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Client Report No. 11933

Optimising spray application efficiency for Dothistroma control – characterisation of spray formulation properties

Stefan Gous and Brian Richardson

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Stefan Gous and Brian Richardson

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EXECUTIVE SUMMARY

The formulations and application volumes currently in use for the operational control of Dothistroma are based on research undertaken 20-25 years ago. The aim of this investigation is to determine if the methods currently in use can be improved.

Objective

The study included a review of alternative copper fungicides and oils available in New Zealand and investigated the potential for changing formulations to reduce application costs. A total of six copper fungicides and eight spray oils were tested at three different oil to water ratios. The main objectives were:

- To investigate if alternative, more cost-effective copper fungicides and oils are available in New Zealand for Dothistroma control.
- To lower the application volume by changing the spray formulation.

Key results

- Four copper fungicides i.e. cuprous oxide, copper oxychloride, Kocide DS and Du Pont GX 569 produced sprayable mixtures with all spray oils.
- Cuprous oxide consistently produced larger spread areas than copper oxychloride.
- Cuprous oxide at 860g/ha metallic equivalent copper produced uniform stable suspensions with all of the test oils.
- BP dothi oil and Syntol mineral oil produced the largest spread areas.
- An increase in oil percentage in the spray mixture, resulted in larger spread on the leaf surface.

Application of results

- Cuprous oxide mixed with either BP dothi oil or Syntol mineral oil could be used with confidence in operational Dothistroma control operations. However, phyto-toxicity and persistency of copper mixed with Syntol oil needs to be tested.

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Further work

- Persistence tests of copper: Copper retention on pine needles following application of new spray mixes needs to be tested and compared with the standard application method.
- Photo-toxicity tests: New oils need to be tested for any signs of phyto-toxicity on *Pinus radiata*.
- New, smarter fungicide formulations: This project only investigated copper as a potential fungicide for Dothistroma control. Synthetic fungicides are used in many agricultural crops with great success and could potentially provide similar if not better fungicidal protection properties for Dothistroma control.
- Scanning electron microscopy: This project characterised the spread of potential oils to be used in mixtures with copper fungicides for Dothistroma control. However, it is not known if the copper is deposited only at the point of initial droplet impact on the needle surface, or whether it is subsequently redistributed as the oil spreads over the leaf surface over a period of several hours. Scanning election microscopy could be used to quantify copper distribution on needle surfaces.
- Operational trials are required before any changes in operational procedures can be recommended.

Keywords: Dothistroma, copper fungicides, spray oils

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Introduction

Dothistroma septosporum (syn. Dothistroma pini) was first discovered in New Zealand, near Tokoroa, in 1962 and identified by Gilmour in 1964 (Gilmour 1967; Ridley and Dick, 2001). Conidia (spores produced asexually) are released from fruiting bodies, germinate, and hyphae then penetrate the needles of *Pinus radiata* through the stomata (Gadgil, 1967). Toxins are released by the fungus into the needle which stimulate a plant response causing lesions, needle cast, and subsequently tree growth loss (Bassett *et al*., 1970).

Once the crown infection level reaches 25%, plantations are treated with an aerial application of copper fungicides (Bulman *et al*., 2004). An average of 70 000 ha of plantation forest are annually treated against Dothistroma in New Zealand. In severe cases, two annual sprays might be required, one in October – November and the second in January – February. Copper fungicides are non-systemic and form a protective barrier for 4-6 weeks on the needle surface, thereby preventing the fungi from entering the plant host (Ridley and Dick, 2001). Fungicides also reduce inoculum by stopping the release of conidia from fruiting bodies (Bulman *et al*., 2004). Spray coverage on the target foliage surface is therefore of vital importance. High coverage is achieved by applying the spray mix using micronair nozzles which produce a droplet spectrum with a volume mean diameter (VMD) of approximately 65µm.

The formulated spray mix used in Dothistroma control consists of three components, a copper fungicide, a mineral spray oil and water. The mix is applied at a nominal rate of 5 litres per hectare total spray. This is made up of a copper fungicide (860g metallic equivalent), 2 litres of mineral spray oil and made up to volume with water.

Traditionally two copper fungicides, cuprous oxide and copper oxychloride, and two spray oils, Caltex winter spray oil and BP Dothi oil have been used in operational Dothistroma control.

This project was carried out in three steps.

- In the first step, a thorough search for alternative available copper fungicides and spray oils was undertaken.
- Secondly, alternative fungicide and oil mixtures were characterised and compared to current spray mixtures used for Dothistroma control, according to their stability.
- In step 3, spread tests of the most stable mixtures were compared for their ability to spread on foliage surface.

Section I - Alternative copper fungicides and spray oils

Fungicides

A search was undertaken to find available copper fungicides that could be used to control Dothistroma needle blight in *P.radiata* plantations in New Zealand. Table 1 shows a range of copper fungicide products, their percentage active ingredient (a.i.) and the weight of product required to apply 860 grams metallic equivalent of copper per hectare. All these products are wettable powders, except the Agpro cupric-hydroxide 350 SC, which is a suspension concentrate (SC) liquid. With the exception of Du Pont GX569 copper hydroxide, all these products are registered for use in New Zealand and can therefore be used in any commercial operational application.

Table 1. Copper fungicides, percentage active ingredient and weight of product required to obtain 860g a.i./ha metallic equivalent for Dothistroma control.

Product name	% a.i.	kg product/ha
Cuprous oxide	75	1.14
Copper oxychloride	50	1.71
Copper hydroxide tech	65	1.31
Cupric-hydroxide 350 SC (Agpro)	35	2.44
Kocide 2000 DS	35	2.44
GX569 copper hydroxide (Du Pont)	30	2.85

Spray oils

Table 2 shows the eight spray oils that were sourced and tested for their use in the Dothistroma control project. The six copper fungicides, above, and the eight spray oils, were prepared at two water to oil ratios (60%/40% and 50%/50%) and the mixtures were tested for their solubility and stability. In all cases a standard formulation was used as a benchmark for comparison with all the other formulations.

Table 2. Spray oils used in this project and their suppliers.

Product name	Supplier
Mineral crop oil	Agpro NZ
Spray maximiser – vegetable oil	Agpro NZ
Dothi oil	BP New Zealand
DC-Tron NR	Caltex
DC–Tron Plus	Caltex
Winter spray oil	Caltex
Mineral oil	Syntol
Vegetable oil	Syntol

Benchmark formulation

The standard formulated spray mixture for Dothistroma needle blight control consists of 2 litres spray oil, 860g/ha metallic equivalent copper fungicide (1.14kg Cuprous oxide or 1.71 kg Copper oxychloride) made up to 5 litres with water. For this project the following components were selected and mixed as the benchmark formulation.

