Project title:	**Calabrese: towards an integrated approach to controlling bacterial spear rot**
Report:	First annual report (of work done in 1999)
Project number:	FV 104b
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Location:	Commercial crops of calabrese in the East of Scotland
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Date commenced:	1 June 1999
Expected completion:	31 May 2001
Key words:	Calabrese, broccoli, spear rot, head rot, disease control, *Pseudomonas, Erwinia*

CONTENTS

PRACTICAL SECTION FOR GROWERS

Spear rot, caused predominantly by the bacterium *Pseudomonas fluorescens* is the most important disease of calabrese. In some fields and seasons it causes extensive crop loss (Box 1).

Box 1 – High Risk Situations for Calabrese Spear Rot

1. Wet weather, particularly warm, wet weather.
2. Warm days and cool nights, leading to dew formation : therefore often troublesome in autumn.
3. Sheltered fields with reduced air movement.
4. Coastal fields prone to sea fog.
5. Excessive nitrogen fertiliser or organic manures applied.
6. A susceptible variety.
7. Damage to the wax coating of heads, for example, caused by a late pesticide spray.
8. Inappropriate application of irrigation during heading.

In common with many other bacterial diseases there are relatively few available controls for calabrese spear rot (Box 2).

Box 2 – Control Measures for Calabrese Spear Rot

1. Copper oxychloride as Cuprokylt. Specific Off-Label Approval 0993/92. 5kg product when heads 2cm across and seven days later. Consult approval document for full details.
2. Avoid fields with a high number of risk factors (Box 1) particularly for susceptible autumn crops.
3. Selection of partially resistant varieties.

Application of copper oxychloride is the main control measure but this is poorly effective under conditions of high disease pressure. This project, FV 104b, aims to improve the control of spear rot by investigating alternative strategies for using copper oxychloride, new adjuvants and bactericides, the role of nitrogen in disease and the use of mulches. The aim is an integrated strategy which will reduce losses to spear rot and thereby increase the profitability of the calabrese crop.

1. The Role of Nitrogen in Disease

Spear rot was assessed at two sites following application of different amounts of nitrogen fertiliser.

Nitrogen Fertiliser Applied kg/ha	Spear Rot % Head Area Affected	
	Site 1	Site 2
100	23.7	0.6
170	21.6	1.6
240	55.1	4.4
310	67.7	6.0

[At Site 1 (Redford, Angus) there was no field infection of spear rot. Results are reported after inducing spear rot on harvested heads by laboratory incubation under alternating warm and cool temperatures. Results for Site 2 (Bow of Fife, Fife) report field infection of spear rot]

At Site 1 harvested yields and soil analysis suggested that 170 kg/ha Nitrogen was necessary to achieve full potential marketable yield. Similar measurements were not made at Site 2 but differing previous cropping suggests a higher nitrogen requirement of around 200 kg/ha.

ACTION POINTS FOR GROWERS

- Increasing applications of nitrogen fertiliser tend to increase the severity of spear rot, however, this effect is less important than the effect on crop yield.
- Therefore, ideally, do not apply more nitrogen fertiliser than necessary for maximum yield – this is wasteful and increases the risk of spear rot.
- and, Ideally, do not apply less nitrogen fertiliser than necessary for maximum yield – this will reduce the risk of spear rot but will usually cause a greater loss of yield from nitrogen deficiency.
- but, Measuring the nitrogen requirement of a crop with precision is very difficult : when prediction techniques suggest a range of possible nitrogen fertiliser applications choosing the lower application will reduce the risk of spear rot, particularly in high risk situations (Box 1).

2. The Effect of Mulches on Spear Rot

Earlier trials suggested that a soil covering mulch may reduce the severity of spear rot, possibly by preventing splash of pathogenic bacteria from soil onto calabrese plants.

Spear rot was assessed on calabrese plants planted through various mulches.

Mulch	Spear Rot % Head Area Affected
None – Bare Soil	17.6
Paper – 100% Ground Covered	1.0
Paper – 50% Ground Covered	3.7
Straw – 100% Ground Covered from Planting	0.0
Paper – 100% Cover + 100 kg/ha N	5.3
Straw – 100% Ground Cover from 6 Leaves	1.4

[Field infection with spear rot in this trial was low – results are reported after inducing spear rot on harvested heads by laboratory incubation under alternating warm and cool temperatures]

ACTION POINTS FOR GROWERS

- Mulching reduced the severity of spear rot, however, more work is needed to refine mulching systems which may offer economic control.
- The best control of spear rot was achieved by completely covering the ground with the mulch from planting.
- Mulching gave no increase in yield, nor did it make cropping earlier.
- Growers using mulches for other reasons, for example, organic weed control, should aim for good ground cover to obtain incidental suppression of spear rot.

3. Alternative Strategies for Copper Oxychloride, New Bactericides

Copper oxychloride as Cuprokylt with Agral wetter added gave good control of spear rot when applied at 5 kg/ha to heads 2cm across and seven days later. Alternative adjuvants to Agral did not give improved control, although different results may be obtained where disease pressure is more severe. Cuprokylt without any adjuvant gave control equal to Cuprokylt plus Agral. Surfactants such as Agral aid infection of calabrese heads by spear rotting bacteria, however, without adjuvant the spray cover of Cuprokylt visually appears unacceptable. Increasing the number of Cuprokylt treatments, at the same or reduced dose, did not improve spear rot control and in many cases gave unacceptable phytotoxicity. The novel bactericide CGA 245704 appeared ineffective against calabrese spear rot.

ACTION POINTS FOR GROWERS

- The standard Cuprokylt programme (Box 2) gave good spear rot control. No modified programmes gave improved control.
- Timing of the first Cuprokylt spray is important: when the heads are about 2cm across. Poor control often results from applying Cuprokylt to large heads as a 'fire brigade' treatment.
- Until further results suggest otherwise, Cuprokylt sprays should remain the main defence against spear rot.

SCIENCE SECTION

1. Introduction

Bacterial spear rot is the most important disease of calabrese, *Brassica oleracea var Italica*, causing extensive crop loss. Current control measures rely on application of the only approved bactericide for this disease, copper oxychloride, formulated as Cuprokylt. In wet years, such as 1998, levels of spear rot are particularly high across the UK and many calabrese fields are rendered completely unmarketable by spear rot, despite treatment with copper oxychloride. Copper oxychloride is poorly effective under conditions of severe disease pressure and improved control measures are clearly required.

The cause of calabrese spear rot in Scotland – the bacteria *Pseudomonas fluorescens* and *Erwinia carotovora* was established by SAC scientists during the early 90s and reported in HDC Project FV 104 (1995). Results from this project and the earlier HDC Project FV 8 (1989) led to the off-label approval for copper oxychloride, gave some indication of a relationship between nitrogen fertiliser application and calabrese spear rot (Robertson 1988) and an indication that a ground covering mulch may reduce severity of spear rot. Work in North America has also suggested a role of nitrogen and irrigation in spear rot incidence (Canaday & Wyatt 1992), Toivonen *et al* (1994).

Experience suggests that no single method will give satisfactory control of calabrese spear rot. Consequently, the ultimate aim of this project is to integrate agronomic and chemical controls to reduce losses from spear rot and thereby increase the quality and profitability of the calabrese crop. In the first year of this two year project, three control strategies for calabrese spear rot were studied:

1. The manipulation of nitrogen fertiliser applications.
2. The use of ground covering mulches.
3. Chemical controls: alternative strategies for the use of copper oxychloride, new adjuvants and novel bactericides.

