Protective Fungicide Applications for Citrus Disease

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Introduction

For the sake of agricultural labor-saving, some heavy machines recently have become popular for the application of agricultural chemicals. As for controlling citrus disease, the helicopter, speed sprayer or sprinkler is used occasionally in the fields.

But it has been traditionally said that the fungicide, especially the protective fungicide, must be deposited uniformly all over the plant leaves in the form of fine spray so the usage of these heavy machines still remains with some uncertainties in such a traditional method of fungicide applications.

We have been suspicious of the necessity of such so-called indispensable conditions in the applications of protective fungicide on citrus disease control.[5]

Therefore, we have gradually investigated the entire mechanism of fungicide effects and consequently procured a new more adequate idea for the fungicide application method which is superior to the traditional one.

The results of experiments are as follows:

Ideas for fungicide application

1) Traditional idea

Generally, the fungicides could be classified into two types by their effects—one is the protective fungicide and the other is the direct fungicide—and the former, the residual fungicide,[1] has been considered as protecting the plant from the attack of pathogenies by the thin layer of spread fungicide covering the plant surfaces with it.

Accordingly, this kind of fungicide has been sought to have the convenient qualities for this purpose and it has been used under a fixed conceptional view.

TANAKA said in his text[4] that the protective fungicide must be sprayed with a high pressure from the smaller spout of sprayer which is equipped, if possible, with a stirrer within, and the fine spray of fungicide jetted at a distance of about 30 cm from the plants must be deposited uniformly on the upper and lower leaf surfaces as to cover the plant with a thin film of fungicide when it has been dried.

Nowadays, Bordeaux mixture or inorganic copper derivative is mainly used as the fungicide to control citrus disease and the application of these heavy chemicals is used with the greatest care possible.

So these heavy machines which could not minutely distribute the fungicide on the lower leaf surfaces were regarded as an unavailable instrument, and consequently these conceptions had been a great barrier to promote the idea of labor-saving in the disease control operation.

2) Recent idea

Besides the above mentioned qualities required as a protective fungicide, the large amount of deposition, the stronger adherence to plants and the longer duration of efficiency of the fungicide have been also sought.

It is acknowledged that the decline of the efficiency of deposited fungicide is caused by the rainfall distribution, hydrolyzed or light decomposition, evaporation and sublimation.

But the author would rather make use of the effective ingredient carried away by rainfall for the control against the pathogens.

Horsfall has given the term of "redistribution of chemicals" to the dispersion of effective ingredient of sprayed fungicide caused by rainfall.[1)]

We have considered that such dispersed effective ingredient may be useful as a contact fungicide by its direct contact action against the pathogens, and that, for the control of main citrus diseases, the citrus scab (*Elsinoe fawcetti*) and the melanose (*Diaporthe citri*), which have been caused usually by the dispersion of rainfall, the action of redistributed ingredient of sprayed fungicide seems to be very effective.

The traditional idea on the fungicide application was to protect the plant against the pathogens by covering the plant with the fungicide deposition (Fig. 1, A), but the recent idea (Fig. 1, B) is based on a presumption that the active ingredients of the fungicide sprayed on the upper surface of leaves on top of the plant, being distributed by rainfall, should give a fungitoxic effect as a contact fungicide to the pathogens which have been dispersed by rain (a).

In some cases, by this principle, the redistributed ingredient of fungicide could be also applied on the prevention against the pathogens resided in the plant lesions as an eradicant fungicide (b).

Furthermore, the redistributed active ingredient which has been deposited in the form of a thin film on the plant surface could be

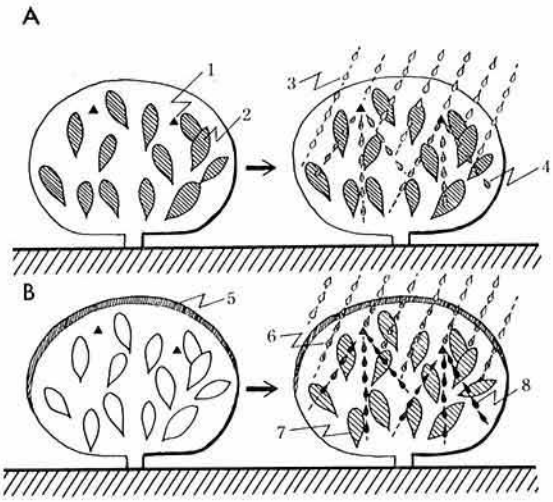

Fig. 1. Utilization of protective fungicide against the rain dispersal disease and the idea on fungicide application utilizing the active ingredient dispersed by rain

A. Utilization of protective fungicide
1. Pathogens
2. Leaf covered with the deposits of protective fungicide
3. Raindrop
4. Raindrop contained pathogens

B. Utilization of the active ingredient dispersed by rain
5. Fungicide applied on the surface of tree-crown
6. Raindrop contained the active ingredient of fungicide, (redistribdtion)
7. Leaf covered with the deposits of active ingredient, (effect as a protective fungicide)
8. Raindrop contained the active ingredient of fungicide and pathogens (effect as a contact or eradicant fungicide)

effective as a protective fungicide (c).