- Cuprous oxide at 1.14 kg product per hectare
- 2 litres of Caltex winter spray oil
- made up to volume (5 l/ha) with water

This is the standard mixture against which all the other spray mixes were tested. Although viscosity was not directly measured, another test criterion was that alternative formulations must produce a “sprayable” mixture.

In the benchmark formulation, the respective volumes of each component is: 40% oil, 8% copper fungicide (Cuprous oxide) and 52% water.

Section II - Spray mixture stability
Methods

Spray mixture stability and viscosity

The stability test is important to determine if the emulsion produced is sprayable. It is also used to determine if the copper fungicide will go into suspension and how long it takes to settle from the mixture.

All six copper products from Table 1 were tested at the metallic equivalent of 860g a.i./ha for their stability in the spray mixture. These products were mixed with 3 litres of water and 2 litres of Caltex winter spray oil to compare their stability in suspension. Copper hydroxide tech, Agpro cupric-hydroxide 350 SC, Kocide 2000 DS and Du Pont, GX569 copper hydroxide, produced a paste-like suspension with viscosity too high to be sprayable. Figure 1 shows the paste-like nature of Kocide 2000 DS at 860g metallic equivalent in the mixture. Both Kocide 2000 DS and Du Pont, GX569 copper hydroxide were recommended at lower metallic equivalent rates of 530g/ha and 260g/ha respectively. At these lower rates both products produced a sprayable mixture with much lower viscosity. Copper hydroxide tech and the Agpro Cupric-hydroxide 350 SC were not considered in further work.

Figure 1a & 1b. Agpro copper hydroxide tech and Kocide 2000 DS, pastelike spray mixtures.

Relative stability
An easily repeatable method was developed to compare the spray mixture. All of the powdered copper products were suspended into the oil-water emulsion. The mixing procedure was to suspend the copper fungicide powder in oil, then water was added.

The suspension was then allowed to settle. In most cases the three components of the suspension clearly separated after two hours with very little change thereafter. Figure 2 shows the three separated components after 2 hours. It was decided to use the depth of the copper/oil/water suspension component, (between two arrows) to assess the relative stability of the solution. Therefore, the larger the column containing the three components of the spray mix, and longer this component remained as an emulsion/suspension, the more stable the mixture. Measurements were taken at 0, 10, 20, 30, 60, 120, 1440 minutes after initial vigorous agitation. Figures 3 – 6 show the four copper fungicides formulated in the eight different oils, 24 hours (1440 minutes) after agitation.

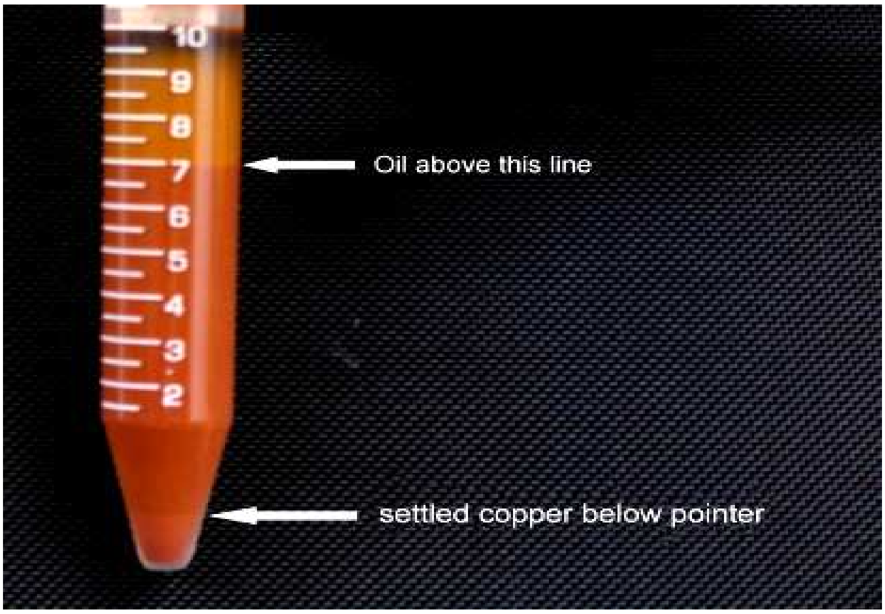

Figure 2. Three separated components of spray mixture.

The oils in the photos were always ordered:

- Caltex winter spray oil
- Caltex DC Tron plus
- Caltex DC Tron NR
- Agpro crop oil
- Agpro spray maximiser
- Syntol mineral oil
- Syntol vegetable oil
- BP dothi oil

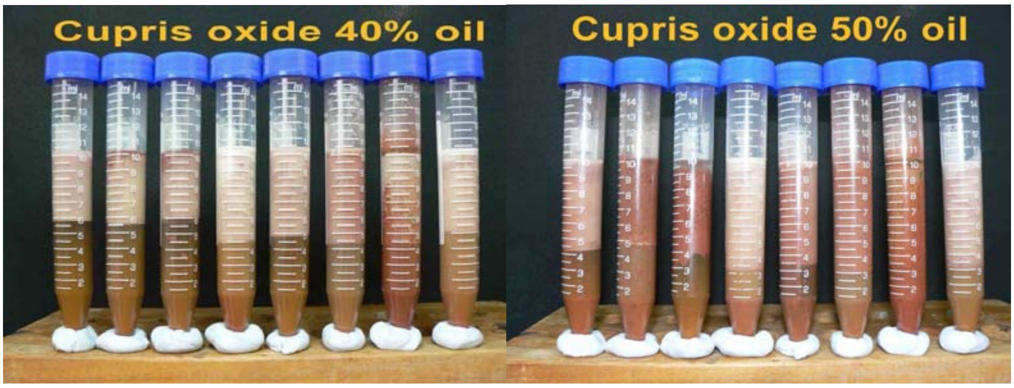

Figure 3a & 3b. Cuprous oxide stability in 40% and 50% oil after 24 hours.

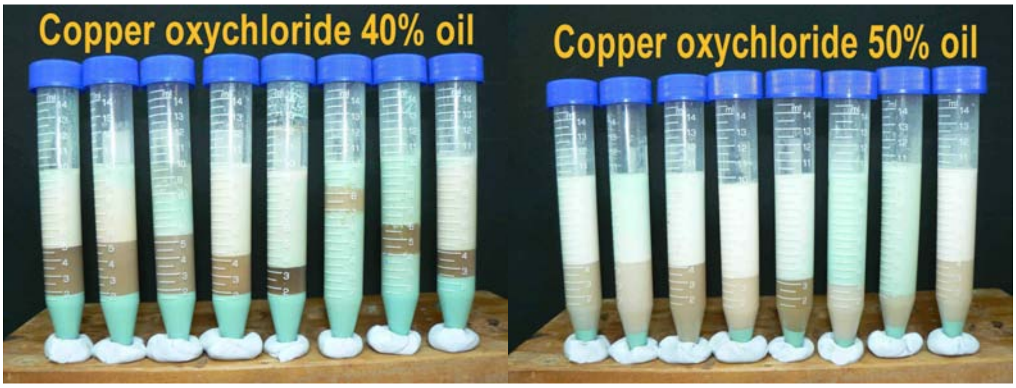

Figure 4a & 4b. Copper oxychloride stability in 40% and 50% oil after 24 hours.

