Project title: **Calabrese: towards an integrated approach to controlling bacterial spear rot**

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Project number: FV 104b

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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. A new Specific Off-Label Approval 0115/2001 uses data from this project and supersedes SOLA 0993/92. Under the "old" SOLA, the "standard treatment" programme was two applications of 5kg product, the first when heads are 2cm across and the second at seven days later. Results from this project show that the standard programme can be improved – see Box 5. Consult approval document before use.
2. Avoid fields with a high number of risk factors (Box 1) particularly for susceptible autumn crops.
3. Selection of partially resistant varieties.

Aims

Application of copper oxychloride as the "standard programme" (Box 2) 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 that will reduce losses to spear rot and thereby increase the profitability of the calabrese crop.

Note on disease assessment

Experiments were carried out in the field in 1999 and 2000 using natural infection, ie no inoculation of crops was used. Disease levels were low in 1999 but high in 2000. Symptoms of spear rot and watersoaking were assessed; the latter is a precursor to rot. Symptoms were assessed in terms of severity (the percentage area of each head affected by symptoms) and incidence (the percentage number of heads affected): see Glossary for further explanation of these terms.

1. The Role of Nitrogen in Disease

Spear rot was assessed at two sites in 1999 following application of different amounts of nitrogen fertiliser.

Nitrogen Fertiliser Applied kg/ha	**Spear Rot**		
	Site 1	**Site 2**	
	% Head Area Affected	% Head Area Affected	% of Heads Affected
100	23.7	0.6	5.8
170	21.6	1.6	16.7
240	55.1	4.4	32.1
310	67.7	6.0	31.3

[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 disease-conducive conditions. 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.

BOX 3 - ACTION POINTS FOR GROWERS: Nitrogen Application

- Increasing applications of nitrogen fertiliser lead to an 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 might reduce the severity of spear rot, possibly by preventing splash of pathogenic bacteria from soil onto calabrese plants.

In 1999 spear rot was assessed on calabrese plants planted through various types of mulch:

Mulch	**Spear Rot** % Head Area Affected	% of Heads Affected
None – Bare Soil	17.6	95
Paper – 100% Ground Covered	1.0	15
Paper – 50% Ground Covered	3.7	50
Straw – 100% Ground Covered from Planting	0.0	0
Paper – 100% Cover + 100 kg/ha N	5.3	70
Straw – 100% Ground Cover from 6 Leaves	1.4	40

[Site: Bow of Fife, Fife. Field infection with spear rot in this trial was low – results are reported after inducing spear rot on harvested heads by laboratory incubation under disease-conducive conditions]

In 2000 more detailed studies were made of straw mulches:

Mulch	Spear Rot: Mulch Applied at Planting: % Head Area Affected	Mulch Applied at Planting: % of Heads Affected	Mulch Applied at Late Vegetative Stage: % Head Area Affected	Mulch Applied at Late Vegetative Stage: % of Heads Affected
None	16.3	48.8	8.2	30.0
Whole Straw 2-3cm Deep	4.7	24.2	2.8	11.7
Shredded Straw 0.5-1cm Deep	9.6	36.7	3.8	20.4
Shredded Straw 2-3cm Deep	5.9	25.0	3.8	17.9

[Site: Bow of Fife, Fife. Results from field observations]

BOX 4 - ACTION POINTS FOR GROWERS: Use of Mulches

- Although mulching reduced spear rot, achieving the effective ground cover needed to obtain commercially useful control appears uneconomic.
- Mulching had no effect on yield, nor did it make cropping earlier.
- Growers using mulches for other reasons, for example, weed control in organic systems, 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 gave significant control of spear rot when applied at 5kg/ha to heads 2cm across and seven days later in most of the trials reported here. Addition of adjuvants did not, in general, give statistically significant improvements in control but an adjuvant containing 96% di-l-p-menthene, which was the best of the adjuvants tested, did give statistically significant reductions in the incidence and severity of watersoaking.

More than two applications of Cuprokylt at 5kg/ha often gave unacceptable phytotoxicity. However, repeated applications of lower doses gave improved control of spear rot and were not phytotoxic provided the total dose did not exceed 15kg/ha. Applying Cuprokylt in a water volume of 600l/ha rather than 1200l/ha or 1800l/ha significantly improved control of spear rot.

The effect on spear rot of repeated smaller doses of Cuprokylt (water volume 600l/ha; total Cuprokylt dose 10kg/ha):

		Spear Rot	
Number of treatments	**Cuprokylt dose/Treatment kg**	% Head Area Affected	% of Heads Affected
Nil	Nil	30.6	69.2
2	5.0	3.8	20.8
3	3.3	2.2	15.0
4	2.5	0.3	2.5
5	2.0	1.1	5.9

[Site: Denbrae, St Andrews, 2000. Results from field observations]

The novel bactericide CGA245704 was ineffective against spear rot. The nutrient mix DM31 was phytotoxic. Tribasic copper sulphate gave inferior control of watersoaking and spear rot compared to copper oxychloride as Cuprokylt. Calcium chloride gave some reduction in the incidence and severity of spear rot but this was not statistically significant: the incidence and severity of watersoaking were actually increased by calcium chloride. Potassium phosphite significantly reduced the incidence and severity of spear rot compared to the untreated control but was less effective than Cuprokylt. Of the potential alternative bactericides tested only potassium phosphite may be useful: and then as a supplement to Cuprokylt rather than as a single treatment. Potassium phosphite is not currently approved as a pesticide in the UK.

BOX 5 - ACTION POINTS FOR GROWERS: Use of Bactericides

- The standard Cuprokylt programme (superseded SOLA 0993/92; Box 2) gave useful spear rot control.
- Timing of the first Cuprokylt spray in the standard programme is important: when the heads are about 2cm across. Poor control in commercial practice often results from applying Cuprokylt to large heads as a ‘fire brigade’ treatment, when pathogen numbers are already too high.
- Repeated application of low doses of Cuprokylt in 600l water/ha gave much improved disease control compared to the standard programme.
- Under the new SOLA (0115/2001), better control would be obtained with 4 or 5 applications of 3kg/ha in 600l water/ha, beginning at the late vegetative stage of the crop. The use of water volumes lower than 600l/ha with this programme requires investigation.
- Addition of adjuvants, in particular those containing di-l-p-menthene, and possibly potassium phosphite, may improve the efficacy of Cuprokylt. Further work is needed on these, especially to assess their integration into a Cuprokylt programme.
- Until further results suggest otherwise, Cuprokylt sprays should remain the main defence against spear rot.

CAUTION: PHYTOTOXICITY OF COPPER OXYCHLORIDE

Copper oxychloride as Cuprokylt consistently gave the best control of calabrese spear rot in the trials reported here, however, it can cause browning of buds in calabrese heads and, if used inappropriately, can render crops unmarketable.

In these trials, Cuprokylt was used to treat relatively small numbers of calabrese plants in Scotland, usually in September, but sometimes in late August. The risk of phytotoxicity will be considerably greater in warmer climates at warmer times of year. The risk of phytotoxicity will also be increased by applying more Cuprokylt than described and by reducing water volumes.

Growers are recommended to initially treat only small trial areas of calabrese with Cuprokylt when growing new cultivars, using new spraying equipment or deviating in any other way from standard procedures. Spraying Cuprokylt should be avoided in hot, sunny weather.

Growers are reminded that any use of Cuprokylt in accordance with Specific Off-Label Approval 0115/2001 is entirely at their own risk.

The treatments described in this report were experimental. Growers must satisfy themselves that any commercial use of products described complies with the requirements of pesticide legislation at the time of application.

SCIENCE SECTION

1. Introduction

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. Many calabrese fields have been rendered completely unmarketable by spear rot, despite treatment with copper oxychloride. To date copper oxychloride has been 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 (Campbell et al., 1995). Results from this project and the earlier HDC Project FV 8 (Robertson & Brokenshire,1992) 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). Some publications have also dealt with the subject of cultivar susceptibility (Canaday et al., 1991; Darling et al., 2000). The most widely grown cultivar, cv Marathon, is moderately susceptible to spear rot (Darling et al., 2000).

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. 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_20_5 and 75kg/ha K_20. 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, thus giving 30 recordable plants per plot.

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 that 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.

