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Chemical control of *Alternaria* brown spot on Minneola tangelo in South Africa

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Summary

The effectiveness of several groups of fungicides was compared with that of copper and mancozeb for their ability to control *Alternaria* brown spot on Minneola tangelo. Variables used for comparing fungicides in order of importance were: performance index, the number of exportable fruits per tree, the number of fruits per tree free of *Alternaria* lesions and total number of fruits per tree. Percentage exportable fruits was not a reliable variable for comparing treatment efficiency.

During the 1992/1993 evaluations iprodione, difenoconazole, and procymidone showed promising control of the disease. Other than for difenoconazole, members of the triazole group were not effective, especially at dosages below 10 g a.i. 100 litre^{-1} water. Moderate control of *Alternaria* brown spot was obtained using copper and mancozeb. During the 1993/1994 season spray programmes with copper oxychloride, mancozeb, maneb plus zinc oxide, procymidone, iprodione, and tebuconazole were compared in field trials, for the control of *Alternaria* brown spot on Minneola tangelo. Mancozeb applied at 2-weekly intervals was the most effective spray programme, followed in order of efficiency by programmes using procymidone, maneb plus zinc oxide, and mancozeb applied at 4- and at 3-weekly intervals. Iprodione and tebuconazole were not particularly effective in this evaluation, although they performed significantly better than the control treatment. Trees treated with copper oxychloride produced poorly, in spite of a high percentage exportable fruits.

Key words: *Citrus*, chemical control, fungicides

Introduction

The presence of *Alternaria* brown spot in several major citrus producing areas of South Africa is a serious threat to the cultivation of susceptible cultivars (Kellerman, Le Grange & Irving, 1979; Visser & Irving, 1980). According to Whiteside (1979), fruit drop is the most important contributor to losses caused by this disease. Losses between 30% and 100%, some referring to yield and others to rind blemish, have been reported in several countries

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(Whiteside, 1976; Kellerman *et al.*, 1979; Visser & Irving, 1980; Solel, 1991). During the 1990/1991 growing season there was severe fruit loss, rind blemish, defoliation and die-back of twigs due to *Alternaria* infection on 300 Minneola trees at La Motte (Tzaneen, Northern Province) due to an ineffective chemical spray programme (Swart, unpublished data). These trees took two seasons to recover and produce normal yields, resulting in substantial losses due to low yield and blemished fruits.

Minneola tangelo is a hybrid of the susceptible tangerine cv. Dancy (*C. reticulata* Blanco) and the grapefruit cv. Duncan (*C. paradisi* Macf.), and is highly susceptible to infection by *Alternaria spp.* (Kohmoto, Akimitsu & Otani, 1991; Solel, 1991).Brown spot of mandarins and tangelos is caused by a specialised form of *Alternaria alternata* (Fr.) Keissler and host-specific toxins are involved in symptom development (Nishimura & Kohmoto, 1983; Whiteside, 1988; Kohmoto *et al.*, 1991; Solel, 1991). Several other publications refer to the causal organism as *Alternaria citri* Ellis & Pierce (Kiely, 1964; Pegg, 1966; Whiteside, 1976; Kellerman *et al.*, 1979; Visser & Irving, 1980). Simmons (1990; 1992) however, expressed a conviction that most *Alternaria spp.* obtained from citrus substrates have been incorrectly identified as *A. citri* but he also criticised the pooling of morphologically distinct *Alternaria spp.* as pathotypes of *A. alternata* on the basis of host-specific toxin production.

Symptoms on leaves vary from small brown spots surrounded by distinct halos, to large necrotic areas. Darkening of veins and defoliation have also been reported (Whiteside, 1976; 1986; 1988; Solel, 1991). Infection of young shoots causes elongated cankers and die-back of defoliated twigs. When immature fruits are infected, extensive fruit drop can occur and, therefore, a decrease in yield (Whiteside, 1979). Losses due to unacceptable blemishes can occur on fruits remaining on the trees (Kellerman *et al.*, 1979; Whiteside, 1979; Visser & Irving, 1980; Solel, 1991).

The most important factors influencing *Alternaria* brown spot are climatic conditions, host phenology and fruit maturity (Kiely, 1964; Pegg, 1966; Whiteside, 1976; 1988). Young foliage, twigs and immature fruits are most susceptible to infection (Kiely, 1964; Pegg, 1966; Whiteside, 1976; 1988), while climatic conditions, such as extended, interrupted wet periods also enhance infection (Kiely, 1964; Pegg, 1966; Whiteside, 1976; 1988; Holley, Hall & Hofstra, 1985; Rotem, 1990; 1991; Otero *et al.*, 1994). *A. alternata* survives during the winter on infected leaves, stems and out-of-season fruits and inoculum is present in orchards throughout the growing season (Whiteside 1976; 1988). Under favourable climatic conditions, germination of conidia, infection and lesion development takes place within 1 to 4 days, and more rapidly on younger than on older host tissue (Pegg, 1966; Whiteside, 1976; Kohmoto *et al.*, 1991; Solel, 1991).