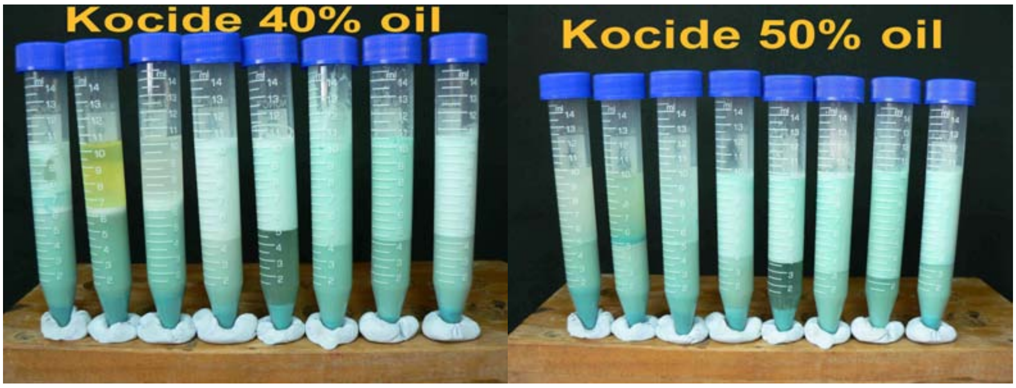

Figure 5a & 5b. Kocide 2000 DS stability in 40% and 50% oil after 24 hours.

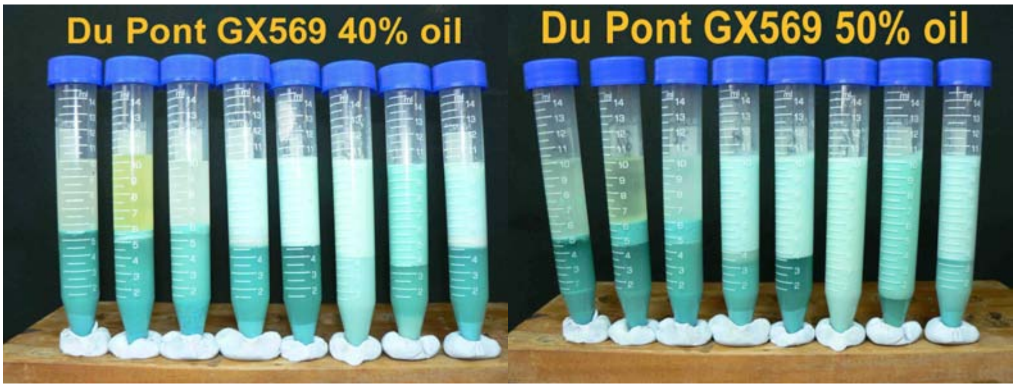

Figure 6a & 6b. Du Pont, GX569 Copper hydroxide stability in 40% and 50% oil after 24 hours.

Re-suspension

The ability to re-suspend the spray mixtures were tested by allowing the mixture to settle for 24 hours or more. These mixtures were then shaken up to re-suspend the settled copper in the mixture. The relative time and ease required to re-suspend the copper was taken.

Results of stability tests

The purpose of these tests was to determine if alternative oils, together with the different copper powder fungicides, would produce more or less stable mixtures. Two benchmark oils were therefore selected against which other oils were compared, these were Caltex winter spray oil and BP dothi oil.

The volume of the copper/oil/water emulsion was recorded as a percentage of the total volume to determine the relative stability of the fraction. If an oil produced a more stable mixture than another oil, the line on the graph for this oil will be above the selected benchmark. This means it maintained a larger fraction of the total volume as the combined suspension/emulsion, than the selected benchmark at a given time. For all of these comparisons, Caltex winter spray oil was used as the benchmark oil.

With the exception of copper oxychloride, the other three copper fungicides were very easy to re-suspend into the mixture, requiring between 10 to 15 seconds of agitation. Copper oxychloride was very difficult to re-suspend, taking 6 to 8 times longer and requiring much more rigorous agitation than mixtures containing the other three copper fungicides.

Cuprous oxide stability test

At 860 gram metallic equivalent copper per hectare, cuprous oxide powder produced uniform suspensions with all of the test oils. Figure 7 shows that, with the exception of Caltex DC Tron plus and Caltex DC Tron NR, all the oils produced more stable mixtures than Caltex winter spray oil. Syntol vegetable oil and BP dothi oil produced the most stable mixture with cuprous oxide. Although initial settling of the cuprous oxide powder occurred within 10 minutes after agitation, very little agitation was required to re-suspend the mixture.

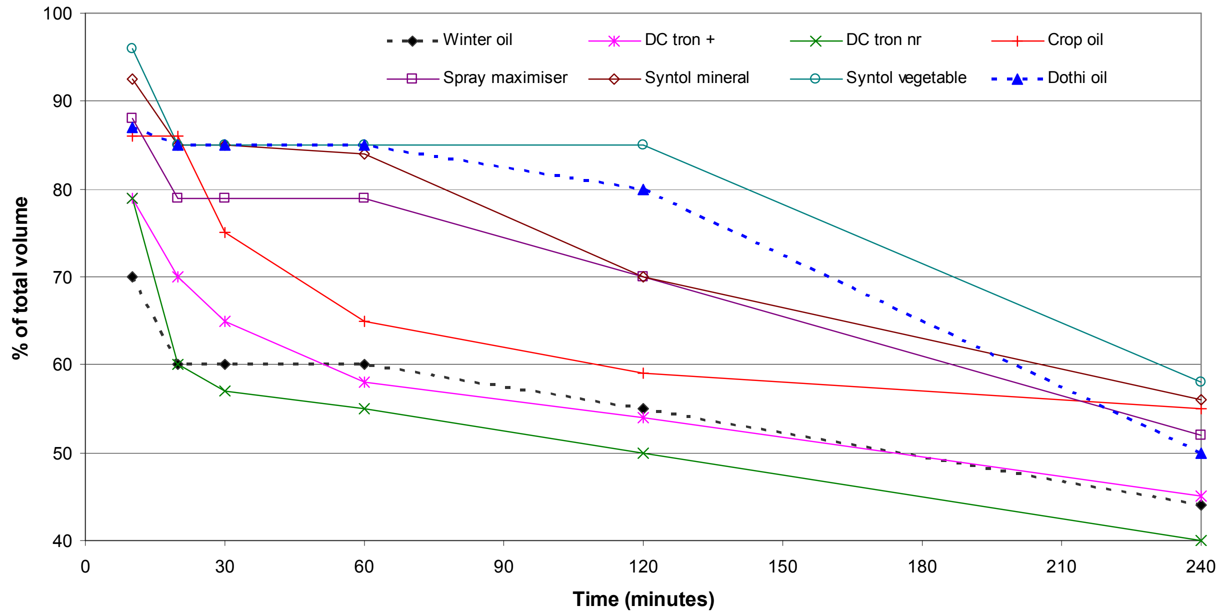

Figure 7. Cuprous oxide stability test for eight different spray oils over time.

