Project Title:	Evaluation of sterilants and novel active ingredients for the control of fungal and bacterial diseases in bulb onions
Project number:	FV 264
Project leader:	Hugh Poths Vegetable Consultancy Services Ltd The Finches, Cake Street Old Buckenham Attleborough Norfolk NR17 1RU Tel. 01507 602472 E-mail: hugh.poths@virgin.net
Report:	Final Report
Previous report:	none
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Location of project:	Frederick Hiam Ltd, Brandon Fields Estate, Lime Kiln Farm, Brandon, Suffolk IP27 0SE.
Project coordinator:	P. Rayns, G's Growers Ltd, Hainey Farm, Barway, Ely, Cambs, CB7 5TZ.
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The results and conclusions in this report are based on field experiments conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

Authentication

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

Hugh Poths
Project Leader
VCS

Signature .... Date ....

Steven J Roberts
Consultant
Plant Health Solutions

Signature .... Date ....

Report authorised by:

Tom Will
Consultant
VCS

Signature .... Date ....

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Grower Summary

Headline

- None of the treatments gave a consistent reduction in downy mildew or increase in yield when compared to the untreated control.
- Although on average the 'standard' spray programme gave a significant increase in yield, the standard treatment alone did not did not give a yield increase compared to the untreated control.
- Taken together, these results call into question the financial benefit of intensive fungicidal spray programmes for the control of onion downy mildew.

Background and expected deliverables

Despite advances in forecasting programs and recent fungicide approvals, downy mildew of onions remains a recurrent problem, demanding an intensive and expensive fungicide program, and, despite which, localised aggressive attacks still occur. A typical fungicide program costs £290/ha (total industry costs £2,610,000). Yield losses directly attributed to downy mildew can reach 30% but are more typically in the order of 10%. As every 1% loss in yield equates to £100/ha, total losses amount to £1000/ha. However there may also be additional losses from rejected bulbs due to progressive downy mildew and/or secondary bacteria, and in extreme circumstances the crop becomes unmarketable.

Losses from bacterial pathogens most commonly occur in irrigated crops (80% of UK production). The incidence of bacteria-infected bulbs is consistently between 2% and 10% by number but can exceed 50% following hail damage in wet seasons. The bacteria isolated include *Burkholderia gladioli, Pseudomonas* spp. and *Erwinia* spp. There are currently no chemicals which have been shown to give effective control of bacterial diseases.

The rapid loss of active ingredients as EU directive 91/414 is implemented has led to the more frequent use of those fungicides which remain available. This reduced number of active ingredients is having an adverse effect on resistance management and increasing the likelihood of detectable residues. Several of the currently remaining fungicides are persistent and can leave residues (e.g. Iprodione, Chlorothalonil and Mancozeb); whereas public pressure is increasingly leading to demand for produce containing zero residues. There is therefore an urgent need to trial eradicant fungicides/bactericides that do not leave detectable residues in onions.

The project examined the efficacy of sterilants and novel products for the control of both fungal and bacterial onion foliage and bulb diseases. Downy mildew and bacterial diseases were the primary targets, but the incidence of other foliar fungal disease was also monitored. Three compounds were examined in the trials: Grevit (grapefruit extract), Jet 5 and Vitafect. Grevit has shown promise for control of bacterial diseases in work done in Poland and Jet 5 and Vitafect are established broad-spectrum disinfectants which are 'plant-safe' and have no residue problems.

The industry must be pro-active and explore the use of 'safe' products: by exploring several novel alternatives for disease control, the project aimed to develop the principles of an integrated crop management system offering a more sustainable option for the future control of the targeted problems.

Summary and main conclusions

Field trials to examine the effects of several biocides/novel compounds, alone or in combination with a standard fungicide spray programme, on onion downy mildew and bacterial diseases were conducted at two sites. Trial areas were direct-drilled with onion cv. Red Baron, known to be susceptible to downy mildew. The experimental treatments consisted of a combination of two treatment factors: a base treatment (*Standard, None*) and five additional treatments (*Control, Grevit, Jet 5, No copper, Vitafect*) to give 2 x 5 = 10 treatment combinations. However, as *None plus Control* and *None plus No copper* were effectively the same, this meant there were nine treatment combinations (Table 1). Each spray treatment combination was applied on seven occasions at 7 to 14 day intervals to four replicate plots at each site. Disease levels were monitored and bulb disease and yield assessed at harvest and after storage.

Table 1. Summary of experimental treatment combinations.

Treatment code	Replicates	Detail
N+Cont (= N+NoCu)	16	Un-sprayed control
N+Grap	8	Grevit (grapefruit extract) only
N+Jet5	8	Jet 5 only
N+Vita	8	Vitafect only
S+Cont	8	Standard spray programme (field standard)
S+Grap	8	Standard spray programme with Grevit incorporated
S+Jet5	8	Standard spray programme with Jet 5 incorporated
S+NoCu	8	Standard spray programme excluding copper
S+Vita	8	Standard spray programme with Vitafect

9 Treatments, 80 plots.

The effects of the different spray programmes on the development of downy mildew and yield are shown in Figure 11 and Figure 2.

- Statistically significant differences in disease were found only at the third assessment and these were often contradictory.
- None of the biocides/novel compounds gave any consistent benefits in terms of disease or yield, although some treatment combinations gave significant reductions in disease levels.
- Overall, plots receiving the standard treatment gave a significantly greater marketable yield (24.1 kg ≡ 33.5 t/ha) than those receiving none (21.3 kg ≡ 29.5 t/ha); this was generally the result of a significantly greater weight of bulbs in the two larger size grades.
- The biocides/novel compounds did not have any statistically significant effect on marketable yield, either with or without the standard treatment. Yields at Site 1 were significantly lower than at Site 2.
- The field standard fungicide treatment alone was no better than the untreated control in terms of either disease or yield.
- Apparently inconsistent effects on disease levels may be the result of de-waxing by certain treatment combinations.

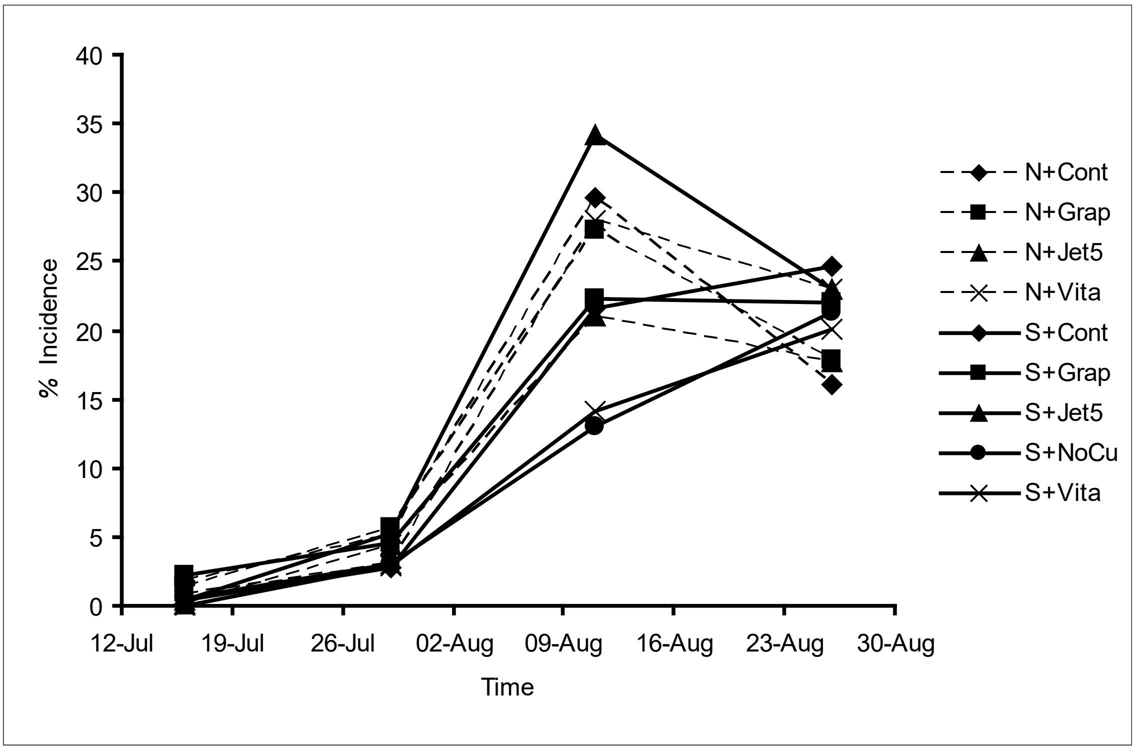

Figure 1. Change in incidence of downy mildew with time. Values represent the means of plots receiving the different spray treatments.