Control of *Alternaria* brown spot is difficult, since symptom development is rapid and sporulation of the pathogen occurs soon after infection (Pegg, 1966; Solel, 1991). For some time, only contact fungicides such as copper products, mancozeb and procymidone were registered for the control of *Alternaria* brown spot of soft citrus in South Africa (Vermeulen *et al.*, 1992; Nel *et al.*, 1993), but, iprodione has since been added to the list (Krause, Nel & van Zyl, 1996). Copper fungicides are effective and economical to use, but can cause darkening of blemishes and an increase in the number of certain insects and mites on fruits. Furthermore, copper can be phytotoxic to trees if accumulated in soil (Whiteside, 1983). Poor control of *Alternaria* brown spot on Minneola tangelo with mancozeb has been reported by Kellerman *et al.* (1979). The objective of this study was to compare the efficacy of programmes with fungicides belonging to groups with contact or locally systemic (dicarboximides) and systemic (triazoles) modes of action with registered copper and mancozeb fungicides in field trials. The rationale was to find a broad spectrum of fungicides and economically feasible spray programmes that control brown spot disease of soft citrus effectively, under environmental conditions that are conducive to disease development.

Materials and Methods

Field trials were conducted on 10-yr-old Minneola tangelo trees (canopy volume 48 m^3) on the farm La Motte situated 31 km ENE of Tzaneen, South Africa (23°46′ latitude and 30°28′ longitude). This area is 488 m above sea level and climatic conditions are typical of a sub-tropical, summer rainfall zone. The long-term mean daily maximum temperature was 30.4°C in the mid-summer (December to January) and 24.2°C in mid-winter (June to July) according to Gilbert (1992). The mean daily minimum temperature for this period was 19.9°C for mid-summer and 8.3°C for mid-winter. The average annual rainfall for the same period was 808 mm.

Each plot consisted of three adjacent trees and treatments were replicated five times in a randomised block design. During the 1992/1993 growing season fungicides were evaluated for their efficacy to control *Alternaria* brown spot (Table 1). Of these fungicides, the most efficacious and affordable fungicides were compared in different spray programmes without the addition of adjuvants during the 1993/1994 season. Full cover applications (25 litres per tree) were made with handguns (43H-4 GunJet with a D4 orifice disc supplied by Spraying Systems Co, North Avenue at Schmale Road, Wheaton, Illinois 60187, USA) at 15 bar pressure and a rate of 5 litre min^{-1}, (using a Honda GX240 motor from Honda motor Co., Japan and a General pump, model T44 from International Technical Co., Italy).

1992/1993 Growing season

Mancozeb at 160 g a.i. 100 $litre^{-1}$ water was applied twice, during September and October 1992, prior to petal drop. This was followed by three applications of the test fungicides during November and December 1992, and February 1993 respectively (Table 2). All trees except those in the control treatment were sprayed with mancozeb at 160 g a.i. 100 $litre^{-1}$ water during March 1993. Fruits from the middle tree of each treatment were harvested during June 1993.

1993/1994 Growing season

Several fungicides were tested in various combinations, dosages, and spray intervals for their ability to control *Alternaria* brown spot (Table 3). All fungicide programmes began with an application of mancozeb or copper oxychloride in September 1993 at bud break in order to reduce initial *Alternaria* inoculum. This application was followed by different programmes,

Table 1. *Fungicides evaluated for their ability to control Alternia brown spot on Minneola tangelo*

Active ingredient (a.i.)	Trade name	Formulation[a]
Mancozeb	Dithane	800 g kg^{-1} wp
Copper oxychloride	Demildex	850 g kg^{-1} wp
Iprodione	Rovral	250 g $litre^{-1}$ sc
Procymidone	Sumisclex	250 g $litre^{-1}$ sc
Difenoconazole	Score	250 g $litre^{-1}$ ec
Flutriafol	Impact	125 g $litre^{-1}$ sc
Epoxiconazole	Opus	125 g $litre^{-1}$ sc
Bromuconazole	Granit	200 g $litre^{-1}$ sc
Tebuconazole	Folicur	250 g $litre^{-1}$ ec
Flusilazole	Nustar	250 g $litre^{-1}$ ec
Fenbuconazole	Indar	5 g $litre^{-1}$ ec
Maneb/zinc oxide	Trimangol	435/4.7 g $litre^{-1}$ ec

[a]wp = wettable powder, sc = suspension concentrate, ec = emulsifiable concentrate.