Copper oxychloride stability test

Within the first 20 minutes after agitation, Caltex winter spray oil and BP dothi oil produced the most stable mixture with copper oxychloride. Thereafter their stability deteriorated rapidly (figure 8). Agpro crop oil, Agpro spray maximiser, Syntol mineral oil and Syntol vegetable oil all produced mixtures that were similar or more stable than the benchmark. The performance of Caltex winter oil was much better with copper oxychloride than with cuprous oxide. This result implies that performance can be optimised by matching oils to the copper product selected.

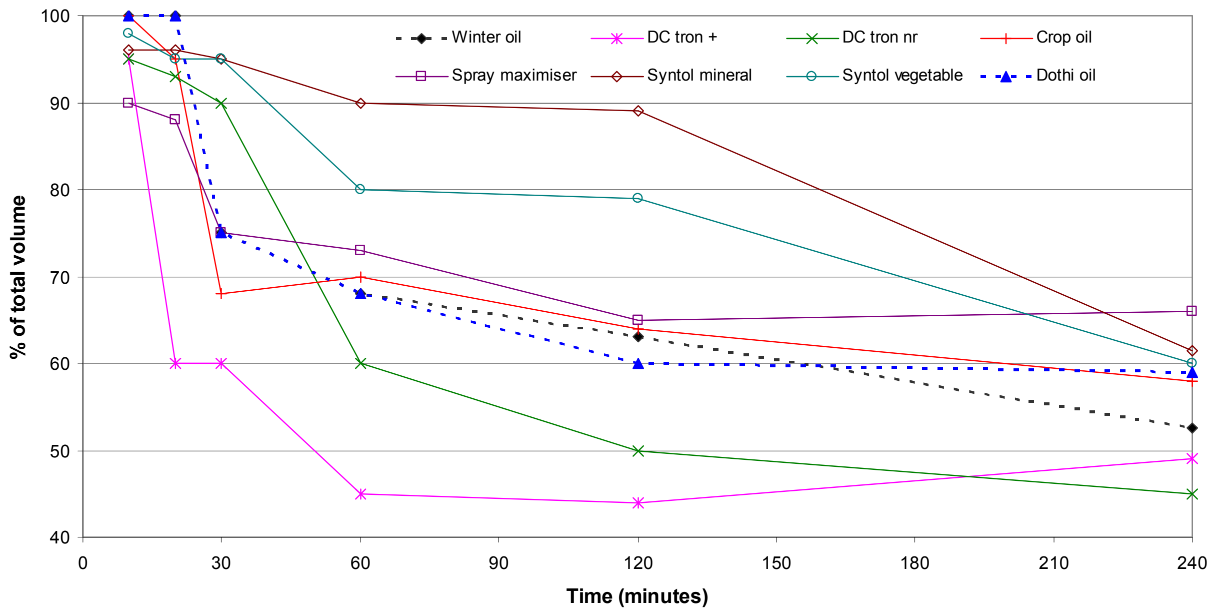

Figure 8. Copper oxychloride stability test for eight different spray oils over time.

Kocide stability test

Kocide at 860g/ha metallic equivalent copper produced a formulation with a viscosity too high to be sprayable. Therefore, this test mixture only had 530g/ha metallic equivalent copper. With the exception of Caltex DC Tron plus and Caltex DC Tron NR, all the oils produced more stable formulations than Caltex winter spray oil when mixed with Kocide (figure 9). The benchmark formulation produced the least stable formulation, with 25% settling within the first 10 minutes after agitation. The two vegetable oils produced the second and third most stable mixtures.

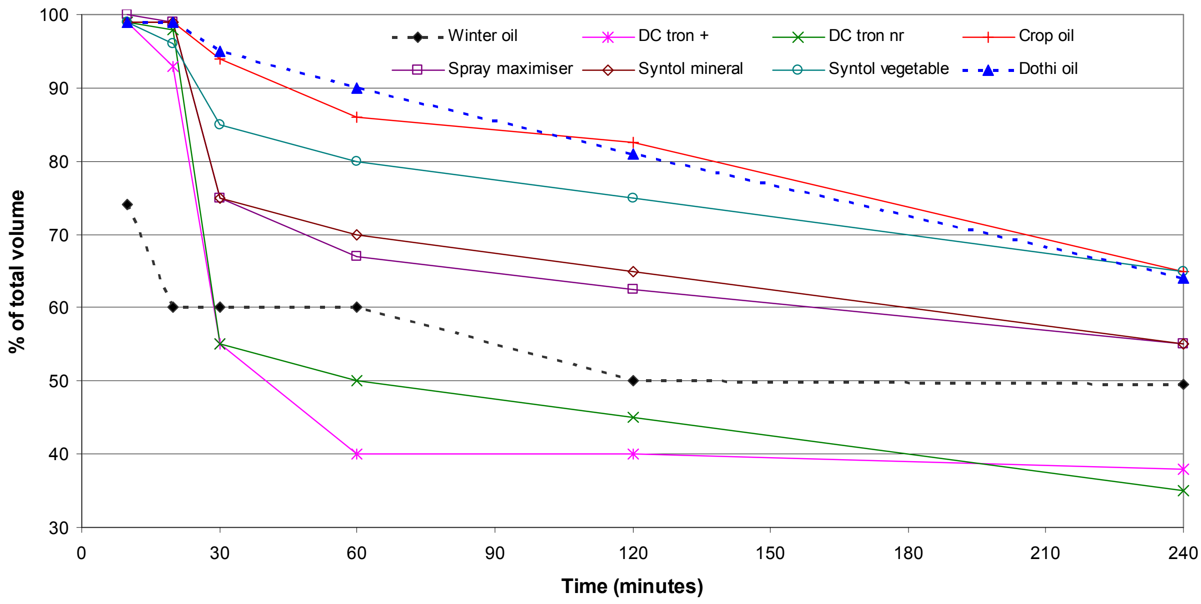

Figure 9. Kocide stability test for eight different spray oils over time.

Du Pont, GX569 Copper hydroxide

Similar to Kocide, the GX569 copper hydroxide (at 860g/ha metallic equivalent copper), produced a mixture with a viscosity too high to be sprayable. At the recommended rate of 260g/ha metallic equivalent copper, GX569 copper hydroxide produced a sprayable solution.