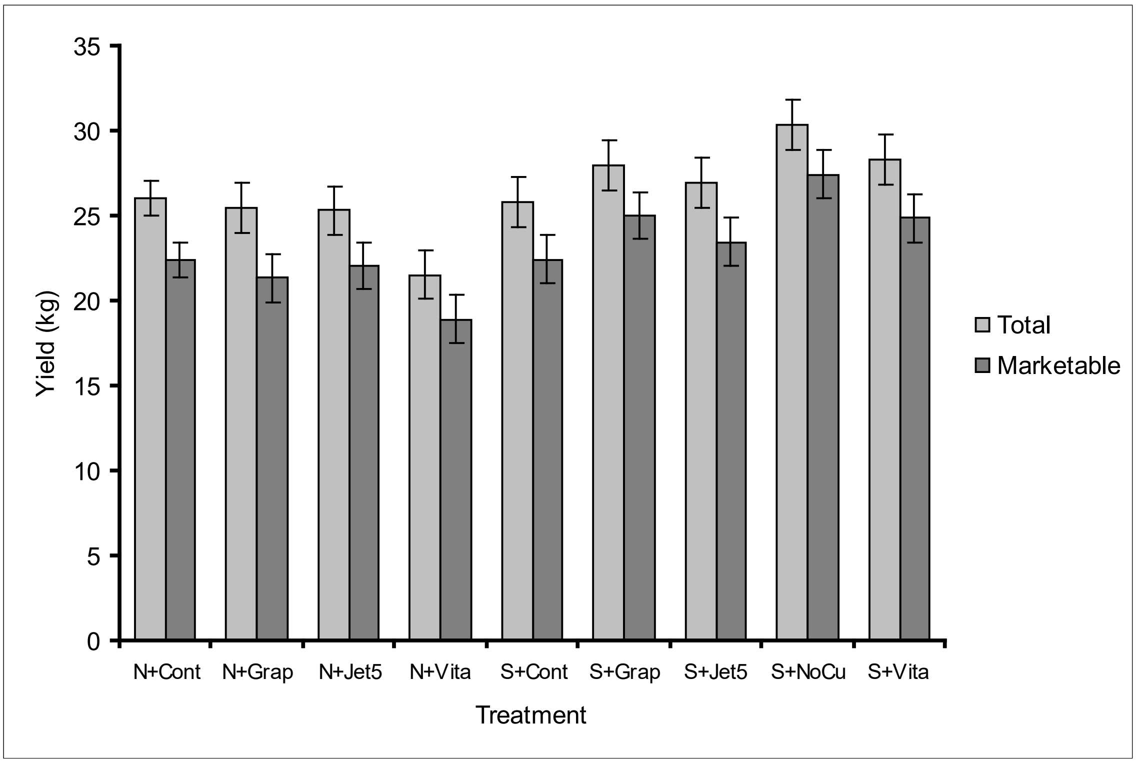

Figure 2. Total and marketable yield of stored bulbs in onion downy mildew spray trial. Values are the means of the harvested area (7.2 m^2) from each plot. Vertical lines represent standard errors.

Financial benefits

Taken together, these results do not provide any clear evidence for any benefit from the inclusion of any of the biocides/novel compounds in spray programmes for the management of downy mildew or bacterial disease in bulb onions. Furthermore the results also bring into question whether there is any consistent (economic) benefit from the standard spray programme. Table 2 gives an indication of the total costs and benefits from each treatment combination for a crop valued at £65 per tonne, ex-field, and suggests that only *standard without copper* (S+NoCu) gave an economic benefit. Although there was evidence *on average* of a yield benefit from the standard spray programme (4 t/ha ≡ 260 £/ha), this was not justified by the cost of the standard fungicide programme (256 £/ha)

Table 2. Costs and benefits associated with each fungicidal treatment combination for control of downy mildew.

Treatment code	Yield (t/ha)	Yield gain[1] (t/ha)	% increase[1]	Value gain[1,2] (£/ha)	Cost of treatment[3] (£/ha)	Net benefit[1] (£/ha)
N+Cont	31.1	0.0	0.0	0	0	0
N+Grap	29.6	-1.5	-4.9	-99	175	-274
N+Jet5	30.6	-0.5	-1.6	-32	256	-288
N+Vita	26.3	-4.9	-15.7	-317	291	-608
S+Cont	31.2	0.0	0.1	3	256	-253
S+Grap	34.7	3.6	11.5	233	361	-128
S+Jet5	32.5	1.4	4.6	92	442	-350
S+NoCu	38.1	7.0	22.4	453	226	227
S+Vita	34.5	3.4	10.9	220	477	-257

[1] Compared to un-treated control (N+cont)
[2] Based on an ex-field value of £65 per tonne
[3] Based on typical prices for each product, and assumed price of £10/ per litre for Grevit.

Action points for growers

- Growers should question whether they are obtaining any real financial benefit from the frequent application of fungicides to control downy mildew in bulb onions.

Science Section

Introduction

Despite advances in disease forecasting systems and recent fungicide approvals, downy mildew, caused by *Peronospora destructor*, continues to be a recurrent problem for onion growers. In their attempts to control the disease, growers operate an intensive and expensive fungicide programme, which will typically cost £290/ha (total industry costs £2.6 M) (VCS data). Despite such intensive spray programmes, yield losses directly attributed to downy mildew can reach 30% but are more typically in the order of 10% (VCS estimate). As every 1% yield reduction equates to £100/ha, total losses can amount to £1000/ha. There may also be additional losses resulting from rejection of bulbs due to progressive downy mildew and/or secondary bacterial rots and in extreme circumstances the crop becomes unmarketable.

Losses from bacterial pathogens most commonly occur in irrigated crops which comprise 80% of UK production. The incidence of bulbs with bacterial infections is consistently between 2% and 10% but can exceed 50% following hail damage in wet seasons (VCS estimate). The bacteria isolated include *Burkholderia gladioli, Pseudomonas* spp. and *Erwinia* spp. There are currently no chemicals which have been shown to give effective control of bacterial diseases.

The rapid loss of active ingredients as EU directive 91/414 is implemented has led to the more frequent use of those fungicides which remain available. This reduced number of active ingredients is having an adverse effect on resistance management and increasing the likelihood of detectable residues. Several of the active ingredients in the currently remaining fungicides are persistent and can leave residues (e.g. iprodione, chlorothalonil and mancozeb); whereas public pressure is increasingly leading to demand for produce containing zero residues. There is therefore an urgent need to trial eradicant fungicides/bactericides that do not leave detectable residues in onions.

Research carried out by Prof. Jozef Robak, Research Institute of Vegetable Crops Skierniwice, Poland, has suggested that one or two spray applications of grapefruit extract can completely check bacterial disease development in onions, even in heavily affected crops (Robak 2003).