<u>Disease assessment</u>

Any watersoaking (see glossary) or spear rot occurring in the field was assessed by (1). estimating, on each head, the proportion of head area affected, and (2). counting the number of heads affected in each plot (n = 30). The former is described as disease *severity*, the latter as disease *incidence.* See the glossary for further explanation of these terms.

In 1999, spear rot levels in the field were low, owing to dry weather during head maturation. In this case, mature heads (5 or 10 per plot) were cut and removed to the laboratory where they were incubated in controlled environment chambers under conditions which induced spear rot symptoms: 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) as above. This gave an idea of the presence and numbers of pathogenic bacteria on the heads at harvest – the assumption made is that, given suitable environmental conditions in the field, those heads would have shown symptoms if left *in situ*. Experiments which validated this technique were carried out in 1995 (Campbell et al., 1995). Conditions at harvest in 2000 meant that disease induction was unnecessary.

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 topsoil and a hard, sandy subsoil at a depth of 45-60cm.

A 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_20_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 Chemical Control of Spear Rot

In 1999 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 early/mid 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 filled 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.

In 2000 chemical control trials were carried out at the Bow of Fife in a field adjacent to that described in section 2.1.2 or at Denbrae Farm, St Andrews (Mr J Mason). Denbrae Farm is about 3.5km NSW of St Andrews. Ordnance Survey Reference NO 475151. Soil is of the Winton series (an imperfectly drained reddish brown till derived mainly from sandstones and shales).

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

Experimental treatments were applied using a Cooper-Pegler Maxi-pro sprayer fitted with fan nozzles producing a medium spray at three bar pressure. Spray application volume was 600l/ha unless altered for the experimental treatments. Each trial was laid out as a randomised block design with four replicates of each treatment except the application volume trial which was a randomised factorial design with three replicates. 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 the dates indicated below and phytotoxicity scored where appropriate.

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.

2.2.1 Cuprokylt (Copper oxychloride) Dose Rate and Application Volume Trials

2.2.1.1 Dose Rate Trial 1999

The effect of increasing the Cuprokylt dose up to a total application of 25kg/ha (applied as five applications of 5kg/ha) was studied.

Treatments applied were:

Table 2.2.1.1 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 was the recommendation current in 1999.

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

2.2.1.2 Split Dose Trial 2000

The off-label approval for Cuprokylt on calabrese current in 1999/2000 (0993/92, now superseded) allowed two treatments of 5kg/ha each. The effect of applying the same total dose (10kg/ha) but divided into more individual treatments was assessed in a trial at Denbrae Farm.

Treatments applied were:

Table 2.2.2.2 Cuprokylt (Copper Oxychloride) Split Dose Trial

Number of Applications	Dose Rate at Each Application kg/ha	Dates of Application				
0	0			n/a		
2	5				13.09.00	19.09.00
3	3.3			30.08.00	13.09.00	19.09.00
4	2.5		23.08.00	30.08.00	13.09.00	19.09.00
5	2	16.08.00	23.08.00	30.08.00	13.09.00	19.09.00

No adjuvants were added to the spray solutions. The calabrese heads were a little over 2cm across on 13 September 2000. Heads were assessed for spear rot and watersoaking on 10 and 18 October 2000. On 10 October samples of five mature spears were collected from each plot and analysed for copper content.

2.2.1.3 Application Volumes Trial 2000

Commercial experience suggests applying Cuprokylt in higher water volumes reduces phytotoxicity. The effect was studied in a trial at Denbrae Farm using a total application of 15kg/ha Cuprokylt divided into different numbers of spray treatments.

Treatments applied were:

Table 2.2.1.3 Cuprokylt Application Volumes Trial 2000

Number of Treatments	**Cuprokylt Individual Treatment Rate kg/ha**	**Water Volume l/ha**	**Date of Application**			
2	7.5	600				
2	7.5	1200			13.09.00	19.09.00
2	7.5	1800				
3	5.0	600				
3	5.0	1200		30.08.00	13.09.00	19.09.00
3	5.0	1800				
4	3.75	600				
4	3.75	1200	23.08.00	30.08.00	13.09.00	19.09.00
4	3.75	1800				
5	3.0	600	16.08.00			
5	3.0	1200	23.08.00	30.08.00	13.09.00	19.09.00
5	3.0	1800				

No adjuvants were added to the spray solutions. The calabrese heads were a little over 2cm across on 13 September 2000. Heads were assessed for spear rot and watersoaking on 18 October 2000.

2.2.2 Cuprokylt (Copper Oxychloride) Adjuvant Trials

There are a wide variety of adjuvants on the market and much confusion over the terminology used to describe their properties. For example, in The UK Pesticide Guide ("The Green Book"), the adjuvant di-1-p-menthene (trade names Nu Film 17/Emerald/Pin-O-Film) is described, depending on the trade name, as a wetter, sticker, extender, anti-transpirant, coating agent and surfactant. Perhaps all of these are valid descriptions of the properties of di-1-p-menthene, but they do not help in making a rational choice of adjuvant for use with a pesticide. There appears to be no consensus for classification of adjuvants by the pesticides industry – however, Fig 2.2.2.1 is one scheme for classification of adjuvants, according to their major *purpose*, and is the scheme we use here.

Field experiments were carried out in 1999 and 2000 with the aim of testing suitable adjuvants for their ability to improve the efficacy of Cuprokylt. We also wanted to find a replacement for Agral, the standard adjuvant used by many growers with Cuprokylt: our earlier experiments showed that Agral, a non-ionic wetter, can affect the structure of cuticular wax on the calabrese head, making it more susceptible to spear rot. After discussion with industry specialists, a number of adjuvants were chosen based on their representation of a range of adjuvant categories, their known effects on cuticular wax, and their compatibility with Cuprokylt and the crop. The short list is shown in Table 2.2.2.1.

Table 2.2.2.1 Properties of adjuvants used in trials

Adjuvant (trade name)	**Purpose (category)**	**Chemical type**
Agral	Wetting agent	Non-ionic wetter
Arma	Wetting agent	Non-ionic wetter plus cationic fatty acid amine
Banka	Sticker and deposition aid	Pyrrolidone
Designer	Super-wetter/Sticker and deposition aid	Organosilicone plus latex
Fyzol	Adjuvant oil	Mineral oil
Nu Film 17	Sticker and deposition aid	Terpene
Slippa	Wetting agent	Organosilicone plus non-ionic wetter

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

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

Banka (Interagro UK Ltd, Sworders Yard, North Street, Bishops Stortford, Herts) is 29.2% alkyl pyrrolidones.

