CULINARY HERBS:
CONTROL OF RUST AND POWDERY MILDEW

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Final Report

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PRACTICAL SECTION FOR GROWERS

Application

The main aim of this project was to evaluate a range of fungicides against mint rust under a range of growing conditions. A number of fungicides were examined in glasshouse and field experiments and based on this work it is recommended that Hispor 45, Bayfidan and Impact Excel be considered for further trials and residue analysis. Flaming was also examined as a possible means of controlling rust and although results in a second trial were variable, evidence from the first trial suggests that flaming may be a useful, albeit expensive, means of controlling rust on mint in the field.

Summary of field trial work

METHODS USED

The fungicides were evaluated over a period of three years. In the first year, trials were sited near Norwich, near Ross-on-Wye and at Auchincruive. In the second year, trials were repeated at the Norwich and Auchincruive sites. After problems with the Norwich and Ross-on-Wye sites, the third year trials were conducted at Auchincruive only. All of the trials used a randomised block design with four replicates and plots measuring 2 x 3.5 m with a 0.5 m gap between plots.

After initial glasshouse trials of 14 rust fungicides from a range of fungicide groups, eight were selected for the first and second year field trials. Six fungicides were eliminated because of phytotoxicity. The eight fungicides selected were Bayfidan (0.5 l/ha), Tilt (0.2 l/ha), Hispor 45 (0.3 kg/ha), Impact Excel (1.0 l/ha), Early Impact (0.8 l/ha), Kombat (2.25 kg/ha), Plantvax 20 (2.0 l/ha) and Bayleton (0.2 kg/ha), the only fungicide with an off-label approval for rust control on mint. A range of application rates were tested in the glasshouse trials. The application rates chosen for the field trials were the highest rates which did not cause any visible signs of phytotoxicity. All fungicides were applied in 200 l of water per hectare. Trials received either one or two applications per crop with a three or five week harvest interval.

In the third year, trials were carried out on four of the previously tested fungicides - Bayfidan, Hispor 45, Impact Excel and Kombat, comparing the Effectiveness of either one or two applications, and to determine how many applications would be possible in a typical commercial growing schedule. The effects of the fungicides on oil yield and composition were also investigated by distilling samples from the third crop of 1995 and analysing them using gas chromatography.

A number of criteria were used to assess all of the trials. Measurements were taken on 10 randomly selected stems from each plot. On each stem the height, number of leaves, number of missing leaves and number of infected leaves were all measured. A disease area diagram was then used to estimate the percentage area infected on three pairs of leaves from each stem. This was used to calculate the mean percentage infection. The leaves and stems were then dried and weighed to give a measurement of yield.

RESULTS OBTAINED

The three trial sites varied greatly in climatic conditions, levels of rust and uniformity of plant growth. The Norwich site was in a low rainfall area, had only sporadic outbreaks of rust and very vigorous, homogeneous plant growth. The Ross-on-Wye site had a higher level of rust, was in a wetter climate and had very poor, very variable plant growth. The Auchincruive trial had to be established especially for the project. Auchincruive has a wet climate and levels of rust were exceptionally high in the first and second years. In the third year rust levels were much lower.

The fungicides had their most severe test at Auchincruive, with very high levels of rust. Looking at the results from the first two years at Auchincruive, the efficacy of the fungicides was as good as could be expected. In the first year rust became established very early in the season and the fungicides were applied to an already infected crop. The wet weather aided the spread of the rust and resulted in almost 100 % of the leaves on the controls becoming infected. Despite this heavy infection, all of the fungicides, except Bayleton, reduced the mean infection and the loss of leaves associated with the disease. Hispor 45 produced the highest reduction in mean infection (63 %) and the highest reduction in missing leaves (33 %).

In the secon year at Auchincruive, rust control was poor on the spring trial. The fungicides were applied when the rust was in its systemic stage (bull shoots) before the appearance of the first uredospores. One application failed to control the rust under wet spring conditions with a high inoculum pressure. In the second trial of 1994, the levels of rust were much lower. All of the fungicides significantly reduced the percentage of infected leaves by between 20 % and 66 %. All of the fungicides except Bayfidan, significantly reduced the mean infection by between 26 % and 85 %. Hispor 45 performed best on both of these measurements. None of the fungicides significantly reduced the percentage of missing leaves.

The Norfolk site had insignificant levels of rust during 1993 and 1994. This meant that no conclusions could be made on fungicide efficacy at this site. The uniformity of the crop at this site in 1993 did, however, aid observations on plant growth. From the Norwich results it would appear that some of the fungicides reduce the loss of leaves associated with rust infection, even when the rust is at very insignificant levels in the crop. Hispor 45, Early Impact and Impact Excel all significantly reduced this loss of leaves by 12, 9 and 7 % respectively, by the end of the season.

The Ross-on-Wye site had lower levels of rust than the Auchincruive site. Five of the eight fungicides reduced the mean infection, although not significantly. Impact Excel, Kombat and Hispor 45 produced the greatest reductions. All of the fungicides, except Bayleton, reduced the percentage of infected leaves, although Bayfidan was the only one to produce a significant reduction.

From the 1993 and 1994 trials, four fungicides were selected for the 1995 trials. Hispor 45, Bayfidan, Impact Excel and Kombat were chosen because they provided the highest levels of rust control and had the greatest chance of gaining approval. Other fungicides were considered for inclusion in the 1995 trials, but it was decided that even if they performed significantly better than the previously examined fungicides, efficacy data from one trial would be insufficient. It was decided therefore that the 1995 trials should be used to supplement the data on fungicides already examined.

The good weather over the 1995 season allowed three harvests to be conducted. In colder seasons, processors would expect only two harvests. The spring and autumn crops had a long enough growing time to allow two fungicide applications with a three week harvest interval. The summer crop was harvested six weeks after the spring crop. This allowed time for only one fungicide application with a three week harvest interval. On the spring and summer crops, plots received either one application with a 5 week harvest interval, or two applications with a three week harvest interval. In 1995, the levels of rust at the Auchincruive site were very much lower than in previous years, especially early in the season. In the autumn crop, which had the highest levels of rust, all of the fungicides significantly reduced the mean infection by between 59 and 98 %. The reductions in the percentage of infected leaves were more variable and ranged from 1 - 92 %. Two applications of Bayfidan and Hispor 45 performed best, producing reductions in the mean infection of 92 % and 62 % respectively and reductions in the percentage of infected leaves of 97 % and 98 % respectively. Data on crop yield were inconclusive this year.

Samples taken from the autumn trial were dried and steam distilled to extract the spearmint oil. No significant differences in oil yield were recorded. Gas chromatographic analysis showed no significant differences in oil composition. None of the fungicides caused any deleterious side-effects on the plants.

DISCUSSION AND ACTION POINTS FOR GROWERS

Bayleton 5 was the only fungicide available for rust control on mint at the beginning of this project. Growers had, however, expressed dissatisfaction with its efficacy. The results from the 1993 and 1994 trials confirmed that it was ineffective and that other means of control were needed.

Difficulties were experienced at all three trial sites. None of the sites provided uniform crop growth combined with moderate levels of rust. These were the only sites made available to the project which were within one days travelling distance of Auchincruive. Despite the problems, three of the eight fungicides (Hispor 45, Bayfidan and Impact Excel) performed reasonably well throughout the project.

Where rust is expected to be a problem, it is recommended that the fungicides are applied as a prophylactic. They may still, however, provide unsatisfactory levels of control in the early spring. Very few bull shoots are required to initiate an epidemic of mint rust. If a large number of systemically infected bull shoots are present, then other means of control may be more effective. The crop could be treated with contact herbicide, flamed or ploughed under. All of these measures should break the life cycle of the rust, if carried out correctly, and reduce the inoculum available for future infections. Although delaying the crop by several weeks, these measures should produce a healthier re-growth and allow fungicides a better chance of controlling later infections.

In areas where rust is a problem, two applications of fungicides can provide good levels of control during the summer and autumn. Most UK mint growers do not experience problems with rust until late summer / early autumn. In a three harvest year, a single application on the summer crop followed by two applications on the autumn crop should provide adequate control. In a two harvest year, the first crop may require one or two applications depending on the risks to the crop i.e. have other control measures been taken, are the climatic conditions suitable for rust and is there a history of rust on that site at that time of year. The second crop that year would probably require two applications to protect it for the longer growing period.

The fungicides were applied in 200 l of water per hectare. This provided good crop coverage on newly-emerged crops. On crops receiving a second application, this volume may need to be increased depending on the density of the crop. Better crop coverage may provide higher levels of disease control.

It is recommended therefore, that Hispor 45, Bayfidan and Impact Excel be considered for further trials and residue analysis.

SCIENCE SECTION

INTRODUCTION

Mint is the common name given to the genus *Mentha*. Mints belong to the family Lamiaceae which contains several important culinary herbs e.g. Oregano (*Origanum majorana* L.), Thyme (*Thymus vulgaris* L.) and Rosemary (*Rosmarinus officinalis* L.). The current taxonomy recognises 18 species and 13 hybrid species of mint (Chambers, 1992). The most important mint grown in this country is spearmint (*Mentha spicata* L.).

Mints are grown commercially all over the World, mainly for their volatile oils. The oils are used to flavour many products including toothpastes, chewing gums and confectionary. In Britain mints are grown for the fresh herb trade, for drying or processing and for the pot trade. In 1986 it was estimated that 70 hectares of mint were grown in the U.K., not including nurseries producing for the pot trade (Anon , 1986). The industry in this country is therefor a small one in comparison with the 12000 - 16000 hectares grown in the North American states of Indiana, Michigan and Wisconsin (Green, 1985).

The disease which causes the greatest problems to the mint industry Worldwide is rust. This disease is caused by the fungus *Puccinia menthae* Pers., a pathogen restricted to certain members of the Lamiaceae. It is an autoecious rust i.e. it can complete it's entire life-cycle on the same host. Under favourable conditions the fungus can cause severe damage to mint crops. In the early Spring infected stems become abnormally thickened and distorted, while during the Summer and Autumn both leaves and stems may become covered in pustules ranging from yellow to almost black in colour.

The rust not only affects the appearance of the plants, which is important for the fresh and pot trades, but it also affects yield by increasing defoliation and destroying oil glands. A study carried out in New Zealand on Peppermint crops attributed 37 % of the leaves lost by the plants to infection with rust (Harvey, 1979). Infection early in the season can also greatly retard the development of side-shoots and reduce the production of rhizomes and stolons by two thirds (Horner, 1955).

Many different approaches to the control of mint rust have been tested in different countries around the World. In Britain three different methods have been tried. Two of these methods involve a sanitation approach, one using heat, the other herbicide. Hot- water treatment of rhizomes at between 40.6 °C and 46.1 °C for 10 minutes has been used successfully to kill rust present in the mint without harming the plant (Anon , 1985). The other sanitary method involves the use of paraquat, which is applied soon after the infected shoots appear in the early Spring. This kills the above ground shoots along with any rust present. The mint will then regrow into a relatively rust free environment. The problem with both of these methods is that they do not protect the mint from re-infection.

One fungicide (Bayleton 5) has an off-label approval for the control of rust on mint in Britain. Newer, more effective fungicides are, however, required.

The aims of this project are to investigate both chemical and more novel means of controlling rust on mint. At a later stage, and if time permits, the other main disease which affects mint, powdery mildew, caused by the fungus *Erysiphe biocellata* Ehrenb. will be investigated.

MATERIALS AND METHODS

Growth of stock plants

Healthy black peppermint *(Mentha x piperita* L.) plug plants were obtained from Muntons microplants. These plants were grown on in 2 litre pots filled with Fisons Levington M3 compost. The plants were kept in a growth cabinet providing a temperature of 25 °C during the day and 17 °C at night. The fluorescent tubes and incandescent bulbs in the cabinet provided a 16 hour photoperiod. The stock plants were grown in a growth cabinet to reduce problems with pests and diseases and to encourage optimal growth during the winter months. Biosprayday (Permethrin) was also used to control pests, mainly aphids, when necessary.

Propagation of mint

Commercially, most mints are propagated via the transplantation of rhizomes. This method was found to produce very variable plants. The mints were therfore propagated by the use of stem cuttings to give the uniformity necessary in experiments. Approximately 8 cm long nodal stem cuttings were taken, dipped in Strike hormone rooting powder (0.25% w/w naphthylacetic acid & 2.25 % w/w captan) and struck in P84 plug trays, using the same compost as for stock plants. The trays of cuttings were then covered with a clear plastic bag and placed in the base of the growth cabinet, beneath the stock plants, to provide partial shade. The cuttings root in approximately 7-10 days. Once rooted, the cuttings were removed from the plastic bag and grown on for several days under the same conditions as the stock plants.

The cuttings usually form well rooted plugs 14-17 days after striking. The plugs were then potted on into 8 cm optipots and grown on for several days in the glasshouse before treatments were administered. The experiments are carried out in a glasshouse kept at 20 ^{o}C + or - 3 ^{o}C during the day and 11 ^{o}C + or - 3 ^{o}C at night. Natural daylight was supplemented with 400 W mercury vapour lamps to provide a 16 hour photoperiod.

Inoculation of mint with rust

Fresh rust uredospores were collected from rust stock plants using a camel hair brush dipped in a 0.01% solution of Tween 20. The solution was then altered to give a concentration of 40 000 spores per ml. Inoculation involved spraying this spore solution onto the lower surface of the mint leaves until runoff occurs. Plants were enclosed in a clear plastic bag for 48 hrs to provide the humidity necessary for spore germination. Stock plants were inoculated regularly to maintain a supply of fresh rust spores.

Screening programme for rust fungicides

14 rust fungicides, belonging to groups with different modes of action, were selected for the pot screening programme on mint rust.

Table 1 Fungicides selected for the pot screening programme.

MANUFACTURER	TRADE NAME	ACTIVE INGREDIENTS
BASF	Corbel	79.5 % w/w Fenpropimorph
Bayer	Bayleton 5	5 % w/w Triadimefon
	Bayleton	25 % w/w Triadimefon
	Bayfidan	22.9 % w/w Triadimenol
Ciba-Geigy	Glint 500 EC	12.7 % w/w Propiconazole & 38.1 % w/w Fenpropimorph
	Hispor 45WP	25%w/w Propiconazole & 20% w/w carbendazim
	Tilt 250 EC	21.7 % w/w Propiconazole
Du Pont	Punch C	25 g/l Flusilazole & 12.5 g/l Carbendazim
Hoechst	Kombat WDG	12.4 % w/w Carbendazim & 63.3 % w/w Mancozeb
ICI	Early Impact	8.5 % w/w Flutriafol & 13.5 % w/w Carbendazim
	Impact Excel	3.9 % w/w Flutriafol & 24.6 % w/w Chlorothalonil
	Patrol	82.4 % w/w Fenpropidin
Schering	Sprint	22.7 % w/w Prochloraz & 37.9 % w/w Fenpropimorph
Uniroyal	Plantvax 20 EC	20 % w/w Oxycarboxin

Experiments were carried out with 7 fungicides at a time. Concentrations similar to the manufacturer's recommendations for other crops were chosen for the initial trials. If recommended concentrations varied greatly between the approved crops then an average concentration was chosen. The initial experiment on both groups of fungicides was carried out to examine problems of phytotoxicity; therefore none of the plants were inoculated with rust.

In subsequent experiments, each fungicide was applied to 8 black peppermint plants 2 days prior to inoculation with rust and to 8 plants 2 days after inoculation. The fungicides were applied to run-off using hand held aerosol sprayers.

After the 2 initial experiments using concentrations similar to the manufacturers' recommendations, concentrations were chosen depending on the efficacy of the fungicides and any phytotoxicity problems. The aim was to select fungicides producing 100 % control and no side-effects. Selected fungicides which achieved this aim were tested at lower concentrations. The concentrations used in each experiment are displayed in Table 2.

Table 2 Concentrations of fungicides screened in pot trials

	CONCENTRATION OF FUNGICIDE (%) IN EXPERIMENT		
FUNGICIDE	**(a) & (b)**	**(c) & (d)**	**(e) & (f)**
Corbel	0.40	0.35	0.20
Bayleton 5	0.10	0.10	-
Bayleton	0.25	0.10	0.10
Bayfidan	0.25	0.25	0.20
Glint 500 EC	0.50	0.40	0.20
Hispor 45 WP	0.25	0.20	0.15
Tilt 250 EC	0.30	0.20	0.10
Punch C	0.30	0.25	0.15
Kombat WDG	1.125	1.125	-
Early Impact	0.60	0.40	0.20
Impact Excel	1.00	1.00	0.50
Patrol	0.50	0.30	0.10
Sprint	1.50	1.00	0.50
Plantvax 20 EC	2.00	1.50	1.00

Assessment of plants

The rust normally sporulated 16 days after inoculation, at which stage the plants could be assessed. The 4 lower leaves on each plant were assessed for the number of rust pustules per cm^{-2} of leaf. The number of pustules on the whole leaf were counted and then the area of the leaf was measured using a leaf area meter. The number of pustules per cm^{-2} of leaf was then calculated.

A visual assessment of any phytotoxic effects, for example stunting, necrosis and deformities caused by the fungicides,was also made.

Field trials of fungicides against mint rust

AIM : To evaluate rust fungicides against mint rust under field conditions.

Trial sites

Three sites around Britain were chosen to host the fungicide trials for 1993. The sites were:

1. SAC, Auchincruive, Nr AYR, Scotland.
2. J. Bond & Son, Heath Farm, Blofield, Nr NORWICH, Norfolk.
3. J. Lambe,Castle Farm, Upton Bishop, ROSS-ON-WYE, Herefordshire.