2. Materials and Methods

2.1 The Effect of Nitrogen Fertiliser Application on Calabrese Spear Rot

Two investigations of the effect of nitrogen fertiliser application on calabrese spear rot were undertaken in 1999. The main trial was undertaken at Crofts Farm, Redford, Carmyllie, Angus: a site with a history of calabrese spear rot. Calabrese was grown with and without application of nitrogen in the base fertiliser and different applications of top dressed nitrogen. Soil analysis was undertaken to study the fate of the applied nitrogen and crop yield was measured.

A second trial was undertaken at the Bow of Fife, by Cupar, Fife. This site had suffered particularly severe spear rot in previous years and a simple trial was undertaken to supplement results from Crofts Farm, should spear rot prove uncommon in 1999. This site had already received a commercial base application of nitrogen so different top dressings only could be imposed. No yields were recorded.

2.1.1 Nitrogen Trial at Crofts Farm, Angus

Crofts Farm, Redford, Carmyllie, Angus (Mr A MacDonald) is 9km north west of Arbroath, Ordnance Survey Reference NO 567434. Soil is of the Balrownie series (Imperfectly drained brown forest soil comprising water-sorted material generally less than 60cm thick overlying till derived from lower old red sandstone sediments). Chemical soil analysis indicated pH of 7.2, high phosphorus status and moderate potassium (SAC interpretive scale).

Immediately before planting a fertiliser application was made to the whole trial area to supply 75kg/ha $P_2 0_5$ and 75kg/ha $K_2 0$. A base dressing of ammonium nitrate to supply 100kg/ha N was applied to appropriate plots. The trial was laid out in a randomised block design with four replicates of the treatments below.

Table 2.1.1 Nitrogen Trial at Crofts Farm, Angus – Treatments

Treatment	Base Fertiliser Kg/ha N	Early Top Dressing kg/ha N	Late Top Dressing kg/ha N
1	100	0	0
2	100	70	0
3	100	140	0
4	100	210	0
5	100	0	70
6	100	0	140
7	100	0	210
8	0	0	0
9	0	70	0
10	0	140	0
11	0	210	0

The trial was planted on 6 July 1999 using module raised ('345' trays) plants of variety Marathon spaced 45cm apart in rows 60cm apart. Each plot comprised three rows of 12 plants. The two end plants of each plot were left as guards and not recorded.

Early top dressing treatments were applied on 15 July 1999. At this time the modules had produced numerous, but short, roots into surrounding soil. Late top dressing treatments were applied on 27 July. The crop now had six to seven true leaves and plots which had not yet been top dressed showed a blue tinge to the foliage indicating nitrogen deficiency.

The trial subsequently received the same cultural treatments as the surrounding commercial crop. Two replicates were harvested on 21 September 1999 and two on 22 September. At harvest all heads were cut, trimmed to a standard length of 12.5cm from top of the head to base of the stem and weighed. Heads were recorded as marketable or unmarketable, together with the reason for unmarketable. Hollow stemmed heads were recorded. Ten marketable heads selected at random were assessed on a 1-5 scale for quality characteristics using characters developed for NIAB variety trialling.

Quality characteristics assessed were: colour (1=light, 5=dark), bud size (1=large buds, 5=small buds), evenness of bud size (1=uneven, 5=even), head shape (1=flat, 5=domed), degree of clustering of buds in head (1=clustered, 5=smooth) and the angle of branches within the head (1=acute, 5=obtuse). In each case a score of 5 equals a desirable characteristic and a score of 1 an undesirable characteristic.

Any watersoaking (see glossary) or spear rot occurring in the field was assessed by estimating the proportion of head area affected. A further assessment of spear rot was made by collecting a random sample of five heads per plot, splitting these in two longitudenally (to reduce the volume of material handled) and incubating at alternating warm (12 hours at 20°C with lighting) and cool temperatures (12 hours at 4°C in darkness) for seven days. The area affected by watersoaking and spear rot on each head was then assessed as incidence (number of heads affected by disease) and severity (% area of head affected by disease).

Available nitrogen in the soil was assessed by measuring nitrate and ammonium content of soil samples collected at depths of 0-20cm and 20-40cm before starting the trial and, for selected treatments, immediately after harvest. At this site, there was a clear boundary between top soil and a hard, sandy subsoil at a depth of 45-60cm.

A further sample of five half heads (split longitudinally) was collected and sent for laboratory analysis of the content of dry matter, major and trace elements.

Statistical analysis of results was carried out by analysis of variance. Angular transformation (Arc sine transformation) was applied to percentages of disease severity and incidence before analysis.

2.1.2 Nitrogen Trial at Bow of Fife, Fife

The Bow of Fife (Over Rankeilour Farms) is 6km south west of Cupar. Ordnance Survey Reference NO 322126. Soil is of the Butterwell series (imperfectly drained brown forest soil comprising till derived from upper old red sandstone sediments, mainly sandstone with partially sorted surface layers). Chemical soil analysis indicated pH of 6.5, moderate phosphorus status and moderate potash status (SAC interpretive scale).

Treatments were superimposed onto a commercial crop of calabrese variety Marathon planted on 9 July 1999. Before planting 800kg/ha 13:13:21 N: P_2O_5: K_2O compound fertiliser was applied commercially: equivalent to 104kg/ha Nitrogen. Each plot comprised five rows of 12 plants with plants spaced 45cm apart in rows 60cm apart. The two outside rows and the two end plants of each plot were used as guards and not recorded: 30 plants per plot were therefore used. Each treatment was replicated four times in a randomised block design.

Top dressings were applied as ammonium nitrate. Early top dressing treatments were applied on 19 July and late top dressing treatments on 3 August 1999. All other cultural treatments were the same as the surrounding commercial crop.

Table 2.1.2 Nitrogen Trial at the Bow of Fife – Treatments

Treatment	Base Fertiliser kg/ha N	Early Top Dressing kg/ha N	Late Top Dressing kg/ha N
1	100	0	0
2	100	70	0
3	100	140	0
4	100	210	0
5	100	0	70
6	100	0	140
7	100	0	210

No yield or quality assessments were made. Field records of watersoaking and spear rot were made on 12 October 1999. At the same time heads were collected for chemical tissue analysis. Statistical analysis was carried out by angular (arc sine) transformation where appropriate, analysis of variance and correlation and regression between measures of disease and nitrogen nutrition.

2.2 The Effect of Mulching on Calabrese Spear Rot

This trial was carried out at Bow of Fife in the same planting, and adjacent to, the nutritional trial above. Seven mulching treatments were compared in a randomised block design experiment with four replicates.

Mulching treatments applied at planting (9 July 1999) were:

1. No mulch.

2. 172cm wide bed (three rows) completely covered with paper mulch. Module plants planted through.

3. Three rows planted in 172cm wide bed. Two strips of 43cm wide paper mulch placed between rows to give 50% ground cover.

4. Approximately 8cm deep mulch of barley straw applied immediately after planting.

5. 172cm wide bed completely covered with paper mulch. Module plants planted through on 14 July (five days after the other treatments). [Previous trials had suggested mulching treatments advance the maturity of calabrese by about five days – this treatment was therefore designed to achieve simultaneous maturity with treatment one, no mulch].

6. 172cm wide bed completely covered with paper mulch. 100kg/ha nitrogen applied before mulching. [The additional nitrogen was added to promote development of spear rot and study the effectiveness of mulching in a high risk situation].

7. Approximately 8cm deep mulch of barley straw applied when plants had developed six true leaves (3 August).

Treatments were designed to study different mulching materials (paper or straw) and the degree of ground cover needed to achieve control of spear rot. The ground was left incompletely covered (treatment 3) or covered for only a part of the crop's life (treatment 7).

Mature heads (approximately 20% of the total) were cut on 30 September with the remainder harvested on 6 October. Marketable and total yields, head quality, spear rot incidence and watersoaking incidence were recorded and analysed as described in section 2.1.1. Nitrogen trial at Crofts Farm, Angus.