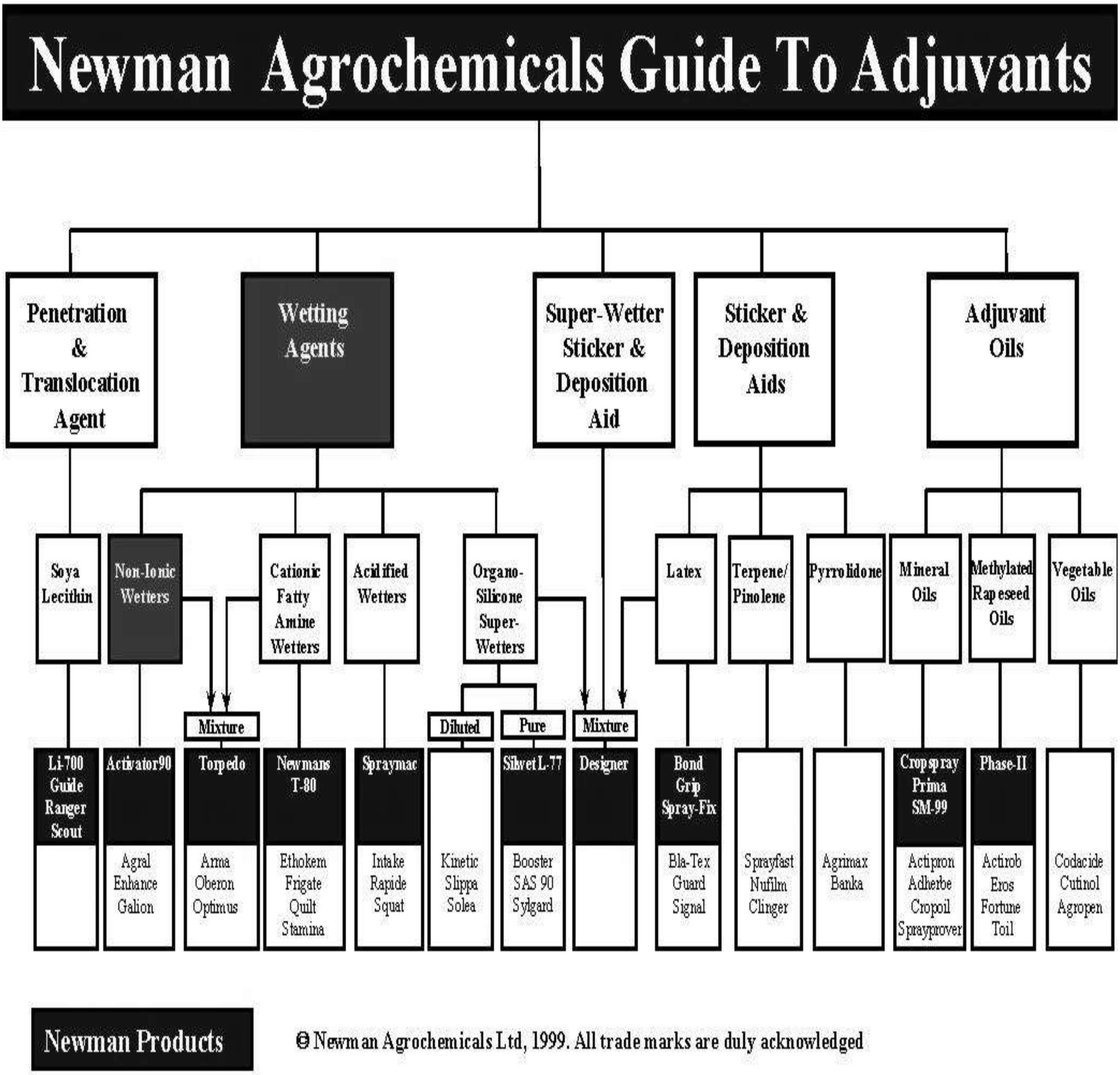
Designer (Newman Agrochemicals Ltd, Swaffham Bulbeck, Cambridge CB5 0LU) is 8.4% Organosilicone wetter and 50% synthetic latex.

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

Nufilm17 (Intracrop, Byemoor Farm, Melmerby, Leyburn, N.Yorks) is 96% di-l-p-menthene.

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

Fig 2.2.2.1 Classification of adjuvants (reproduced courtesy of Newman Agrochemicals Ltd)



2.2.2.1 1999 Trial, Easter Grangemuir, Pittenweem, Fife.

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 2.2.2.2 Cuprokylt Adjuvant Trial (1999)

Adjuvant	Dilution Rate Per Litre Spray
Nil	n/a
Agral	0.3ml
Slippa	1.5ml
Arma	1.5ml
Fyzol	6.7ml

2.2.2.2 2000 Trial, Bow of Fife, Fife.

In 2000 the following adjuvants were added to sprays of Cuprokylt at 5kg/ha applied when the heads were a little less than 2cm across (5 September) and on 13 September.

Table 2.2.2.3 Cuprokylt Adjuvant Trial (2000)

Bactericide	Adjuvant	Dilution Rate Per Litre Spray
Cuprokylt	Agral	0.3ml
Cuprokylt	Nufilm17	0.9ml
Cuprokylt	Designer	1.25ml
Cuprokylt	Banka	1.5ml
Cuprokylt	Nil	n/a
Nil	Nil	n/a

Heads were assessed for spear rotting and watersoaking on 6 October when samples of five heads were also collected for analysis for copper content.

2.2.3 Novel Bactericide Trials

2.2.3.1 1999 Trial

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

Table 2.2.3.1 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.

2.2.3.2 2000 Trial

In 2000 the potential bactericides shown in the table were compared with a standard Cuprokylt programme in a trial at Denbrae Farm.

Table 2.2.3.2 Novel Bactericide Trial 2000

Bactericide	Number of Applications	Dose Rate at Each Application /ha	Application Dates		
Cuprokylt	2	5kg		13.09.00	19.09.00
Calcium Chloride	2	23kg		13.09.00	19.09.00
DM31 Nutrient Mix	2	6l (1% soln)		13.09.00	19.09.00
Phosphite (Nutri-phite Peak)	3	2l	30.08.00	13.09.00	19.09.00
$CaC1_2$+DM31+Phosphite	2	23kg/6l/2l		13.09.00	19.09.00
None	n/a			n/a	
Tribasic Copper Sulphate (PC700)	2	1l		13.09.00	19.09.00

Laboratory grade calcium chloride (100% Ca $C1_2$) was used at 23kg/ha. This is equivalent to commercial grade calcium chloride (77% Ca $C1_2$) at 30kg/ha.

Nutri-phite Peak (P+K) (Biagro Western Sales 35803 Road 132 Visalia, California; agents Intracrop, Byemoor Farm, Melmerby, Leyburn, N Yorks) is a solution of potassium phosphite (KH_2P0_3 and K_2HP0_3) containing 28% P_20_5 and 26% K_20. The phosphite ion may be toxic to some plant pathogens and may aid natural plant defences.

PC700 (trade name Cuproxat outside of UK; agents Intracrop, Byemoor Farm, Melmerby, Leyburn, N Yorks) contains 345g/l tribasic copper sulphate mixed with a surfactant, and sold as a product to correct Cu deficiency in arable, field fruit and vegetable crops.

DM31 is a coded product (Omex, King's Lynn) and is a mix of nutrients (including Cu, Zn, S, Mg) claimed to be toxic to some plant pathogenic fungi and bacteria.

Calabrese heads were a little over 2cm across on 13 September. Heads were assessed for spear rotting, watersoaking and phytotoxicity on 10 October and 20 October 2000.

2.3 The Effect of Mulches on Spear Rot

2.3.1 1999 Trials

In 1999 a mulching 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).

2.3.2 2000 Trial

In 2000 further studies were made of straw mulching: it was felt chopped or shredded straw might be managed commercially and would be relatively cheap. Shredded straw (chopped into lengths of 10-12cm) was applied as a mulch to calabrese at two depths: 0.5 to 1cm (a thin covering) or 2 to 3cm. Plots with no mulching treatments or a whole straw mulch (as used in 1999) were used for comparative purposes. Two trials were established with mulching treatments applied at different crop growth stages: at planting (14 July) or at the late vegetative stage (15 August). Two plots of each mulching treatment were included in each replicate: one was treated with Cuprokylt as described in section 2.2 and the other left untreated. Where mulching treatments were applied at planting Cuprokylt was applied at 5kg/ha when the heads were 2cm across (30 August) and again on 5 September. When mulching treatments were applied at the late vegetative stage the first Cuprokylt spray was applied at the time of mulching (15 August) with the objective of reducing the bacterial population to low levels, which would be maintained by the mulch isolating the crop from bacteria in the soil. A second Cuprokylt spray was applied on 30 August.

Spear rot and watersoaking were assessed on 4 October.

2.3.3 Laboratory experiment: Survival of *Pseudomonas fluorescens* on straw mulch

A laboratory experiment was conducted to determine if straw provided a suitable medium for growth of the pathogen. The effectiveness of a straw mulch in controlling spear rot could be due to its unfavourable environment for bacterial growth, or merely a physical barrier to splash of inoculum from soil onto young plants – or both.

Barley straw, as used for the mulching experiments in 2000, was placed to a depth of about 1cm on the surface of soil in 15 cm pots. The straw was inoculated by spraying each pot with 50ml of bacterial suspension containing 1 X 10^8 viable cells/ml. For inoculation, a strain of *P. fluorescens* (5006 rif^R) was used, isolated previously from broccoli to which resistance to the antibiotic rifampicin was introduced as a marker. A marked strain was necessary since straw is likely to contain other natural strains of *P. fluorescens* which would interfere with the counts of the bacterium inoculated to the straw.

At varying periods up to 10 days after inoculation, counts of *Pf* 5006 rif^R were made from the straw: 10g of straw from each of four replicate pots was removed, bacteria dislodged by agitation in a stomacher, then dilutions plated on to King's B agar containing 50ug/ml rifampicin. Ensuing bacterial colonies were counted after 2 days' growth on agar at 26^0C.