The two English sites were chosen since they are both in areas where mint is grown on a field scale under differing climatic and cultural conditions.

The site at Auchincruive had to be created since there were no commercial plantings of mint in the area. One spearmint plant obtained from R & G Stevens, Lucas Green Nurseries, Lucas Green Road, West End, Woking, Surrey, was propagated using stem cuttings. The plug plants required an application of 0.5% Fungaflor (18.8 % Imazalil) during propagation to prevent infection with powdery mildew. Fungaflor was chosen since it is very short acting and would therefore have little effect on the plants once in the field. The 4100 plug plants were planted out at 20 cm apart in the plots on 18/5/93. Overhead irrigation was used to assist establishment of the plants. Weeds proved to be a major problem in the plots and since no herbicides are approved for post-emergence applications on mint, the plots were weeded by hand.

The trial sites were divided into 36 plots each measuring 2m x 3.5m surrounded by a 0.5m gap. Each trial was also surrounded by a 0.5m guard row to protect the commercial crop from spray drift. The 8 treatments plus a control were arranged in a randomised block design with 4 replicates.

The fungicides

The following fungicides were selected from the glasshouse screening programme to go forward to the field trial stage of the work.

FUNGICIDE	CONCENTRATION
Bayfidan	0.25 %
Bayleton	0.10 %
Tilt 250	0.10 %
Hispor 45WP	0.15 %
Impact Excel	0.50 %
Early Impact	0.40 %
Kombat WDG	1.125 %
Plantvax 20EC	1.00 %

For the first application of fungicides, a compressed air plot sprayer, with a 2m boom, was used. This sprayer was used at a pressure of 2.0 bar and produced a swath width of 2.1m. The second application of fungicides was administered using a calor gas plot sprayer. This sprayer was operated at 2.5 bar with a swath width of 2.79m.

Due to differing climatic conditions and cultural practices, each site received a different spray regime. The sites at Auchincruive and in Norfolk each received 2 applications of fungicides, with differing intervals between each, while the site in Herefordshire received only 1 application. There were two harvests at the Norfolk site in 1993. The first harvest did not receive a fungicide application since rust had not been a problem at that time of year. The second harvest received 2 fungicide applications. The first treatments were applied on 19/7/93, followed 5 weeks later by the second application (23/8/93), which was 3 weeks before harvest. Assessments were carried out 3 and 5 weeks after the first application and at harvest. Due to weather conditions and management of the site at Castle Farm, Ross-on-Wye, only one harvest was taken from the trial plots. The trial was sprayed on 16/7/93 and assessed 3 weeks later on 6/8/93. The first application of fungicides was made (26/5/94). No assessment of the rust was made at this stage. The percentage coverage of the plots with mint was, however, estimated using the Auchincruive site in 1994, after the mint had emerged in early March, the trial was sprayed with paraquat (22/4/94) to reduce the weed problem and to improve the uniformity of infection between plots. The paraquat, however, failed to kill the mint and all of the weeds. The mint was slightly stunted with some tip burn. This problem has been encountered by some commercial mint growers.

The first systemically infected bull shoots were noticed in early May. Before the first uredospores were observed, the first application of fungicides was made (26/5/94). No assessment of rust was made but the % coverage of the plots with mint was, however, estimated using a 1 - 5 scale to assess how well the mint had survived the Winter.

SCORE	PERCENTAGE COVER
1	1 - 20
2	21 - 40
3	41 - 60
4	61 - 80
5	81 - 100

The first full assessment and harvest took place on the 4/6/94, 5 weeks after spraying. Due to poor weather conditions only one application of fungicide was given to this first crop. After harvest, paraquat and simazine were applied to control weeds and reduce the level of rust.

The first application of fungicide on the second crop took place on 15/8/94 when the crop was approximately 15 cm high. No pustules were found, although a full assessment was not carried out at this stage. The second application took place 3 weeks later on 6/9/94. An assessment and harvest are due to take place on 27/9/94.

The site at Heath Farm near Norwich was used again for the 1994 trial. This site had provided very uniform crop growth in 1993 and so even if rust infection was low, the effect of the fungicides on crop growth could be evaluated. The trial was conducted over the first two harvests of the season. Each crop was only sprayed once due to low levels of infection. The first crop was sprayed on 15/5/94 and harvested 5 weeks later on 18/6/94. The second crop was sprayed on 21/7/94 and harvested on the 9/8/94. The plots were assessed at the first harvest, the second spraying and the second harvest.

In 1995, a field trial was carried out at Auchincruive using 4 of the fungicides tested previously - Bayfidan, Hispor 45, Impact Excel and Kombat. The effectiveness of either one or two applications was compared, and the number of applications that might be possible in a commercial growing schedule was determined. In addition, the effects of the fungicides on oil yield and composition were investigated by distilling samples from the crop and analysing them using gas chromatography.

Assessment

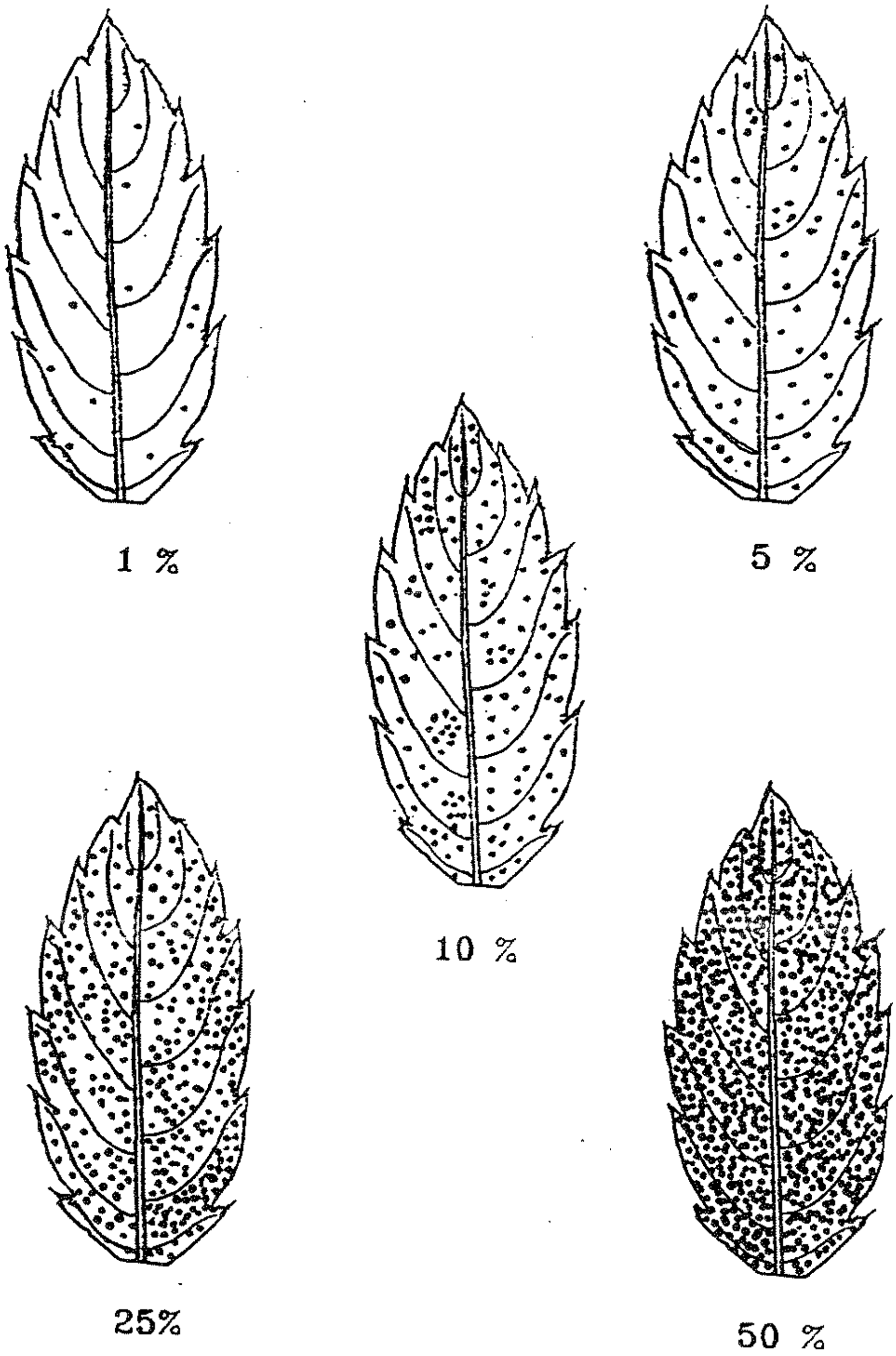
An assessment was carried out at each site before spraying and harvesting, except at Auchincruive, where no assessment was made at the first spraying. In each plot, 10 stems of mint were chosen at random , avoiding plants which were in the outside 20 cm of each plot. The height, number of leaves, number of missing leaves and number of infected leaves were all recorded. A pair of leaves in each third of the main stem were chosen and the percentage infection of rust, assessed. A disease key for spearmint rust was created for use in these field trials and is shown in Figure 1. The leaf pairs chosen were the bottom pair, a pair in the centre and the top mature pair. All of the leaves were then removed from the stems and dried separately at 50 ^{O}C for 5 days, to give a measure of yield.

During the last assessment at Auchincruive, samples of mint from each plot were taken and dried at 40 ^{O}C for 4 days. Drying at 40 ^{O}C rather than 50 ^{O}C reduces volatilisation of the mint oil. Steam distillation will be used later to extract the volatile oil from these samples which will then be analysed using gas chromatography.

The control of mint rust by flaming - 1993

AIM : To evaluate flaming as a possible control method for rust on mint.

Figure 1 Spearmint rust key



The trial site

A flaming trial was held at Red Deer Farm, Earls Croome, Nr WORCESTER. A field of the Moroccan type of spearmint (*Mentha cordifolia*) was flamed in mid February, just after shoot emergence, using a tractor mounted Propane flamer (Barter) with 12 burners. The tractor speed was approximately 0.7 km/hr. After flaming, the field was covered with 17g agryl for 6 weeks to encourage regrowth of the mint

Two adjacent plots, each measuring 4m x 5m were marked out at each end of the field. The majority of the field was flamed, except for a small area which contained the 2 unflamed plots. The flamed and unflamed plots were 92.4 m apart to reduce the risks of re-infection from the unflamed plots. The mint was assessed in the same way as described for the fungicide trial (Experiment 2), with 4 assessments carried out during the growing season.

A site was chosen at Castle farm, Upton Bishop, Ross-on-Wye, Herefordshire, to host the flaming trial in 1994. The trial was carried out on an established field of spearmint. The plots had to be of varying widths i.e. 1.5m for the HOAF flamer, 1.4m for the Barter flamer, 2.0m for the paraquat treatment and 1.5m for the control, to accommodate the different widths of the equipment. All of the plots were 12m long.

Two different flamers were used in this trial. The Barter flamer is the traditional propane fuelled contact flamer. This particular machine had 2 banks of 6 burners rather than the normal single bank of 12. A fire blanket was fitted around the metal guard to reduce heat loss and to improve safety.

The second flamer was a newer model produced by HOAF. The HOAF KB 1.5 crop debris burner is designed for use in glasshouses. This flamer uses contact and infrared radiation to heat the plants. The contact heat is produced from a row of 12 burners which also heats the wire mesh which is the source of the infrared heat.

The paraquat was applied at a rate of 5l/ha in 200l of water using an Azo plot sprayer at 2.0 bar pressure. The rest of the field surrounding the trial was also paraquated to reduce sources of re-infection.

The treatments were applied when the mint was approximately 4 cm high on the 8 th and 9 th of April. Attempts were also made to measure the temperature at the soil surface when the flamers passed over at different speeds. This was done by burying a thermocouple, attached to a wooden board, under the soil surface, leaving 4 cm of the thermocouple above the soil. The thermocouple was linked up to a chart recorder which graphed millivolts against time.

The first assessment was carried out just before the first harvest, 10 weeks after flaming (17/6/94). The second assessment was carried out 6 weeks after the first harvest (11/8/94)

The effects of rust fungicides on the germination of mint rust uredospores

AIM : To determine whether the fungicides examined in the field trials, affect the germination of mint rust uredospores.

Preparation of agar plates

Each fungicide was tested over a range of 4 concentrations to examine the abilitiy to affect the germination of *Puccinia menthae* uredospores. Fifteen 200ml conical flasks were filled with 0.5g of agar powder and 48.5 ml of distilled water and then autoclaved. After cooling, 0.5ml of a fungicide solution was added (10%, 1%, 0.1% or concentrate) to each of 3 flasks. The flasks were then mixed thoroughly and poured into Petri dishes. The resulting concentrations of the fungicides in the agar were 1%, 0.1%. 0.01% and 0.001%. Distilled water (0.5 ml) was added to each of the 3 control plates. Once the agar set, a cross was drawn on the base of each plate to divide it into quarters for assessment purposes.

To test the effects of the fungicides on spore germination, a 1 ml sample of a spore solution was then added to the Petri dishes. The spore solution was prepared from freshly produced uredospores added to a 0.01% solution of Tween 20. The concentration of the spores in solution was then adjusted to 40 000/ml. Initial work was carried out to determine whether washing the spores to free them of any endogenous germination inhibitors would increase germination. This was found to be unnecessary.

After the addition of the spore solution, the agar plates were incubated in the dark at 14 ^{o}C +/- 1^{o}C .

TABLE 3 The phytotoxic effects of rust fungicides on mint

FUNGICIDE	CONCENTRATION (%)	PHYTOTOXICITY LEVEL	PHYTOTOXICITY SYMPTOMS
Corbel	0.40	+ + +	S, D, N
Bayleton 5	0.10	-	-
Bayleton	0.25	+ +	N
Bayfidan	0.25	-	-
Glint 500 EC	0.50	+ + +	S, D, N
Hispor 45 WP	0.25	+	S, N
Tilt 250 EC	0.30	+ +	N
Punch C	0.30	+ +	S, D, N
Kombat WDG	1.125	-	-
Early Impact	0.60	+	N
Impact Excel	1.00	-	-
Patrol	0.50	+ + +	F
Sprint	1.50	+ + +	N
Plantvax 20 EC	2.00	+	N

- = No symptoms S = Stunting

+ = Slight symptoms D = Deformities

++ = Moderate symptoms N = Necrosis

+++ = Severe symptoms F = Fatal

The effects of rust fungicides on mint rust and their phtotoxicity to mint.

These experiments examined the control of rust, as well as phytotoxicity problems. All of the fungicides produced 100 % rust control at both application times, (Table 4).

The fungicides which caused severe damage in experiments 1 (a) & (b) also did so in these experiments i.e. Patrol, Glint 500 EC, Corbel, and Sprint. Punch C caused moderate amounts of damage.

Table 4 The effects of rust fungicides on mint rust and their phytotoxicity to mint

FUNGICIDE	CONC	APPL TIME	% CONTROL	PHYTOTOXICITY LEVEL	PHYTOTOXICITY SYMPTOMS
Corbel	0.35	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Bayleton 5	0.10	-2	100	-	-
		+2	100	-	-
Bayleton	0.10	-2	100	-	-
		+2	100	-	-
Bayfidan	0.25	-2	100	-	-
		+2	100	-	-
Glint 500 EC	0.40	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Hispor 45 WP	0.20	-2	100	+	D, N
		+2	100	+	D, N
Tilt 250 EC	0.20	-2	100	+	N
		+2	100	+	N
Punch C	0.25	-2	100	+ +	S, D, N
		+2	100	+ +	S, D, N
Kombat WDG	1.125	-2	100	-	-
		+2	100	-	-
Early Impact	0.40	-2	100	-	-
		+2	100	-	-
Impact Excel	1.00	-2	100	-	-
		+2	100	-	-
Patrol	0.30	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Sprint	1.00	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Plantvax 20 EC	1.50	-2	100	+	N
		+2	100	+	N

- = No symptoms S = Stunting

+ = Slight symptoms D = Deformities

++ = Moderate symptoms N = Necrosis

+++ = Severe symptoms F = Fatal

[a] Application time, in days, is in relation to inoculation i.e. -2 is 2 days pre-inoculation and +2 is 2 days post-inoculation.

Two of the fungicides in a repeat experiment (Table 5) did not produce 100 % control of the rust. Early Impact as a pre-inoculation treatment only maintained 50 % control, while as a post-inoculation treatment it achieved 100 % control. This indicated that this concentration (0.2%) would be too low for the field trials, and thus the concentration (0.4%) from experiment 1(a) was selected, since it produced 100 % control and no phytotoxicity problems. The other fungicide which produced less than 100 % control was Plantvax 20. Used as a pre-inoculation treatment it gave 95 % control of rust infection (Table 5).

Table 5 The effects of rust fungicides on mint rust and their phytotoxicity to mint.