Two biocides, Jet 5 (peroxyacetic acid) and Vitafect (benzalkonium chloride) are widely used in horticulture as they are 'plant-safe' and have no residue problems. Both of these compounds have been shown to inhibit the growth of a range of bacterial plant pathogens, including the onion pathogen *Burkholderia. gladioli* subsp. *alliicola* (examined as a control organism) at half-strength concentration and above as part of a previous HDC project (HNS 91: Roberts and Akram 2002).

The project examined the efficacy of these three compounds for the control of both fungal and bacterial onion foliage and bulb diseases. By exploring these novel alternatives for disease control, the project will help to develop the principles of an integrated crop management system offering a more sustainable option for the future control of the targeted diseases.

The overall aim of the project was:

> *to identify alternative disease management options, which will reduce the use of currently available pesticide active ingredients;*

with specific objectives:

(a) *to determine and compare the efficacy of sterilants and novel active ingredients for the control of downy mildew and other fungal diseases in bulb onions;*

(b) *to determine and compare the efficacy of sterilants and novel active ingredients for the control of bacterial diseases in bulb onions.*

Materials and Methods

Experimental approval

As the compounds to be examined in the trials were not approved pesticides, it was necessary to apply for and obtain experimental approval from the Pesticides Safety Directorate.

Design

The field layout is shown in Figure 1. The trials were conducted at two sites on a grower's farm in Suffolk (Grid references: Site 1, TL 752708; Site 2, TL 787685). The sites were selected as having a high risk of downy mildew and were on light Breckland type soils to ensure a high irrigation requirement, making the crop more susceptible to bacterial disease. At both sites the previous crop was Spring Barley. The experimental treatments were considered as a factorial combination of two treatment factors: a base treatment (*Standard, None*) plus five additional treatments (*Control, Grevit, Jet 5, No copper, Vitafect*) to give 2 x 5 = 10 treatment combinations. However, as *None plus Control* and *None plus No copper* were effectively the same this meant there were nine treatment combinations (Table 1). Each treatment was applied to four replicate plots of onion cv. Red Baron at each site. Plots were sited within a field of a commercial crop of the same cultivar and arranged in a randomised block design. Each plot was 8 m long and 2 beds wide with 1.8 m (4–row) beds. There was a 'gap' of 1-bed spacing between plots widthways and 2 m between plots lengthways. The 'gaps' contained un-treated beds of the same onion cultivar. Prior to the initiation of the different experimental treatments, the plots in the trial areas were treated according to 'standard production practice' (see Table 2 and Table 3).

Drilling and general husbandry

Base fertiliser (P, K, Mg) was applied in early January and land was prepared just prior to drilling. Pelleted (Propell) seed of cv Red Baron was obtained from Elsoms. Seed had been treated with a fungicide: Hy-TL (a.i. thiabendazole and thiram). The trial plots and surrounding crops were drilled on 21 (Site 2) and 24 (Site 1) Feb. 2004. Pre/post emergence herbicides, top dressings etc. applied as part of standard commercial practice are summarised in Table 2 and Table 3.

Irrigation and rainfall

Raingauges were located at both sites and irrigation requirements were be assessed using capacitance probes. Irrigation was applied when soil moisture deficit (SMD) exceeded 25 mm until full crop canopy was achieved, and 37 mm from bulbing onwards.

Experimental treatment regimes

The sequences of sprays applied in experimental treatments are summarised in Table 4. A summary of the individual products, their active ingredients and approval status is given in Table 5. All spray treatments were applied in a total volume of 400 l water/ha. DACOM was used to provide forecasts of downy mildew risk periods.

Foliar disease assessments

The first disease assessments were done on 15-20 July and the dates of the subsequent disease assessments are given in Table 2 and Table 3.

At each assessment, disease incidence (the number of diseased plants) was recorded in randomly selected 1 m lengths of row in four randomly selected rows. Within each plot, rows were numbered 1 to 8 and their lengths divided into 8 x 1 m sections; to avoid edge effects rows 1 and 8 and lengths 1 and 8 were excluded from assessments.. Randomisations were obtained using the SAMPLE directive in Genstat (Payne *et al.* 2003). As each 1 m of row contained approx. 20 plants, approximately 80 plants were assessed in each plot. Disease severity was recorded on a 0-4 scale for the first five diseased plants in each of the sections of row assessed for disease incidence. In addition to the incidence and severity of both downy mildew and bacterial disease, the presence of other diseases was also recorded.

Hot-box samples

Hot-boxing is a method for predicting the likely incidence of bacterial storage rots in onions which was developed as part of HDC project FV 111 (Davies and Taylor 1995). Samples of ten marketable bulbs (good shape, not bolting, thin necks, fully formed) were lifted from each of four randomly selected metre sections of row within the central six rows x 6 m of each plot on 01 and 02 Sept to give a sample of 40 bulbs for each plot. Randomisations were obtained using the SAMPLE directive in Genstat (Payne *et al.* 2003). Most of the foliage had died down and any residual foliage was pulled or twisted off by hand, to avoid any potential for cross-contamination by the use of knives. Substantial roots were present on the majority of bulbs, these were also twisted off. Samples of bulbs were placed in a net bag with a label and the remainder of the bulbs in each of the sampled metre sections of row were removed to avoid confusion during sampling for yield. The bagged samples were transferred to a 'hot-box' store for 14 d at >60% RH.

After 14 d at 30°C, the bulbs were split and the number of bulbs with bacterial disease and other symptoms [neck rot (*Botrytis allii*), basal rot (*Fusarium oxysporum*), *Penicillium* spp., *Aspergillus* spp.] recorded.

Yield and quality

To assess yield, bulbs were harvested from the middle 4 m section of the four central rows (i.e. rows 4, 5, 6 and 7) in each plot on 08 Sept. Where the middle 4 m section of row included a section already removed for 'hot-box' samples, the next 1 m section along the same row was harvested, so that the total harvest from each plot still represented an area of 4 m x 4 rows (7.2 m^2). Bulbs were placed in net bags and transferred to a store where they were subjected to a three stage curing process (Stage 1: Duct- 28°C, 55% RH, 2 d; Stage 2: Duct - 28°C, 60% RH, 3-4 weeks; Stage 3: cooling to ambient, 15°C), and then held at 0.5°C, approx. 88% Crop RH, from 10 Nov onwards.

Bulbs were removed from storage on 21 Jan 2005, after storage for approx. 4 months, graded (<55, 55-70, 71-80, >80 mm in diameter), and the weight of bulbs in each size grade recorded. In addition, a sample of 40 marketable bulbs from each plot was split and assessed for disease in the same way as for the 'hot-box' samples.

Data and Statistical analysis

Data from each disease assessment were recorded in Excel™ spreadsheets. Data for disease incidence and severity were analysed using the generalised linear modelling (GLM) procedures of Genstat (Payne *et al.* 2003). For disease incidence data, the model was specified with binomial error distribution and a logit link-function. Severity data was analysed as ordinal categorical data using a proportional odds model as suggested by McCullagh & Nelder (1989).

In each case a series of nested models was fitted to the data and used to generate an accumulated analysis of deviance. This was then used to assess the relative importance of terms in the model on the basis of mean deviance ratios, as suggested by McCullagh & Nelder (1989). Estimates of means and their standard errors were obtained using the PREDICT directive of Genstat, with standard errors based on the residual mean deviance for the appropriate model stratum.

Yield data were analysed using least squares regression to produce an analysis of variance table. The significance of effects was assessed by comparisons of variance ratios with the F statistic (F-test).

Results

Crops began to emerge around 06 April. Intensive rainfall in mid March led to leaching and residual herbicide damage. Good growth and rapid development through June resulted from the frequent rain and good light levels. Over the nine week irrigation monitoring period, 139.5 mm of irrigation water and rainwater were collected in the rain gauges at both sites.