The benchmark oil formulation produced the least stable formulation, with almost 50% copper settlement within 10 minutes after agitation (Figure 10). Syntol vegetable oil produced the most stable solution, with only 35% copper settlement after 24 hours.

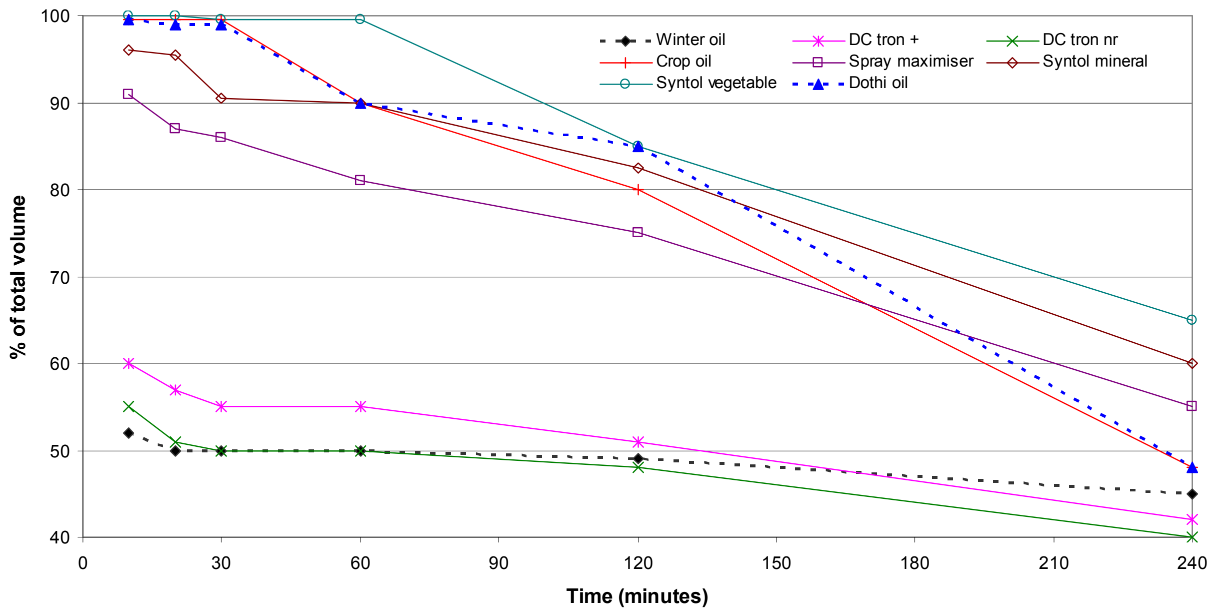

Figure 10. Du Pont, GX569 Copper hydroxide test for eight different spray oils over time.

Key findings:

- Copper starts to settle from the suspension within minutes after agitation stops, therefore it was assessed 3 times within the first 30 minutes after agitation stopped.
- Comparing the two benchmark oils, BP dothi oil outperformed the Caltex winter spray oil and produced more stable mixtures with all of the copper fungicides.
- Both Caltex DC Tron plus and NR consistently produced less stable mixtures than the other oils.
- Syntol mineral and vegetable oils in most cases produced very stable mixtures and compared very favourably with BP dothi oil.
- Syntol vegetable oil formed the most stable emulsion with almost no copper settling from the suspension 7 days after agitation (results not shown but available from the senior author on request).
- Kocide and Du Pont GX569 (at the lower rates) in BP dothi oil produced mixtures that were more stable than cuprous oxide or copper oxychloride. However, at these much lower copper rates, efficacy and persistency will have to be tested before any recommendations can be made.

Section III - Spread tests of solutions

Spray oils may increase the efficacy of copper against *Dothistroma* by either improved retention or better coverage on the foliage. Optimising retention and/or coverage creates the potential to reduce copper rates and total spray volume without compromising efficacy. The spread of the oil and copper over the needle surface are important factors to consider when a spray mixture is selected for Dothistroma needle blight control.

Methods

A series of trials were undertaken to characterise the relative spread of the different oil/copper formulations. These trials are discussed individually below. Spreading properties were determined by applying 0.5 μl droplets (10 replications) of spray mixture to the adaxial surface of cabbage leaves (an indicator species). Spread areas were measured 1 and 20 hours after application. Uvitex – OB, a UV-fluorescent dye was incorporated in the mixtures at 5 mg/ml to facilitate measurements by image analysis under UV light (Gaskin and Murray 1998). An analysis of variance was done to compare treatment means.

Trial 1: Spread test of cuprous oxide mixed with eight test oils

Cuprous oxide at 860 g/ha metallic equivalent was mixed with the eight test oils (table 2) at a ratio of 40% oil to 60% water. For each of the mixtures 0.5 μl droplets were placed onto cabbage leaves. Spread areas were measured after 1 and 20 hours to determine the relative spread.

Trial 2: Spread test of four copper fungicides in Caltex winter oil

Four copper fungicides (cuprous oxide, copper oxychloride, Kocide DS and GX569) were mixed with Caltex winter spray oil and water at a ratio of 40% and 50% oil to water. Cuprous oxide and copper oxychloride were used at 860g/ha metallic equivalent copper while Kocide DS and GX569 copper hydroxide were used at 530g/ha and 260g/ha metallic equivalent copper, respectively. Spread was measured on cabbage leaves as in trial 1 above.

Trials 3, 4 and 5: Spread test of two copper fungicides in four oils at 40%, 50% and 100% oil

Copper oxide and copper oxychloride at 860g/ha metallic equivalent copper were mixed with Caltex winter spray oil, Syntol mineral oil, Syntol vegetable oil and BP Dothi oil at 40% (trial 3), 50% (trial 4) and 100% (trial 5) oil respectively. Spread areas were measured on cabbage leaves as in previous trials. In each trial 10 replications were used. An analysis of variance was performed to determine if mean spread areas differed significantly.

Results

Results of the spread tests are discussed individually below.

Trial 1: Spread test of cuprous oxide mixed with eight test oils

Figure 11 shows the relative droplet spread of the eight test oils 1 and 20 hours after application. Twenty hours after droplet placement, BP dothi oil and Syntol mineral oil produced significantly larger spread areas than the benchmark, Caltex winter spray oil. All other oils tested, with the exception of Caltex DC tron NR, produced similar spread patterns after 20 hours.