FUNGICIDE	CONC	APPL TIME	% CONTROL	PHYTOTOXICITY LEVEL	PHYTOTOXICITY SYMPTOMS
Corbel	0.20	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Bayleton	0.10	-2	100	-	-
		+2	100	-	-
Bayfidan	0.20	-2	100	-	-
		+2	100	-	-
Glint 500 EC	0.20	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Hispor 45 WP	0.15	-2	100	+	N
		+2	100	+	N
Tilt 250 EC	0.10	-2	100	-	-
		+2	100	-	-
Punch C	0.15	-2	100	+ +	S, N
		+2	100	+ +	S, N
Early Impact	0.20	-2	50	-	-
		+2	100	-	-
Impact Excel	0.50	-2	100	-	-
		+2	100	-	-
Patrol	0.10	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Sprint	0.50	-2	100	+ + +	S, D, N
		+2	100	+ + +	S, D, N
Plantvax 20 EC	1.00	-2	100	-	-
		+2	95	-	-

- = No symptoms S = Stunting

+ = Slight symptoms D = Deformities

++ = Moderate symptoms N = Necrosis

+++ = Severe symptoms F = Fatal

[a] Application time, in days, is in relation to inoculation i.e. -2 is 2 days pre-inoculation and +2 is 2 days post-inoculation.

Field trials of fungicides against mint rust

Auchincruive 1993

Mean Infection

The mean percentage infection is a measurement compiled from the percentage infections on the 3 leaf pairs per plant which were examined. The percentage infections on the three leaf pairs followed a similar pattern to that shown in the mean percentage infection (Figures 2 & 3), although the mean level of infection on each leaf pair did differ. The lower leaves were more highly infected than the middle leaves, which were more highly infected than the upper leaves.

All of the fungicides tested against mint rust greatly reduced the mean percentage infections, except for Bayleton (Figures 2 & 3). At the first assessment the fungicide which produced the greatest reduction in rust infection was Plantvax 20 EC (49.55%), closely followed by Hispor 45 WP (44.90%), Impact Excel (39.45%), Bayfidan (37.93%), Early Impact (32.65%), Tilt 250 EC (32.11%) and Kombat (30.23%). Bayleton did not reduce the percentage infection, it actually increased it by 4.02 %. This was, however, not significant. The mean infection on control plants was 11.18 %.

At the second assessment, all of the fungicides which showed activity at the first assessment also showed activity at this time. The fungicide which gave the best control was Hispor 45 WP, producing a 62.93 % reduction in rust. The other fungicides gave reductions of between 28.63 % and 45.60 %. Bayleton did reduce the mean percentage infection at this assessment, but by only 7.26 %, which was not significant (Figure 3).

Percentage infected leaves

At the first assessment all of the fungicides significantly reduced the percentage of leaves which were infected with rust. 86.62 % of the leaves in the control were infected, compared with 55.52 % in the plots treated with Hispor 45 WP, the fungicide which performed best at this assessment. In the plots treated with the other fungicides , between 64.35 % and 81.41 % of the leaves were infected (Figure 4).

When the second assessment was carried out infection levels in the plots were very high,

Figure 2 The effects of rust fungicides on the mean percentage infection of rust on mint : Assessment 1.

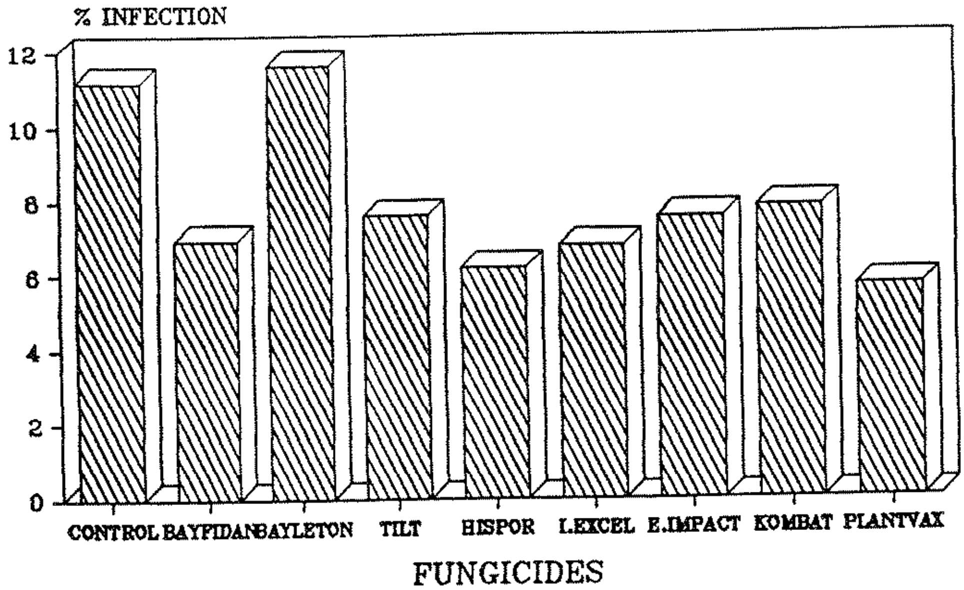


Figure 3 The effects of rust fungicides on the mean percentage infection of rust on mint : Assessment 2

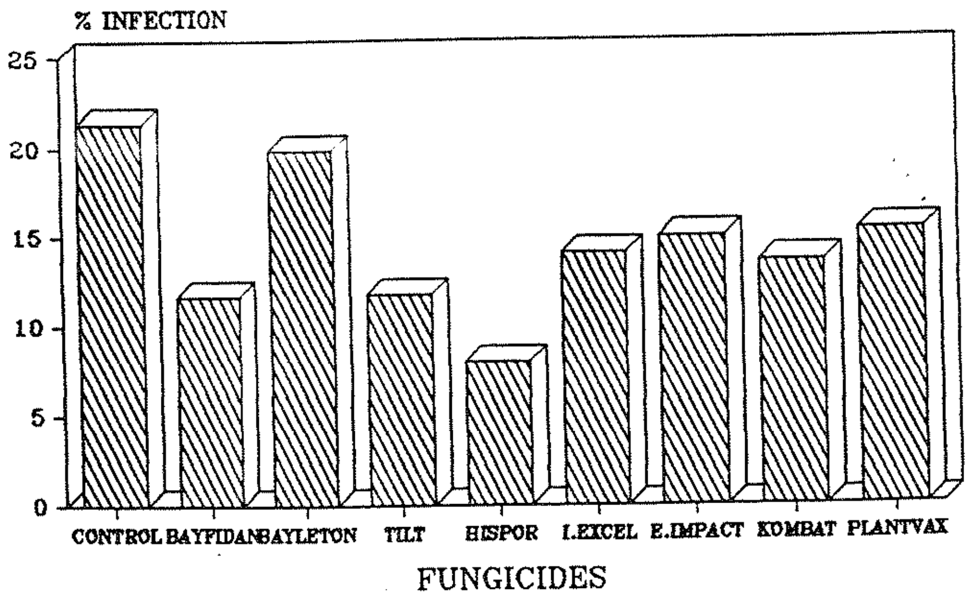


Figure 4 The effects of rust fungicides on the percentage of mint leaves infected with rust : Assessment 1.

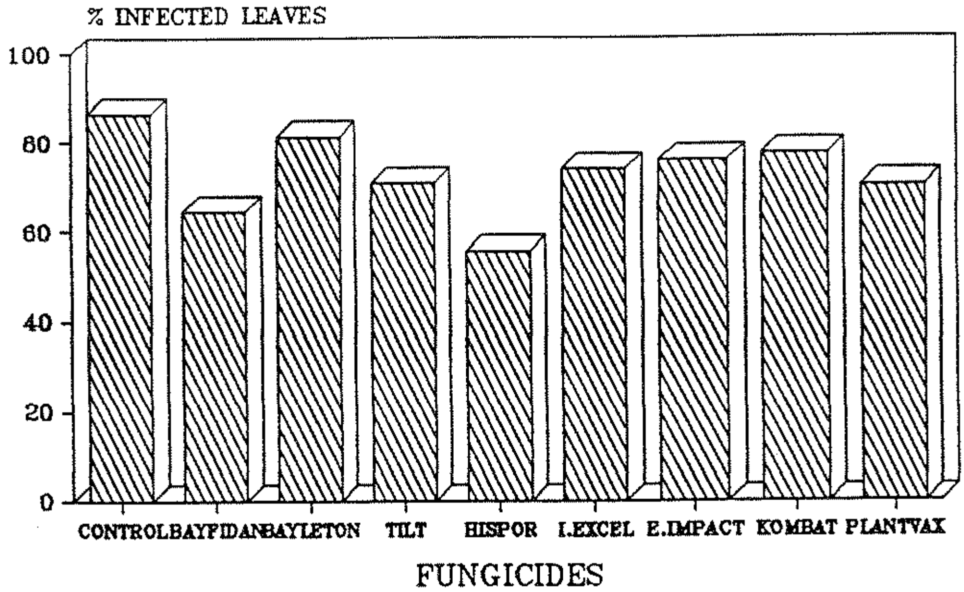
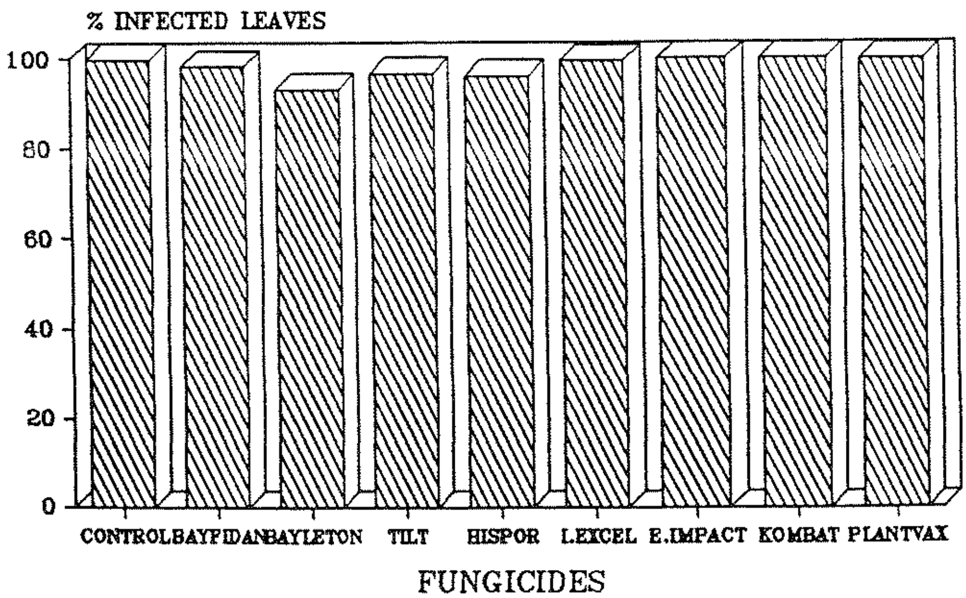


Figure 5 The effects of rust fungicides on the percentage of mint leaves infected with rust : Assessment 2.



resulting in almost all of the leaves in every treatment being infected. In the controls 99.88 % of the leaves were infected. In the plots treated with fungicides between 93.19 % and 100 % of the leaves were infected (Figure 5).

Percentage missing leaves

In the control plots 17.6 % of the leves were missing at the first assessment. The fungicide treatments had little effect on this, with values ranging from 13.88 % to 21.50 %. Plots treated with Early Impact had the fewest missing leaves (13.88%) followed closely by Hispor 45 WP (14.10%). Plants treated with Tilt 250 EC had the largest number of missing leaves (21.50%) (Figure 6).

At the second asessment, all of the fungicide treatments except Bayleton, reduced the percentage of missing leaves (Figure 7). The percentage of missing leaves in the controls rose to 59.63 % compared to only 17.60 % at the first assessment. The plants which were treated with Hispor 45 WP had the fewest missing leaves (26.92%). Plants treated with Bayleton lost 56.67% of their leaves, which was not significantly different from the control (Figure 7).

Total dry weights

No significant differences were found between plots treated with fungicides and the control plots, at the first assessment. The mean total dry weights ranged from 6.84 g to 9.32g for 10 stems (Figure 8).

Differences in plant dry weights emerged at the 2nd assessment (Figure 9). Hispor 45 WP, Plantvax 20 and Early Impact all produced plants significantly heavier than the control. All other treatments, except Bayleton, produced plants slightly heavier than the control, although these differences were not significant. The mean total dry weight of the plants treated with Bayleton was lower than the control, 7.72g compared to 8.04g. The mean dry weights of the other treatments ranged from 8.04g to 11.81g.

Height

At both assessments, the mean height of the fungicide treated plants did not differ significantly

Figure 6 The effects of rust fungicides on the percentage of missing leaves of mint : Assessment 1.

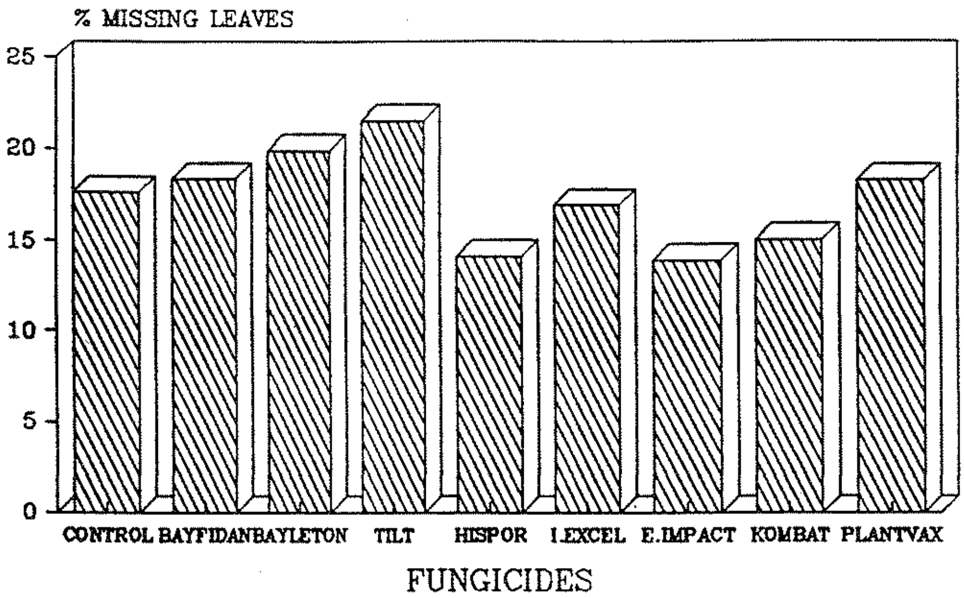


Figure 7 The effects of rust fungicides on the percentage of missing leaves of mint : Assessment 2.

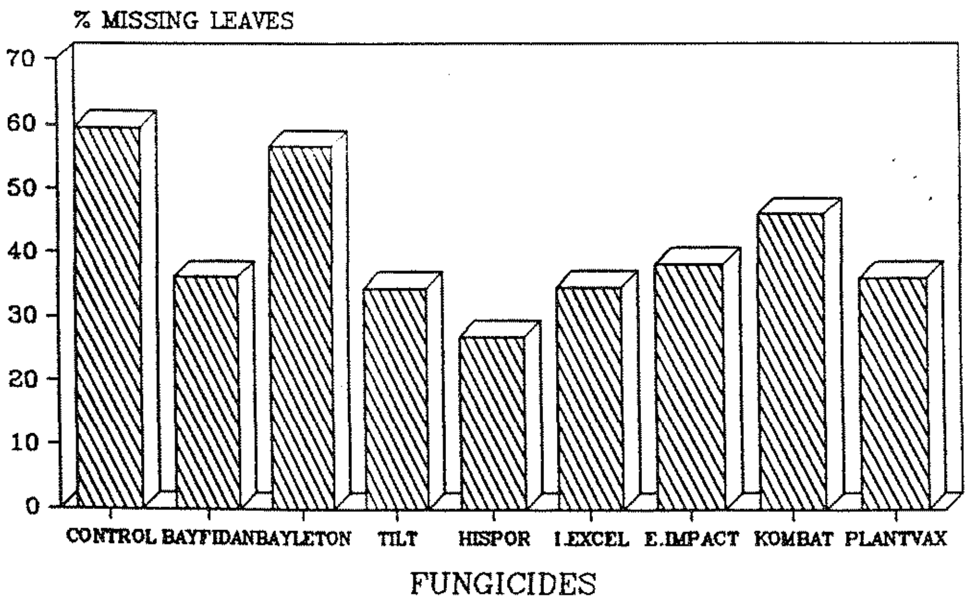


Figure 8 The effects of rust fungicides on the mean total dry weights of mint : Assessment 1.