Table 2. *Comparison of different fungicides for their ability to control* Alternaria *brown spot on Minneola tangelo during the 1992/1993 growing season*

Treatment	Performance index	Number of exportable fruits	Number of fruits free of lesions	Total number of fruits
Control	0.17	388	98	900
Mancozeb (160)[a]	0.32	575	354	818
Copper oxychloride (160)	0.31	560	347	695
Iprodione (50)	0.58	958	749	980
Procymidone (50)	0.37	695	399	784
Procymidone (25)	0.26	548	213	894
Difenoconazole (10)	0.42	796	451	1032
Difenoconazole (5)	0.37	710	392	929
Flutriafol (10)	0.33	655	302	846
Flutriafol (5)	0.29	605	250	786
Epoxiconazole (10)	0.27	551	252	819
Epoxiconazole (5)	0.20	402	180	660
Bromuconazole (10)	0.20	423	176	804
Bromuconazole (5)	0.27	567	232	937
Tebuconazole (10)	0.27	584	217	982
Tebuconazole (5)	0.20	482	119	772
Flusilazole (10)	0.29	647	203	988
Flusilazole (5)	0.19	422	140	965
Fenbuconazole (5)	0.33	698	283	1153
SED (df = 54)	0.06	110	70	179

[a]Dosages in g a.i. 100 litre^{-1} water are given in parenthesis after the fungicide name.

applied at various time intervals between 30 September 1993 and 20 January 1994. Treatment names in the text refer to the active ingredients of fungicides applied. Mancozeb and copper oxychloride were applied at 2-, 3- and 4-weekly intervals. Two programmes, one consisting of a mixture of mancozeb and copper oxychloride and the other consisting of maneb plus zinc oxide were also applied at 4-weekly intervals. Procymidone, iprodione and tebuconazole were applied in two different types of programmes. The programmes with short initial spray intervals (Treatments 4, 5 and 6), started with copper oxychloride treatments at bud break, followed by another application of copper oxychloride 4 wk later. Applications of the test fungicides occurred 8, 15 and 21 wk after the initial copper oxychloride application. Programmes, with long initial spray intervals (Treatments 7, 8 and 9), started with an early copper oxychloride treatment at bud break, followed by applications of the test fungicides at 4, 12 and 18 wk after the initial copper oxychloride application. All programmes, except control treatments, were concluded with mancozeb during February 1994. Fruits from the middle tree of each treatment were harvested in June 1994.

Data collection and analysis

All fruits from sample trees were picked and sorted into three infection classes at the end of each growing seasons. Class 1 included fruits free of brown spot lesions, Class 2 fruits that had one to five lesions, and Class 3 fruits with more than five lesions. Fruits in the latter class were unacceptable for export due to rind blemish. The number of fruits in each class was determined for all treatments and the number and percentage exportable fruits (Classes 1 and 2) were calculated. A performance index (PI), calculated by means of the following equation, was also used as a variable for comparing fungicide efficacy:

$$PI = \frac{(a \times 2) + (b \times 1) + (c \times 0)}{300}$$

where; a = number of fruits in Class 1/mean number of fruits for the control treatment × 100
b = number of fruits in Class 2/mean number of fruits for the control treatment × 100
c = number of fruits in Class 3/mean number of fruits for the control treatment × 100

One outlier in each treatment of five replicates was omitted from the data analysis during both seasons to reduce variation within treatments. Analysis of variance (ANOVA) was performed on the total number of fruits, the number of fruits without lesions, the number of exportable fruits and the PI of fruits for each treatment. ANOVA was also performed on the arcsin transformation of percentage exportable fruits in each treatment.

Results

During both years of evaluation, results clearly indicated that percentage exportable or infected fruits did not provide a reliable comparison of fungicide efficacy. During both seasons, a poor correlation ($r = 0.58$; $R^2 = 32\%$ for 1992/1993 and $r = 0.42$; $R^2 = 17\%$ for 1993/1994) was obtained between the percentage exportable fruits and the number of exportable fruits per tree. Results showed that PI, was best for evaluating fungicide efficacy and was highly correlated with the number of exportable fruits per tree ($r = 0.97$; $R^2 = 93\%$ for 1992/1993 and $r = 0.99$; $R^2 = 98\%$ for 1993/1994). However, because PI is an arbitrary figure, results in this study are also presented in terms of the number of exportable fruits per tree, number of fruits free of lesions and total number of fruits per tree.