3. Results

3.1 Effect of Nitrogen fertiliser application on spear rot

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 (assessment dates 21, 22 Sep 1999)

	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 application 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 (assessment dates 21, 22 Sep 1999)

Nitrogen Applied kg/ha Base	Early Top Dress	Late Top Dress	Spear Rot % Severity Incubated[1]		% Hollow Stem	Colour	Bud Evenness	Quality Scores 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	-	-	-

[1] Disease recorded following incubation of heads in the laboratory under disease-conducive conditions
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 were 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 (assessment date 12 Oct 1999)

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 at harvest (assessment dates 21,22 Sep 1999 [Redford]; 12 Oct 1999 [Bow of Fife])

Nitrogen Applied kg/ha			Dry Matter %		Nitrogen % DM		Nitrogen g/kg Fresh wt	
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 the Crofts Farm correlated poorly with nitrogen content of head dry matter (correlation factor 0.275), 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 content 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 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 of yield.

3.2 Chemical Control of Spear Rot

3.2.1 Cuprokylt (copper oxychloride) Dose Rate and Application Volume Trials
3.2.1.1 Dose Rate Trial (1999)

Incidence and severity of watersoaking and spear rot following application of Cuprokylt at different doses is shown in Table 3.2.1.1.

Table 3.2.1.1 Cuprokylt Dose Rate Trial – Effect on Spear Rot (Pittenweem, Fife. Assessment dates 14, 15 Oct 1999)

Cuprokylt Dose kg/ha	**Watersoaking Incidence %**	**Severity %**		**Spear Rot Incidence %**	**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.

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.

3.2.1.2 Split Dose Trial 2000

The effect of splitting the standard 10kg/ha dose of Cuprokylt between two to five applications on watersoaking and spear rot is shown in Table 3.2.1.2.

Table 3.2.1.2 Split Dose Trial 2000: Spear Rot (Denbrae, St Andrews)

Assessment 1 (10 October 2000)

		Watersoaking				Spear Rot			
Number of Treatments	**Cuprokylt Dose/ Treatment kg**	**Incidence %**		**Severity %**		**Incidence %**		**Severity %**	
Nil	**Nil**	24.3	*(29.3)*	9.1	*(17.4)*	17.5	*(24.6)*	4.4	*(11.8)*
2	**5.0**	15.8	*(22.8)*	7.3	*(14.5)*	8.3	*(15.9)*	1.0	*(5.1)*
3	**3.3**	13.3	*(21.3)*	5.1	*(12.6)*	7.5	*(13.3)*	1.1	*(5.0)*
4	**2.5**	10.0	*(18.4)*	3.5	*(10.6)*	5.0	*(12.7)*	0.7	*(4.3)*
5	**2.0**	10.3	*(18.4)*	2.8	*(9.5)*	3.3	*(7.4)*	0.5	*(2.8)*
LSD 5%			*(6.86)*		-		-		*(5.10)*
LSD 1%			-		-		-		-

Numbers in italics/brackets are angular transformations of percentages.

Assessment 2 (18 October 2000)

Number of Treatments	Cuprokylt Dose/ Treatment kg	Watersoaking Incidence %		Watersoaking Severity %		Spear Rot Incidence %		Spear Rot Severity %		Head Copper Content ppm
Nil	Nil	92.5	*(74.1)*	56.2	*(48.6)*	69.2	*(56.5)*	30.6	*(33.6)*	4.2
2	5.0	69.2	*(57.3)*	34.2	*(35.6)*	20.8	*(27.1)*	3.8	*(11.1)*	33.4
3	3.3	50.0	*(45.0)*	21.4	*(26.8)*	15.0	*(22.6)*	2.2	*(8.3)*	18.3
4	2.5	19.1	*(25.8)*	5.5	*(13.2)*	2.5	*(7.9)*	0.3	*(2.8)*	14.7
5	2.0	30.0	*(33.2)*	7.5	*(15.8)*	5.9	*(13.9)*	1.1	*(5.4)*	21.4
LSD 5%			*(9.65)*		*(5.40)*		*(4.63)*		*(3.21)*	10.15
LSD 1%			*(13.53)*		*(7.56)*		*(6.49)*		*(4.50)*	14.23
LSD 0.1%			*(19.13)*		*(10.69)*		*(9.18)*		*(6.36)*	20.11

Numbers in italics/brackets are angular transformations of percentages.

At the second assessment application of Cuprokylt always significantly reduced the severity and incidence of watersoaking and spear rot.

At the second assessment applying 10kg of Cuprokylt as four doses of 2.5kg each gave best results. However, at the first assessment which is more commercially relevant, five applications of 2kg each gave slightly better results.

3.2.1.3 Application Volumes Trial 2000

The effect of dividing a total dose of 15kg/ha Cuprokylt into different numbers of applications applied in different water volumes on the control of watersoaking and spear rot is shown in Table 3.2.1.3.

Table 3.2.1.3 Application Volumes Trial 2000: Spear Rot (Denbrae, St Andrews. Assessment date 18 Oct 2000)

			Watersoaking				Spear Rot			
Number of Treatments	**Cuprokylt Individual Treatment Rate kg/ha**	**Water Volume l/ha**	**Incidence %**		**Severity %**		**Incidence %**		**Severity %**	
2	**7.5**	**600**	46.7	*(42.9)*	13.6	*(21.5)*	16.7	*(23.8)*	3.3	*(10.5)*
2	**7.5**	**1200**	56.7	*(48.8)*	32.1	*(34.4)*	8.9	*(17.1)*	2.0	*(8.0)*
2	**7.5**	**1800**	91.1	*(72.7)*	43.4	*(41.2)*	24.5	*(29.6)*	4.9	*(12.8)*
3	**5.0**	**600**	32.2	*(34.3)*	7.9	*(16.2)*	7.8	*(16.1)*	0.9	*(5.5)*
3	**5.0**	**1200**	55.5	*(48.2)*	21.9	*(27.7)*	10.0	*(18.4)*	2.2	*(8.4)*
3	**5.0**	**1800**	68.9	*(56.5)*	26.7	*(31.0)*	14.5	*(22.2)*	3.4	*(10.7)*
4	**3.75**	**600**	32.2	*(34.2)*	9.5	*(17.4)*	4.5	*(10.0)*	0.3	*(2.7)*
4	**3.75**	**1200**	54.4	*(47.9)*	24.2	*(28.7)*	16.7	*(23.4)*	2.3	*(8.6)*
4	**3.75**	**1800**	40.0	*(39.2)*	12.8	*(20.5)*	12.2	*(20.2)*	3.1	*(10.0)*
5	**3.0**	**600**	20.0	*(25.6)*	4.3	*(11.6)*	2.2	*(7.0)*	0.1	*(1.7)*
5	**3.0**	**1200**	44.4	*(41.7)*	21.2	*(26.8)*	12.2	*(19.5)*	2.9	*(9.8)*
5	**3.0**	**1800**	51.1	*(45.9)*	24.9	*(28.8)*	18.9	*(25.6)*	2.4	*(8.8)*
LSD 5%				*(13.91)*		*(10.38)*		*(8.68)*		*(2.29)*
LSD 1%				*(18.90)*		*(14.11)*		*(11.80)*		*(3.12)*
LSD 0.1%				*(25.43)*		*(18.98)*		-		*(4.19)*
MEANS										
2	**7.5**	-	64.8	*(54.8)*	29.7	*(32.3)*	16.7	*(23.5)*	3.4	*(10.4)*
3	**5.0**	-	52.2	*(46.3)*	18.8	*(25.0)*	10.8	*(18.9)*	2.2	*(8.2)*
4	**3.75**	-	42.2	*(40.4)*	15.5	*(22.2)*	11.1	*(17.9)*	1.9	*(7.1)*
5	**3.0**	-	38.5	*(37.7)*	16.8	*(22.4)*	11.1	*(17.4)*	1.8	*(6.8)*
LSD 5%				*(8.03)*		*(5.99)*		-		*(1.32)*
LSD 1%				*(10.91)*		*(8.15)*		-		*(1.80)*
LSD 0.1%				-		-		-		*(2.42)*
-	-	**600**	32.8	*(34.3)*	8.8	*(16.7)*	7.8	*(14.2)*	1.2	*(5.1)*
-	-	**1200**	52.8	*(46.7)*	24.9	*(29.4)*	12.0	*(19.6)*	2.4	*(8.7)*
-	-	**1800**	62.8	*(53.6)*	27.0	*(30.4)*	17.5	*(24.4)*	3.5	*(10.6)*
LSD 5%				*(6.95)*		*(5.19)*		*(4.34)*		*(1.15)*
LSD 1%				*(9.45)*		*(7.06)*		*(5.90)*		*(1.56)*
LSD 0.1%				*(12.71)*		*(9.49)*		*(7.93)*		*(2.10)*

Numbers in italics/brackets are angular transformations of percentages.