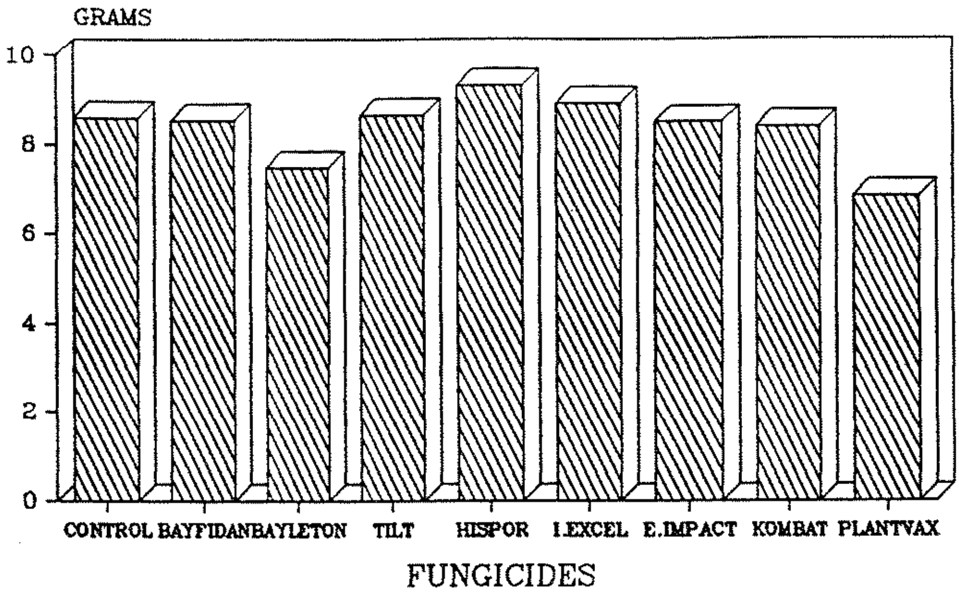
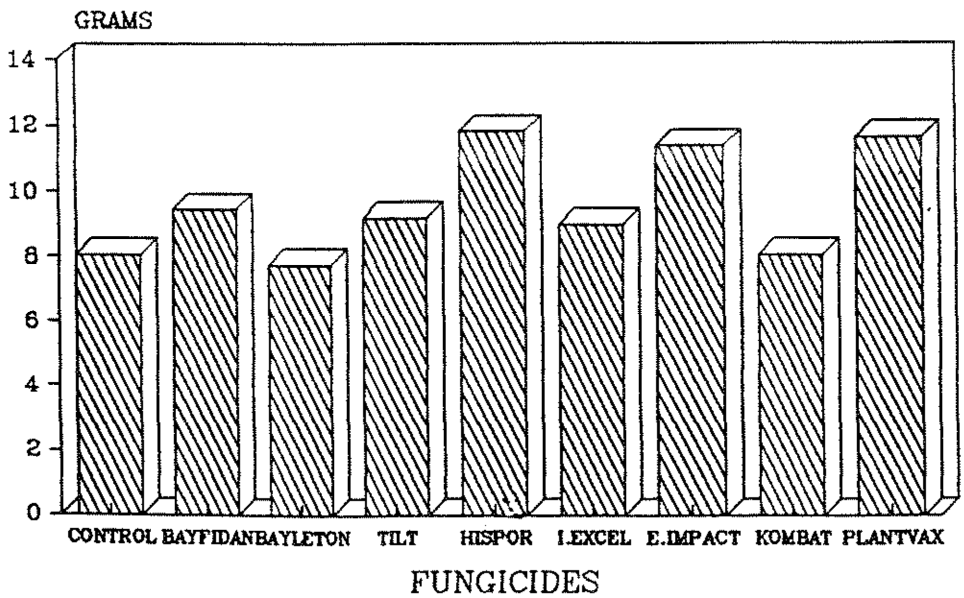


Figure 9 The effects of rust fungicides on the mean total dry weights of mint : Assessment 2.



from the control (Figures 10 & 11). At the first assessment, mean heights ranged from 20.54 cm to 22.42 cm. At the second assessment mean heights ranged from 21.20 cm to 23.30 cm.

Field Trial: Norfolk 1993

Mean Infection

The levels of rust infection were very low throughout the whole growing season. Due to this very low infection, no differences between fungicide treated plots and the controls were detected at any of the assessment (data not shown).

Percentage Infected Leaves

By the second harvest only 1.6 % of the leaves in the controls were infected. There were no significant differences between the controls and the treated plots at any of the assessments (data not shown).

Percentage Missing Leaves

At the first assessment 20% of the leaves in the controls were missing. None of the fungicides significantly reduced that figure. The plants treated with Plantvax 20 had significantly more missing leaves than the control.

At the second assessment the percentage of missing leaves in the controls had risen to nearly 40%. All of the fungicides reduced this loss. Hispor 45, Early Impact and Impact Excel significantly reduced the percentage of missing leaves by between 14 and 18% (Figure 12).

At the harvest, a similar pattern was observed. The 3 fungicides which performed best at the second assessment also did so at this assessment (Figure 13).

Height

At the first assessment the controls had a mean height of 22 cm. Fungicide treated plants were slightly taller than the controls, except for those treated with Bayleton and Hispor 45. Impact Excel and Kombat significantly increased height (Figure 14).

Figure 10 The effects of rust fungicides on the mean heights of mint plants : Assessment 1.

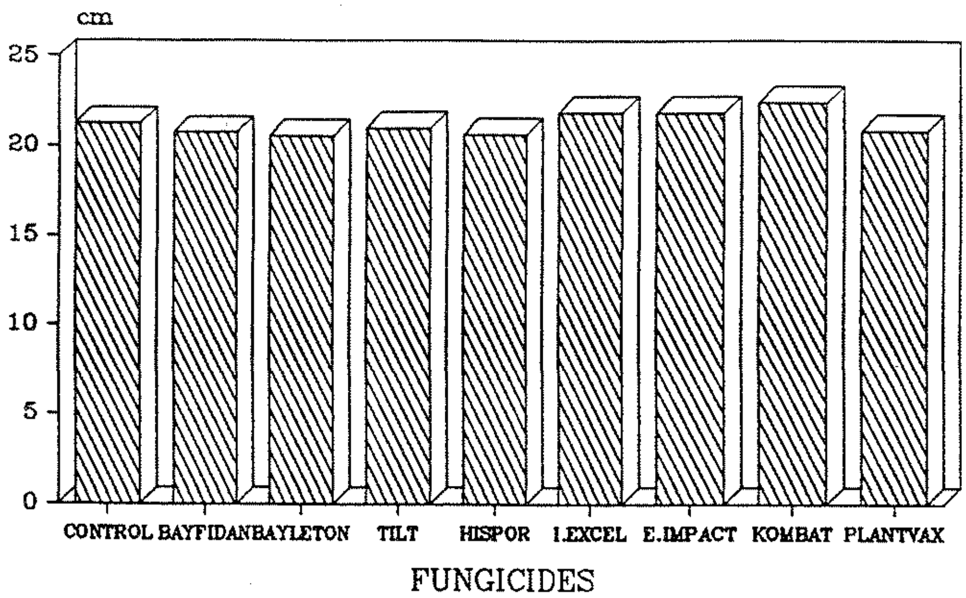


Figure 11 The effects of rust fungicides on the mean height of mint plants : Assessment 2.

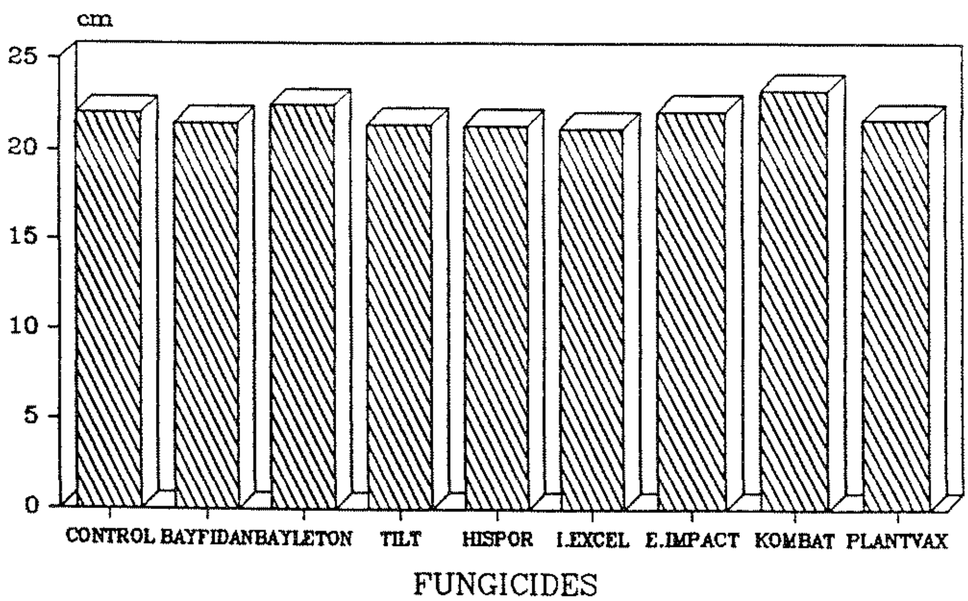


Figure 12 The effects of rust fungicides on the percentage of missing leaves : assessment 2 - Norwich

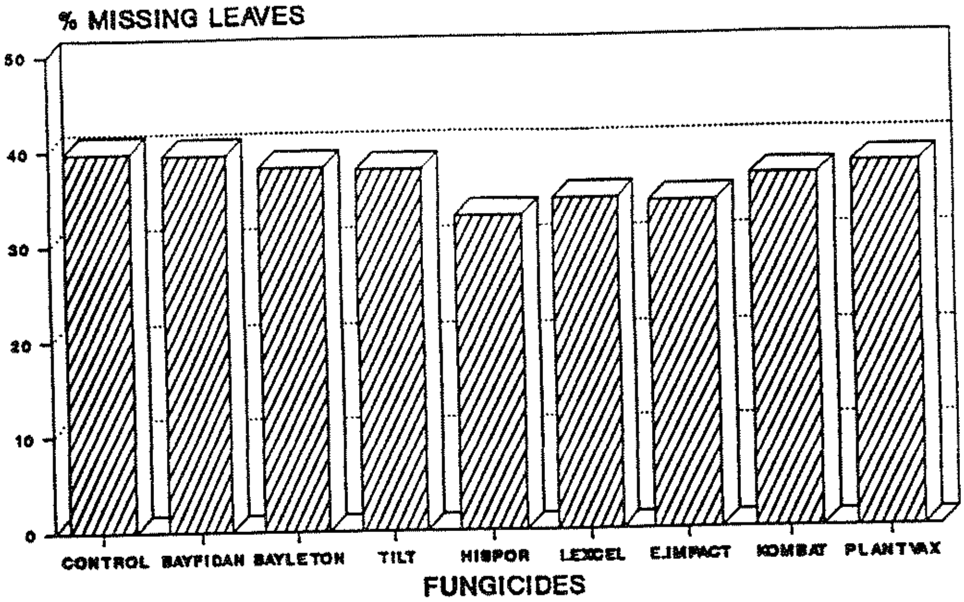


Figure 13 The effects of rust fungicides on the percentage of missing leaves : assessment 3 - Norwich

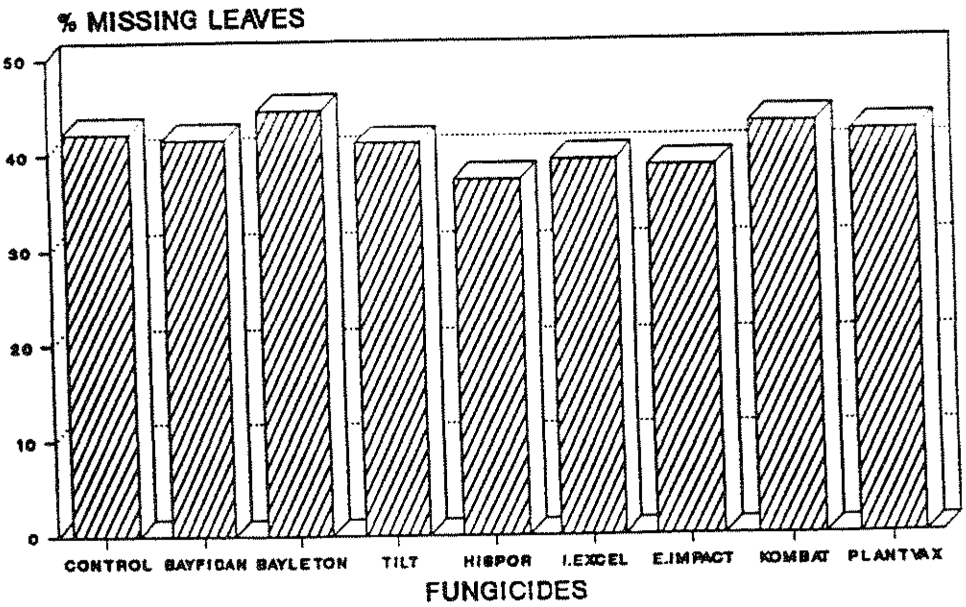


Figure 14 The effects of rust fungicides on the mean heights of mint plants : assessment 1 - Norwich

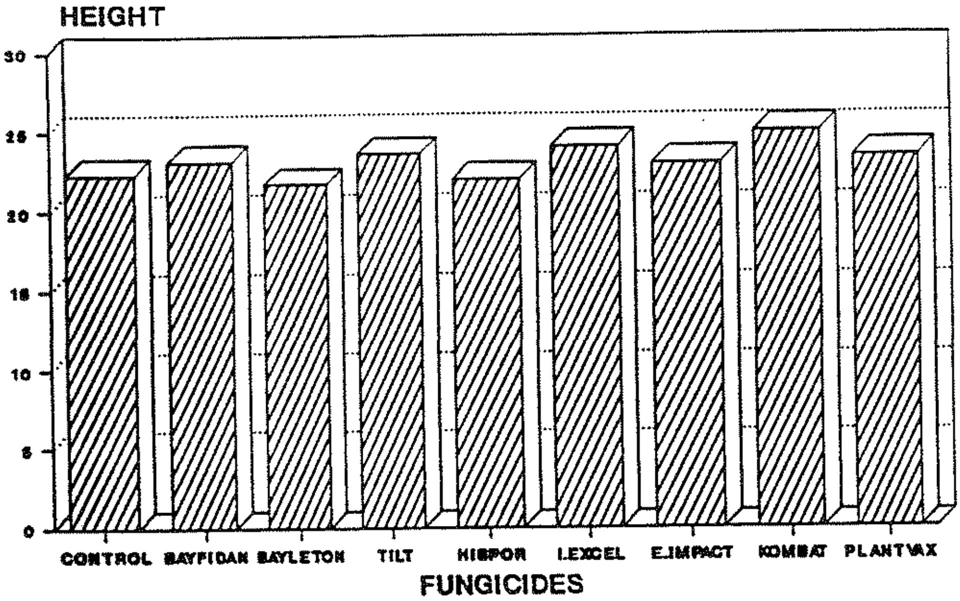
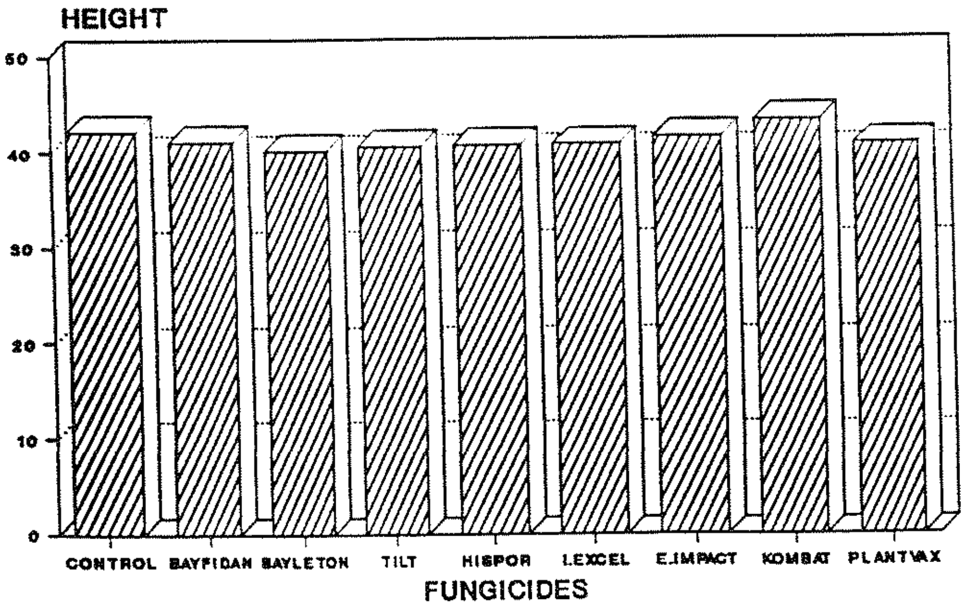


Figure 15 The effects of rust fungicides on the mean heights of mint plants : assessment 3 - Norwich



At the second assessment, only Kombat significantly increased height.

By the time of the final assessment none of the fungicides significantly increased height. The mint plants treated with Bayleton and Tilt were significantly shorter than the controls (Figure 15).

Field Trial : Herefordshire 1993

Mean Infection

The amount of rust found at this site was more than at the Norfolk site but much less than at Auchincruive. 5 of the 8 fungicides reduced the mean infection, although not significantly. Impact Excel, Kombat and Hispor 45 produced the greatest reductions (Figure 16).

Percentage Infected Leaves

In the control plots 16 % of the leaves were infected with rust. All of the fungicides, except Bayleton, reduced this figure. Bayfidan was the only fungicide to significantly reduce the percentage of infected leaves, while Bayleton significantly increased it by 62 % (Figure 17).

Percentage Missing Leaves

37 % of the leaves on the controls were missing at harvest. Impact Excel was the only fungicide to significantly reduce this figure. The other fungicides appeared to have little effect (Figure 18).

Height

The mean height of the control plants was 41.9 cm. 4 of the 8 fungicdes caused slight but not significant increases in height. Bayfidan was the only fungicide to significantly increase it, by 17 % (Figure 19).