1992/1993 Growing season

Treatments refer to the active ingredients (a.i.) of fungicides applied during November and December 1992 and February 1993 (Table 1 and 2). The average yield per tree ranged from 660–1153 fruits per tree. Due to drought conditions during the early part of the growing season there was little infection of immature fruits and resultant fruit-drop, therefore, yield in all treatments was relatively good. For the rest of the season, a total of 330 mm of rain was measured over 20 days, of which 233 mm of rain occurred during the period when fruits were most susceptible to *Alternaria* infection (38 mm, 166 mm and 29 mm of rain was measured in November, December and January respectively). These wet conditions enhanced infection of fruits, especially in the untreated control treatment, which caused severe rind blemish.

Comparison of PIs of treatments (Table 2) showed that iprodione at 50 g a.i. 100 litre^{-1} water gave better ($P = 0.05$) control of *Alternaria* brown spot than any other treatment evaluated in this trial. Iprodione at 50 g a.i., difenoconazole at 10 g a.i. and 5 g a.i., and procymidone at 50 g a.i. 100 litre^{-1} water had better ($P = 0.05$) PIs than the control treatment. Difenoconazole at 10 g a.i. 100 litre^{-1} water was also better ($P = 0.05$) than bromoconazole at 10 g a.i. 100 litre^{-1} water and epoxiconazole, tebuconazole and flusilazole at 5 g a.i. 100 litre^{-1} water.

Only iprodione at 50 g a.i. 100 litre^{-1} and difenoconazole at 10 g a.i. 100 litre^{-1} had more ($P = 0.05$) exportable fruits per tree than the control treatment, with averages of 958, 796 and 388 exportable fruits per tree, respectively (Table 2). In order of efficacy, iprodione at 50 g a.i., followed by difenoconazole at 10 g a.i., procymidone at 50 g a.i., difenoconazole at 5 g a.i., mancozeb at 160 g a.i. and copper oxychloride at 160 g a.i. 100 litre^{-1} water had 749, 451, 399, 392, 354 and 347 fruits free of *Alternaria* lesions, respectively. *These treatments* were better ($P = 0.05$) than the control treatment with 98 fruits free of *Alternaria* lesions.

Table 3. *Spray programmes for different fungicide*[a] *treatments evaluated during the 1993/1994 growing season*

Treat-ment	Dates of fungicide application													
	1993										1994			
	2 Sept	30 Sept	15 Oct	21 Oct	01 Nov	11 Nov	25 Nov	2 Dec	9 Dec	21 Dec	6 Jan	13 Jan	20 Jan	28 Feb
1	Water[b]	Water	—	—	Water	—	—	Water	—	—	—	Water	—	M(160)
2	C(255)[c]	C(255)	—	—	P(30)	—	—	P(30)	—	—	—	P(30)	—	M(160)
3	C(255)	C(255)	—	—	I(30)	—	—	I(30)	—	—	—	I(30)	—	M(160)
4	C(255)	C(255)	—	—	P(50)	—	—	P(50)	—	—	—	P(50)	—	M(160)
5	C(255)	C(255)	—	—	I(50)	—	—	I(50)	—	—	—	I(50)	—	M(160)
6	C(255)	C(255)	—	—	T(30)	—	—	T(30)	—	—	—	T(30)	—	M(160)
7	C(255)	P(50)	—	—	—	—	P(50)	—	—	—	P(50)	—	—	M(160)
8	C(255)	I(50)	—	—	—	—	I(50)	—	—	—	I(50)	—	—	M(160)
9	C(255)	T(30)	—	—	—	—	T(30)	—	—	—	T(30)	—	—	M(160)
10	C(255)	C(85) + M(80)	—	—	C(85) + M(80)	—	C(85) + M(80)	—	—	C(85) + M(80)	—	—	C(85) + M(80)	M(160)
11	M(160)	M(160)	M(160)	—	M(160)	M(160)	M(160)	—	M(160)	M(160)	M(160)	—	M(160)	M(160)
12	(C255)	C(170)	C(170)	—	C(170)	C(170)	C(170)	—	C(170)	C(170)	C(170)	—	C(170)	M(160)
13	M(160)	M(160)	—	M(160)	—	M(160)	—	M(160)	—	M(160)	—	M(160)	—	M(160)
14	C(255)	C(170)	—	C(170)	—	C(170)	—	C(170)	—	C(170)	—	C(170)	—	M(160)
15	M(160)	M(160)	—	—	M(160)	—	M(160)	—	—	M(160)	—	—	M(160)	M(160)
16	C(255)	C(170)	—	—	C(170)	—	C(170)	—	—	C(170)	—	—	C(170)	M(160)
17	M(160)	M(160)	—	—	N(87)	—	N(87)	—	—	N(87)	—	—	N(87)	M(160)

[a] Abbreviations for fungicides are: M = mancozeb; C = copper oxychloride; P = procymidone; I = iprodione; T = tebuconazole; N = maneb/zinc oxide.
[b] Control treatment.
[c] Dosages in a.i. 100 litre^{-1} water are given in parenthesis after each fungicide abbreviation.