Favourable conditions encouraged downy mildew to establish in over-wintered crops in June and this progressed to main crops in early July. The first sprays were applied on 29 June. The first downy mildew symptoms were seen in the trials around 12 July. Symptoms of foliar bacterial disease were not seen in the trials.

Crops developed lush growth through July and August with poor leaf wax. Higher than normal rainfall in late August and early September delayed harvest and lead to some crops senescing prior to harvest. Both downy mildew and Fusarium disease levels were the highest for several years. The percentage of bulb double centres was noticeably high which is normally taken as an indication of crop stress.

Foliar disease

Incidence

The change in disease incidence with time for each treatment is shown in Figure 21. Disease levels increased rapidly during the last week of July and first two weeks of August when the weather was warm and humid. The analyses of deviance for each disease assessment date are given in Table 6 and the means for each treatment are given in Table 7. The deviance ratio indicates the relative importance (significance) of each term in the model (treatment factor). There were significant differences between treatments only at the third assessment, however the effects were not consistent as indicated by the significant interaction term. Thus the biocides/novel compounds appeared to have different effects in the presence/absence of the standard fungicide treatment. The standard programme without copper and standard plus Vitafect had significantly lower disease levels than the other treatments whereas the standard plus Jet 5 had the highest disease levels. Overall the standard spray treatments generally gave lower disease levels than nothing, but the addition of Jet 5 appeared to increase disease levels. On the other hand Jet 5 alone appeared to be as effective as the standard spray programme.

Severity

In general, severity followed a similar pattern to disease incidence (Figure 3). The analyses of deviance for each disease assessment are given in Table 6. The fitting algorithm failed completely for assessment 4 and partially for assessments 1 and 2, thus a full statistical analysis was possible only for assessment 3. At assessment 3, the severity scores for the standard programme without copper and standard plus Vitafect were significantly more likely to be in the lowest category than the other treatments.

Bulb disease

Hot box

Due to the relatively small number of bulbs in each disease category, these were combined for analysis. The percentages of diseased bulbs are shown in Table 8, and the analysis of deviance is shown in Table 9. There were no significant effects of treatments on the percentage of diseased bulbs.

Stored

The percentages of diseased bulbs are shown in Table 8, and the analysis of deviance is shown in Table 9. There were no significant effects of treatments on the percentage of diseased bulbs although there were significantly more diseased bulbs from Site 1 (9%) than from Site 2 (5%).

Yield

The total and marketable yields of bulbs are shown in Figure 4 and the distribution of bulbs amongst the different size grades is shown in Figure 5. Marketable bulbs were defined as those with a size of greater than 55 mm. The analyses of variance are shown in Table 10 and Table 11. The values for Pr>F give an indication of the significance of the different treatment factors: values less than 0.05 (5%) are considered significant; smaller values are more significant.

Overall, plots receiving the standard treatment gave a significantly greater marketable yield (24.1 kg ≡ 33.5 t/ha) than those receiving none (21.3 kg ≡ 29.5 t/ha); this was generally the result of a significantly greater weight of bulbs in the two larger size grades. However, it should be noted that there was no difference between the untreated control and the standard without addition, and the highest yielding treatment was the standard without copper. The biocides/novel compounds had no effect on marketable yield, either with or without the standard treatment. Yields at Site 1 were significantly lower than at Site 2.

Total yields followed a similar pattern to marketable yields, and were significantly greater for the standard treatment compared to none, and the addition of biocides/novel compounds had no effect.

Yields in the two larger size grades were significantly greater for those plots receiving the standard treatment compared to none. For the >80 mm grade there was also a significant interaction effect; with the standard without copper and standard plus Vitafect giving significantly more than the other treatments. There were no significant differences between treatments in the yield of bulbs in the two smaller size grades.

Discussion

Overall, none of the individual treatments appeared to have any consistent effects on the levels of downy mildew in the field, or on yield, or any effect on bulb diseases either in 'hot-boxing' or after storage for 4 months. Statistically significant differences in disease were found only at the third assessment and these were often contradictory. The mean yield of plots receiving the standard treatment was significantly higher than the mean for those receiving none, but this was not consistently represented in the individual treatments.

Standard

The standard treatment consisted of a sequence of Dithane 945, followed by Dithane 945 plus Invader, then Invader alone, with alternating inclusion of Cuprokylt. Although this treatment alone appeared to give a reduction in disease at the third assessment compared to the untreated control, this difference was not significant and there was no improvement in yield. In contrast, the average disease levels across all plots receiving the standard did not differ from those receiving none, whereas the average yield was greater.

Copper

Comparison of the standard with copper alone and without copper suggests that inclusion of copper increased disease levels. However, copper was also included with the biocides/novel compounds; these gave both higher and lower disease levels making any conclusions difficult. Copper is included in onion spray programmes primarily as a bactericide: no bacterial disease was recorded on the foliage in the field and very little was recorded in the harvested bulbs, therefore the absence of any benefit from copper may have been due to a lack of bacterial disease pressure.

Grevit

There was no evidence of any benefit from the application of Grevit alone or combined with the standard spray programme in terms of disease control or yield. Significant claims have been made for the efficacy of this product against downy mildew and bacterial diseases in Poland (Robak, 2003). However, we have been unable to find any definitive published results from trials to support these claims.

Jet 5

Jet 5 alone appeared to reduce downy mildew to levels comparable with the standard treatment; when included as an addition to the standard it appeared to give a significant increase in disease levels, but with no impact on final yield. It is possible these apparently contradictory effects on disease levels were the result of de-waxing, when combined with the standard treatments, which in turn made the leaves more susceptible to infection.

Vitafect

Vitafect alone had no effect on disease levels and gave yields lower than the untreated control; when included as an addition to the standard it gave the lowest disease levels and one of the highest yields. It is difficult to find an explanation for such contradictory effects.

Taken together, these results do not provide any clear evidence for any benefit from the inclusion of any of the biocides/novel compounds in spray programmes for the management of downy mildew or bacterial disease in bulb onions. Furthermore the results also bring into question whether there is any consistent (economic) benefit from the standard spray programme. Table 12 gives an indication of the total costs and benefits from each treatment combination for a crop valued at £65 per tonne, ex-field, and suggests that only the standard without copper gave an economic benefit. Although there was evidence *on average* of a yield benefit from the standard spray programme (4 t/ha ≡ 260 £/ha), this was not justified by the cost of the standard fungicide programme (256 £/ha)

It should be noted that during this trial, disease was recorded only on green tissues; it is therefore likely that the disease levels reported here represent an under-estimate of the total amount of disease present in the crops.

Throughout the trial and especially later in the season, there was an impression that certain treatment regimes may have had an adverse effect on leaf cuticle wax: either removing the wax or affecting its surface characteristics (wetability). The leaf cuticle wax provides the primary barrier to infection by pathogens and there is evidence in the literature that its removal may increase susceptibility to disease. Given the large number of spay applications in this trial, we speculate, therefore, that some of the apparently inconsistent effects of treatments on disease may have been due to the impact of particular treatment combinations on leaf wax. Thus, it may be possible to obtain more effective disease management by the selection of compounds/formulations and fungicide sequences which minimise adverse effects on the leaf cuticle, and/or with the use of fewer spray applications.

Although Invader has some trans-laminar activity, none of the compounds applied in this trial can be considered to have full systemic activity. In a year of high disease pressure, with frequent sporulation risk periods, such as 2004, it is possible that protectants cannot be applied with sufficient frequency to limit epidemic progress, therefore the inclusion of fully systemic fungicides with activity against down mildew in spray programmes may lead to improved disease control.

Conclusions

- None of the treatments gave adequate control of downy mildew.
- The field standard fungicide treatment alone was no better than the untreated control.
- None of the biocides/novel compounds gave any consistent benefits in terms of disease or yield, although some treatment combinations gave significant reductions in disease levels.
- Apparently inconsistent effects on disease levels may be the result of de-waxing by certain treatment combinations.