Applying Cuprokylt treatments in 600 l/ha water gave significantly better control of watersoaking and spear rot than using 1,200 or 1,800 l/ha water.

Applying Cuprokylt at 3.75 kg/ha four times gave significantly greater reductions in spear rot severity and watersoaking incidence and severity than two applications of 7.5 kg/ha Cuprokylt.

Five applications of 3 kg/ha Cuprokylt did not give results significantly different to four applications of 3.75 kg/ha.

There was a significant interaction between the effects of treatment number and application volume on spear rot: use of lower application volumes (600 l/ha) appeared particularly valuable when the total dose was split into four or five treatments. Five applications of 3 kg/ha Cuprokylt in 600 l/ha water gave particularly good control of spear rot.

3.2.2 Cuprokylt (Copper Oxychloride) Adjuvant Trial

3.2.2.1 1999 Trial

The effect of adding different adjuvants to Cuprokylt on spear rot control is shown in Table 3.2.2.1.

Table 3.2.2.1 Cuprokylt Adjuvant Trial 1999: Spear Rot (Pittenweem, Fife. Assessment date 14 Oct 1999)

		Watersoaking			**Spear Rot**			
Bactericide	**Adjuvant**	**Incidence %**	**Severity %**		**Incidence %**	**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. Cuprokylt without adjuvant gave control just as good as when any adjuvant was used and without phytotoxicity.

3.2.2.2 2000 Trial

The effect of adding adjuvants to Cuprokylt on spear rot control is shown in Table 3.2.2.2.

Table 3.2.2.2 Cuprokylt Adjuvant Trial 2000: Spear Rot (Bow of Fife, Fife. Assessment date 6 Oct 2000)

		Watersoaking				Spear Rot				
Bactericide	**Adjuvant**	**Incidence %**		**Severity %**		**Incidence %**		**Severity %**		**Copper Content at Harvest ppm**
Cuprokylt	**Agral**	37.5	*(37.7)*	25.6	*(30.2)*	25.0	*(29.4)*	8.5	*(15.8)*	15.6
Cuprokylt	**Nufilm17**	35.5	*(34.6)*	21.8	*(27.4)*	21.7	*(27.7)*	4.4	*(11.7)*	23.0
Cuprokylt	**Designer**	50.0	*(44.7)*	31.9	*(33.8)*	35.0	*(35.5)*	11.9	*(19.3)*	16.9
Cuprokylt	**Banka**	43.4	*(41.1)*	25.4	*(30.1)*	21.7	*(27.7)*	5.3	*(12.8)*	18.5
Cuprokylt	**Nil**	60.9	*(52.1)*	41.9	*(40.0)*	35.0	*(36.2)*	8.1	*(16.4)*	19.2
Nil	**Nil**	91.7	*(78.2)*	73.5	*(59.5)*	51.7	*(46.0)*	14.2	*(21.6)*	4.7
LSD 5%			*(15.32)*		*(10.71)*		*(9.52)*		-	7.10
LSD 1%			*(21.18)*		*(14.81)*		*(13.16)*		-	9.82
LSD 0.1%			*(29.27)*		*(20.47)*		-		-	-

Numbers in italics/brackets are angular transformations of percentages.

No significant phytotoxicity was observed in the 2000 trial. As in 1999 all treatments containing Cuprokylt significantly reduced the incidence and severity of watersoaking and the incidence of spear rot.

In general, addition of adjuvant to Cuprokylt did not significantly improve control of watersoaking or spear rot. However, addition of Nufilm 17 to Cuprokylt did significantly reduce the incidence and severity of watersoaking and gave the lowest incidence and severity of spear rot in the trial. Nufilm 17 also gave the greatest copper content of heads at harvest. Nufilm 17 did not give significantly better control of spear rotting or watersoaking than Agral when used as an adjuvant with Cuprokylt.

Cuprokylt is formulated as a wettable powder and no adjuvants are recommended by the manufacturers on the label. Without adjuvant, however, visual distribution of Cuprokylt after spraying calabrese heads appears unacceptable. Bacteria involved in calabrese spear rot produce surfactants to aid infection. Addition of a traditional non-ionic surfactant to Cuprokylt sprays, therefore, appears undesirable. Alternative adjuvants such as Nufilm 17 may give useful improvements to the control of Cuprokylt of spear rot, particularly in view of the relatively low cost of these treatments. However, none of the adjuvants tested dramatically improved the efficacy of Cuprokylt and adjuvants are only likely to be commercially significant as a supplement to other modifications of spray programmes and crop culture.

3.2.3 Novel Bactericide – CGA 245704

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

Table 3.2.3.1 Evaluation of CGA 245704 for Spear Rot Control (Pittenweem, Fife. Assessment date 14 Oct 1999).

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.

3.2.4 Novel Bactericide Treatments

Results achieved by the application of novel potential bactericides in comparison with the standard Cuprokylt programme are shown in table 3.2.4.1.

Table 3.2.4.1 Evaluation of Novel Bactericides (Denbrae, St Andrews).

Assessment 1 (10 October 2000)

Treatment	Watersoaking Incidence %		Watersoaking Severity %		Spear Rot Incidence %		Spear Rot Severity %	
Cuprokylt 2 x 5 kg/ha	5.0	*(12.7)*	1.3	*(6.2)*	6.7	*(13.0)*	0.3	*(2.8)*
Calcium Chloride	22.5	*(28.1)*	8.6	*(16.8)*	16.6	*(24.0)*	3.2	*(10.1)*
DM31 Nutrient Mix	21.7	*(27.3)*	7.0	*(14.7)*	18.3	*(24.7)*	3.1	*(9.5)*
Potassium phosphite	11.7	*(19.0)*	3.9	*(10.0)*	14.1	*(21.2)*	2.3	*(8.3)*
$CaCl_2$ + DM31 + Phosphite	32.5	*(34.2)*	16.2	*(22.5)*	26.7	*(30.0)*	4.8	*(10.9)*
None	15.8	*(22.4)*	2.6	*(8.5)*	28.3	*(31.9)*	6.3	*(14.0)*
Tribasic Copper Sulphate	15.0	*(22.3)*	5.8	*(12.9)*	13.3	*(21.0)*	2.2	*(8.2)*
LSD 5%		*(7.93)*		*(5.67)*		*(9.78)*		*(5.56)*
LSD 1%		*(10.86)*		*(7.76)*		-		-
LSD 0.1%		*(14.80)*		*(10.58)*		-		-

Numbers in italics/brackets are angular transformations of percentages.

Assessment 2 (20 October 2000)

Treatment	Watersoaking Incidence %		Watersoaking Severity %		Spear Rot Incidence %		Spear Rot Severity %	
Cuprokylt 2 x 5 kg/ha	86.7	*(70.4)*	61.9	*(52.1)*	25.0	*(28.9)*	5.8	*(12.3)*
Calcium Chloride	95.0	*(79.0)*	64.7	*(51.5)*	71.7	*(57.9)*	23.6	*(29.0)*
DM31 Nutrient Mix	93.3	*(77.6)*	55.6	*(48.3)*	83.3	*(69.0)*	39.9	*(38.9)*
Potassium Phosphite	90.0	*(74.4)*	60.3	*(50.9)*	48.3	*(44.3)*	14.9	*(21.5)*
$CaCl_2$ + DM31 + Phosphite	69.2	*(57.9)*	34.8	*(35.8)*	93.4	*(75.7)*	64.4	*(53.8)*
None	83.3	*(66.6)*	44.7	*(42.0)*	85.8	*(68.0)*	46.5	*(43.0)*
Tribasic Copper Sulphate	88.4	*(72.7)*	58.5	*(50.0)*	74.2	*(60.3)*	35.1	*(36.1)*
LSD 5%		-		*(8.94)*		*(12.90)*		*(8.82)*
LSD 1%		-		*(12.24)*		*(17.67)*		*(12.08)*
LSD 0.1%		-		-		*(24.06)*		*(16.46)*

Numbers in italics/brackets are angular transformations of percentages.