Fungicide treatments had no significant ($P = 0.42$) effect on the total yield per tree during the 1992/1993 evaluation (Table 2).

1993/1994 Growing season

Climatic conditions during the 1993/1994 growing season were also favourable for *Alternaria* brown spot development. In total, 461 mm of rain was measured from September to June when fruits were harvested. Most rain (369 mm) fell during the 4 months after petal drop (October to January), when Minneola fruits are most susceptible to *Alternaria* infection (Kiely 1964; Pegg, 1966; Whiteside, 1976). Rain was recorded on 21 days during this period, which enhanced *Alternaria* infection substantially.

Brown spot lesions were observed as early as 11 October 1993 on foliage, young twigs and fruits in control treatments. Severe infection of fruits, especially on untreated trees, was observed early in December 1993. This infection was probably associated with moist conditions (87 mm of rain) on 5 consecutive days from 24 to 28 November 1993. Climatic conditions continued to be favourable for *Alternaria* brown spot development during December 1994 when 164 mm of rain was measured on 6 days.

Analysis of PIs (Table 4), showed that mancozeb, applied at 2-weekly intervals (Treatment 11), performed better ($P = 0.05$) than all other programmes except for procymidone (Treatment 4), maneb plus zinc oxide (Treatment 17), mancozeb applied at 4-weekly (Treatment 15) and at 3-weekly intervals (Treatment 13), in order of efficacy. All fungicides evaluated were better ($P = 0.05$) than the control treatment (Treatment 1). The PIs for the three copper oxychloride programmes (Treatments 12, 14 and 16) showed a tendency to be lower than similar mancozeb programmes (Treatments 11, 13 and 15), but were not

Table 4. *Comparison of different spray programmes for their ability to control* Alternaria *brown spot on Minneola tangelo during the 1993/1994 growing season*

Codes[a]	Programmes[b]	Performance index	Number of exportable fruits	Number of fruits free of lesions	Total number of fruits
1	Control	0.03	67	17	186
2	2×C(3×P)M(30)	0.20	302	278	304
3	2×C(3×I)M(30)	0.24	369	329	379
4	2×C(3×P)M(50)	0.37	564	516	572
5	2×C(3×I)M(50)	0.26	397	378	400
6	2×C(3×T)M(30)	0.19	298	254	313
7	C(3×P)M(50)	0.24	391	306	412
8	C(3×I)M(50)	0.16	251	218	254
9	C(3×T)M(30)	0.29	460	377	490
10	C(5×C/M)M(85/80)	0.29	435	417	437
11	(11×M)(160)	0.48	738	663	764
12	(10×C)M(170)	0.26	393	367	394
13	(8×M)(160)	0.37	452	444	468
14	(7×C)M(170)	0.26	395	380	397
15	(7×M)(160)	0.33	516	420	623
16	(6×C)M(160)	0.27	430	351	434
17	2×M(4×N)M(87)	0.37	591	463	678
SED (df = 48)		0.06	96	87	95

[a] Fungicide treatment codes refer to programmes in Table 3.

[b] Dosages in g a.i. 100 litre^{-1} water are given in parenthesis and refer to fungicide abbreviations in parenthesis. Abbreviations for fungicides are: M = mancozeb; C = copper oxychloride; P = procymidone; I = iprodione; T = tebuconazole; N = maneb/zinc oxide.

significantly different from them. Some of the other fungicides, especially procymidone (50 g a.i. 100 litre^{-1} water, Treatment 4), sprayed at short (4 wk) initial spray intervals also controlled *Alternaria* brown spot effectively. The next best of these treatments was tebuconazole, applied at 100% petal drop at a dosage of 30 g a.i. 100 litre^{-1} water (Treatment 9). This treatment gave good control of *Alternaria* brown spot in spite of a relatively long initial spray interval early in the season. Iprodione at 50 g a.i. 100 litre^{-1} water and a long initial spray interval (Treatment 8), tebuconazole (Treatment 6) and procymidone (Treatment 2) each applied at 30 g a.i. 100 litre^{-1} water, gave inferior disease control.