Recommendations for further work

- The effect of different fungicide sequences on leaf waxing should be investigated.
- The basis and origin of the current ‘standard practice’ should be investigated.
- There is a need to devise more effective spray programmes and seek alternative, more effective products.

Acknowledgements

The authors would like to thank Frederick Hiam Ltd for providing the trial sites and sprayer operator Mr Alan Fuller who applied all the experimental treatments.

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Tables and Figures

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9 Treatments, 80 plots.

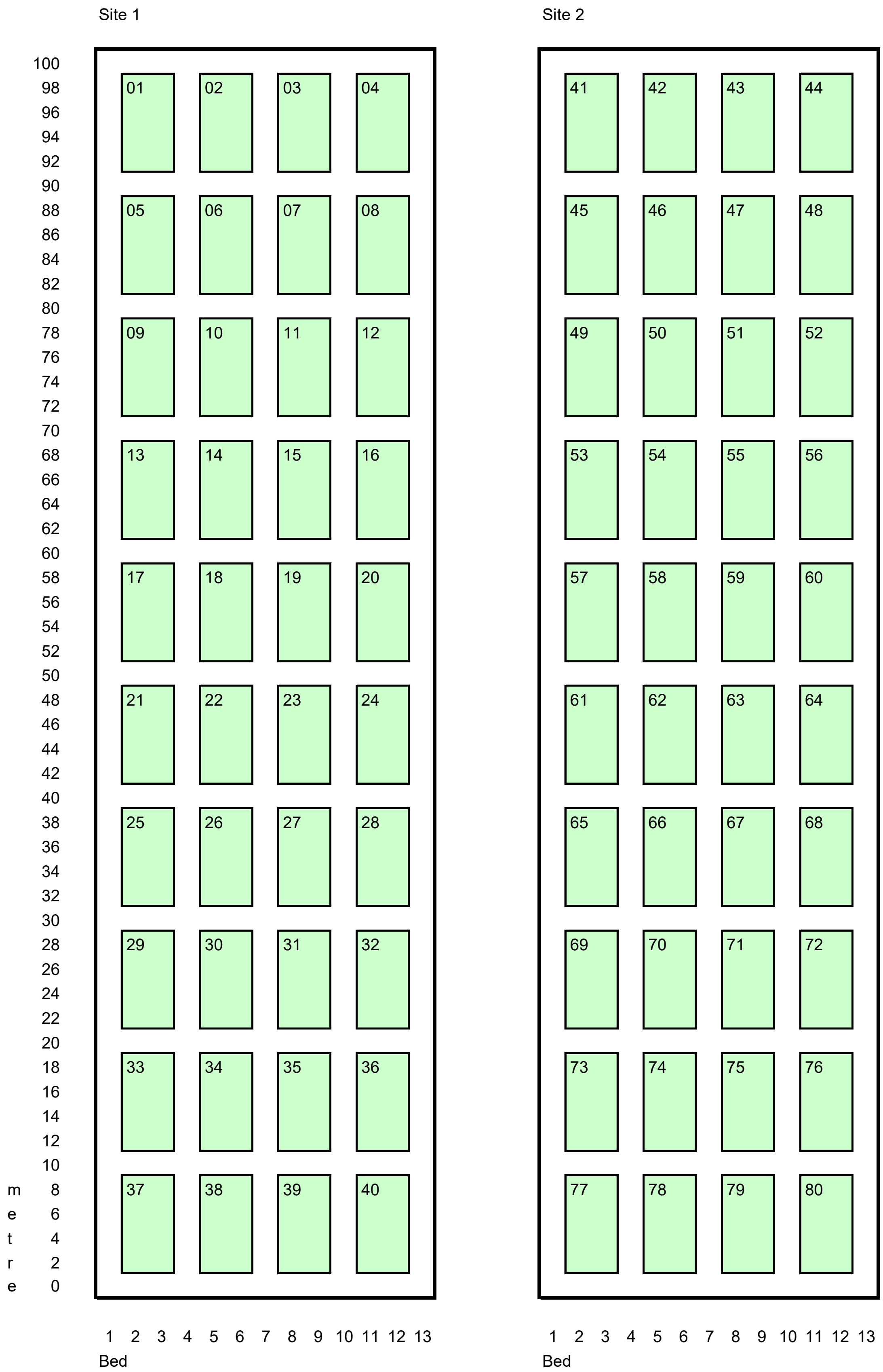

Figure 1. Field layout of onion downy mildew trials.

Table 2. Experiment diary and summary of non-experimental treatments applied to Site 1.

Date	GS	Operation	Product (rate per ha)
		Land prepared	
24-Feb		Crop drilled	
25-Feb		Pre-emergence herbicide applied	Ramrod Flowable (9.0 l)
			Stomp 400SC (1.65 l)
13-Apr		Herbicide applied	Ramrod Flowable (4.5 l)
			Stomp 400SC (1.0 l)
01-May		Herbicide applied	Totril (0.35 l)
07-May	1 TL	Insecticide and trace elements applied	Manganese sulphate (3.0 kg)
			Decis (0.3 l)
13-May		Herbicide applied	Basagran SG (0.2 kg)
			Starane 2 (0.25 l)
24-May	2-3 TL	Herbicide applied	Totril (0.35 l)
			Starane 2 (0.35 l)
01-Jun		Trace elements applied	Headland Boron 15 (1.5 l)
			Manganese sulphate (5.0 kg)
14-Jun		Herbicide applied	Aramo (0.8 l)
21-Jun		Herbicide applied	Totril (0.6 l)
			Fortrol (0.15 l)
29-Jun		Exp. treatments applied	see Table 4
06-Jul		Herbicide applied	Totril (0.7 l)
			Fortrol (0.2 l)
13-Jul	7 TL	Exp. treatments applied	see Table 4
15-Jul		1st disease assessment	
23-Jul		Exp. treatments applied	see Table 4
29-Jul		2nd disease assessment	
30-Jul		Exp. treatments applied	see Table 4
06-Aug	8-9 TL	Exp. treatments applied	see Table 4
11-Aug		3rd disease assessment	
13-Aug	Bulbing	Exp. treatments applied	see Table 4
16-Aug	10% fallover	Sprout suppressant	Rouge (2.75 kg)
			Rapide (0.4 l)
20-Aug		Exp. treatments applied	see Table 4
26-Aug		4th disease assessment	
02-Sep		Hot-box samples harvested	
08-Sep		Crop harvested	
15-Sep		Hot-box samples assessed	
21-Jan		Yield of stored bulbs assessed	

Table 3. Experiment diary and summary of non-experimental treatments applied to Site 2.

Date	GS	Operation	Product (rate per ha)
29-Sep		Herbicide applied	Glyphosate 360 (4.0 l)
			Stinger (0.2 l)
		Land prepared	
21-Feb		Crop drilled	
24-Feb		Pre-emergence herbicide applied	Ramrod Flowable (9.0 l)
			Stomp 400SC (1.65 l)
20-Apr		Herbicide applied	Ramrod Flowable (4.5 l)
			Stomp 400SC (1.0 l)
05-May	1 TL	Herbicide applied	Totril (0.35 l)
13-May		Insecticide and trace elements applied	Decis (0.3 l)
			Manganese sulphate (3.0 kg)
14-May		Herbicide applied	Totril (0.35 l)
			Starane 2 (0.35 l)
24-May	2-3 TL	Herbicide applied	Totril (0.35 l)
			Starane 2 (0.35 l)
01-Jun		Trace elements applied	Headland Boron 15 (1.5 l)
			Manganese sulphate (5.0 kg)
08-Jun		Herbicide applied	Totril (0.35 l)
			Starane 2 (0.5 l)
21-Jun		Herbicide applied	Totril (0.6 l)
			Fortrol (0.15 l)
29-Jun	5-6 TL	Exp. treatments applied	see Table 4
07-Jul		Herbicide applied	Totril (0.7 l)
			Fortrol (0.2 l)
13-Jul		Exp. treatments applied	see Table 4
15-Jul	7 TL		
20-Jul		1st disease assessment	
23-Jul		Exp. treatments applied	see Table 4
29-Jul		2nd disease assessment	
30-Jul		Exp. treatments applied	see Table 4
06-Aug	8-9 TL	Exp. treatments applied	see Table 4
11-Aug		3rd disease assessment	
13-Aug	Bulbing	Exp. treatments applied	see Table 4
17-Aug	10% fallover	Sprout suppressant applied	Rouge (2.75 kg)
			Rapide (0.4 l)
20-Aug	Bulbing	Exp. treatments applied	see Table 4
26-Aug		4th disease assessment	
02-Sep		Hot-box samples harvested	
08-Sep		Crop harvested	
15-Sep		Hot-box samples assessed	
21-Jan		Yield of stored bulbs assessed	

Table 4. Summary of fungicides applied in each experimental treatment.

