addition there is also an external consultation process. All classifications remain as provisional until these steps have been taken." Sodium bisulphate is therefore not covered at present under this Directive. Finally, HSE stated that an appropriate COSHH assessment should be conducted prior to using sodium bisulphate. The applicable risk and safety phrases would be shown on the product data sheet.

Before firm recommendations can be made, some questions should be addressed. Although concentrations of thiabendazole fell rapidly in the HWT tanks, concentrations lower than the recommended 1.1 mg of active ingredient per ml may still be effective in controlling basal rot. At what concentration does thiabendazole cease to be effective? If an acidifier is used, and lower concentrations of thiabendazole are found to be effective, would reduced-rate Storite dip treatments be possible? Large cost savings would result from using half- or quarter-rate Storite with a cheap acidifier like sodium bisulphate. Are there any implications from using reduced rates of Storite for the development of resistance or tolerance to thiabendazole? As the loss of thiabendazole by settling-out at the bottom of HWT tanks may be an important factor, improved tank circulation should be addressed. Topping-up procedures that maintain the target pH should be designed. The effects of the acid solution on HWT systems also need to be ascertained, along with the practicalities of disposal, possibly following neutralisation. It is hoped that some of these questions will be addressed in further studies.

If successful, acidification may prove useful where bulbs are being treated with other pesticides. The following fungicides, used in narcissus growing, are listed in a Hortichem leaflet (see Reference list) as being susceptible to alkaline hydrolysis: benomyl, chlorothalonil, captan, carbendazim, dichlofluanid, iprodione, mancozeb, maneb and thiram. Prochloraz, a fungicide of particular interest to the bulbs industry, in not listed in this publication. The implications of acidification for prochloraz do not appear to have been tested experimentally. However, it is reported that prochloraz is stable, with only 5% being degraded at 43°C after 3 weeks (AgrEvo, personal communication). Chlorpyrifos and dimethoate, used to control large narcissus fly, are also liable to alkaline hydrolysis.

Information circulating in the bulb industry on whether an acidifier should be added to Storite fungicide when bulbs are treated by spraying on-line after lifting differs between growers. The present investigation showed no advantage of adding an acidifier (Croptex Z.I.P.) when using full-rate Storite under our conditions. Presumably the high rate of Storite used in bulb sprays (1 litre product to 4 litres water), compared with HWT, gives more than adequate acidification and buffering capacity.

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