DM31 (alone or in mixture) gave unacceptable phytotoxicity; discussions with the supplier suggest that the dose would need to be reduced to remove phytotoxic effects. Cuprokylt gave the best control of spear rot, significantly better than most other treatments at both assessments. Potassium phosphite treatments significantly reduced spear rotting compared to untreated control. Tribasic copper sulphate gave significant control of spear rot at the first assessment only. Calcium chloride gave some reduction in spear rotting but this was not statistically significant.

The results suggest none of the alternative bactericides will give effective control of spear rot when used alone. Potassium phosphite, however, reduced spear rot by an amount which could be useful in combination with Cuprokylt. This requires investigation but because Cuprokylt and Phosphite are unrelated chemically the mixture may give usefully better control than Cuprokylt alone. It must, however, be noted that Potassium phosphite is not registered as a pesticide in the UK.

3.3 Mulching Trials

3.3.1 <u>1999 Trials</u>

The effects of mulching on the timing of cropping, marketable yields and total yield (marketable and unmarketable heads) are shown in Table 3.3.1.1.

Table 3.3.1.1 Mulching Trial, Bow of Fife 1999 – Crop Yields (Assessment dates 30 Sep [20% of crop harvested] and 6 Oct 1999 [remainder harvested])

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 3.3.1.2.

Table 3.3.1.2 Mulching Trial, Bow of Fife 1999 – Spear Rot (assessment dates 30 Sep and 6 Oct 1999)

	Spear Rot % Severity				Spear Rot % Incidence	
Mulch	**Field[1]**		**Incubated[2]**		**Incubated[2]**	
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.
[1] Observations in field
[2] Observations following incubation of heads in laboratory to induce spear rot

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.

3.3.2 2000 Trials

The effect of straw mulches applied at planting and at the late vegetative stage on watersoaking and spear rot is shown in tables 3.3.2.1 and 3.3.2.2 respectively.

Table 3.3.2.1 Effects of Straw Mulching at Planting on Watersoaking and Spear Rot (Bow of Fife, Fife. Assessment date 4 Oct 2000).

Mulch	Cuprokylt	Watersoaking Incidence %		Watersoaking Severity %		Spear Rot Incidence %		Spear Rot Severity %	
None	**2x5kg**	98.4	*(84.8)*	62.6	*(52.4)*	57.5	*(49.5)*	20.5	*(25.8)*
None	**None**	96.7	*(81.0)*	69.5	*(56.6)*	40.0	*(38.1)*	12.0	*(18.4)*
Whole Straw	**2x5kg**	85.8	*(68.2)*	42.4	*(40.6)*	30.0	*(33.1)*	4.9	*(12.5)*
Whole Straw	**None**	90.9	*(73.4)*	59.8	*(50.7)*	18.4	*(24.4)*	4.5	*(11.5)*
0.5-1cm Shredded Straw	**2x5kg**	95.8	*(79.9)*	62.2	*(52.1)*	39.2	*(38.7)*	11.8	*(19.7)*
0.5-1cm Shredded Straw	**None**	99.2	*(87.4)*	71.5	*(57.7)*	34.2	*(35.3)*	7.4	*(15.4)*
2-3cm Shredded Straw	**2x5kg**	90.0	*(74.0)*	49.7	*(44.8)*	27.5	*(30.9)*	6.5	*(14.2)*
2-3cm Shredded Straw	**None**	90.0	*(75.0)*	56.0	*(48.5)*	22.5	*(27.0)*	5.3	*(12.8)*
LSD 5%			-		*(7.46)*		*(12.19)*		*(7.49)*
LSD 1%			-		*(10.16)*		-		-
MEANS									
	2x5kg	92.5	*(76.7)*	54.2	*(47.5)*	38.6	*(38.1)*	10.9	*(18.0)*
	None	94.2	*(79.2)*	64.2	*(53.4)*	28.8	*(31.2)*	7.3	*(14.5)*
LSD 5%			-		*(3.73)*		*(6.10)*	-	-
LSD 1%			-		*(5.08)*		-	-	-
None		97.6	*(82.9)*	66.1	*(54.5)*	48.8	*(43.8)*	16.3	*(22.1)*
Whole Straw		88.4	*(70.8)*	51.1	*(45.6)*	24.2	*(28.8)*	4.7	*(12.0)*
0.5-1cm Shredded Straw		97.5	*(83.6)*	66.9	*(54.9)*	36.7	*(37.0)*	9.6	*(17.5)*
2-3cm Shredded Straw		90.0	*(74.5)*	52.9	*(46.6)*	25.0	*(29.0)*	5.9	*(13.5)*
LSD 5%			*(8.77)*		*(5.28)*		*(8.62)*		*(5.30)*
LSD 1%			-		*(7.18)*		*(11.73)*		*(7.22)*

Numbers in italics/brackets are angular transformations of percentages.

Cuprokylt significantly reduced the severity of watersoaking but significantly increased the incidence of spear rot.

Mulching with whole straw or a 2-3cm depth of shredded straw significantly reduced both severity and incidence of watersoaking and spear rot. A thin 0.5-1cm depth of shredded straw was generally ineffective: probably because the soil surface was inadequately covered.

There was no interaction between Cuprokylt and mulching treatment.

Table 3.3.2.2 Effects of Straw Mulching at Late Vegetative Stage on Watersoaking and Spear Rot Bow of Fife, Fife. Assessment date 4 Oct 2000).

Mulch	Cuprokylt	Watersoaking Incidence %		Watersoaking Severity %		Spear Rot Incidence %		Spear Rot Severity %	
None	**2x5kg**	95.9	*(80.2)*	59.1	*(50.3)*	35.8	*(36.5)*	10.0	*(17.5)*
None	**None**	95.9	*(82.0)*	71.4	*(57.9)*	24.1	*(29.1)*	6.4	*(14.4)*
Whole Straw	**2x5kg**	88.3	*(73.0)*	53.7	*(47.1)*	16.7	*(20.3)*	5.0	*(10.6)*
Whole Straw	**None**	95.0	*(80.9)*	56.7	*(49.0)*	6.7	*(12.4)*	0.6	*(3.5)*
0.5-1cm Shredded Straw	**2x5kg**	99.2	*(87.4)*	57.1	*(49.1)*	16.6	*(23.9)*	2.5	*(8.9)*
0.5-1cm Shredded Straw	**None**	95.0	*(79.0)*	58.0	*(49.6)*	24.1	*(29.4)*	5.1	*(12.8)*
2-3cm Shredded Straw	**2x5kg**	89.2	*(73.7)*	50.8	*(45.5)*	20.0	*(25.4)*	3.9	*(11.1)*
2-3cm Shredded Straw	**None**	93.4	*(75.7)*	58.8	*(50.2)*	15.8	*(23.0)*	3.6	*(10.8)*
LSD 5%			-		*(6.36)*		-		*(6.44)*
MEANS									
	2x5kg	93.2	*(78.6)*	55.2	*(48.0)*	22.3	*(26.5)*	5.4	*(12.0)*
	None	94.8	*(79.4)*	61.2	*(51.7)*	17.7	*(23.5)*	3.9	*(10.4)*
LSD 5%			-		*(3.18)*		-		-
LSD 1%			-		-		-		-
None		95.9	*(81.1)*	65.3	*(54.1)*	30.0	*(32.8)*	8.2	*(16.0)*
Whole Straw		91.7	*(77.0)*	55.2	*(48.1)*	11.7	*(16.4)*	2.8	*(7.0)*
0.5-1cm Shredded Straw		97.1	*(83.2)*	57.6	*(49.4)*	20.4	*(26.7)*	3.8	*(10.8)*
2-3cm Shredded Straw		91.3	*(74.7)*	54.8	*(47.8)*	17.9	*(24.2)*	3.8	*(11.0)*
LSD 5%			-		*(4.50)*		*(9.77)*		*(4.55)*
LSD 1%			-		-		-		*(6.19)*

Numbers in italics/brackets are angular transformations of percentages.

Cuprokylt significantly reduced the severity of watersoaking but had no significant effect on spear rot or watersoaking incidence.

Whole straw mulching gave the most consistent reductions in watersoaking and spear rot.