Comparison of programmes in terms of the number of exportable fruits per tree, revealed the same ranking of fungicide efficacy displayed when PI was used for evaluation (Table 4). The largest number of exportable fruits (Class 1 plus 2) was obtained with mancozeb at 2-weekly intervals (Treatment 11) with 738 fruits per tree. Other programmes that resulted in high numbers of exportable fruits per tree, were maneb plus zinc oxide (Treatment 17) with 591, procymidone (Treatment 4) with 564, mancozeb every 4 wk (Treatment 15) with 516, mancozeb every 3 wk (Treatment 13) with 452 and tebuconazole (Treatment 9) with 460 exportable fruits per tree. The number of exportable fruits for procymidone (Treatment 2), tebuconazole (Treatment 6) and iprodione (Treatment 8) were not significantly ($P = 0.05$) different from the control treatment (Treatment 1).

The greatest number of fruits per tree free of *Alternaria* lesions was obtained with mancozeb applied at 2-weekly intervals (Treatment 11), followed by procymidone (Treatment 4), maneb plus zinc oxide (Treatment 17), mancozeb at 3-weekly intervals (Treatment 13), mancozeb at 4-weekly intervals (Treatment 15), and copper oxychloride plus mancozeb (Treatment 10). All treatments had more fruits ($P = 0.05$) free of *Alternaria* lesions per tree than the control treatment (Treatment 1).

During the 1993/1994 season, mancozeb applied at 2-weekly intervals (Treatment 11), gave the highest yield of all fungicide programmes evaluated, followed by maneb plus zinc oxide (Treatment 17), mancozeb at 4-weekly intervals (Treatment 15), and procymidone (Treatment 4). These yields were all higher ($P = 0.05$) than the control treatment.

Discussion

Results of this study indicate that the percentage of marketable fruits per tree is not a reliable measure of the efficacy of fungicides for control of *Alternaria* brown spot of citrus, because loss in yield is not reflected. Fruit-drop, caused by the early infection of young fruits by *A. alternata*, is more detrimental than the effect on the rind quality of fruits (Whiteside, 1979). Therefore, the number of marketable (exportable) fruits is considered a more representative variable than percentage exportable fruits, although information on disease severity (fruit quality) is lost. Fruit quality also plays an important role when marketing *Citrus*, but improvement of the number of exportable fruits per tree is the most important contributor to potential income.

The number of exportable fruits per tree was closely correlated with PI. The use of PI has the advantage that both increase in yield, compared to the number of fruits in the control treatment, and rind quality, are taken into consideration. We, therefore, suggest that the most valuable variables to use when assessing the efficacy of fungicides against *Alternaria* brown spot disease are: (1) PI, which represents the performance of the treatment as an arbitrary figure taking into account the number of fruits in each of three infection classes relative to the number of fruits in the control treatment, (2) the number of exportable fruits per tree (a measure of value and fruit quality), (3) the number of fruits per tree free of lesions (a measure of quality) and (4) the total number of fruits per tree (a measure of yield).

Generally, higher yields and lower levels of infection were observed on trees of all treatments during the 1992/1993 season than the 1993/1994 season. The lower yield during the latter season was possibly caused by below normal fruit bearing in alternate years, a phenomenon common to soft citrus cultivars in South Africa (De Lange, 1975). However, loss of fruits caused by *A. alternata* infection, certainly played an important role due to early rains which occurred during October 1993. This confirmed the relationship between rainy conditions and severe *Alternaria* brown spot and resultant fruit drop reported by Kiely (1964), Pegg (1966) and Whiteside (1976).

Results of the 1992/1993 evaluations showed that iprodione, difenoconazole and procymidone out-performed the other fungicides tested. The efficacy of iprodione confirms reports by Hutton (1989), Oren *et al.* (1992), and Timmer & Zitko (1991). The number of fruits free of lesions on mancozeb- and copper oxychloride-treated trees, as well as the relatively low cost of these two fungicides, suggested they should be included in further evaluations. Most of the triazoles at 10 g a.i. 100 litre^{-1} and 5 g a.i. 100 litre^{-1} water could not control *Alternaria* brown spot effectively during the 1992/1993 season. Difenoconazole, however, did give effective control at both these dosages. Difenoconazole inhibits ergosterol biosynthesis and exhibits translaminar as well as acropetal translocation (Dahmen & Staub 1992*a*; 1992*b*). Enhanced efficacy of difenoconazole can thus be attributed to superior persistence on and in leaf surfaces (Dahmen & Staub, 1992*a*). Difenoconazole, however, is extremely expensive and was discarded during further evaluations.

Tebuconazole is also a triazole with systemic qualities but gave poor results at 10 g a.i. 100 litre^{-1} and 5 g a.i. 100 litre^{-1}. However, tebuconazole is 50% cheaper than difenoconazole and did show inhibition of mycelial growth and spore germination during *in vitro* studies and reduced brown spot, compared to an untreated control treatment, in field trials conducted at higher dosages (Schutte, personal communication). Preliminary field trials, done by the author, also showed that tebuconazole at 25 g a.i. 100 litre^{-1} controlled *Alternaria* brown spot effectively (unpublished data) and was, therefore, included in further evaluations.