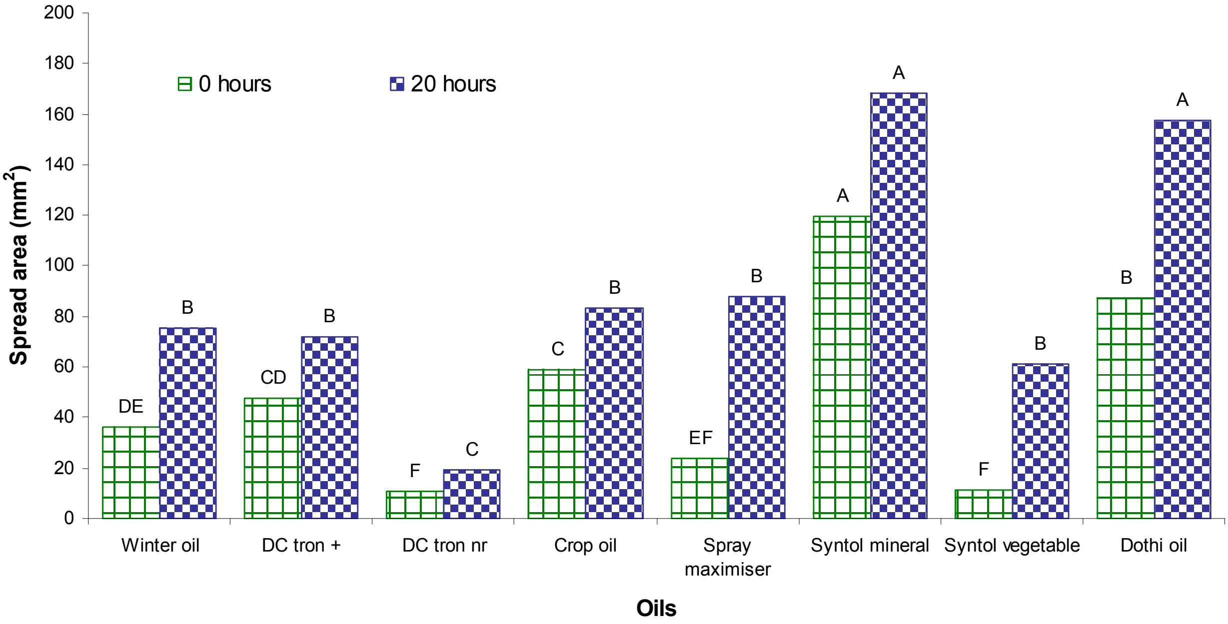

Figure 11. Spread areas of cuprous oxide mixed with eight different oils at 40% oil.
Bars topped by the same letter are not significantly different ($P < 0.05$)

Trial 2: Spread test of four copper fungicides in Caltex winter oil

The results of trial 2 are summarised in Figure 12. Spread tests show an interaction between the copper fungicide and the percentage oil in the spray mixture. Spread areas for three of the four fungicides (cuprous oxide, copper oxychloride and GX569 copper hydroxide) show that the spread areas of the 50% oil mixtures were significantly greater than for the 40% oil mixtures. At 40% oil there is a higher fungicide effect on the spread of the droplet than at 50% oil. GX569 copper hydroxide produced the greatest spread at 40% oil than any of the other fungicides.

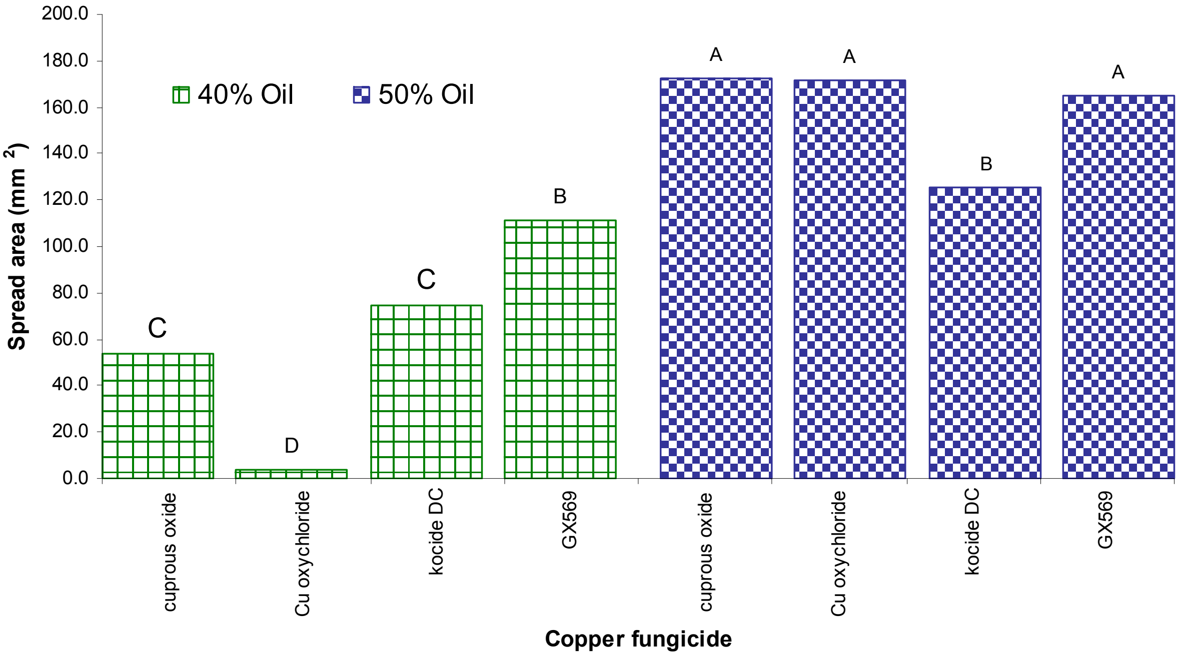

Figure 12. Spread areas on cabbage leaves of different copper formulations with Caltex winter oil at 40% and 50% oil 20 hours after treatment.

Bars topped by the same letter are not significantly different ($P < 0.05$)

Trial 3: Spread test of cuprous oxide and copper oxychloride at 40% oil

At 40% oil, cuprous oxide, when mixed with the tested oils, consistently produced larger spread areas than copper oxychloride mixed with the same oils (Figure 13). Syntol mineral oil and BP dothi oil, produced significantly larger spread areas than Caltex winter spray oil and Syntol vegetable oil. These results show that both the copper fungicide and the oils have a significant effect on the spread areas produced.