2.3 Chemical Control of Spear Rot

Chemical control trials were carried out at Easter Grangemuir Farm (Mr I Brown) which is about 3km north of Pittenweem, Fife – Ordnance Survey Reference NO 546041. Soil is of the Dreghorn series (freely drained brown forest soil comprising raised beach deposits derived mainly from carboniferous sediments).

Three trials were undertaken on a commercial planting of Marathon planted in early July and harvested October. Apart from the experimental treatments all other cultural treatments were the same as applied to the surrounding commercial crop.

All experimental spray treatments were applied in a volume of 600l/ha water using a Solo 456 hand held sprayer fitted with a fan nozzle, medium spray, applied at three bar pressure. Each trial was laid out as a randomised block design with four replicates of each treatment. Plot size for all trials was three rows of 12 plants. The two plants at the end of each row were left as guard plants and not recorded. The incidence and severity of watersoaking and spear rot on each head was recorded on 14 October 1999 and each plot was scored (0-5 scale) for phytotoxicity on 15 October.

2.3.1 Cuprokylt (Copper Oxychloride) Dose Rate Trial

Treatments applied were:

Table 2.3.1 Cuprokylt (Copper oxychloride) Dose Rate Trial

Number of Applications	Dose Rate at Each Application kg/ha	Dates of Application		
2	5		15.09.99	22.09.99
3	3.3	09.09.99	15.09.99	22.09.99
3	5	09.09.99	15.09.99	22.09.99
5	5	09.09.99	15.09.99	22.09.99
			29.09.99	06.10.99
0	0		n/a	

Agral non-ionic wetter was added at the rate of 0.3ml per litre spray solution. The calabrese heads were about 2cm across on 15 September 1999. Two applications of 5kg/ha Cuprokylt is the current recommendation.

At maturity (14.10.99) samples of five heads were collected from each plot and analysed for copper content.

2.3.2 Cuprokylt (Copper Oxychloride) Adjuvant Trial

The following adjuvants were added to sprays of Cuprokylt at 5kg/ha applied when the heads were approximately 2cm across (15 September 1999) and seven days later.

Table 2.3.2 Cuprokylt Adjuvant Trial

Adjuvant	Dilution Rate Per Litre Spray
None	n/a
Agral	0.3ml
Slippa	1.5ml
Arma	1.5ml
Fyzol	6.7ml

Agral (Zeneca Crop Protection, Fernhurst, Hazlemere, Surrey) is 92% w/w alkyl phenol ethylene oxide condensate and organic solvent.

Slippa (Interagro (UK) Ltd, Sworders Barn, North Street, Bishop's Stortford, Herts) is 655g/l polyalkyleneoxide modified heptamethyl trisiloxane and non-organic wetters.

Arma (Interagro (UK) Ltd) is 500g/l alkoxylated fatty amine plus 500g/litre polyoxethylene monolaurate.

Fyzol 11E (AgrEvo UK Ltd, East Winch, King's Lynn, Norfolk) is 99% highly refined paraffinic oil.

2.3.3 Novel Bactericide

The novel bactericide CGA 245704 was compared with a standard Cuprokylt programme at the rates shown below.

Table 2.3.1 Trial of Novel Bactericide

Bactericide	Number of Applications	Dose Rate at Each Application/ha	Application Dates		
CGA 245704	3	12.5g ai	09.09.99	15.09.99	22.09.99
CGA 245704	3	50g ai	09.09.99	15.09.99	22.09.99
CGA 245704	3	50g ai	09.09.99	15.09.99	22.09.99
Cuprokylt	2	5kg product		15.09.99	22.09.99

Agral non-ionic wetter was added at the rate of 0.3ml per litre spray solution. On 15 September the calabrese heads were approximately 2cm across.

3. Results

3.1 Nitrogen Fertiliser Trials

3.1.1 Nitrogen Trial at Crofts Farm, Angus

Measurements of the initial soil mineral nitrogen content and soil mineral nitrogen content at harvest for selected treatments are shown in Table 3.1.1.1 together with marketable crop yield.

Table 3.1.1.1 Nitrogen Fertiliser Trial Crofts Farm, Angus - Yields and Soil Nitrogen

	Nitrogen Applied kg/ha			Soil Nitrogen kg/ha			
Base	Early Top Dressing	Late Top Dressing	Total	Initial	Final	% Fertiliser Left in Soil	Marketable Yield kg/m^2
0	0	0	0	62	42	0	0.26
0	70	0	70				0.81
100	0	0	100	62	53	0	0.95
0	140	0	140				0.93
100	70	0	170				1.20
100	0	70	170				1.28
0	210	0	210	62	133	34	1.12
100	140	0	240				1.11
100	0	140	240				1.28
100	0	210	310	62	210	48	1.24
100	210	0	310	62	195	43	1.33
	LSD 5%						0.180
	LSD 1%						0.243
	LSD 0.1%						0.322

Initial soil nitrogen measured before any fertiliser added to depth of 0.4m.

Final soil nitrogen measured after harvest to depth of 0.4m.

Increasing total nitrogen fertiliser application from nil to 170kg/ha N increased marketable yield from 0.26kg/m^2 to 1.24kg/m^2. However, increasing nitrogen fertiliser application above a total of 170kg/ha gave no further consistent increases in marketable yield. 170kg/ha total nitrogen was therefore the optimum economic fertiliser application.

Nitrogen applications of up to 100kg/ha N were completely taken up by the crop, or lost from the soil by other routes: with nitrogen applications of up to 100kg/ha N there was less nitrogen in the soil at harvest than was present at planting. However, when fertiliser nitrogen application was increased from a total of 210kg/ha to 310kg/ha, approximately 72kg/ha of the extra 100kg/ha nitrogen remained in the soil at harvest, suggesting little of the additional nitrogen was absorbed by the crop. This suggests that fertiliser nitrogen applications of up to, around, 150kg/ha N were taken up by the crop but applications beyond this level tended to accumulate in the soil.

Timing of nitrogen fertiliser application (i.e. early or late top dressing) had no apparent effect on marketable yield. There were no statistically significant differences between yields at total fertiliser applications of 170kg/ha N, 240kg/ha N or 310kg/ha N regardless of whether the top dressing component was applied early or later in the crop's life.

The effect of nitrogen fertiliser application on incidence of spear rot and head quality characteristics is shown in table 3.1.1.2.

Table 3.1.1.2 Nitrogen Fertiliser Trial Crofts Farm, Angus – Spear Rot and Head Quality

Nitrogen Applied kg/ha			Spear Rot			Quality Scores					
Base	**Early Top Dress**	**Late Top Dress**	**% Severity Incubated**		**% Hollow Stem**	**Colour**	**Bud Evenness**	**Bud Size**	**Head Shape**	**Branch Angle**	**Clus/ Tering**
100	0	0	23.7	*(28.8)*	8.3	4.7	3.6	2.0	5.0	2.9	2.9
100	70	0	21.2	*(27.3)*	11.6	4.7	3.4	1.9	5.0	2.9	3.1
100	140	0	30.1	*(33.3)*	4.2	4.8	2.6	1.8	5.0	2.9	2.9
100	210	0	67.7	*(55.8)*	12.5	4.9	2.9	1.5	4.9	2.9	3.0
100	0	70	22.0	*(27.8)*	14.1	4.8	3.0	2.0	5.0	3.2	3.0
100	0	140	80.0	*(66.8)*	20.0	4.8	3.1	2.5	5.0	2.7	3.0
100	0	210	67.6	*(55.6)*	10.8	4.9	3.0	1.5	5.0	3.2	3.0
0	0	0	22.5	*(28.3)*	0.0	1.7	2.3	4.0	4.8	3.5	1.9
0	70	0	13.1	*(21.1)*	5.8	3.9	3.5	3.3	5.0	3.4	3.3
0	140	0	8.7	*(16.8)*	4.2	4.1	3.6	2.9	5.0	3.4	3.2
0	210	0	18.7	*(25.4)*	8.3	4.7	2.9	1.8	4.8	3.0	3.1
	LSD 5%			*(10.82)*	-	0.55	0.41	1.00	-	-	0.57
	LSD 1%			*(14.57)*	-	0.75	0.55	1.34	-	-	0.76
	LSD 0.1%			*(19.31)*	-	0.99	0.73	1.78	-	-	-

Numbers in italics/brackets are angular transformations of percentages.