Thin (0.5-1cm) and thick (2-3cm) mulch of shredded straw did not give significantly different control of watersoaking or spear rot. This contrasts to the effect of mulches applied at planting: thin mulches were less likely to blow away when applied after a crop canopy was established.

There was no interaction between Cuprokylt and mulching treatments.

3.3.3 Laboratory experiment: Survival of *Pseudomonas fluorescens* on straw mulch

P. fluorescens was able to establish on straw and reached a population size of 1.4 X 10^7 colony forming units (cfu) per gram fresh weight of straw at 6 days after inoculation. By 10 days, when the final counts were made, the population was declining, its size had decreased to 6 X 10^6 cfu/gram fresh weight straw. From previous experiments on calabrese heads inoculated with *P. fluorescens*, the population size seen here on straw is smaller, although for direct comparisons between the two, these should ideally be made at the same time under the same conditions. Based on this limited information, we conclude that straw can support growth of the pathogen, but is a less favourable environment then the calabrese head: the effectiveness of straw as a mulch material to reduce spear rot is therefore partly due to this, and partly to its action as a physical barrier.

4. Conclusions

4.1 Nitrogen Nutrition and Spear Rot

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.

4.2 Chemical Control of Spear Rot

Copper oxychloride as Cuprokylt consistently gave the best control of spear rot amongst the chemical treatments tested. In the trials the control achieved using a standard programme of 5kg/ha Cuprokylt in 600l/ha water when calabrese heads were 2cm across and seven days later was better than commercial experience would suggest. We believe many commercial growers fail to make best use of Cuprokylt by delaying for too long the first application.

Applying a programme of five Cuprokylt sprays, beginning at the late vegetative stage of the crop, at an individual dose of 3kg/ha and water volume of 600l/ha gave exceptional control of spear rot. This underlines the importance of controlling bacterial numbers on the leaves, which we believe to be the major source of inoculum for the heads. Control was much better when sprays were applied in 600l/ha water than 1200 or 1800l/ha. The effects of using water volumes less than 600l/ha require investigation. Use of more than five sprays in a programme is unlikely to be commercially feasible.

A programme of multiple low dose sprays of Cuprokylt in low water volumes was easily the most effective experimental treatment in these trials. However, the use of an adjuvant containing di-l-p-menthene, and possibly potassium phosphite, may give usefully improved control at low cost.

4.3 Mulching

Reductions in the incidence and severity of spear rot after applying mulches to the soil surface of calabrese crops were demonstrated in these trials. These trials confirmed previous results (Campbell et al., 1995): mulching reduces spear rot incidence by about 50% compared to untreated. Good control, however, was only obtained when the soil surface was completely and effectively covered by the mulch. If areas of soil were left uncovered, or became uncovered because the mulch blew about, control of spear rot was much reduced. At present, treatments which provide the required efficacy of soil coverage are probably impractical and not cost-effective. If mulches are used for other purposes, such as weed control in organic crops, there will be incidental beneficial effects on spear rot. The effect of polymer soil stabilising spray solutions such as those used for prevention of wind erosion may be worth investigation.

4.4 Integrated Control

The trials suggest Cuprokylt should remain the ‘backbone’ of spear rot control programmes. The use of a multiple low dose spray programme in low water volumes could give much better control than the current standard programme of two sprays of 5kg/ha. A multiple spray programme is permissible under the new SOLA 0115/2001. This finding is based on only a small number of plots and requires confirmation and investigation of appropriate water volumes. An appropriate adjuvant and phosphite may give supplementary control (NB phosphite is not approved as a pesticide in UK). Further work is advised in order to provide a firm message on integrating the most effective and practical treatments, viz. multiple low-dose Cuprokylt, adjuvant and phosphite. It may be that the additive effects of this combination of treatments will have a greater effect on disease reduction than these treatments used alone.

The efficacy of mulching treatments has been demonstrated but is unlikely to be useful until additional mulching materials or machinery for mulching become available. Provided excessive nitrogen fertiliser is not being applied there is unlikely to be any useful effect of manipulating nitrogen fertilisation on calabrese spear rot.

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; this is due to the degradative effect which the bacteria have on the plant wax. Florets showing watersoaking may, or may not, go on to develop spear rot.

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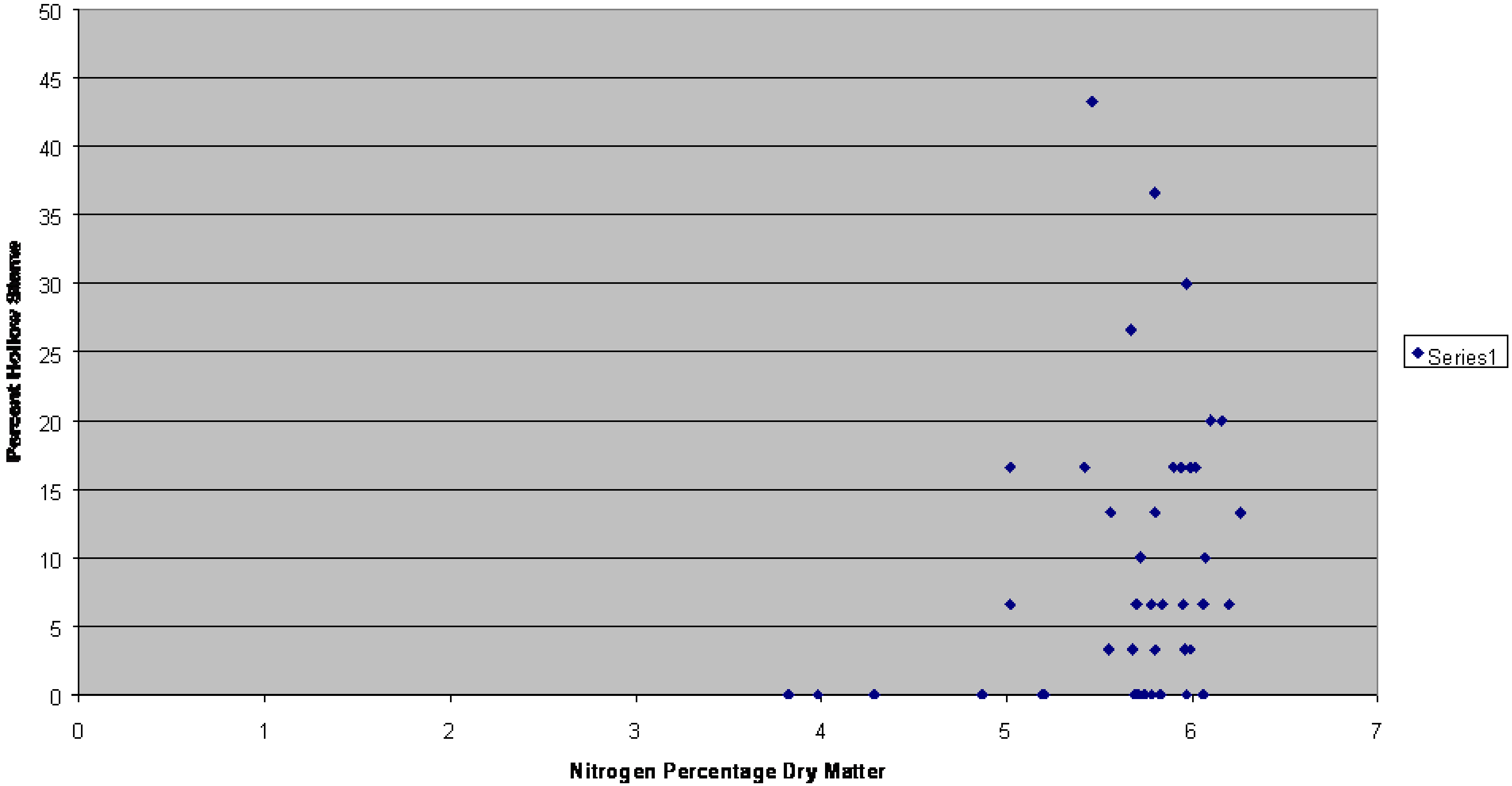
APPENDIX 1