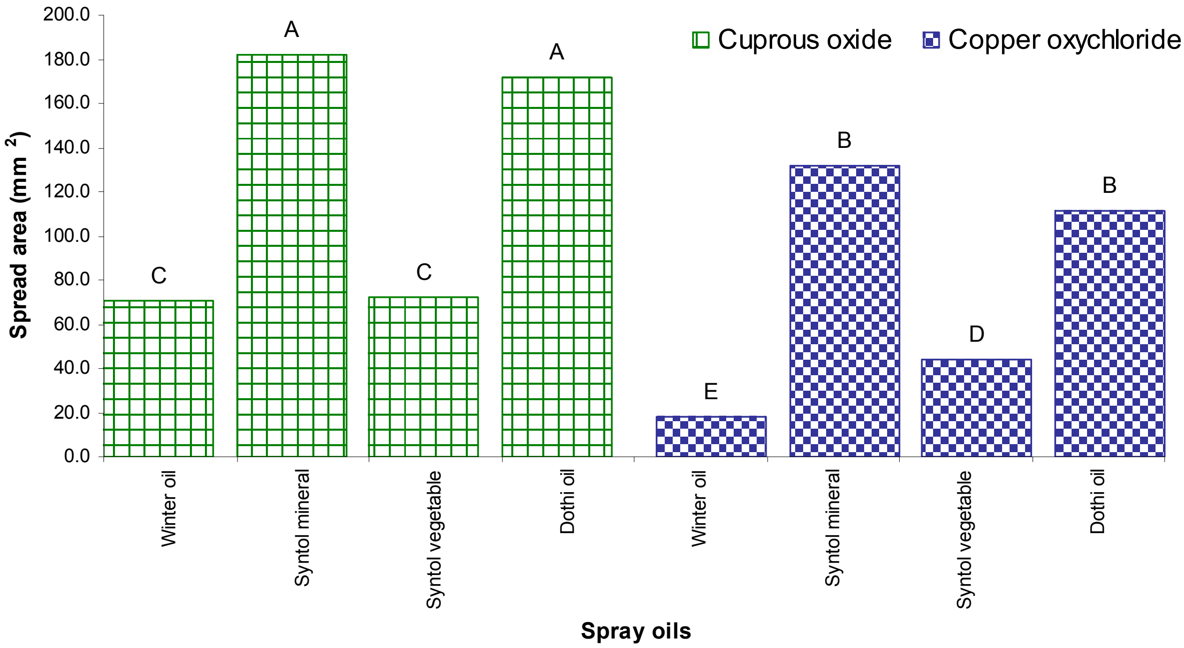

Figure 13. Spread areas of cuprous oxide and copper oxychloride with four oils (40%), 20 hours after treatment..

Bars topped by the same letter are not significantly different (P < 0.05)

Trial 4: Spread test of cuprous oxide and copper oxychloride at 50% oil

At 50% oil mixture, cuprous oxide, produced larger spread areas than copper oxychloride with the same oil (Figure 14) but the result was not as clear as that obtained form the 40% oil formulation. Both Syntol mineral oil and BP dothi oil produced significantly larger spread areas than Caltex winter spray oil and Syntol vegetable oil when mixed with Cuprous oxide. The results clearly show that the interactions of fungicides and oils have a significant effect on the spread areas produced.

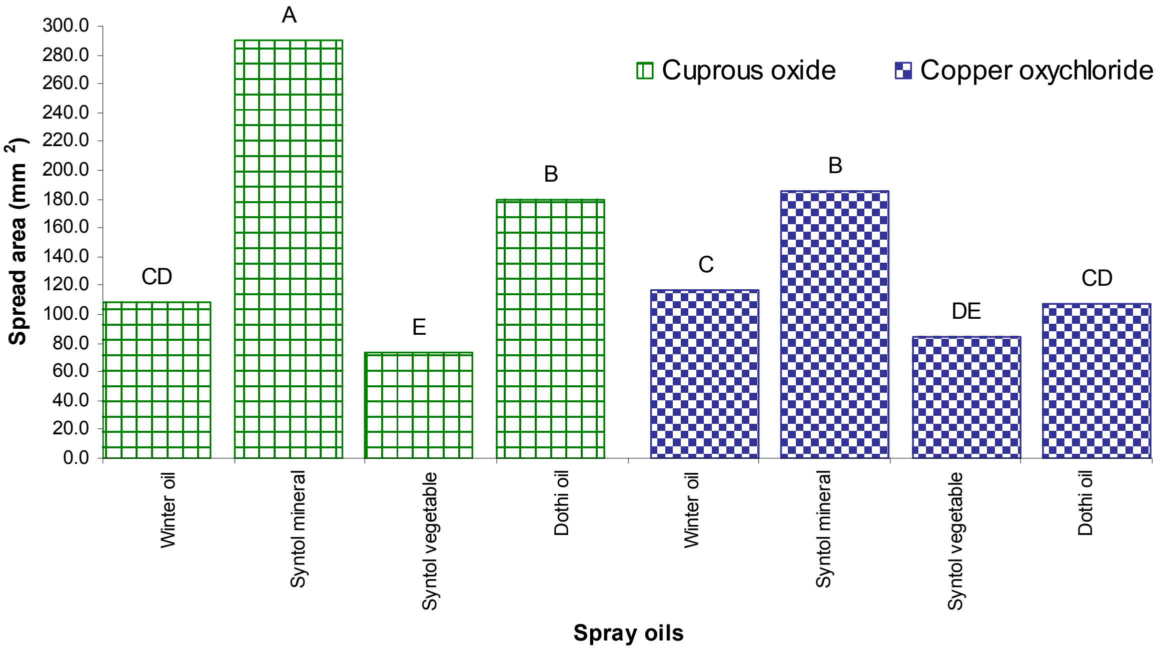

Figure 14 Spread areas of cuprous oxide and copper oxychloride with four oils mixed at 50% oil.

Bars topped by the same letter are not significantly different (P < 0.05)

Trial 5: Spread test of cuprous oxide and copper oxychloride at 100% oil

With 100% oil mixes, the results were consistent with the two previous trials. Cuprous oxide again consistently produced larger spread areas than copper oxychloride when mixed with the same oil, except when mixed with Syntol mineral oil (Figure 15). However, at 100% oil, Caltex winter spray oil and Syntol mineral oil produced the largest spread areas. Although BP dothi oil still produced large spread areas, they were significantly smaller than the spread areas from the Caltex winter spray oil. These results also show that both the fungicides and oils have a significant effect on the spread areas produced by the different formulations.