Field Trial: Auchincruive 1994

Percentage Survival

The mint which survived best from one season to the next and therefore had the greatest

Figure 16 The effects of rust fungicides on the mean percentage infection of rust on mint : Assessment 3 - Ross-on-Wye

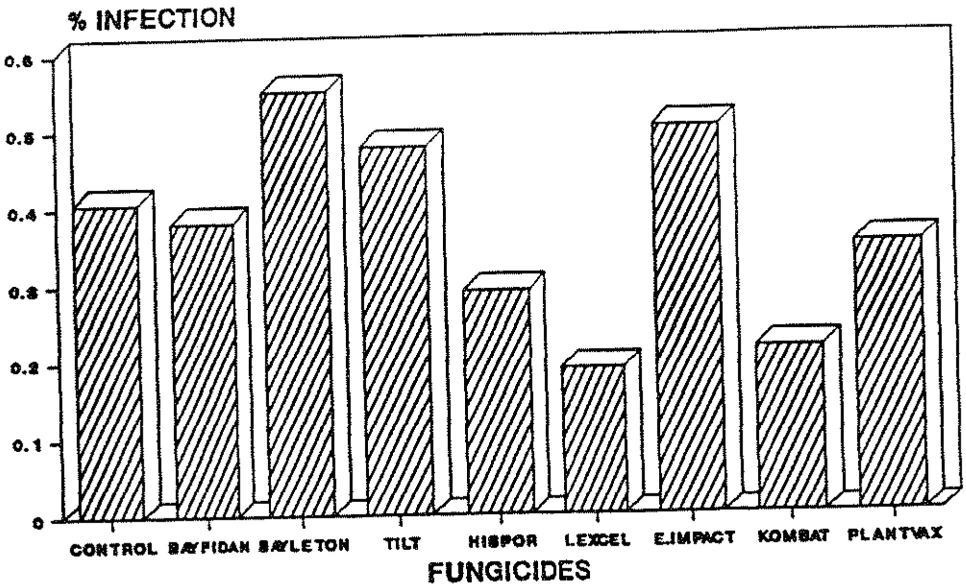


Figure 17 The effects of rust fungicides on the percentage of mint leaves infected : Assessment 3 - Ross-on-Wye

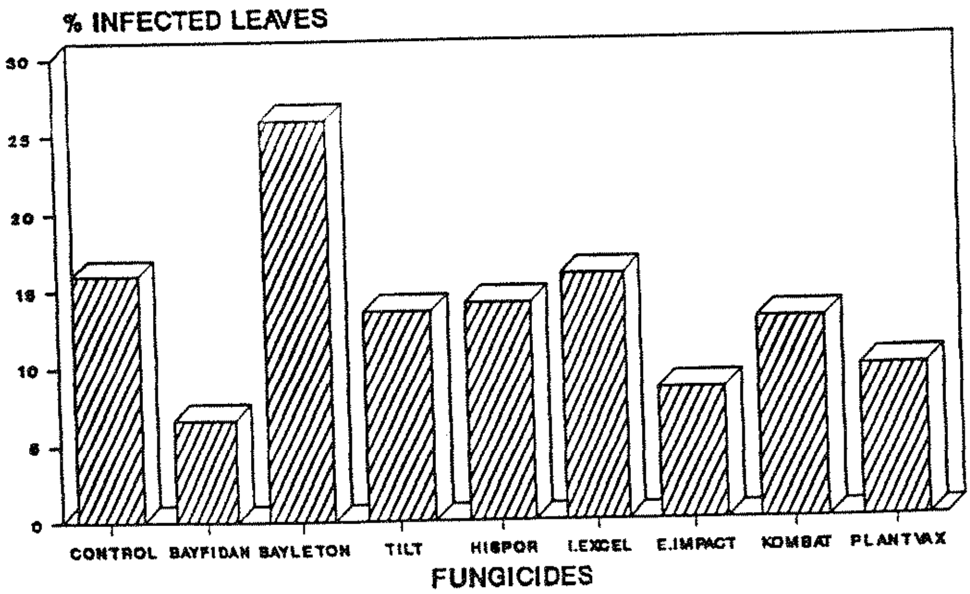


Figure 18 The effects of rust fungicides on the percentage of missing leaves of mint : Assessment 3 - Ross-on-Wye

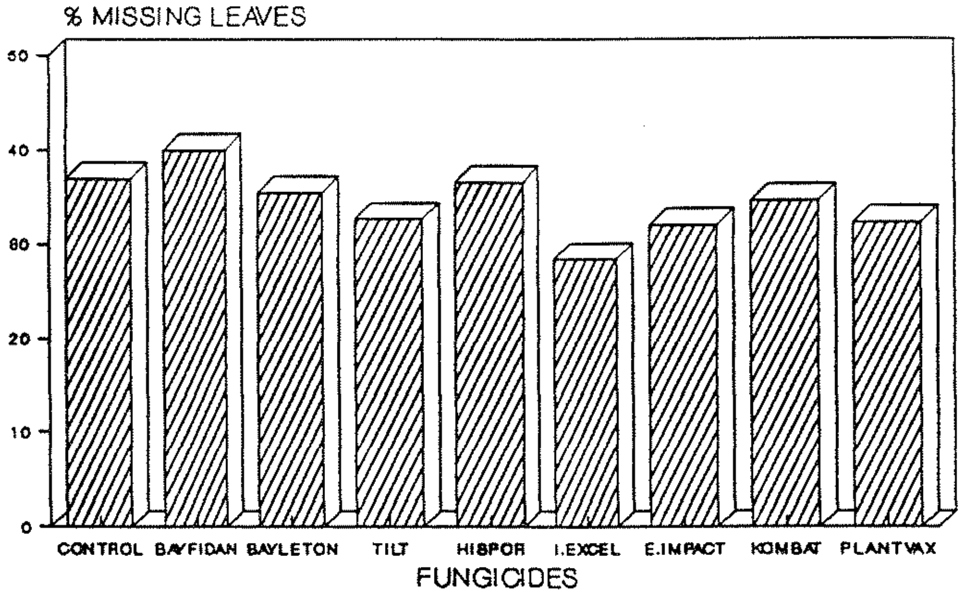
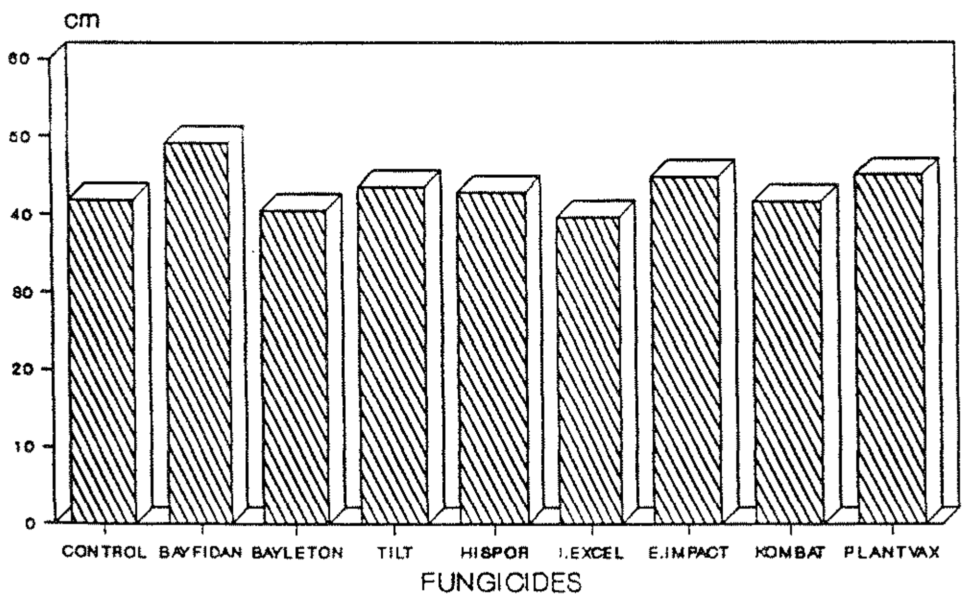


Figure 19 The effects of rust fungicides on the mean heights of mint plants : Assessment 1 - Ross-on-Wye



percentage cover on the plots was the mint treated with Hispor 45, scoring a mean of 4. The mint treated with Early Impact and Bayfidan also did well. The control plots and the plants treated with Kombat had the lowest percentage cover, scoring a mean of only 1.75 (Table 6).

Table 6 The effects of fungicides on the percentage cover of mint : assessment 1 -Auchincruive.

TREATMENT	SCORE
Control	1.75
Bayfidan	3.50
Bayleton	2.25
Tilt 250	2.50
Hispor 45	4.00
Impact Excel	3.00
Early Impact	3.75
Kombat	1.75
Plantvax	2.75

Mean Percentage Infection

Bayfidan was the only fungicide to significantly reduce the mean infection. Bayleton was found to significantly increase the mean infection by 34 % (Figure 20).

Percentage Infected Leaves

The levels of rust infection at this first assessment were very high with 69 % of the leaves in the controls infected. None of the fungicides significantly reduced infection. Some of the fungicides actually increased the percentage of infected leaves (Figure 21).

Percentage Missing Leaves

At the first assessment 41 % of the leaves on the controls were missing. The only fungicide to significantly reduce this value was Kombat with 34 % of the leaves missing. Bayleton significantly increased the percentage of missing leaves with a mean of 50 % missing (Figure 22).

Figure 20 The effects of rust fungicides on the mean percentage infection of rust on mint: assessment 1 - Auchincruive

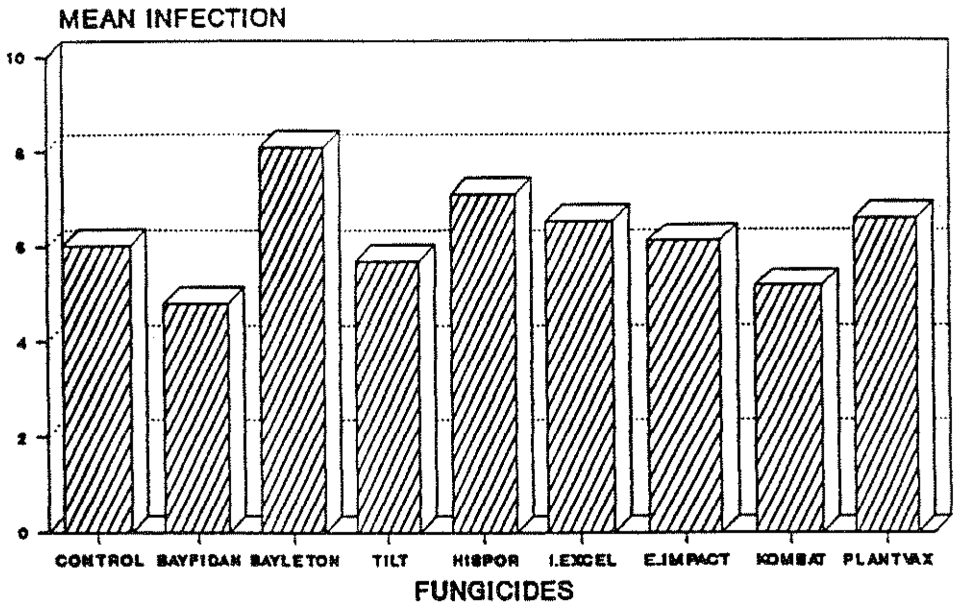


Figure 21 The effects of rust fungicides on the percentage of mint leaves infected: assessment 1 - Auchincruive

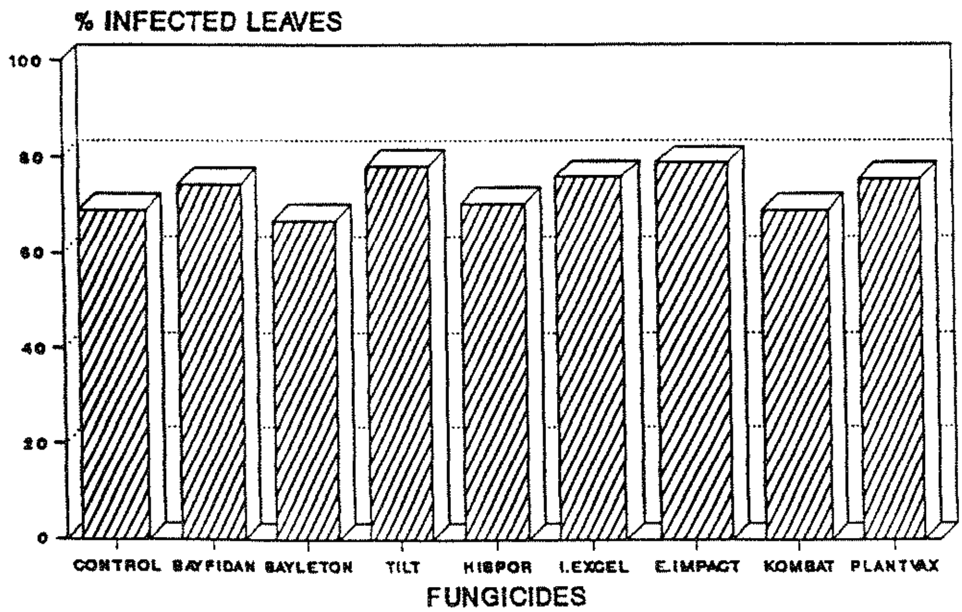


Figure 22 The effects of rust fungicides on the percentage of missing leaves : assessment 1 - Auchincruive

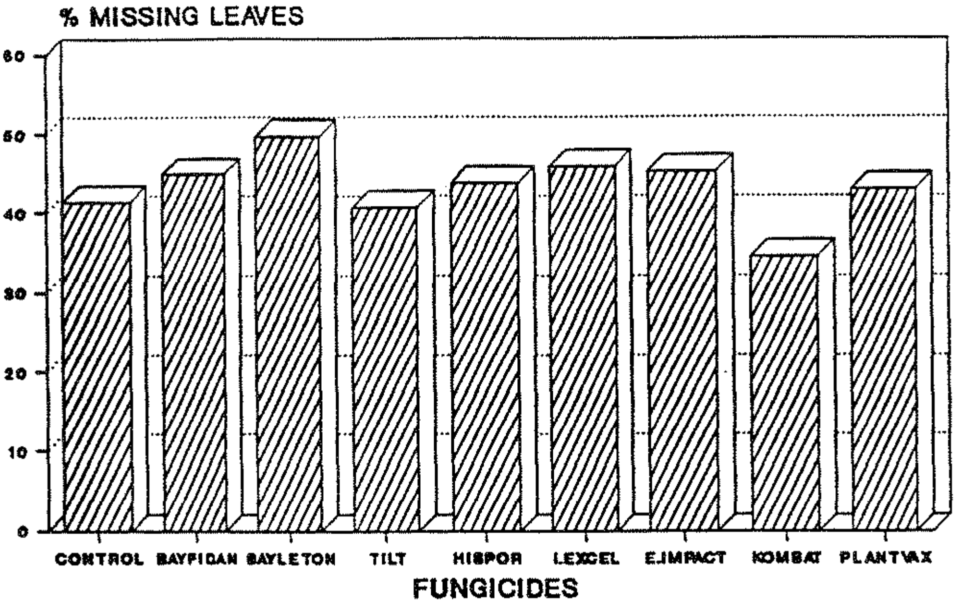
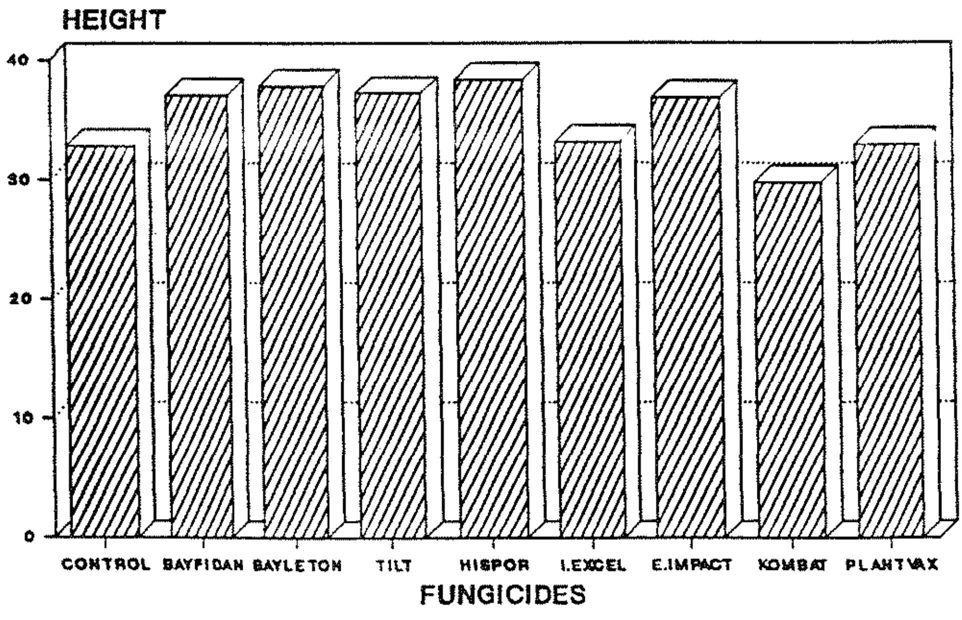


Figure 23 The effects of rust fungicides on the mean heights of mint plants : assessment 1 - Auchincruive



Height

The mean height of the mint plants in the controls was 32.84 cm. Treatment with all of the fungicides except Kombat increased the height of the plants. Bayfidan, Bayleton, Tilt 250, Hispor 45 and Early Impact all significantly increased height by between 12 and 17 % (Figure 23).

Field Trial: Norfolk 1994

Mean Infection

There was little difference in the mean percentage infection recorded at the first harvest. Although the levels of infection were very low, it was noticed that mean infection on the Bayleton treated plants was significantly higher than in the controls (data not shown).