Quality Scores

Colour	1 = light	5 = dark
Bud Evenness	1 = uneven	5 = even
Bud Size	1 = large	5 = small
Head Shape	1 = flat	5 = domed
Branch Angle	1 = acute	5 = obtuse
Clustering	1 = buds in clusters	5 = smooth heads

At harvest spear rot infection in the trial was trivial. Spear rot was induced by incubating harvested heads under conditions of alternating cool and warm temperatures.

Following incubation spear rot tended to be more severe where most nitrogen fertiliser had been applied. Spear rot was fairly severe, however, (22.5% of head area affected) when no nitrogen fertiliser was applied. Plants from this treatment had the appearance of severe nitrogen deficiency and this stress may have favoured spear rot infection.

Two treatments received a total of 240kg/ha nitrogen fertiliser: 100kg/ha base plus 140kg/ha applied as early top dressing or late top dressing. These treatments gave very different spear rot severities (30 and 80%). However, these results appear anomalous, in general there was no effect of timing of top dressing on spear rot severity.

There were no statistically significant differences in the proportion of heads with hollow stems between treatments. Heads with hollow stems occurred in patches in the trial, consequently, on this site the hollow stems probably resulted from soil factors rather than nitrogen nutrition. Calculation of correlation factors (cf) between the proportion of hollow stems and nitrogen content of head dry matter (cf = 0.284) and the nitrogen content of fresh matter (cf = 0.072) suggested no significant linear relationship between head nitrogen content and incidence of hollow stems (appendix 2).

Bud colour and bud size were both affected by the amount of nitrogen fertiliser applied. Buds tended to become darker and bigger as more nitrogen fertiliser was used. Statistically significant differences were also recorded in evenness of bud size and degree of bud clustering. When the severely nitrogen deficient treatment where no nitrogen fertiliser was used was excluded, however, no consistent trends were observed in these characteristics. No statistical significance was found in head shape and branch angle scores between treatments.

Adjusting nitrogen fertiliser applications over the range of economic use is very unlikely to have meaningful effects on head quality characteristics.

3.1.2 Nitrogen Trial at Bow of Fife

The nitrogen fertiliser trial at Bow of Fife was supplementary to the main fertiliser trial at Crofts Farm. No yields or head quality characters were recorded. Spear rot occurred in the field and the incidence and severity is shown in table 3.1.2.1.

Table 3.1.2.1 Nitrogen Fertiliser Trial at Bow of Fife – Spear Rot and Watersoaking

Nitrogen Applied kg/ha			Watersoaking				Spear Rot			
Base	Early Top Dressing	Late Top Dressing	Incidence %		Severity %		Incidence %		Severity %	
100	0	0	10.0	*(17.6)*	1.7	*(7.3)*	5.8	*(13.6)*	0.6	*(4.2)*
100	70	0	19.2	*(24.7)*	4.0	*(10.9)*	16.7	*(21.1)*	1.2	*(5.4)*
100	140	0	37.5	*(37.6)*	6.9	*(14.9)*	44.2	*(41.6)*	6.1	*(14.0)*
100	210	0	33.3	*(31.3)*	8.7	*(14.3)*	30.0	*(31.5)*	5.6	*(12.1)*
100	0	70	13.3	*(20.5)*	2.8	*(8.6)*	16.7	*(23.5)*	1.9	*(7.1)*
100	0	140	16.7	*(23.4)*	3.1	*(9.8)*	20.0	*(25.4)*	2.7	*(8.9)*
100	0	210	40.8	*(39.3)*	11.1	*(18.9)*	32.5	*(34.0)*	6.4	*(13.9)*
LSD 5%				*(14.83)*		-		*(14.61)*		*(6.64)*

Numbers in italics/brackets are angular transformations of percentages.

Watersoaking and spear rot recorded 12 October 1999.

Increasing applications of nitrogen fertiliser tended to increase both incidence and severity of watersoaking and spear rot. There was no obvious effect of timing of nitrogen top dressing on watersoaking or spear rotting.

3.1.3 Chemical Analysis of Heads

Chemical analysis of heads for major and trace elements was undertaken at both sites. Nitrogen contents for treatments common to both sites are shown in table 3.1.3.1.

Table 3.1.3.1 Nitrogen Fertiliser Trials – Nitrogen Content of Heads

Nitrogen Applied kg/ha			Dry Matter %		Nitrogen % DM		Nitrogen g/kg Fresh	
Base	Early Top Dressing	Late Top Dressing	R	F	R	F	R	F
100	0	0	7.98	9.70	5.43	4.04	4.3	3.9
100	70	0	7.85	9.53	5.69	4.29	4.4	4.1
100	140	0	7.83	8.88	5.96	4.96	4.7	4.4
100	210	0	7.68	8.85	5.86	4.88	4.5	4.3
100	0	70	7.73	9.60	5.77	4.17	4.5	4.0
100	0	140	7.70	9.18	5.95	4.56	4.6	4.2
100	0	210	7.80	9.23	6.04	4.74	4.7	4.4
	LSD 5%		-	0.456	0.231	0.365	0.21	0.25
	LSD 1%		-	0.624	0.316	0.500	-	0.35
	LSD 0.1%		-	-	0.431	0.682	-	-

R = Redford, Angus site
B = Bow of Fife site

The percentage dry matter content and nitrogen content of dry matter varied much more between sites than between treatments. It, therefore, seems unlikely that these characteristics are related to susceptibility of heads to spear rot: this would imply greater susceptibility of unfertilised plants at Crofts Farm, Redford than heavily fertilised plants at Bow of Fife. Nitrogen content of fresh matter varied much less between sites than nitrogen content of dry matter and may be a better indicator of spear rot susceptibility.

The usefulness of chemical tissue analysis as an indicator of spear rot susceptibility may be limited by the confounding effect of changes in nutrient content as the spears mature.

Analysis results for remaining major and trace elements are shown in appendix 1. In most cases differences between treatments were small compared to the differences between sites, inconsistent or statistically insignificant.

3.1.4 Correlation of Nitrogen and Spear Rot

3.1.4.1 Trial at Crofts Farm, Redford

Spear rot severity on incubated heads from Crofts Farm correlated poorly with nitrogen content of head dry matter (correlation factor 0.275) and nitrogen content of head fresh matter (correlation factor 0.357) but gave a correlation factor of 0.672 (significant at $P<0.001$) with the amount of fertiliser nitrogen applied.

Application of least squares regression suggested the line of best fit was:

Spear rot severity (%) = 0.18 (kg/ha N) + 1.58 (shown in Appendix 3).

This suggests that, within the range of nitrogen fertiliser applications tested (0-310kg/ha N), an additional 100kg/ha N will add 18 percentage points to the severity of spear rot. 100kg/ha N is a large variation in the context of an optimum nitrogen application of 170kg/ha and its effect on spear rot is, therefore, small in relation to its effect on yield.