Treatment	Date						
	29/06/2004	13/07/2004	23/07/2004	30/07/2004	06/08/2004	13/08/2004	20/08/2004
N+Cont	-	-	-	-	-	-	-
N+Grap	Grevit	Grevit	Grevit	Grevit	Grevit	Grevit	Grevit
N+Jet 5	Jet 5	Jet 5	Jet 5	Jet 5	Jet 5	Jet 5	Jet 5
N+Vita	Vitafect	Vitafect	Vitafect	Vitafect	Vitafect	Vitafect	Vitafect
S+Cont	Dithane	Cu oxychloride + Dithane + Invader	Dithane + Invader	Cu oxychloride + Dithane + Invader	Cu oxychloride + Invader	Invader	Cu oxychloride + Invader
S+Grap	Dithane + Grevit	Cu oxychloride + Dithane + Invader + Grevit	Dithane + Invader + Grevit	Cu oxychloride + Dithane + Invader + Grevit	Cu oxychloride + Invader + Grevit	Invader + Grevit	Cu oxychloride + Invader + Grevit
S+Jet5	Dithane + Jet 5	Cu oxychloride + Dithane + Invader + Jet 5	Dithane + Invader + Jet 5	Cu oxychloride + Dithane + Invader + Jet 5	Cu oxychloride + Invader + Jet 5	Invader + Jet 5	Cu oxychloride + Invader + Jet 5
S+Vita	Dithane + Vitafect	Cu oxychloride + Dithane + Invader + Vitafect	Dithane + Invader + Vitafect	Cu oxychloride + Dithane + Invader + Vitafect	Cu oxychloride + Invader + Vitafect	Invader + Vitafect	Cu oxychloride + Invader + Vitafect
S+NoCu	Dithane	Dithane + Invader	Dithane + Invader	Dithane + Invader	Invader	Invader	Invader

Application rates:
Grevit, 1.5 l/ha; Jet 5, 3.2 l/ha; Vitafect, 4.0 l/ha; Copper 2kg/ha; Dithane 945 2 kg/ha; Invader, 2 kg/ha + LI-700 1 l/1000 l.
All amounts refer to product and were applied in 400 l water/ha

Table 5. Summary of fungicidal products applied in experimental treatments, their cost and approval status

Product	Active Ingredient(s)	Rate	Cost/ha	Approval status
Dithane 945	Mancozeb (800 g/kg)	2 kg/ha	7.56	SOLA 1430/2002 (exp 30/06/06)
Cuprokylt	Copper oxychloride (500 g/kg)	2 kg/ha	4.67	SOLA 1127/99 (exp 31/12/08)
Invader	Dimethomorph (75 g/kg) and mancozeb (667 g/kg)	2 kg/ha	19.98	SOLA 2334/2004 (exp 31/12/08)
Grevit	Grapefruit extract (200 g/l)	1.5 l/ha	15.00	Not approved
Jet 5	Peroxyacetic acid (50 g/l)	3.2 l/ha	26.62	Not approved
Vitafect	Biguanadine salts, benzalkonium chloride, QACs, wetters	4.0 l/ha	31.60	Not approved
LI-700	Modified soya lecithin 350 g/l, alkylphenylhydroxypolyethylene 100 g/l, proprionic acid 350 g/l.	0.4 l/ha	2.88	Adjuvant

All applied in total volume of 400 l water/ha.

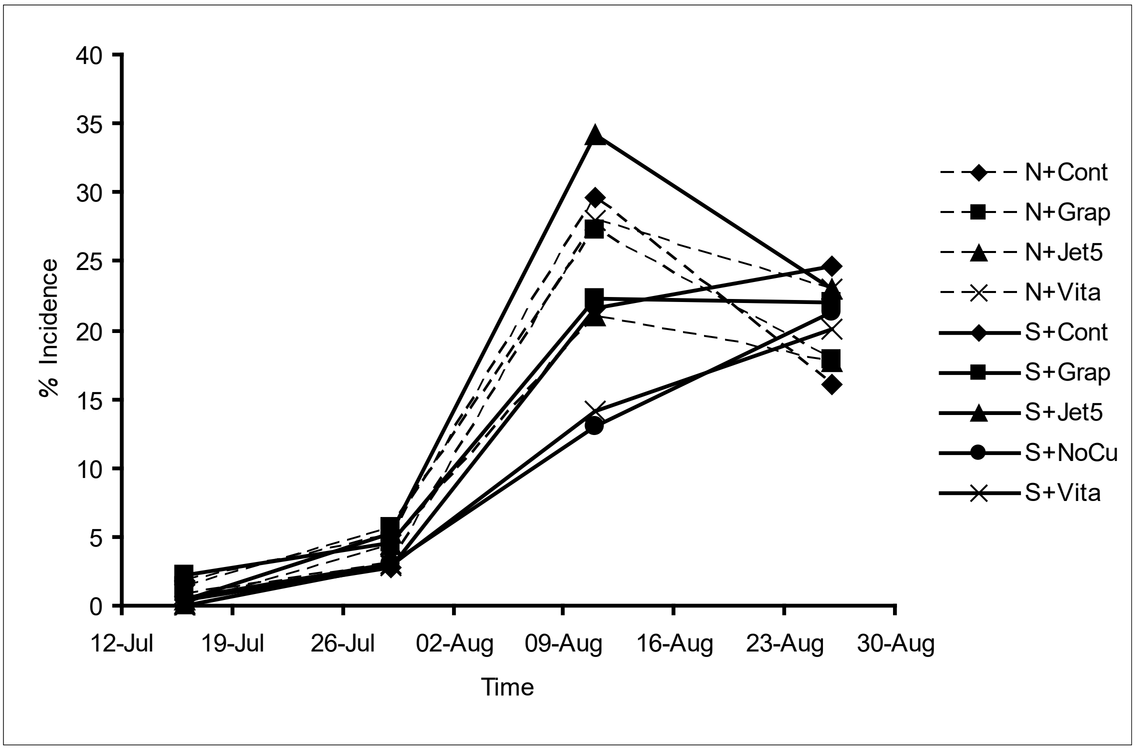

Figure 2. Change in incidence of downy mildew with time.