The second assessment was carried out before any fungicides were applied to the second crop. This assessment found that the mean infection was higher in all of the fungicide-treated plots than in the controls, except for Bayfidan-treated plots, where no rust was found (data not shown).

By the time of the second harvest none of the fungicides had reduced the low levels of disease. In the plots treated with Bayleton, again the mean infection was significantly higher.

Percentage Infected Leaves

The results for the percentage of leaves infected followed a similar pattern to the results for the mean infection. At the first harvest none of the fungicides significantly reduced the percentage of leaves infected. Bayleton significantly increased this value (data not shown).

When the second assessment was carried out it was observed that there was not an even distribution of rust between plots. The plots in which Bayleton and Tilt 250 were to be sprayed had significantly higher percentages of leaves infected. The other fungicide plots generally had slightly higher levels of rust than the controls, except for those treated with Hispor 45 and Bayfidan (data not shown).

By the end of the second harvest the levels of rust had increased slightly. Bayfidan, Tilt 250 and

Kombat reduced the percentage of infected leaves, although not significantly. In the other fungicide treated plots the levels of infected leaves were higher, with Hispor 45 significantly increasing this level (data not shown).

Percentage Missing leaves

Although the fungicides appear to have failed to control the rust they have increased yield by reducing the loss of leaves associated with this disease. At the first harvest, all of the fungicides except Bayleton, Tilt 250 and Plantvax significantly reduced the loss by between 9 and 21 %. Bayleton caused a slight increase in the percentage of leaves lost (figure 24)..

At the second assessment, 12 % of the leaves on the controls were missing. The only plots to show significantly fewer missing leaves were those treated with Tilt 250. Most of the other fungicide plots had slightly fewer missing leaves than the controls (figure 24).

When the final assessment was carried out, 5 of the 8 fungicides had reduced leaf loss. The control plots had lost 39 % of their leaves. Significant reductions of between 9 and 13 % were obtained with the plots treated with Tilt 250, Hispor 45, Impact Excel, Early Impact and Kombat. Bayfidan and Plantvax produced very slight reductions, while Bayleton produced a slight increase in leaf loss (figure 24).

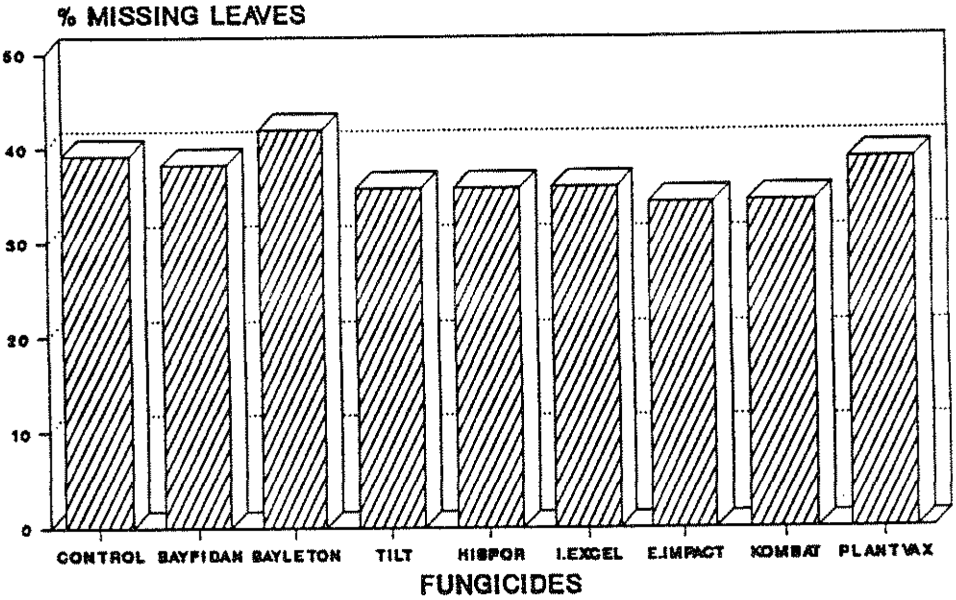
Height

At the first assessment it was found that treating plants with fungicide slightly increased their height. The only fungicides found to significantly increase height were Bayleton and Kombat. No significant changes in height were recorded at the second harvest (data not shown).

Field Trial: Auchincruive 1995

The good weather over the 1995 season allowed 3 harvests to be conducted. In colder seasons, processors would expect only 2 harvests. The spring and autumn crops had a long enough growing time to allow 2 fungicide applications with a 3 week harvest interval. The summer crop was harvested 6 weeks after the spring crop. This allowed time for only 1 fungicide application with a 3 week harvest interval. On the spring and autumn crops, plots received either 1 application with a 5 week harvest interval, or 2 applications with a 3 week harvest interval.

Figure 24 The effects of rust fungicides on the percentage of missing leaves : assessment 3 - Norwich



Mean infection

In 1995 the levels of rust at the Auchincruive site were very much lower than in previous years, especially early in the season (Table 7). In the autumn crop, which had the highest levels of rust, all of the fungicides significantly reduced the mean infection by between 59 and 98 % (Table 7 below).

TABLE 7 Effects of fungicides on the mean rust infection of mint in the field

PRODUCT	No of	SPRING		SUMMER		AUTUMN	
	sprays	% infect	% red	% infect	% red	% infect	% red
Control		0.0050		0.66		1.32	
Bayfidan	1	0.0042	17	0.23	65	0.41	69
	2	0	100	-	-	0.04	97
Hispor 45	1	0.0008	83	0.20	69	0.35	73
	2	0.0004	92	-	-	0.03	98
Impact Excel	1	0.0004	92	0.13	79	0.25	81
	2	0.0004	92	-	-	0.54	59
Kombat	1	0.0037	25	0.06	90	0.41	69
	2	0.0042	17	-	-	0.38	71
SED		0.00176		0.072		0.143	

Percentage infected leaves

The reductions in the percentage of infected leaves were more variable and ranged from 1 - 92 % (Table 7). Two applications of Bayfidan and Hispor 45 performed best, producing reductions in the percantage of infected leaves of 97 % and 98 % respectively

TABLE 8 Effects of fungicides on % infected leaves on mint in the field

PRODUCT	No of sprays	SPRING % infect leaves	SPRING % red	SUMMER % infect leaves	SUMMER % red	AUTUMN % infect leaves	AUTUMN % red
Control		3.11		62.8		69.5	
Bayfidan	1	1.42	54	53.7	14	68.6	1
	2	0	100	-	-	5.4	92
Hispor 45	1	0.39	87	49.9	20	60.5	13
	2	0.18	94	-	-	26.5	62
Impact Excel	1	0.21	93	46.7	26	60.9	12
	2	0.18	94	-	-	51.1	26
Kombat	1	0.93	70	37.6	40	56.3	19
	2	1.89	39	-	-	55.0	21
SED		0.637		4.25		4.77	

Percentage missing leaves

The fungicides had little effect on the percentage of missing leaves. The best results were obtained with two applications of Impact Excel and Kombat, which reduced the percentage of missing leaves by 17 % and 30% respectively (Table 9)

TABLE 9 The effects of fungicides on the % missing leaves in mint in the field

PRODUCT	**No of sprays**	**SPRING** % miss leaves	% red	**SUMMER** % miss leaves	% red	**AUTUMN** % miss leaves	% red
Control		12.07		13.76		32.47	
Bayfidan	1	15.01	+24	14.68	+7	33.44	+3
	2	14.62	+21	-	-	32.83	+1
Hispor 45	1	11.32	-6	13.35	-3	31.61	-3
	2	11.97	-0.83	-	-	30.77	-5
Impact Excel	1	12.25	+1	16.36	+19	33.24	+2
	2	9.62	-20	-	-	27.07	-17
Kombat	1	14.81	+23	13.93	+1	32.36	-0.34
	2	14.02	+16	-	-	22.70	-30
SED		2.327		2.191		2.184	

Plant growth, yield and oil content

Data on crop yield were inconclusive this year (data not shown). Samples taken from the autumn trial were dried and steam distilled to extract the spearmint oil. No significant differences in oil yield were recorded (data not shown). Gas chromatographic analysis showed no significant differences in oil composition and none of the fungicides affected oil content or composition.

The control of mint rust by flaming

1993 trial

The results of this trial have shown how effective flaming can be at reducing rust infection in mint. Both the percentage of leaves infected (Figure 25) and the mean percentage infection present on those leaves (Figure 26) were significantly reduced. By the time of the fourth assessment, in September, 66.10 % of the leaves in the unflamed plots were infected, compared with only 3.36 % in the flamed plots. The mean percentage infection in the unflamed plots reached 8.8 % compared with 0.01 % in the flamed plots.

1994 trial

Mean Infection

At the first assessment the mean infection was very low. None of the treatments significantly reduced this value. There was, however, no rust found in the plots flamed with the HOAF flamer at 0.17 m/s, the slowest speed. The HOAF flamings did not follow a pattern. The plots flamed with the Barter did, however, follow the expected pattern with the slowest speed, 0.26 m/s producing the lowest mean infection and plots flamed at 0.57 m/s, the fastest speed, having the highest mean infection. Treatment with paraquat produced little difference from the control.

By the time of the second assessment, infection levels were much higher. All of the treatments except the 0.26 m/s with the Barter flamer, reduced the mean infection, although not significantly. The pattern seen at the first assessment with the Barter flamer was reversed (Figure 27).

Percentage Infected Leaves

Just over 6 % of the leaves in the controls were infected at the first assessment. The percentage of leaves infected in the HOAF flamings followed a pattern similar to that found with the mean infection. The 0.17 m/s and the 0.45 m/s treatments significantly reduced the percentage of infected leaves. With the Barter treatments only the slowest i.e. the 0.26 m/s flaming, significantly reduced infection. Treatment with paraquat did reduce the percentage of infected leaves, but not significantly (Figure 28).

At the second assessment, 64 % of the leaves in control plots were infected. Only one of the flaming treatments produced a significantly lower percentage of infected leaves than the control: the 0.26 m/s with the HOAF flamer. This did not follow the same pattern observed for the first

Figure 26 The effects of flaming on the mean percentage infection of rust on mint.

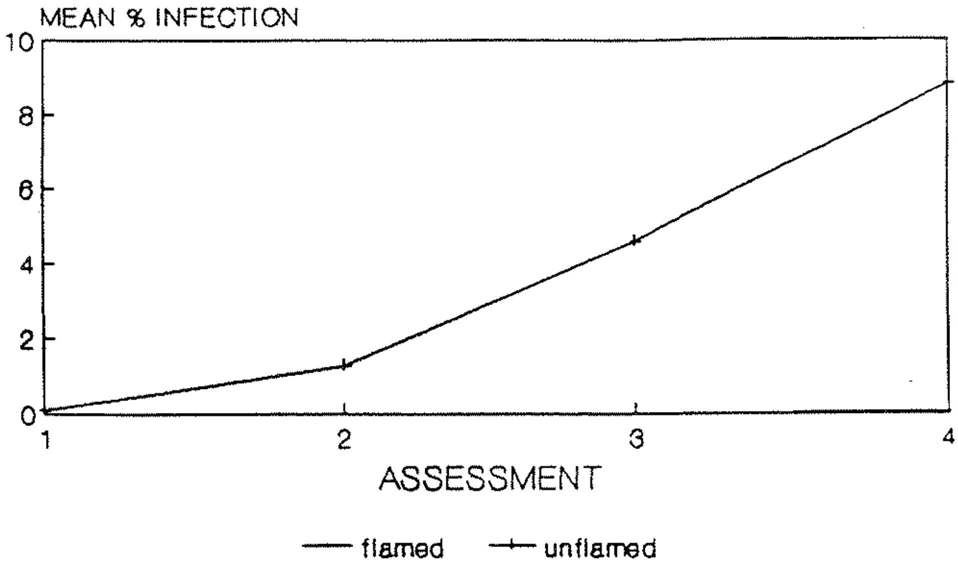


Figure 25 The effects of flaming on the percentage of mint leaves infected with rust.

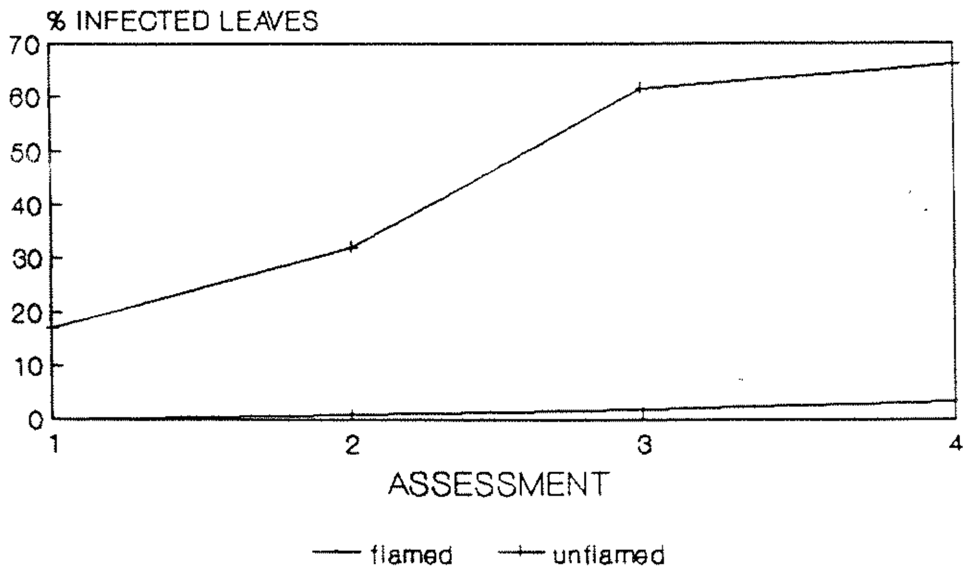


Figure 27 The effects of flaming on the mean percentage infection of rust on mint : assessment 1

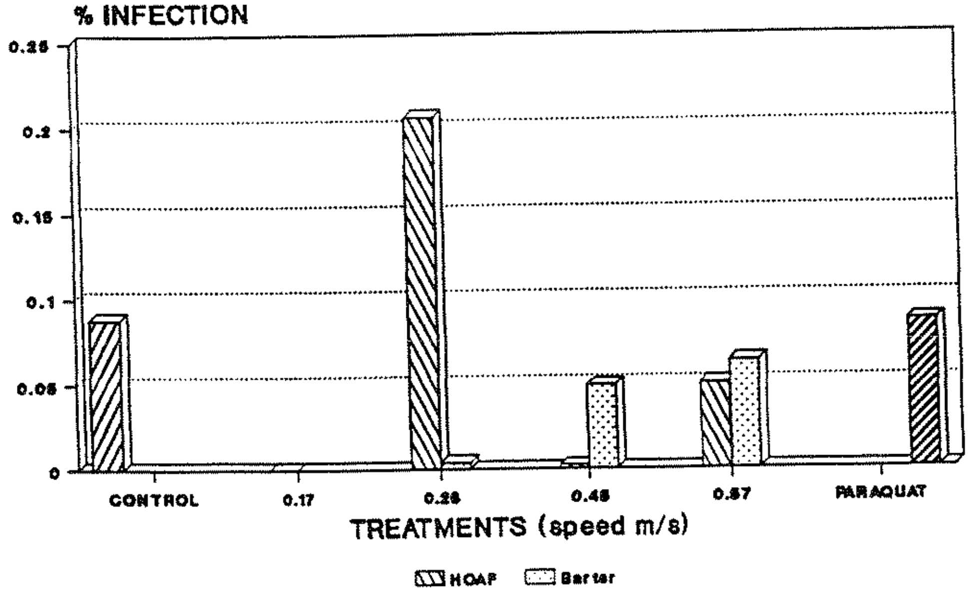


Figure 28 The effects of flaming on the percentage of mint leaves infected with rust : assessment 1

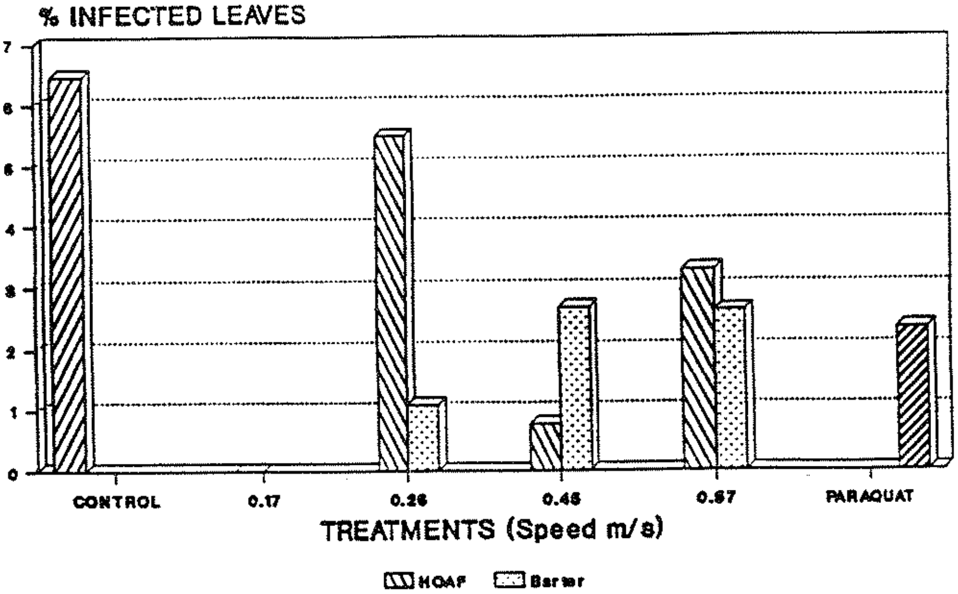
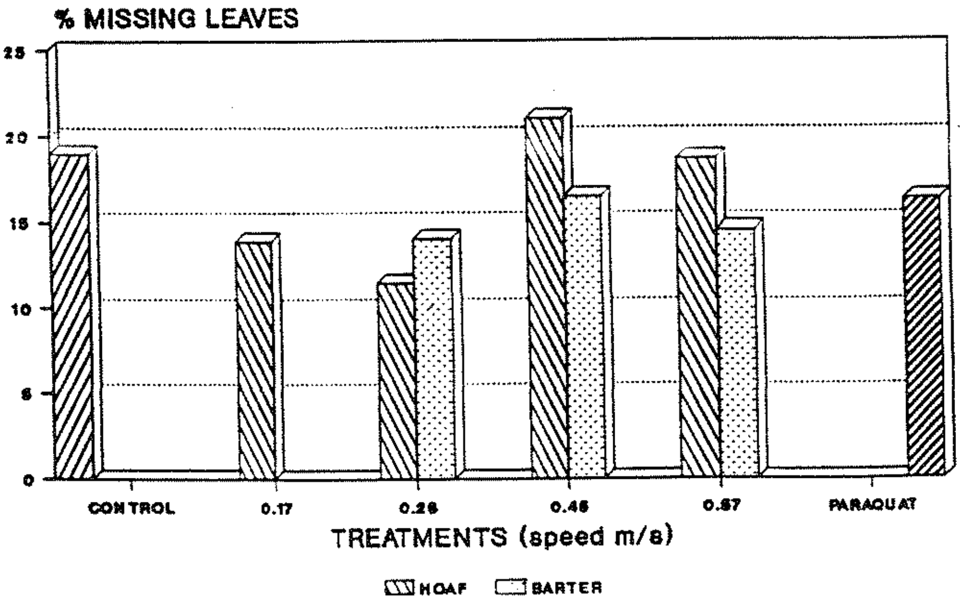


Figure 29 The effects of flaming on the percentage of missing leaves : assessment 1



assessment.