3.1.4.2 Trial at Bow of Fife

At Bow of Fife the correlation factors between spear rot severity and kg/ha nitrogen applied and spear rot incidence and kg/ha nitrogen applied were 0.597 and 0.564 respectively ($P<0.001$). Nitrogen content of the heads and spear rot showed much better correlation than at Crofts Farm. Correlation factors were:

Spear rot severity v nitrogen content dry matter	0.661 ($P<0.001$)
Spear rot incidence v nitrogen content dry matter	0.779 ($P<0.001$)
Spear rot severity v nitrogen content fresh matter	0.628 ($P<0.001$)
Spear rot incidence v nitrogen content fresh matter	0.706 ($P<0.001$)

Spear rot severity and incidence correlated relatively poorly with soil available nitrogen at harvest (correlation factors 0.384 and 0.342 respectively) although the soil analysis results for some plots appeared erroneously high, possibly indicating local contamination.

Application of least squares regression suggested the line of best fit between spear rot incidence and fertiliser nitrogen applied was:

Spear rot incidence (%) = 0.12 (kg/ha N) – 3.55 (shown in Appendix 4).

This is an over simplification as a negative spear rot incidence is suggested when no nitrogen fertiliser is applied, and the relationship may not be linear. However, nitrogen fertiliser application had a similar effect on spear rot incidence at Bow of Fife to the effect on spear rot severity at Crofts Farm - at Bow of Fife addition or subtraction of 100kg/ha N would have added or subtracted 12 percentage points to the incidence of spear rot – a small difference compared to the effect on yield.

3.2 Mulching Trial

The effects of mulching on the timing of cropping, marketable yields and total yield (marketable and unmarketable heads) are shown in Table 3.2.1.

Table 3.2.1 Mulching Trial, Bow of Fife – Crop Yields

Mulch	% Cut First Harvest		Marketable Yield kg/m^2	Mean Head Weight g	Total Yield kg/m^2
None	25.0	*(29.7)*	1.15	380	1.26
Paper 100% Cover	17.5	*(24.5)*	0.98	333	1.09
Paper 50% Cover	30.0	*(32.9)*	1.22	402	1.28
Straw 100% Cover	35.8	*(36.1)*	1.30	409	1.34
Paper Delay Plant	2.5	*(4.6)*	0.59	292	0.69
Paper + Nitrogen	19.2	*(25.2)*	1.04	369	1.14
Straw at 6 Leaves	23.3	*(28.2)*	1.28	384	1.35
LSD 5%		*(12.10)*	0.259	45.1	0.072
LSD 1%		*(16.57)*	0.354	61.8	0.099
LSD 0.1%		-	0.483	84.3	0.135

Numbers in italics/brackets are angular transformations of percentages.

The effect of mulching on spear rot severity and incidence is shown in Table 3.2.2.

Table 3.2.2 Mulching Trial, Bow of Fife – Spear Rot

	Spear Rot % Severity				Spear Rot Incidence %	
Mulch	**Field**		**Incubated**		**Incubated**	
None	0.6	*(3.8)*	17.6	*(24.3)*	95	*(83.4)*
Paper 100% Cover	0.3	*(3.0)*	1.0	*(3.9)*	15	*(16.4)*
Paper 50% Cover	0.2	*(1.8)*	3.7	*(10.8)*	50	*(45.0)*
Straw 100% Cover	0.2	*(1.2)*	0.0	*(0.0)*	0	*(0.0)*
Paper Delay Plant	0.1	*(0.6)*	0.5	*(2.6)*	15	*(16.4)*
Paper + Nitrogen	0.9	*(3.8)*	5.3	*(12.9)*	70	*(57.1)*
Straw at 6 Leaves	0.4	*(2.4)*	1.4	*(6.1)*	40	*(38.9)*
LSD 5%		-		*(5.61)*		*(16.35)*
LSD 1%		-		*(7.69)*		*(22.40)*
LSD 0.1%		-		*(10.48)*		*(30.53)*

Numbers in italics/brackets are angular transformations of percentages.

There were no significant effects of mulching on head quality characteristics (data shown in Appendix 5).

In contrast to earlier experiments, mulching had no statistically significant effect on earliness of cropping. Delaying planting also delayed cropping and yields were reduced. Apart from the delayed planting treatment no mulching treatment gave marketable yields significantly different to no mulch. Mean head weight and total yield were reduced in all treatments where transplanting took place through a mulching material (paper). This probably resulted from the greater difficulty of transplanting through a mulch and failure to achieve effective contact between module and soil.

In the field heads were slightly affected by spear rot. Spear rot was also assessed after laboratory incubation of heads at alternating warm and cool temperatures. Mulching treatments generally reduced the severity of spear rot, particularly when assessed after incubating heads. A 100% cover of straw applied at planting was most effective. Delaying application of the straw mulch reduced the control achieved. Complete ground cover from planting appears essential to maximum control: spear rot was significantly ($P<0.05$) greater on incubated heads when paper mulch was used to cover only 50% of the ground than when the ground was completely covered. Spear rot was significantly ($P<0.05$) greater where nitrogen (100kg/ha) additional to normal commercial application was applied to plants planted through paper mulch. This suggests mulching should be integrated with other controls for spear rot, particularly in high risk situations.

In the absence of beneficial effects on yield, use of mulching for spear rot control must be cheap, simple and unsophisticated. There may be additional benefits of mulching on weed and pest control (cabbage root fly). Further work is required to quantify these factors.

3.3 Chemical Control of Spear Rot

3.3.1 Cuprokylt (copper oxychloride) Dose Rate Trial

Incidence and severity of watersoaking and spear rot following application of Cuprokylt at different doses is shown in Table 3.3.1.1.

All experimental treatments gave significant ($P<0.001$) reductions in spear rot and watersoaking. There were no significant differences in effectiveness of the experimental treatments.

All Cuprokylt treatments gave phytotoxicity symptoms. At low doses a fine dark brown spotting made leaves appear muddy or dirty compared to untreated plots. Affected leaves also appeared to lack bloom. At the highest dose (5x5kg) buds at the crown of the head (those most exposed to the spray) were browned and desiccated. This damage made heads unmarketable and was obviously unacceptable.

Phytotoxicity occurring when a total Cuprokylt dose of 10kg/ha (either 2x5kg or 3x3.3kg) was considered tolerable but phytotoxicity occurring at greater doses was thought unacceptable. Treatments were applied in September: damage is likely to be greater from treatments made in mid-summer or at more southerly locations. The large residues of copper left by higher doses may also preclude these spray programmes.

Table 3.3.1.1 Cuprokylt Dose Rate Trial – Spear Rot

Cuprokylt Dose kg/ha	**Watersoaking Incidence %**	**Watersoaking Severity %**		**Spear Rot Incidence %**	**Spear Rot Severity %**		**Phytotoxicity at Harvest**	**Head Copper mg/kg**
2x5	0.8	0.0	*(0.6)*	3.3	0.3	*(1.4)*	0.5	63
3x3.3	0.0	0.0	*(0.0)*	0.0	0.0	*(0.0)*	1.0	55
3x5	0.0	0.0	*(0.0)*	0.0	0.0	*(0.0)*	2.8	77
5x5	0.0	0.0	*(0.0)*	0.0	0.0	*(0.0)*	4.0	267
None	23.3	5.7	*(12.2)*	32.5	5.6	*(13.5)*	0.0	4
LSD 5%			*(5.18)*			*(2.58)*	0.84	39.9
LSD 1%			*(7.27)*			*(3.62)*	1.18	56.0
LSD 0.1%			*(10.27)*			*(5.11)*	1.67	79.1

Numbers in italics/brackets are angular transformations of percentages.

Phytotoxicity scored: 0 = no phytotoxicity
5 = growth checked
scores greater than c2.5 likely to be unacceptable.