During the 1993/94 season, the highest PI, the largest number of exportable fruits, most fruits free of *Alternaria* brown spot lesions and the highest yield was obtained with mancozeb applied at 2-weekly intervals. The superior results with mancozeb applied at 2-weekly intervals might be explained by the fact that 11 rounds of this fungicide were applied. Eight applications were made between 5 September 1993 and 20 January 1994 which caused sufficient fungicide coverage throughout the first 4 months after flowering when Minneola fruits are most susceptible to infection by *Alternaria* (Kiely, 1964; Pegg, 1966; Whiteside, 1976; 1988). Other programmes with mancozeb also performed well during this season. Good control of *Alternaria* brown spot of soft citrus with mancozeb was also reported by Otero *et al.* (1994), probably because they also used yield as a measure of efficacy. In contrast, Kellerman *et al.* (1979) and Visser & Irving (1980) used percentage marketable fruits or percentage fruits in different infection classes and reported poor control of *Alternaria* with mancozeb at 160 g a.i. 100 litre^{-1} water applied at 4-weekly intervals.

Whiteside (1979) recommended copper sulphate to control *Alternaria* brown spot of tangerine cv. Dancy and the results were expressed in terms of the percentage fruits in picked samples with *Alternaria* induced scars or brown spot lesions (Whiteside, 1979). In contrast, results in our studies showed a high export percentage but a decrease in yield with copper oxychloride when compared to other fungicides, especially mancozeb applied in similar programmes. Low fruit counts, but a high percentage of marketable fruits associated with copper treatments on Dancy tangerines have been reported previously (Timmer & Zitko, 1991), a phenomenon deserving further studies.

Maneb plus zinc oxide, sprayed at 4-weekly intervals, also gave excellent results which were slightly better than the mancozeb programme applied at similar spraying intervals. The fact that the dosage of maneb plus zinc oxide was only 87 g a.i. 100 $litre^{-1}$ water compared to mancozeb at 160 g a.i. 100 $litre^{-1}$ water should also be noted. The efficacy of this programme, applied at 4-weekly intervals allows for further evaluation at higher dosages and/or shorter spray intervals. Poor control of brown spot with contact fungicides can be attributed to their inability to protect fast growing, immature fruits against *Alternaria* infection (Timmer & Zitko, 1991). Therefore, shorter spray intervals with relatively cheap contact fungicides are necessary to ensure good control of this disease.

Procymidone and iprodione are dicarboximides with localised systemic and contact action respectively (Cayley & Hyde, 1980; Danneberger & Vargas, 1982), and high toxicity against several target fungi (Sisler, 1988). The mode of action for this group of fungicides is not fully understood, but according to Sisler (1988), dicarboximides inhibit both spore germination and mycelial growth, modes of action which are essential for the inhibition of *Alternaria* brown spot since lesions are initially caused by host-specific toxins produced by germinating conidia (Pegg, 1966; Whiteside, 1988).

Procymidone, at 50 g a.i. 100 $litre^{-1}$ water, consistently gave effective control of *Alternaria* brown spot without negatively affecting yield during both seasons. A programme containing procymidone plus mancozeb, during wet periods with high disease pressure would be valuable for effective control of *Alternaria* brown spot. The addition of mancozeb will also help to restrict development of resistance in *Alternaria* against procymidone as suggested for iprodione (Hutton, 1989).

At a dosage of 50 g a.i. 100 $litre^{-1}$ water, iprodione gave excellent control during the 1992/1993 season, but poor control during the next season, a discrepancy which may be attributed to different climatic and phenological conditions prevailing during the different seasons of evaluation. Another possibility might be that iprodione is less persistent than procymidone due to the local systemic action of the latter fungicide. These phenomena must be studied further in order to make recommendations regarding the use of iprodione for controlling brown spot disease of Minneola tangelo in South Africa. Oren *et al.* (1992) and Solel (personal communication) reported good control of brown spot disease with iprodione applied at 25 g a.i. 100 $litre^{-1}$ water at 2-weekly intervals but found that this practice was not economically feasible.