Percentage Missing Leaves

19 % of the leaves on the control plants were missing at the first assessment. The 2 slowest treatments with the HOAF flamer and the slowest with the Barter flamer, significantly reduced the percentage of missing leaves by between 26 and 40 % (Figure 29).

The results from the second assessment followed a similar pattern to those from the first assessment. Almost 14 % of the leaves in the control plots were missing. The 0.26 m/s flaming with the HOAF flamer was the only treatment to still have significantly fewer missing leaves.

Height

At the first assessment the mint plants in the control plots had a mean height of 24 cm. The slowest speed of the HOAF flamer, 0.17 m/s, significantly reduced this height to 22 cm. None of the other treatments had a significant effect on height.

At the second assessment there were no significant differences between controls and treatments.

The effects of rust fungicides on the germination of mint rust uredospores

Tilt 250 EC (Figures 30 & 31)

All concentrations of Tilt 250 reduced the germination of the rust uredospores to some degree. With the 0.01 % concentration, the spores were initially greatly inhibited, but after 6-8 hours they appeared to be able to overcome this inhibition and achieve a germination percentage of 91.25 %. After 8 hours, the 0.1 % and the 1 % concentrations allowed 3.25 % and 0 % of the spores to germinate, respectively, while the other 2 lower concentrations had little inhibitory effect on germination (Figure 30).

The effects on the lengths of the germ tubes did not, follow the same pattern as the percentage germination. The 0.01 % concentration of Tilt 250 reduced the lengths of the germ tubes to less than half of the control i.e. 8.86 u compared with 23.29 u for the control. The lowest concentration, 0.001 %, appeared to increase germ tube lengths to 39.61 u after 8 hours (Figure

Figure 30 The effect of Tilt 250 on the germination of *Puccinia menthae* uredospores.

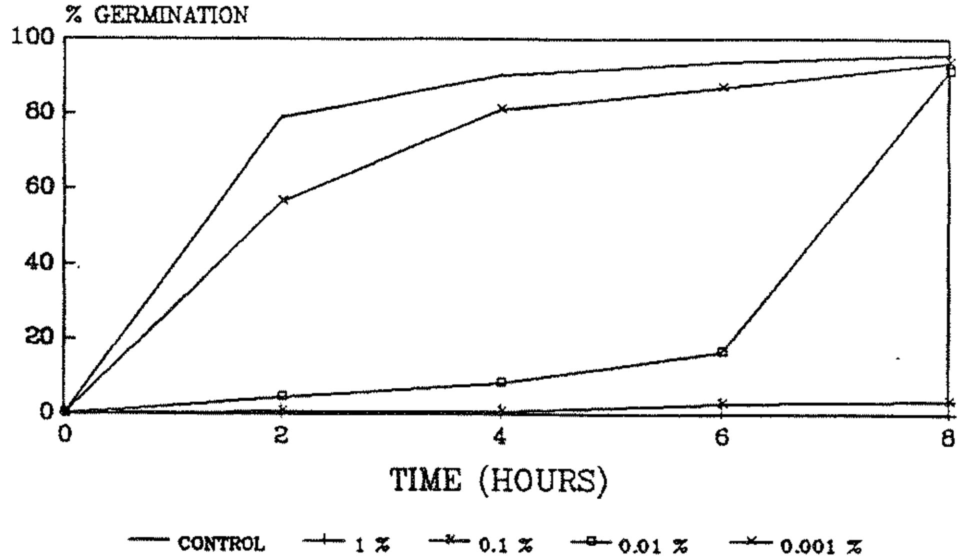
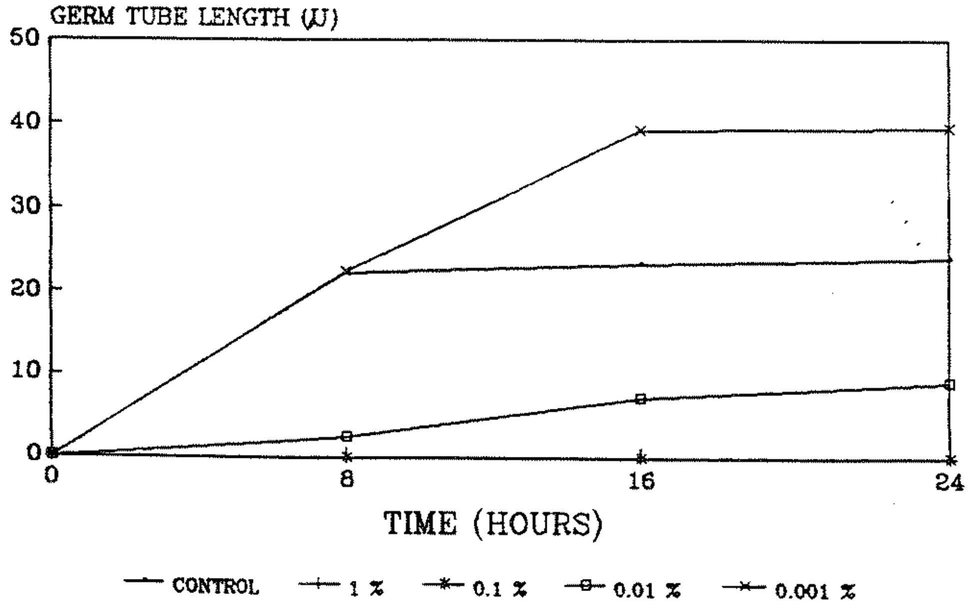


Figure 31 The effect of Tilt 250 on the length of *Puccinia menthae* germ tubes.



31).

KombatWDG (Figures 32 & 33)

All concentrations of Kombat completely inhibited germination of mint rust spores and, as a consequence, there was no germ tube growth.

Impact Excel (Figures 34 & 35)

Impact Excel completely inhibited germination of mint rust spores at all of the tested concentrations.

Bayfidan (Figures 36 & 37)

The lowest concentrations (i.e. 0.01 % and 0.001 %) of Bayfidan were found to have no effect on spore germination. The higher concentrations did, however, supress germination, with the 1 % concentration producing complete inhibition.

All concentrations of Bayfidan reduced the length of germ tubes, with the higher concentrations causing greater reductions. The 0.1 % concentration of Bayfidan, although allowing 18.5 % of the spores to germinate after 8 hours, did greatly affect germ tube growth. Many spores produced 2 germ tubes and so the longer one was measured. There were also swellings and abnormalities in the germ tubes that were produced following treatment with 0.1 % Bayfidan. The germ tubes produced at the lower concentrations appeared to be normal.

Plantvax 20 EC (Figures 38 & 39)

Plantvax at all 4 concentrations reduced the percentage of germinating spores. None of the concentrations, however, caused complete inhibition.

Germ tube growth followed a similar pattern except, that the 0.01 % concentration appeared to stimulate rather than inhibit growth, producing a length of 13.42 u compared to 10.26 u in the control

Figure 32 The effects of Kombat WDG on the germination of *Puccinia menthae* uredospores.

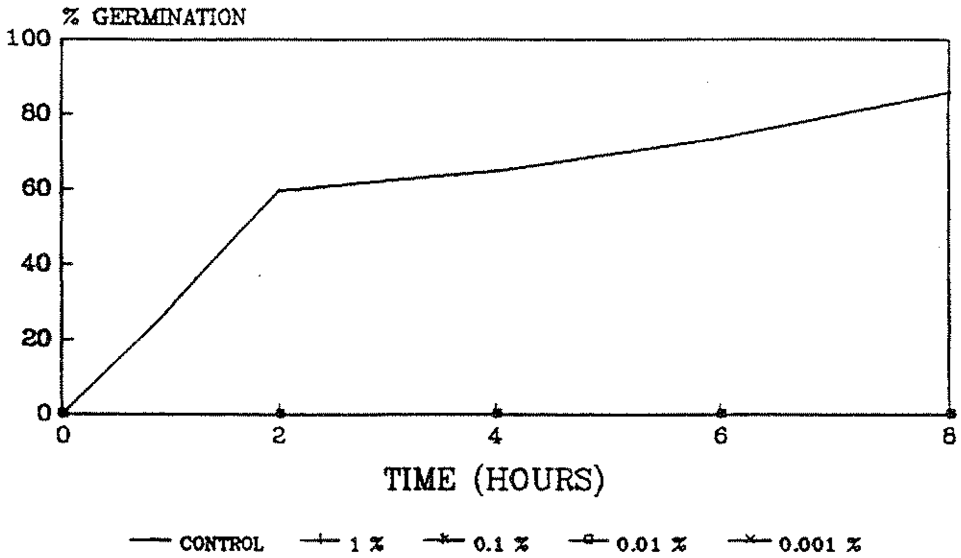


Figure 33 The effects of Kombat WDG on the length of *Puccinia menthae* germ tubes.

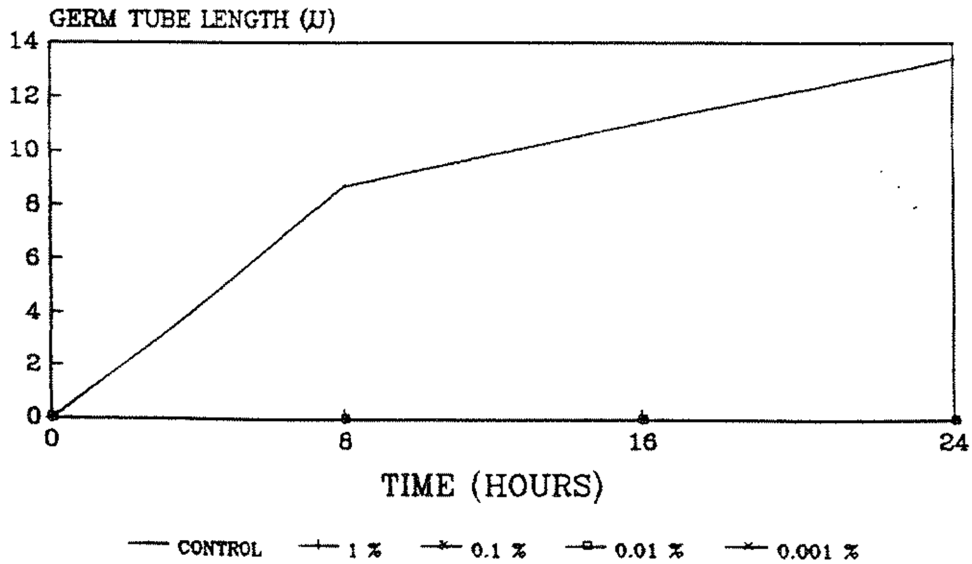


Figure 34 The effects of Impact Excel on the germination of *Puccinia menthae* uredospores.

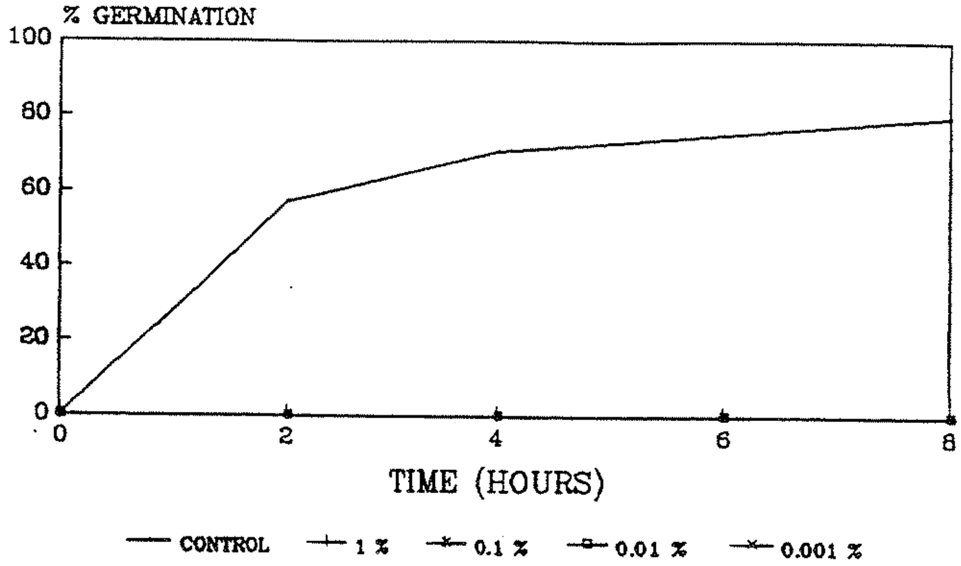


Figure 35 The effects of Impact Excel on the length of *Puccinia menthae* germ tubes.

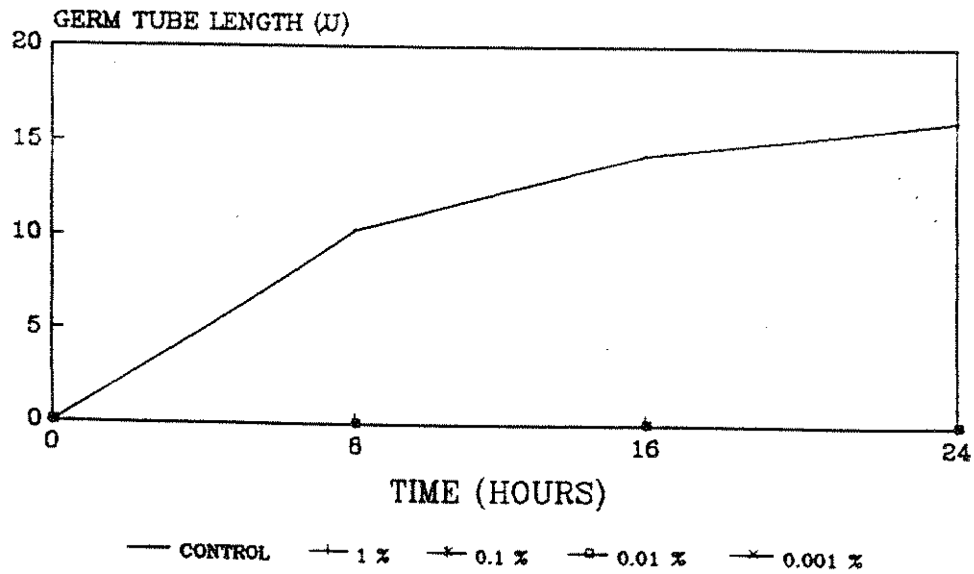


Figure 36 The effects of Bayfidan on the percentage germination of *Puccinia menthae* uredospores.

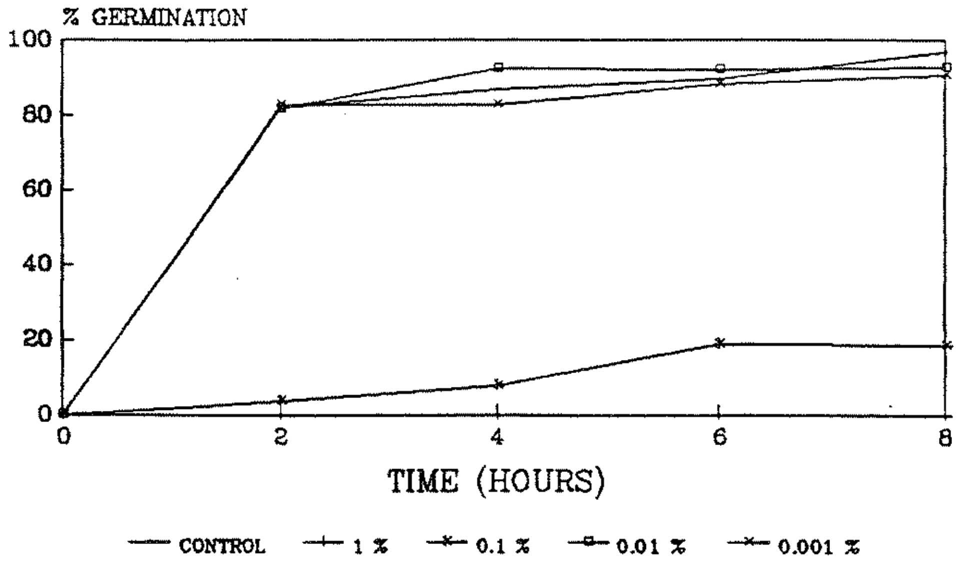


Figure 37 The effects of Bayfidan on the length of *Puccinia menthae* germ tubes.