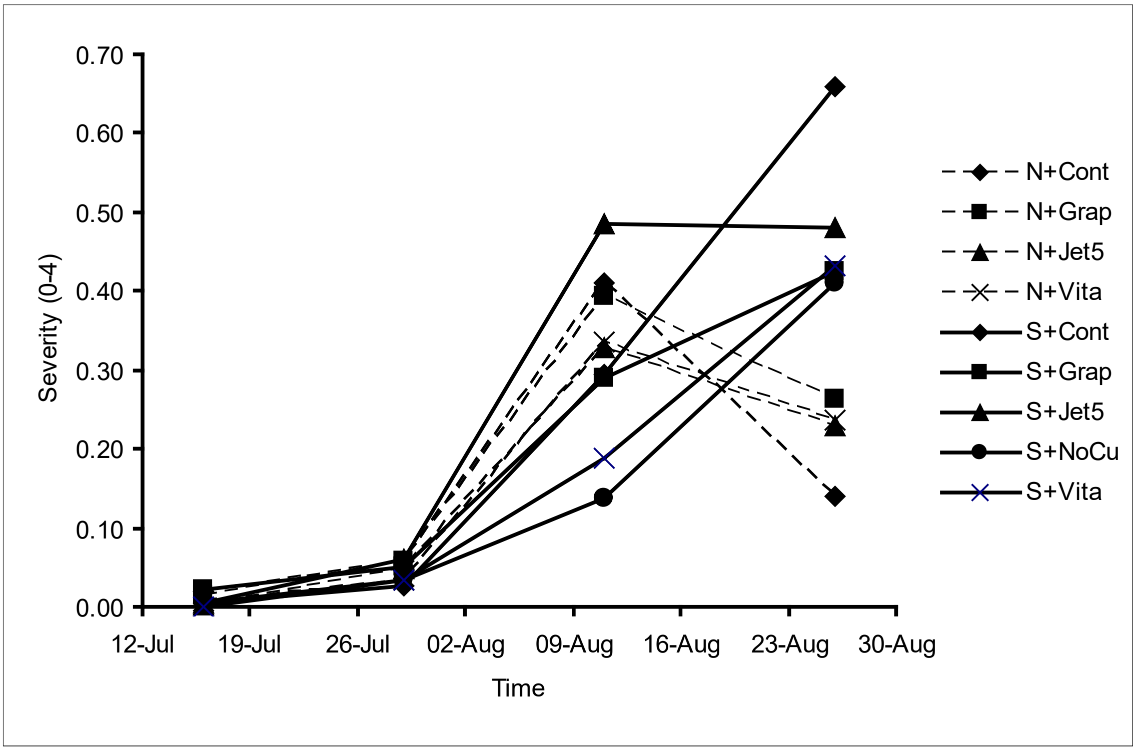

Figure 3. Change in mean disease severity score for downy mildew with time.

Table 6. Analyses of deviance for the proportion of downy mildew infected plants (incidence) and disease severity scores at each disease assessment.

Change	d.f.	Assessment 1 mean deviance	Assessment 1 deviance ratio	Assessment 2 mean deviance	Assessment 2 deviance ratio	Assessment 3 mean deviance	Assessment 3 deviance ratio	Assessment 4 d.f.	Assessment 4 mean deviance	Assessment 4 deviance ratio
Incidence										
Site	1	9.90	2.49	92.73	16.14	4.72	0.23	1	0.23	0.16
Site.Blocks	6	3.98		5.74		20.89	5.09	6		
Standard	1	3.31	3.10	2.25	1.57	24.09	5.87 *	1	4.04	4.04
Additional	4	4.44	4.17	1.97	1.37	9.62	2.34	4	0.30	0.30
Std.Add	3	3.67	3.44	1.76	1.23	17.16	4.18 *	3	1.84	1.84
Plot	64	1.07		1.43		4.10		40	0.77	
Residual	240	0.33		0.76		1.83		77	0.48	
Total	319	0.66		1.30		2.97		132	0.66	
Severity										
Site	1	8.85	2.22	88.31	15.37	38.29	1.83		failed	
Site.Blocks	6	4.25		6.56		31.00				
Standard	1	3.20	3.20	3.33	3.33	34.62	6.84 *			
Additional	4	failed		2.80	2.80	18.83	3.72 *			
Std.Add	3	failed		1.91	1.91	10.96	2.17			
Plot	64	failed		failed		5.06	3.68			
Residual	237	0.32		0.45		1.38				
Total	316	0.43		0.89		3.22				

* - terms considered to be significant.

Table 7. Mean disease incidence of downy mildew at each disease assessment for each treatment combination.

Treatment code	16-Jul Mean	16-Jul s.e.	29-Jul Mean	29-Jul s.e.	11-Aug Mean	11-Aug s.e.	26-Aug Mean	26-Aug s.e.
N+Cont	1.85	0.59	5.15	0.83	29.60	2.92	16.04	2.69
N+Grap	1.44	0.74	5.67	1.22	27.31	3.88	17.79	3.39
N+Jet5	0.20	0.27	4.42	1.09	21.06	3.66	17.76	3.03
N+Vita	0.87	0.59	2.99	0.93	27.89	3.95	23.03	3.95
S+Cont	0.41	0.40	2.74	0.88	21.65	3.80	24.62	2.63
S+Grap	2.19	0.88	4.58	1.07	22.24	3.74	22.06	2.92
S+Jet5	0.38	0.36	5.28	1.18	34.21	4.21	22.94	2.72
S+NoCu	0.62	0.49	3.04	0.96	12.95	3.11	21.37	3.09
S+Vita	0.00	0.00	2.93	0.90	14.06	3.28	20.06	2.53

s.e.: approximate standard error.

Table 8. Percentage of diseased bulbs in hot-boxed and stored onion bulbs.

Treatment code	Hotboxed Mean	Hotboxed s.e.	Stored Mean	Stored s.e.
N+Cont	2.5	0.8	7.5	1.3
N+Grap	4.7	1.6	6.6	1.7
N+Jet5	2.8	1.2	6.6	1.7
N+Vita	2.5	1.2	6.9	1.8
S+Cont	3.4	1.4	7.2	1.8
S+Grap	5.3	1.7	5.3	1.6
S+Jet5	3.7	1.4	7.5	1.9
S+NoCu	2.5	1.2	7.8	1.9
S+Vita	3.7	1.4	8.4	2.0

Table 9. Analyses of deviance for incidence of bulb disease in hot-boxed and stored onion bulbs.

Treatment	d.f.	Hotboxed mean deviance	Hotboxed deviance ratio	Stored mean deviance	Stored deviance ratio	
Site	1	0.35	0.35	14.95	14.95	*
Site.Blocks	6	0.77		0.74		
Standard	1	1.39	0.78	0.08	0.05	
Additional	4	1.74	0.97	0.52	0.32	
Std.Add	3	0.09	0.05	0.40	0.25	
Residual	64	1.79		1.60		
Total	79	1.63		1.58		

d.f. - degrees of freedom.
* - effects considered to be significant.

Table 10. Analyses of variance for the total and marketable yield of onion bulbs

Treatment	d.f.	Total m.s.	Total v.r.	Total Pr>F.	Marketable m.s.	Marketable v.r.	Marketable Pr>F
Site	1	1035.4	39.7	0.001	1212.1	36.6	0.001
Site.Blocks	6	26.1			33.1		
Standard	1	182.4	11.0	0.002	205.4	13.1	<0.001
Additional	4	22.5	1.4	0.260	23.3	1.5	0.218
Std.Add	3	38.3	2.3	0.085	30.3	1.9	0.133
Residual	64	16.6			15.7		
Total	79	33.5			35.5		

d.f. - degrees of freedom; m.s. - mean square or variance; v.r. - variance ratio or F value; Pr>F - probability of a greater F value, smaller = more significant.

Table 11. Analyses of variance for weight of bulbs in each size grade from onion downy mildew spray trial.