3.3.2 Cuprokylt (Copper Oxychloride) Adjuvant Trial

The effect of adding different adjuvants to Cuprokylt on spear rot control is shown in Table 3.3.2.1.

Table 3.3.2.1 Cuprokylt Adjuvant Trial: Spear Rot

Bactericide	Adjuvant	Watersoaking Incidence %	Watersoaking Severity %		Spear Rot Incidence %	Spear Rot Severity %		Phytotoxicity at Harvest
Cuprokylt	**Nil**	0.0	0.0	*(0.0)*	0.0	0.0	*(0.0)*	0.0
Cuprokylt	**Agral**	0.0	0.0	*(0.0)*	0.0	0.0	*(0.0)*	1.3
Cuprokylt	**Slippa**	0.0	0.0	*(0.0)*	0.0	0.0	*(0.0)*	1.5
Cuprokylt	**Arma**	3.3	1.0	*(3.9)*	0.8	0.0	*(0.6)*	1.0
Cuprokylt	**Fyzol**	2.5	1.2	*(5.3)*	4.2	0.5	*(2.7)*	1.3
Nil	**Nil**	22.5	6.9	*(14.7)*	25.0	2.5	*(9.0)*	0.0
LSD 5%				*(5.22)*			*(2.16)*	0.79
LSD 1%				*(7.21)*			*(2.99)*	1.10
LSD 0.1%				*(9.97)*			*(4.14)*	-

Numbers in italics/brackets are angular transformations of percentages.

Phytotoxicity scored: 0 = no phytotoxicity
5 = growth checked
scores greater than c2.5 likely to be unacceptable.

Cuprokylt gave significant (P<0.001) control of watersoaking and spear rot regardless of the adjuvant added. Control achieved by Cuprokylt + Fyzol (99% paraffinic oil) was significantly poorer (P<0.001) than other treatments except Arma.

Cuprokylt without adjuvant gave control just as good as when any adjuvant was used and without phytotoxicity. Cuprokylt is formulated as a wettable powder and no adjuvants are recommended by the manufacturers on the label. Without adjuvant, however, distribution of Cuprokylt after spraying calabrese heads visually appears unacceptable. Bacteria involved in calabrese spear rot produce surfactants to aid infection. Addition of a traditional detergent sufactant to Cuprokylt sprays therefore appears undesirable.

3.3.3 Novel Bactericide – CGA 245704

Results achieved by application of the novel bactericide CGA 245704 in comparison with the standard Crupokylt programme are shown in Table 3.3.3.1.

Table 3.3.3.1 Evaluation of CGA 245704 for Spear Rot Control

Product	Dose/ha	Watersoaking Incidence %		Watersoaking Severity %		Spear Rot Incidence %		Spear Rot Severity %	
CGA245704	3x12.5g ai	21.7	*(24.1)*	4.7	*(10.5)*	24.2	*(29.1)*	3.2	*(11.3)*
CGA245704	3x30g ai	19.2	*(22.6)*	5.0	*(10.5)*	25.8	*(30.0)*	4.3	*(11.1)*
CGA245704	3x50g ai	26.7	*(30.6)*	8.6	*(19.1)*	27.5	*(31.2)*	4.6	*(11.7)*
Cuprokylt	2x5kg product	0.0	*(0.0)*	0.0	*(0.0)*	0.0	*(0.0)*	0.0	*(0.0)*
None	n/a	14.2	*(21.7)*	5.2	*(12.2)*	15.0	*(23.2)*	2.6	*(8.2)*
LSD 5%			*(12.59)*		*(8.08)*		*(8.10)*		*(5.57)*
LSD 1%			*(17.66)*		*(11.33)*		*(11.36)*		*(7.80)*
LSD 0.1%			-		-		*(16.05)*		-

Numbers in italics/brackets are angular transformations of percentages.

Standard Cuprokylt treatment gave good control of watersoaking and spear rot. There was no evidence that CGA 245704 was effective against calabrese spear rot.

4. Conclusion

At the low or moderate disease levels in these trials Copper Oxychloride as Cuprokylt gave effective and consistent control of spear rot when applied to heads 2cm across and seven days later at a rate of 5kg product/ha. Cuprokylt is relatively cheap so should remain the principle control for calabrese spear rot until more effective controls are developed.

Manipulation of spray rates, frequency and physical characteristics (by addition of adjuvants) did not give improved control of calabrese spear rot in these trials, however, further investigations are planned.

Mulches, applied at planting and which completely cover the soil, also show potential in controlling spear rot. Mulches will be relatively expensive and difficult to apply. They may have incidental benefits in weed and pest control but may also suffer disadvantages such as disposal problems. More experience of mulches is needed before their practical usefulness for spear rot control can be properly assessed.

Severity and incidence of spear rot became greater as more nitrogen fertiliser was applied to calabrese. Beneficial effects on spear rot of nitrogen applications less than required to achieve potential yield were outweighed by the yield penalty incurred. Provided excess nitrogen fertiliser is not applied there appears little benefit to be gained from manipulating nitrogen fertiliser applications. Spear rot is only one of many factors to be considered in determining nitrogen fertiliser application. In ambiguous situations consideration of spear rot will favour cautious applications of nitrogen fertiliser.

Commercial experience of spear rot control with Cuprokylt has been much more disappointing than trial results would suggest: A more robust strategy for spear rot control is clearly needed, but it is worth remembering that Cuprokylt is more effective if applied as a preventative spray to young heads, i.e. as under the terms of the off-label approval, rather than as a curative or late preventative spray on mature heads. While refinement of spray programmes with Cuprokylt may be possible, a combination of Cuprokylt treatments and crop mulches at present offers the best prospects for effective control in commercial situations.

GLOSSARY

Spear Rot:	a bacterial rot developing on the florets of calabrese spears. Affected tissue becomes soft and mushy with an accompanying foul smell. Spear rot may be preceded by watersoaking (see below).
Spear Rot Incidence:	a measurement of spear rot infection based on the number of heads affected. For example, if 15 heads of a sample of 50 have some symptoms of spear rot then spear rot incidence is 30%.
Spear Rot Severity:	a measurement of spear rot infection based on the proportion of head area affected. For example, if 25 heads of a sample of 50 are each half rotted then spear rot severity is 25% and if the spear rot heads are completely rotted spear rot severity is 50%.
Watersoaking:	florets of calabrese showing watersoaking are structurally sound but have an appearance of glassiness or permanent wetness. Florets showing watersoaking may, or may, not go on to develop spear rot.

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ACKNOWLEDGEMENTS

We would like to thank Angus MacDonald of Crofts Farm, John Wilson of Over Rankeilour Farms and Ian Brown of Easter Grangemuir for allowing us to use areas of their calabrese crops for these trials and their practical help in establishing and maintaining the trials.

Alastair Ewan of East of Scotland Growers, Simon Jackson, John Sedgewick and Ian Morrison of Kettle Produce made many valuable suggestions in discussions leading to these trials.

We would also like to thank a number of SAC staff who assisted with harvesting the trials and subsequent data analysis: Jeanette Taylor, Pamela Mutch, Adrian Thomson, Brian Pool, Robert Redpath and Alison McGowan.