Programmes with tebuconazole at dosages of 25 g a.i.100 $litre^{-1}$ water (Solel, personal communication) and 30 g a.i. 100 $litre^{-1}$ water, gave some, but unsatisfactory control of *Alternaria* brown spot. Tebuconazole could inhibit infection and abscission of young fruits when applied early in the growing season in spite of relatively long spray intervals. However, when applied later, this fungicide was unable to prevent fruit drop or lesion formation. Lesions are caused within 1 to 3 days by host-specific toxins, produced by germinating *Alternaria* conidia, prior to infection (Pegg, 1966; Whiteside, 1976; Kohmoto *et al.*, 1991). Tebuconazole is a triazole fungicide with a systemic mode of action that interrupts ergosterol biosynthesis (Berg, 1986; Berg *et al.*, 1987; Kuck & Thielert, 1987). Ergosterol biosynthesis inhibitors (EBI) do not usually affect germinating conidia which often have ergosterol reserves, but they can inhibit mycelial growth and sporulation (Hänbler & Kuck, 1987; Brenneman & Murphy, 1991; Dahmen & Staub, 1992*b*), a characteristic which may explain why tebuconazole was unable to stop lesion formation when not applied in good time.

Given the high cost of dicarboximide and triazole fungicides, it is doubtful whether these compounds will compete economically with a contact fungicide such as mancozeb. From our results, it appears that the triazoles would have to be sprayed at dosages of 30 g a.i. 100 $litre^{-1}$ or higher and/or at shorter spray intervals in order to be effective against *Alternaria* brown spot of Minneola. A spray programme with two applications of mancozeb, two applications of difenoconazole plus mancozeb, followed by a final application of mancozeb would cost

Table 5. *Suggested programmes for the control of* Alternaria *brown spot on Minneola tangelo in the summer rainfall area of South Africa*

Type of season[a]	Fungicides and date of application[b]												Approximate[d] cost/tree/ season
	2 Sept	30 Sept	14 Oct	28 Oct	11 Nov	2 Dec	16 Dec	30 Dec	13 Jan	27 Jan	28 Feb	April/May[c]	
Low precipitation	M	M	—	M	—	M	—	M	—	M	M	M	R6.40
Normal precipitation	M	T + M	—	T + M	—	M	—	M	—	M	—	M	R15.20
High precipitation	M	M	M	M	M	M	M	M	M	M	M	M	R9.60
High precipitation	M	P + M	—	P + M	—	P + M	—	—	M	—	M	M	R22.13
High precipitation	M	T + M	—	T + M	—	T + M	—	—	M	—	M	M	R20.00

[a] Low precipitation = 400–600 mm per season with few days of rain; Normal precipitation = 600–80 mm per season; High precipitation = more than 800 mm per season with repetitive wet conditions.
[b] M = Mancozeb at 200 g 100 litre^{-1} water; P + M = procymidone at 200 ml plus mancozeb at 150 g 100 litre^{-1} water; T + M = tebuconazole at 120 ml plus mancozeb at 150 g 100 litre^{-1} water. Fungicides should be sprayed at 25 litre/10-yr-old tree on approximate dates, depending on the first spray application which should be done at 80% petal drop.
[c] Normally no rain occurs during this period in the summer rainfall area of South Africa and no fungicide application is needed. During extended wet conditions, fungicide applications must be considered.
[d] Based on retail prices during the 1996 season.

approximately five times more than seven and three times more than 11 applications of mancozeb alone, respectively.

A multi-disciplinary strategy is needed for effective control of *Alternaria* brown spot disease. Otero *et al.* (1994) showed that the removal of inoculum sources can decrease the disease. Cultural practices such as pruning at the wrong time of the year, overhead irrigation or over fertilisation must also be avoided (Whiteside, 1979). Good cultural practices can decrease disease to some extent, but effective control of the disease is only possible with fungicidal spray programmes.

Chemical programmes should be scheduled to take climatic conditions and tree phenology into consideration. Results of the present study clearly indicate that all fungicides, regardless of their mode of action, have to be sprayed at appropriate times and intervals to ensure sufficient coverage of the fast growing immature Minneola fruits and young foliage in order to ensure effective control of *Alternaria* brown spot disease; this is also true for systemic triazole fungicides (Oren *et al.*, 1992; Solel, personal communication). In this study, the lack of efficacy of the expensive triazole fungicides applied at inappropriate times, supports this view. More economical fungicides should, therefore, be applied at spraying intervals that ensure sufficient protection of susceptible host tissues throughout the growing season. For this reason, mancozeb applied at 2-weekly intervals during periods of high disease pressure and at 4-weekly intervals during normal susceptible periods is recommended for effective, economical control of *Alternaria* brown spot on Minneola tangelo (Table 5). However, it might not be practical to apply such a labour intensive fungicide spray schedule amidst insecticide, herbicide and other orchard programmes that are required. Extended rainy periods can also interfere with spray programmes and force longer than 2- or 3-weekly intervals, which will necessitates the use of locally systemic procymidone or systemic tebuconazole fungicides as suggested in Table 5.

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