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

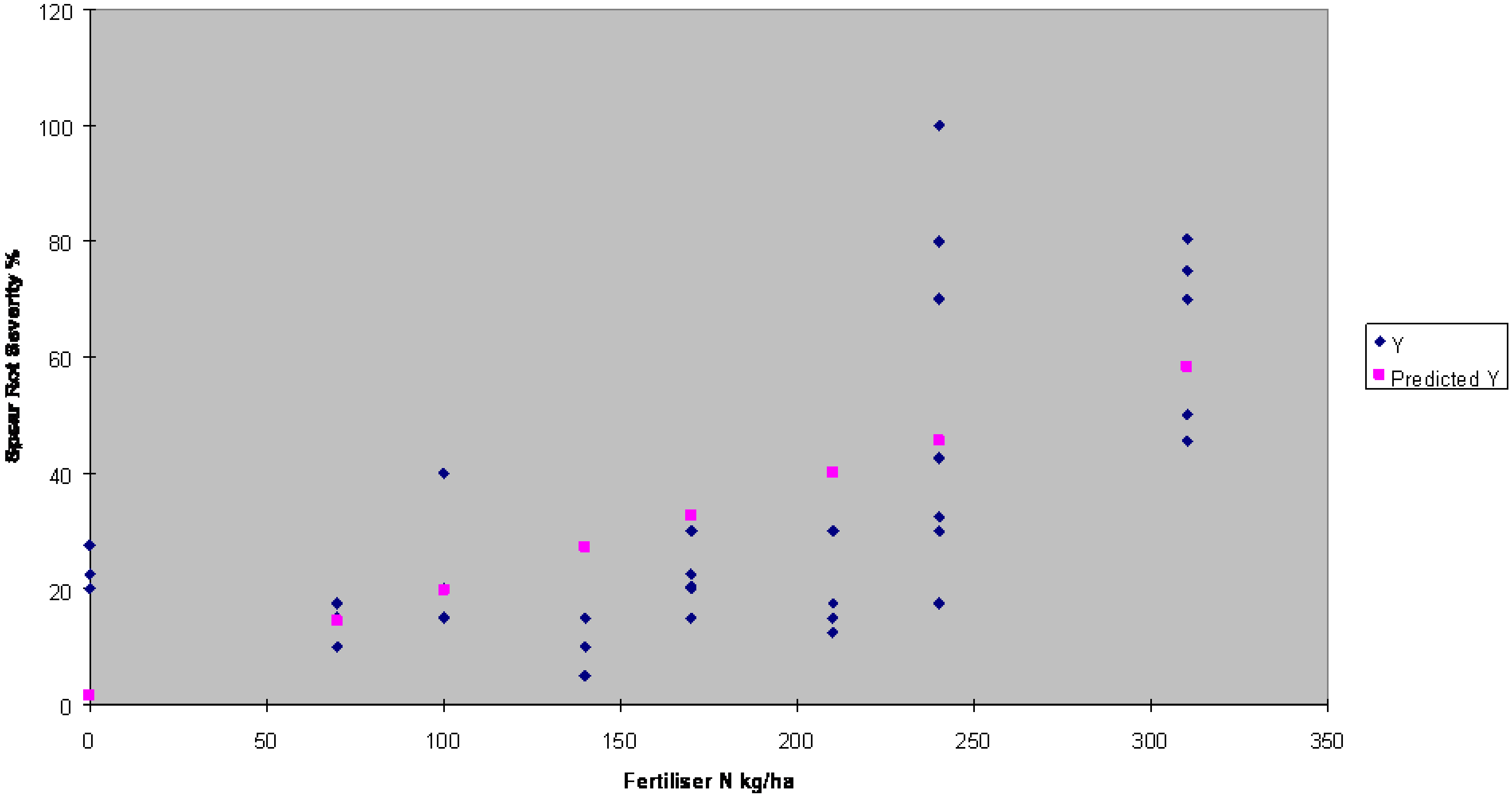
Fertiliser kg/ha N			**Dry Matter %**		**N % DM**		**P % DM**		**K % DM**		**Mn mg/kg DM**		**S % DM**		**Ca % DM**		**B mg/kg DM**		**Mg % DM**	
*B	*ET	*LT	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
100	0	0	7.98	9.70	5.43	4.04	0.82	0.57	4.47	3.64	19.1	16.9	0.97	0.77	0.45	0.41	30.2	25.4	0.23	0.17
100	70	0	7.85	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

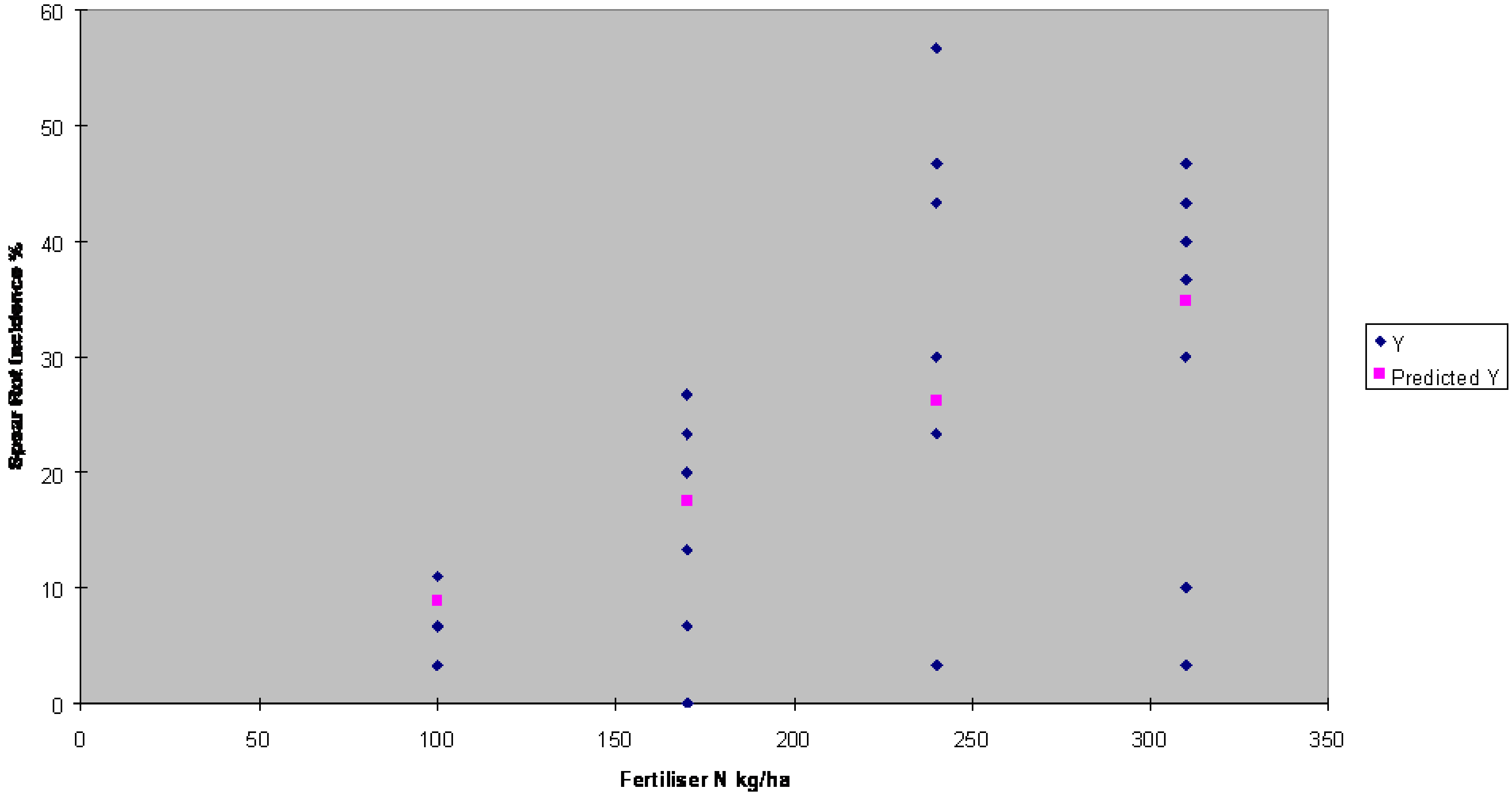
APPENDIX 2 - Nitrogen and Hollow Stems - Crofts Farm



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

Mulch	% Hollow Stem		Colour	Bud Evenness	Bud Size	Head Shape	Branch Angle	Clustering
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.