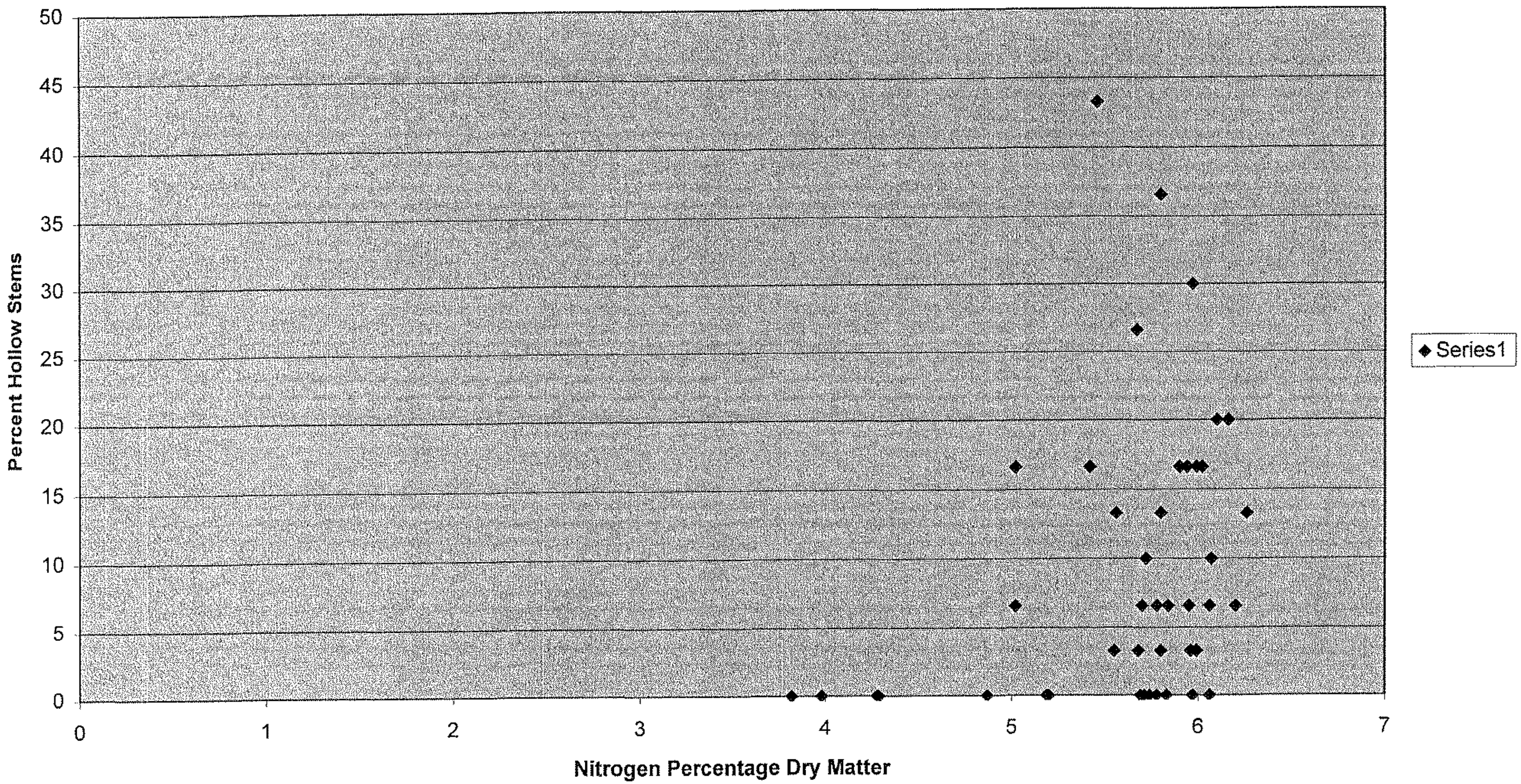
APPENDIX 1

NUTRIENT CONTENT OF HEADS: NITROGEN FERTILISER TRIALS AT CROFTS FARM (C) AND BOW OF FIFE (F)

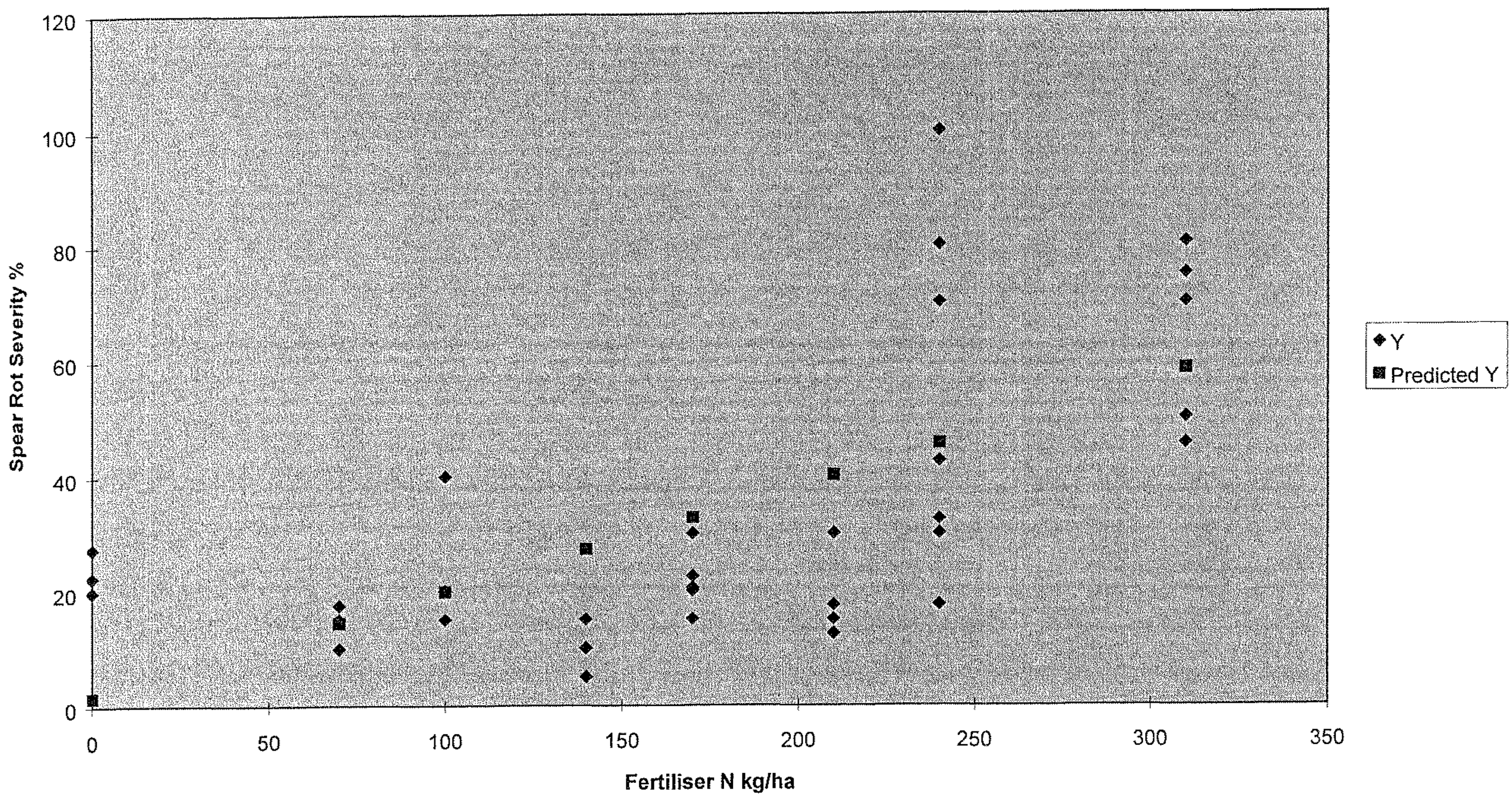
Fertiliser kg/ha N			Dry Matter %		N % DM		P % DM		K % DM		Mn mg/kg DM		S % DM		Ca % DM		B mg/kg DM		Mg % DM	
*B	*ET	*LT	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
100	0	0	7.98	9.70	5.43	4.04	0.82	0.57	4.47	3.64	19.1	16.9	0.97	0.77	0.45	0.41	30.2	25.4	0.23	0.17
100	70	0	7.85	9.53	5.69	4.29	0.81	0.56	4.09	3.58	19.6	17.5	0.89	0.77	0.44	0.41	30.0	25.5	0.22	0.18
100	140	0	7.83	8.88	5.96	4.96	0.83	0.54	4.16	3.35	21.4	18.7	0.92	0.76	0.50	0.37	30.2	26.2	0.24	0.17
100	210	0	7.68	8.85	5.86	4.88	0.82	0.54	3.99	3.56	20.9	19.6	0.87	0.77	0.45	0.41	30.6	26.2	0.22	0.18
100	0	70	7.73	9.60	5.77	4.17	0.83	0.59	4.17	3.56	19.7	17.2	0.90	0.75	0.44	0.40	30.5	26.0	0.23	0.17
100	0	140	7.70	9.18	5.95	4.56	0.84	0.60	4.04	3.62	20.6	18.8	0.87	0.78	0.42	0.37	30.4	26.9	0.22	0.19
100	0	210	7.80	9.23	6.04	4.74	0.84	0.56	4.06	3.47	21.2	17.8	0.88	0.78	0.45	0.37	30.1	26.3	0.23	0.18
LSD 5%			-	0.456	0.231	0.365	-	-	0.219	0.179	1.28	1.39	0.055	-	0.040	-	-	-	0.010	0.010
LSD 1%			-	0.624	0.316	0.500	-	-	0.300	-	1.75	1.91	-	-	-	-	-	-	-	-
LSD 0.1%			-	-	0.431	0.682	-	-	-	-	-	-	-	-	-	-	-	-	-	-