Change	df	<55 mm			55-70 mm			70-80 mm			>80 mm		
		m.s.	v.r.	Pr>F	m.s.	v.r.	Pr>F	m.s.	v.r.	Pr>F	m.s.	v.r.	Pr>F
Site	1	6.96	2.30	0.180	129.0	13.99	0.010	368.9	24.0	0.003	18.05	7.09	0.037
Site.Blocks	6	3.03			9.22			15.4			2.55		
Standard	1	0.68	0.69	0.410	1.68	0.18	0.670	139.9	20.8	<0.001	14.45	10.78	0.002
Additional	4	0.88	0.88	0.481	12.39	1.35	0.260	1.2	0.2	0.952	2.87	2.14	0.086
Std.Add	3	2.92	2.94	0.040	9.69	1.06	0.373	17.1	2.5	0.065	4.17	3.11	0.032
Plot	64	0.99			9.15			6.7			1.34		
Total	79	1.29			10.76			13.8			1.99		

d.f. - degrees of freedom; m.s. - mean square or variance; v.r. - variance ratio or F value; Pr>F - probability of a greater F value, smaller = more significant.

Table 12. Costs and benefits associated with each fungicidal treatment combination for control of downy mildew.

Treatment code	Yield (t/ha)	Yield gain[1] (t/ha)	% increase[1]	Value gain[1,2] (£/ha)	Cost of treatment[3] (£/ha)	Net benefit[1] (£/ha)
N+Cont	31.1	0.0	0.0	0	0	0
N+Grap	29.6	-1.5	-4.9	-99	175	-274
N+Jet5	30.6	-0.5	-1.6	-32	256	-288
N+Vita	26.3	-4.9	-15.7	-317	291	-608
S+Cont	31.2	0.0	0.1	3	256	-253
S+Grap	34.7	3.6	11.5	233	361	-128
S+Jet5	32.5	1.4	4.6	92	442	-350
S+NoCu	38.1	7.0	22.4	453	226	227
S+Vita	34.5	3.4	10.9	220	477	-257

[1] Compared to un-treated control (N+cont)
[2] Based on an ex-field value of £65 per tonne
[3] Based on typical prices for each product, and assumed price of 10 £/l for Grevit (see Table 5)

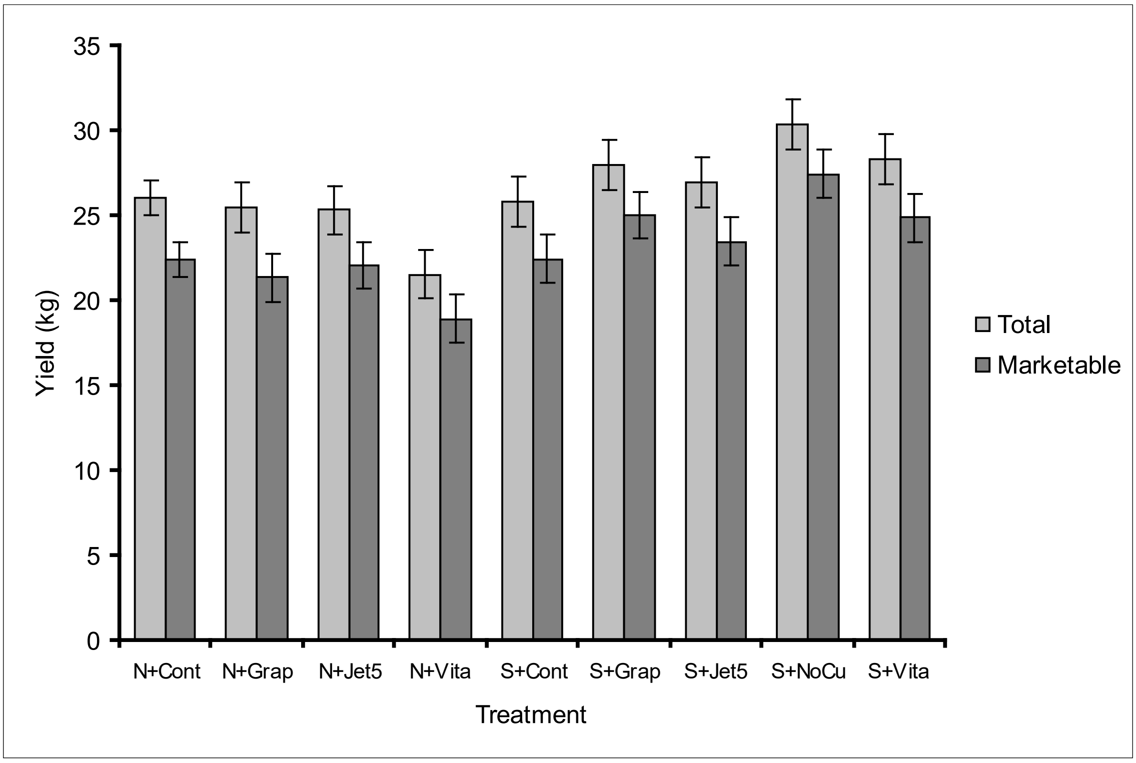

Figure 4. Total and marketable yield of stored bulbs in onion downy mildew spray trial. Values are the means of the harvested area (7.2 m^2) from each plot. Vertical lines represent standard errors.

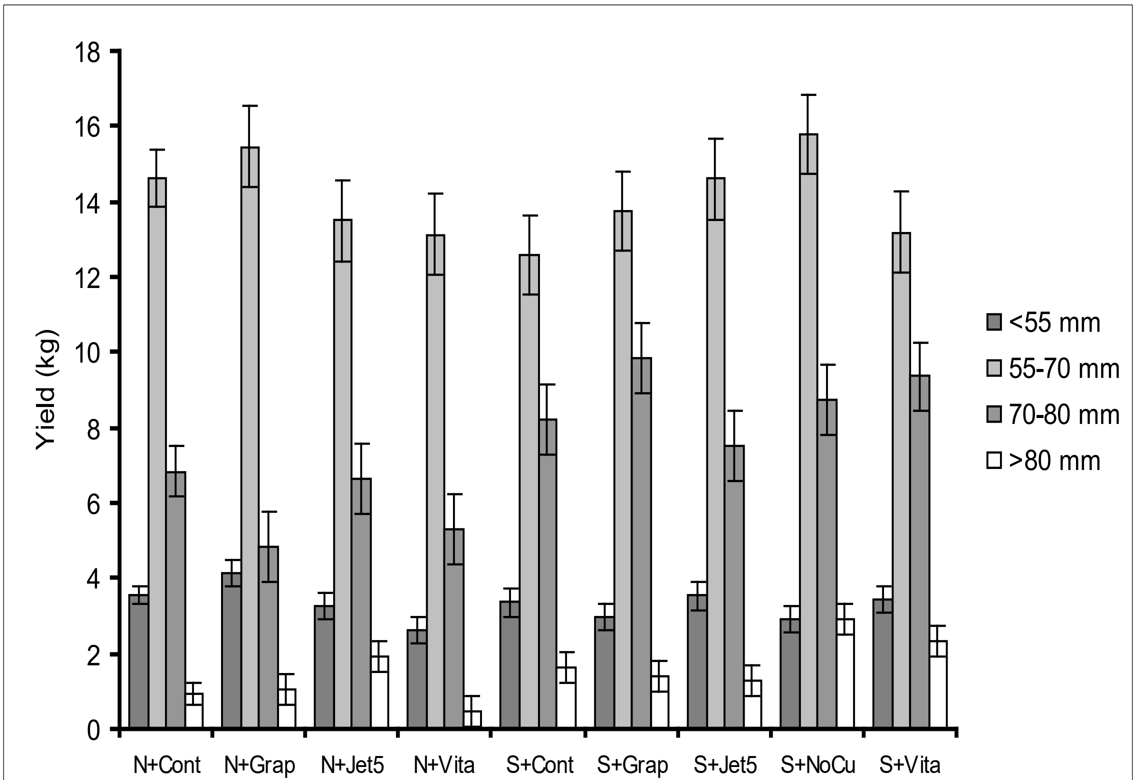

Figure 5. Yield of stored bulbs in each size grade for onion downy mildew spray trial. Values are the means of the harvested area (7.2 m^2) from each plot. Vertical lines represent standard errors.