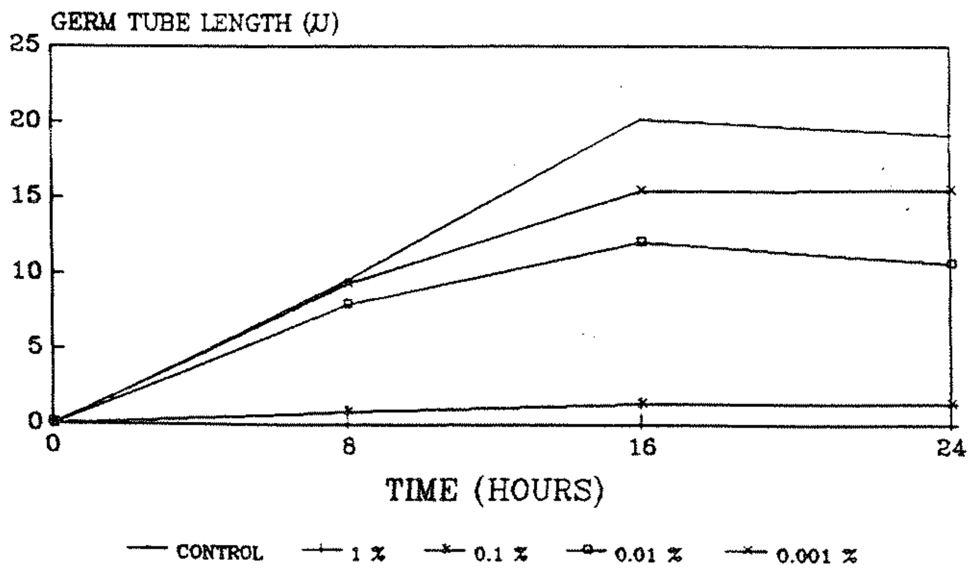


Figure 38 The effects of Plantvax 20 on the percentage germination of *Puccinia menthae* uredospores.

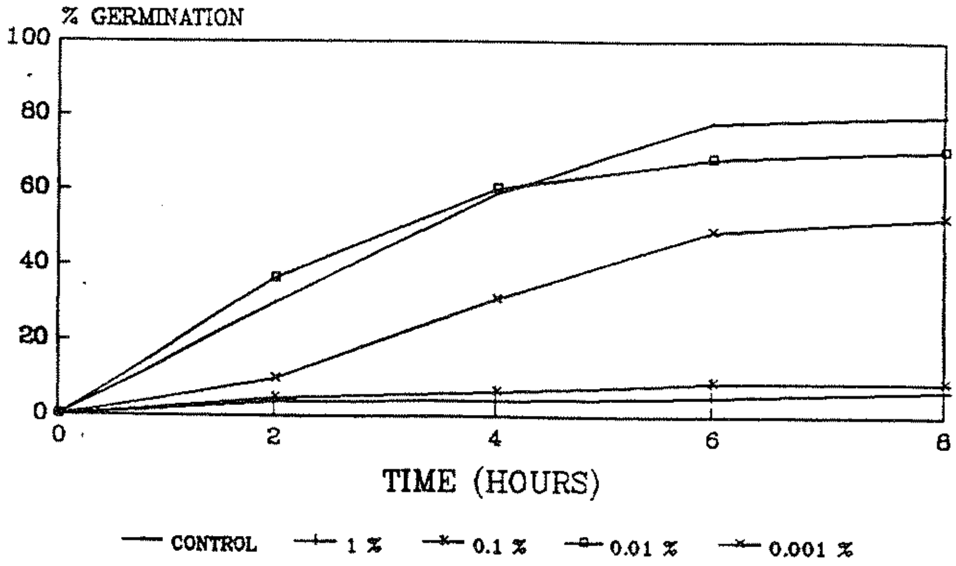
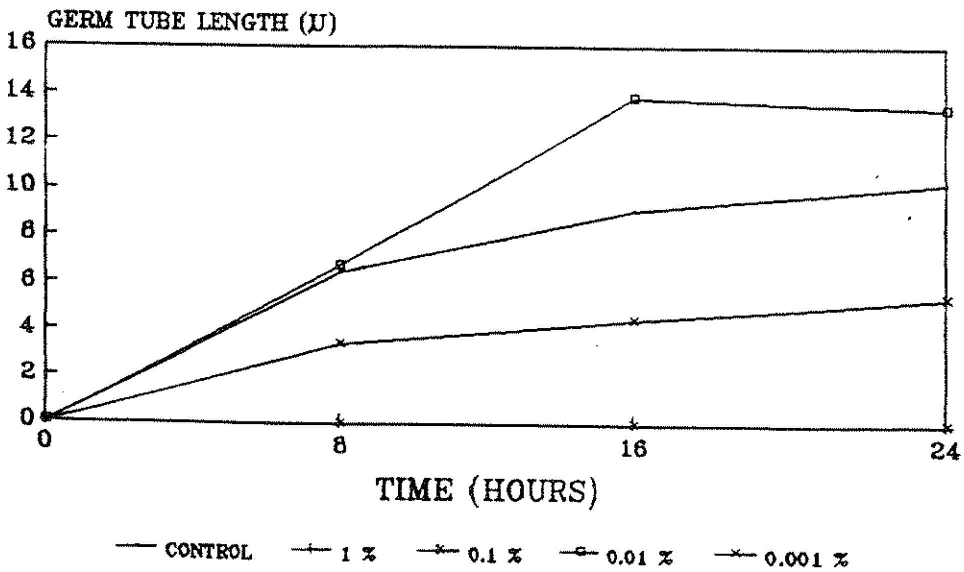


Figure 39 The effects of Plantvax 20 on the length of *Puccinia menthae* germ tubes.



DISCUSSION

Glasshouse evaluation of fungicides

In all three pairs of experiments, the phytotoxic effects of rust fungicides were observed. This was the main determining factor in selecting a fungicide for the field trials, since all fungicides achieved 100 % control of the rust at most concentrations tested. The fungicides which caused the greatest damage were Patrol, Glint 500 EC, Corbel and Sprint. At all three of the tested concentrations they caused severe damage. Glint 500 EC, Corbel and Sprint all contain Fenpropimorph while Patrol contains the closely related fungicide Fenpropidin. It is not known whether the active ingredients or the formulation are causing the phytotoxicity. These fungicides, along with Punch C, were eliminated on grounds of phytotoxicity. Bayleton 5 was not selected for the field trial since Bayleton, with 5 times more active ingredient, would probably achieve better control.

Field trials of fungicides 1993

Differences in rust control and plant growth appeared between the two assessments made at Auchincruive in 1993. The first assessment was carried out 3 weeks after the first application of fungicides, while the second assessment was made 5 weeks after the second application, with an interval of 3 weeks between spray applications.

The levels of rust infection in this trial were high with a mean of nearly 22 % on the lower leaves of the control at the second assessment. The high levels of infection were due to the rust becoming established soon after planting the crop. This early infection prevented the mint from becoming established, producing poor growth rates and reducing the expected yield. The rate of spread of the rust was also underestimated and so the first applications of fungicides were made to a crop which was already infected. Very wet weather prevented an earlier application.

Despite this early infection, all of the fungicides, except Bayleton, did produce reductions in the percentage infection. However the percentage of leaves infected was not reduced probably due to the early establishment of the rust. The high levels of rust increased the rate at which the mint plants lost their leaves. Treatment with any of the fungicides, except Bayleton, significantly reduced this loss by the second assessment. A loss of leaves is a loss of yield, which was confirmed by the data on mean total dry weights.

None of the fungicides produced any visible phytotoxic effects in the field trials and their was little difference in the mean heights of the plants.

The fungicide which performed best overall at Auchincruive was Hispor 45 WP used at 0.15 % w/v . The other fungicides, except Bayleton, all performed well.

At the Norfolk site in 1993, due to the very low levels of rust present in the crop, no conclusions can be drawn on the efficacy of the fungicides. The fungicides do, however, appear to have affected the growth of the crop. The uniformity of the crop greatly aided the growth analysis part of the trial. All of the fungicides except Bayleton and Hispor 45 increased the height of the crop in the first few weeks of growth. The increases were between 3 and 11.5% i.e. 0.7 and 2.6 cm. As the season progressed the effect on height decreased with only Kombat producing a slight increase by the time of the final assessment.

The fungicides also affected the number of leaves on the mint plants. When mint becomes infected with rust, the rate at which it looses its lower leaves increases. At Auchincruive the fungicides that reduced the percentage infection also reduced the loss of leaves. From the results at Heath farm it would appear that some of the fungicides reduce this loss of leaves even when the rust is at very insignificant levels in the crop. Hispor 45, Early Impact and Impact Excel all significantly reduced this loss of leaves by 12 %, 9% and 7% respectively, by the end of the season.

The mint at the Herefordshire site in 1993 was particulary variable with 2 different types of spearmint growing in the trial. The growing conditions at the site were also sub-optimal making it difficult to assess the effects of the fungicides on growth. The fungicides which performed best at this site were Bayfidan and Impact Excel. Bayfidan produced a significant reduction in the percentage of leaves infected although did not reduce the mean infection. Impact Excel did, however, reduce the mean infection and was the only fungicide to significantly reduce the percentage of missing leaves.

Field trials of fungicides 1994 and 1995

The high levels of rust infection at Auchincruive in 1993 appear to have influenced the survival of the mint through the Winter. The plots treated with fungicide had lower levels of rust in 1993 and had a greater percentage cover of the plot in the Spring of 1994 i.e. they survived the Winter better than non-treated plants. Biotrophic fungal pathogens e.g. rusts are known to divert plant assimilates from host growth and development to their own growth and development, thus reducing yield. The growth of the mint plants in 1993 demonstrated how the rust could affect yield during one growing season. These results indicate that the rust may have a longer term effect if the plants are not well established.

The results from the first harvest are disappointing in terms of rust control. The lack of control is probably due to a very high inoculum pressure of aeciospores and the fact that the fungicides were only applied once. Had the weather been better, then a second application of fungicide may have produced better results. The wet weather was also favourable for rust spread and development. The fungicides have been applied twice to the second crop at Auchincruive. It is hoped that these results will substantiate the results from the 1993 trial.

The levels of rust infection were again very low at the site in Norfolk. Because of this, the ability of the fungicides to control rust could not be demonstrated. Unfortunately, the site was not as uniform as in 1993. Rust infection was not evenly distributed throughout the plots making it difficult to draw any conclusions on rust control.

Plant growth was affected by treatment with fungicides. Indeed even though rust infection was very low, the percentage of leaves lost by the crop was significantly reduced by treatment with 5 of the 8 fungicides. Bayleton failed to reduce the loss of leaves and actually slightly increased it.

In the 1995 season, the favourable weather allowed three harvests to be taken. Levels of rust in the crop however, were much lower than had been recorded in previous years. Nevertheless, Bayfidan and Hispor 45 performed best, giving reductions in the mean infection of 92 % and 62 % respectively, and reductions in the percentage of infected leaves of 97 % and 98 % respectively.

Flaming for rust control 1993

In this trial, flaming proved to be a very effective means of controlling mint rust. Other studies using this technique have shown that the mint can quickly become re-infected with rust. However, in this experiment, the crop was practically rust-free for the whole growing season.

Since flaming is a sanitation method and therfore does not protect the crop from infection, the design of a trial can be difficult. If control plots i.e. unflamed plots, are placed adjacent to flamed plots then the rust will probably spread very quickly into the flamed plots. A distance of 92.4 m was kept between the flamed and unflamed plots in this trial, to help prevent re-infection from this source and was successful.

Flaming for rust control 1994

After the success of the small 1993 flaming trial, it was decided that a more detailed study would be carried out in 1994. The aim was to find out if there were differences between the different types of flamers and to determine the most effective speed for flaming. Paraquat was also included to compare the standard sanitary approach used by growers.

The results obtained in 1994 are not as clear cut as those from 1993. The speeds chosen for the 1994 trial were faster than the speed used in the 1993 trial, but slower than those used by other workers(Beresford & Mulholland, 1987). Speed did appear to influence rust control, with the slowest speeds reducing both the mean infection and the percentage of leaves infected, although not significantly. Other workers have shown that faster speeds can be effective. There may be several reasons why all of the speeds in this trial were not successful.

It may be that the timing of the flaming was inappropriate. Other workers have found that March/April was suitable for North America and New Zealand. Flaming is recommended when bull shoots are present in the crop. No bull shoots were observed at the time of flaming or when the assessments were made. It may be that the rust overwintered as uredospores rather than teliospores and so no bull shoots were produced.

Problems were experienced with the HOAF flamer. The machine used was approximately 5 years old. After the flaming was completed, it was discovered that some of the burners were not functioning properly. The ends of the fan shaped nozzle had warped and almost closed over in some cases. This may have reduced the efficacy of this flamer, although the temperatures produced should still have been adequate.

If the actual flaming procedure was effective then the reasons for the poor results may be re-infection. In the 1993 trial little rust spread from the control plots to the flamed plots, which were 92 m apart. The controls were incorporated into the design of the 1994 trial and may have been a source of inoculum which could have re-infected the flamed plots. More assessments on the first crop would have been useful, to determine if the flaming had a short term effect in controlling the rust before re-infection took place. The 1993 trial was practically rust free for the whole growing season, this was not the case in 1994.

The other source of infection could have been the paraquat treatment. If the paraquat was ineffective then the flamed plots could have become re-infected from the paraquated plots and the surrounding field.

Effects of fungicides on germination of rust uredospores

These results indicate that germination of mint rust uredospores is affected differently by different fungicides. Some fungicides e.g. Kombat WDG and Impact Excel, completely inhibited germination at all of the tested concentrations, while others only inhibit germination at the highest concentrations e.g. Tilt 250 EC. These experiments are an initial step towards determining how the infection process on leaf surfaces is actually influenced by applications of fungicides.

CONCLUSIONS

Evidence from both the glasshouse experiments and field trials indicates that several fungicides may be suitable for the control of rust on mint. The data indicate that Bayleton may not be a suitable fungicide for the control of rust on mint. The concentration of Bayleton used in the field trials contained 5 times more active ingredient than would be present in the Bayleton 5 sprayed onto commercial mint crops. Several growers have expressed doubts about the efficacy of

Bayleton 5 and the evidence from this project would support these views.

Despite the difficulties experienced at the field trial sites throughout the project, three of the eight fungicides (Hispor 45, Bayfidan and Impact Excel) performed reasonably well throughout the project and it is recommended that these compounds be considered for further trials and residue analysis.

Where rust is expected to be a problem, it is recommended that the fungicides are applied as a prophylactic. They may still however, provide unsatisfactory levels of control in the early spring. Very few bull shoots are required to initiate an epidemic of mint rust. If a large number of systemically infected bull shoots are present, then other means of control may be more effective. The crop could be treated with contact herbicide, flamed or ploughed under. All of these measures should break the life cycle of the rust, if carried out correctly, and reduce the inoculum available for future infections. Although delaying the crop by several weeks, these measures should produce a healthier re-growth and allow fungicides a better chance of controlling later infections. In areas where rust is a problem, two applications of fungicide can provide good levels of control during the summer and autumn. Most UK mint growers do not experience problems with mint rust until late summer/early autumn. In a three harvest year, a single application on the summer crop followed by two applications on the autumn crop should provide adequate levels of control. In a two harvest year the first crop may require 1 or 2 applications depending on the risks to the crop i.e. have other control measures been take, are the climatic conditions suitable for rust and is there a history of rust on that site at time of year. The second crop that year would probably require two applications to protect it for a longer growing period.

The flaming trial produced very encouraging results in 1993 by keeping the flamed plots practically rust free from February to September. It is unfortunate that flaming did not work as well in the 1994 season, but nevertheless, evidence from workers elsewhere is promising (Beresford & Mulholland, 1987). Flaming could prove to be a useful technique for some growers, particularly in the organic sector. Flaming is a technique familiar to organic growers, who use it to control weeds in vegetable crops. Flaming for disease control may be another use for their equipment.

Flaming works on similar principles to a technique already in use in Britain to control mint rust. Paraquat has been used for a number of years to control both weeds and rust in mint crops. Both flaming and paraquat work by targeting the rust at the weakest point in it's life-cycle. By destroying the infected mint shoots soon after they have emerged in late Winter/early Spring, the rust will be killed too. Flaming also kills any residual teliospores which may be present on the soil surface or plant debris and so the second flush of healthy mint emerges into a cleaner environment.

Paraquat may be effective at controlling mint rust, but it is not known how much longer it will be an approved herbicide and so alternatives should be considered. Flaming may be an effective, albeit expensive alternative.

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