*B = Base Fertiliser
*ET = Early Top Dressing
*LT = Late Top Dressing

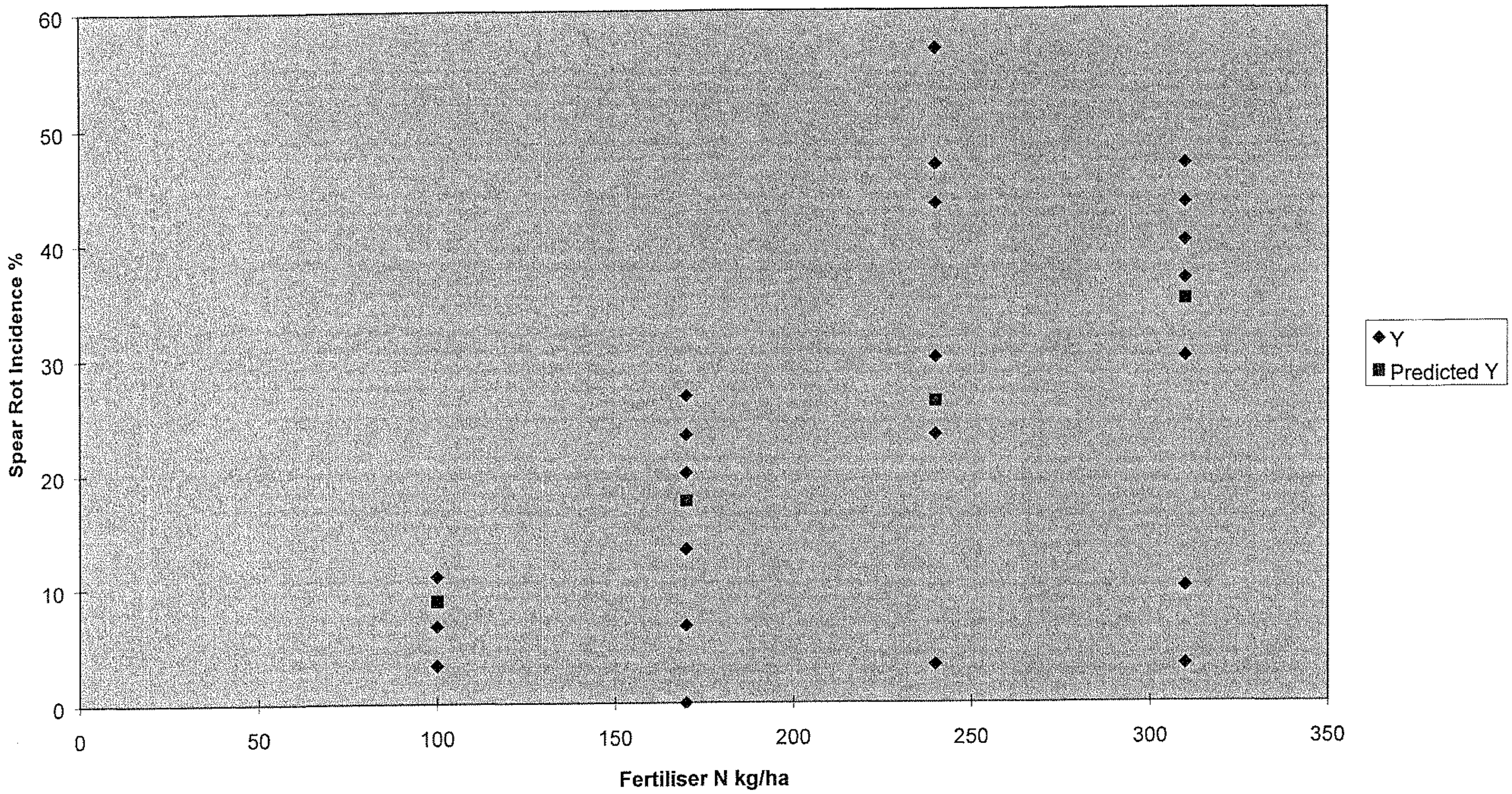
APPENDIX 2 - Nitrogen and Hollow Stems - Crofts Farm



APPENDIX 3 - Nitrogen Fertiliser Applied and Spear Rot Severity - Crofts Farm



APPENDIX 4 - Nitrogen Fertiliser Applied and Spear Rot Incidence - Bow of Fife



APPENDIX 5 – MULCHING TRIAL AT BOW OF FIFE: HEAD QUALITY DATA

	% Hollow Stem		Colour	Bud Evenness	Bud Size	Head Shape	Branch Angle	Clust ering
Mulch								
None	35.8	*(36.4)*	4.1	3.2	1.8	4.8	3.5	3.0
Paper 100% Cover	41.7	*(40.1)*	4.1	3.3	1.7	5.0	3.8	2.8
Paper 50% Cover	41.7	*(40.1)*	4.0	3.1	1.6	4.9	3.5	2.8
Straw 100% Cover	35.8	*(36.5)*	4.0	3.2	1.3	5.0	3.5	2.9
Paper Delay Plant	22.5	*(27.2)*	4.0	3.6	2.1	5.0	3.7	3.1
Paper + Nitrogen	56.7	*(48.8)*	4.0	3.1	1.6	5.0	3.6	3.0
100% Straw at 6 Leaves	63.3	*(52.9)*	4.1	3.4	1.6	5.0	3.6	3.3
LSD 5%		*(10.49)*		-	-	-	-	-
LSD 1%		*(14.37)*		-	-	-	-	-
LSD 0.1%		-		-	-	-	-	-

Numbers in italics/brackets are angular transformations of percentages.

Quality Scores

Colour	=	1=light; 5=dark
Bud Evenness	=	1=uneven; 5=even
Bud Size	=	1=large; 5=small
Head Shape	=	1=flat; 5=domed
Branch Angle	=	1=acute; 5=obtuse
Clustering	=	1=buds in clusters; 5=smooth heads

With the exception of hollow stem there were no significant differences between treatments in any of the quality characteristics.