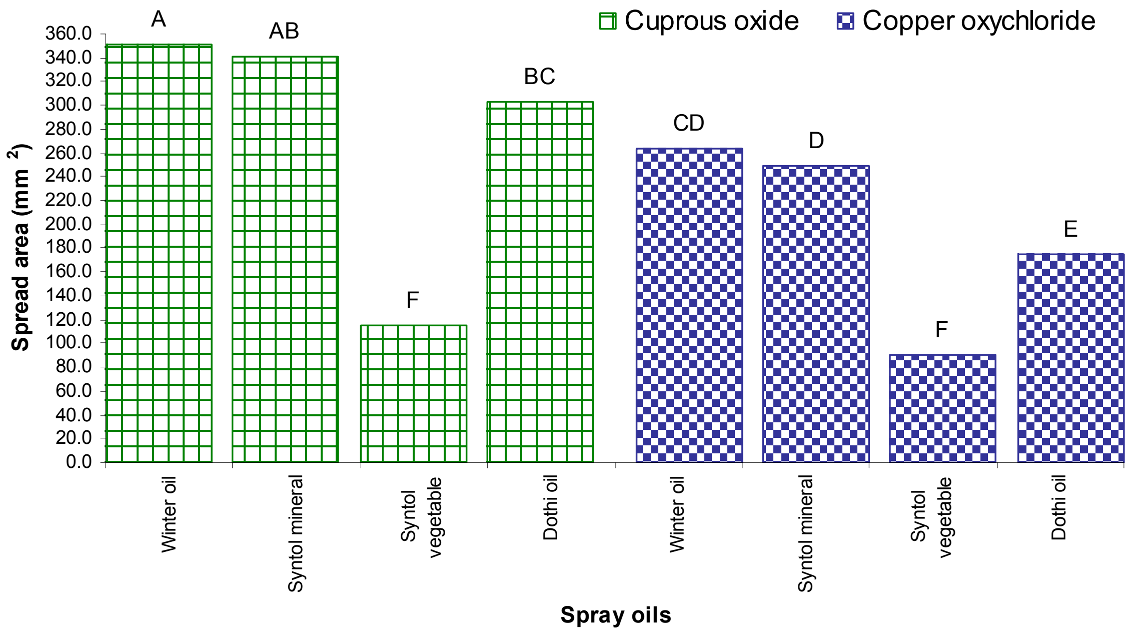

Figure 15. Spread areas of cuprous oxide and copper oxychloride with four oils mixed at 100% oil.

Bars topped by the same letter are not significantly different ($P < 0.05$)

Key findings:

- Relative spread areas from Syntol mineral and BP dothi oil were significantly larger than the other oils tested.
- An increase from 40% to 50% oil in the spray mixture yielded significantly larger spread areas for cuprous oxide, copper oxychloride and GX569.
- Trials 3, 4, and 5 show that mixtures with cuprous oxide consistently produced larger spread areas than copper oxychloride mixed with the same oils.
- An increase in the oil content in most cases resulted in an increase in spread areas on foliage.

Discussion

Two fungicides produced solutions at the recommended rates of 860g a.i./ha that were too viscous to spray. Their efficacy at lower active ingredient rates is unknown, but if warranted, efficacy of these fungicides should be compared with other fungicides applied at the same active ingredient rate.

Spread tests showed that Syntol mineral and BP dothi oil produced significantly larger spread areas than the other tested oils. These two oils have the potential to spread the suspended copper over a greater area over the leaf surface than the other oils, thereby potentially increasing the protection provided by the copper fungicide. This result was repeated with cuprous oxide or copper oxychloride in the spray mixture.

Cuprous oxide consistently produced larger spread areas than copper oxychloride when mixed with the same oil. Cuprous oxide was much more easy to re-suspend into the spray mixture than copper oxychloride. Based on the above results, cuprous oxide should be used in preference to copper oxychloride.

Water has a high surface tension compared with spray oil. As the oil content increased from 40% to 50% to 100% the surface tension of the spray mixture reduced, and spread over the leaf surface increased. Therefore, as the oil content increases, (water content decreases) the potential for the copper to spread over the leaf surface is greater, potentially providing greater protection against Dothistroma. However, it should be recognised that greater spread may not result in greater fungicidal efficacy because firstly, the copper may not be carried evenly in the droplet as it spreads; and secondly, an even distribution of copper over the entire needle surface may not necessarily improve control.

A reduction in water volume implies that a lower total application volume is possible, which will most certainly result in lower application costs. The oil content of the mixtures has a much greater effect on the droplet spread than the choice of which copper fungicide to use.

Summary

- At 860g/ha metallic equivalent copper rates, both Kocide DS and GX569 copper hydroxide produced solutions that were too viscous and could not be sprayed.
- At reduced rates, 530g/ha and 260g/ha respectively, Kocide 2000 DS and GX569 copper hydroxide mix and spread well with the test oils.
- Cuprous oxide at 860g/ha metallic equivalent copper produced uniform suspensions with all of the test oils. Caltex DC Tron plus and Caltex DC Tron NR consistently produced less stable solutions than the benchmark oil.

- Oils and fungicides had an interactive effect on the spread area of the droplet.
- The best copper formulation for spreading after mixing with oils was cuprous oxide. It consistently produced larger spread areas than copper oxychloride in the same oil.
- The best oils for spreading after mixing with the tested copper fungicides were BP dothi oil and Syntol mineral. They produced significantly larger spread areas than the benchmark Caltex winter spray oil.

- As the oil percentage increased, so did the spread area. Therefore, higher rates of oil (50% or 100%) can be mixed with copper formulations and will improve spreading of the resulting droplet.
- Syntol vegetable oil in mixtures with copper formulations did not spread as well as Caltex winter oil or BP dothi oil at 40%, 50% or 100% mixture but it did produce the most stable mixture.
- Droplet spreading may not necessarily equate with spread of copper on the leaf surface.

Future research

- **Persistence and phyto-toxicity:** Results from this project suggest that spray mixtures with Syntol mineral and BP dothi oil should be tested at reduced water rates. As a first step in evaluating the effectiveness of these new spray mixes, it is proposed to evaluate the persistence of copper on pine needles when applied using these mixes compared with the conventional application method. The longer copper persists on pine needle surfaces, the greater the likely effectiveness of the application. Pine seedlings will be sprayed with different oil and water rates, placed outside, and exposed to the natural weathering elements. Periodic copper assessments will reveal whether the different spray mixes change the persistence of copper on pine needles. Simultaneously, visual assessment of the seedlings will show if there are any phyto-toxicity issues.
- **Scanning electron microscope (S.E.M.):** Tests in this study demonstrated that different oil and copper products had a large influence on droplet spread. Everything else being equal, increasing spread may increase the level of protection by maximising the distribution of copper particles over the needle surface. However, droplet spread occurs in two phases. There is an initial spread at the time of impact (when the droplet lands on the needle surface) and there is a secondary spread, that takes place over many hours, as the oil slowly spreads and creeps over the leaf surface. It is important to know whether this secondary spread only represents the oil part of the formulation or whether the oil is also carrying particles of copper. If it is only the oil, there will be no advantage from achieving a high level of secondary droplet spread. It is proposed to investigate whether secondary droplet spread includes both oil and copper or oil only using Scanning Electron Microscopy.
  These results will indicate if the suspended copper also spreads over the leaf surface together with the spray oil. A protocol needs to be developed to measure the deposited copper over the leaf surface using the S.E.M.
- **Operational efficacy trials:** Following the copper persistence and oil spread trials described above, the best two or three treatments will be selected for large replicated operational trials against Dothistroma.
- **Formulation technology** has made considerable advances over the last 20 years. Slow release formulations are common features of many applications such as slow release boron for timber protection. It is possible that smarter, slow release copper formulations could have some advantage for Dothistroma control.

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