In these three actions, the most effective one is not always the same one for it varies by the kinds of used fungicide and applied diseases.

We have carried out some experiments on these three actions (a), (b) and (c) as described hereunder.

Redistribution of the active ingredient of fungicide sprayed over the plant and its efficiency as a contact or eradicant fungicide

1) Controlling action against the spore germination of Diaporthe citr.

In the first experiment, 500 ml of fungicide suspension was sprayed over the three ages nursery plant of the Satsuma orange (Unshu Mikan). After it has been dried, the nursery plant was exposed for three days to the artificial rainfall twice a day and each time, the rainfall was continued for 30 minutes (the amount of rainfall was about 20 mm). After five exposures to such artificial rainfall, the raindrops were collected from the surfaces of leaves and the germination of spores in these raindrops was detected. (Table 1)

The second experiment was also carried out with almost the same treatment but in this case, the raindrops were collected several times according to the passing time, and the germination of spores was also detected.

The sport germination test was carried out as follows; (1) we put a small amount of rainwater gathered from the leaves on a slide-glass, (2) then let fall down one drop of concentrated suspension of spore in it, and (3) kept them at 28°C for 24 hours.

As the results, the excellent protective fungicide against the spore germination, i.e., Difolatan (N-tetrachloro-ethylthio-4-cychlohexene-1.2-dicarboximide 80%) and copper oxyquinoline (8-hydroxyquinoline Cu salt 50%) revealed high efficiency in this experiment, and their strong controlling power on the spore germination showed sufficient effectiveness even after the exposure to a heavy rainfall of more than 1,000 mm.

Table 1. Effect of redistributed active ingredients of fungicides dispersed by rain on the spore germination of *Diaporthe citri* as a contact fungicide

Experiment No. 1

Chemicals	Spore germination
Control (no application)	40%
Basic copper chloride (Cu 44%) × 600	64
Copper oxyquinoline W.P. (50%) × 500	0
Bordeaux mixture 5-4 system	11
Delan W.P. (75%) × 500	43
Difolatan W.P. (80%) × 500	0

Experiment No. 2

Chemicals	Amount of rain mm					
	90	210	330	630	1170	1410
Control (no application)	19	22	17	36	45	37
Copper-oxyquinoline W.P. × 1,000	0	1	0	1	1	5
Bordeaux mixture 5–4 system	3	5	8	15	43	35
Delan W.P. × 500	0	1	1	2	49	56
Difolatan W.P. × 500	0	1	0	1	16	16

The figures in the table indicate the percentage of spore-germination

On the contrary, the Bordeaux mixture showed inferior controlling efficiency in spite of its superior quality as a protective fungicide.

2) Controlling action against the conidia formation of the citrus scab (Elsinoe fawcetti)

The inhibitory efficiency against the conidia formation of the citrus scab was examined by the hanging drop culture with a longitudinal section by hand of citrus scab lesion which was placed in the rainwater gathered from the leaves in the same way as mentioned above and kept at 25°C for 24 hours. The results are shown in Table 2.

The inhibitory efficiency against the conidia formation drastically declined after the rainfall of about 60 mm, but the available inhibi-

Table 2. Eradicative effect of redistributed active ingredient of fungicides dispersed by rain on the conidia-formation of the *Elsinoe fawcetti*

Chemicals	Amount of rain mm		
	20	60	100
Control (no application)	3.0*	3.0	3.0
Basic copper chloride (Cu 44%) × 600	2.0	3.0	3.0
Copper oxyquinoline W.P. (50%) × 500	0.5	1.0	3.0
Bordeaux mixture 5-4 system	2.0	3.0	2.5
Delan W.P. (75%) × 500	0.5	1.0	3.0
Difolatan W.P (80%) × 500	0	0	2.5

* Grades of conidia formation. Its maximum value was 3.0

tory efficiency still remained in Difolatan or in cooper oxyquinoline.

From these experiments, it was shown that the effective fungicide ingredient which was redistributed by rainfall can be made available not only as the contact fungicide but also as the eradicant fungicide against the citrus scab.

3) Redistribution of the active ingredient of fungicide sprayed over the plant and its efficiency as a protective fungicide

For this experiment we have prepared the net of 5-cm meshes, made of mixed cotton and staple fiber spun and the dimension of each used sheet of net is 60×180 cm.

These net sheets have been impregnated with 6 per cent solution of Difolation or Delan (2,3-dinitrilo-1,4-dithia-anthraquinone 75%) for 30 minutes and they have been dried in the air.

Three Satsuma orange trees of 20 ages have been subjected to the experiment on each fungicide. The experiment was started on June 10, the tree crowns were covered with the fungicide impregnated net, and 10 sheets of leaves which had not been touched directly to the covering net were collected five times from each tree at the interval of about two weeks from July 13.

Then a little piece of about 5 mm² was cut off from each leaf and were arranged in a petri dish with their upper surfaces upward.

One drop of the *Diaporthe citri* spore suspension prepared with decoction of citrus leaves was dropped on each leaf and all of them were kept at 28°C for 12 hours in a wet condition, and then the spore germination was examined.

The inhibitory efficiency against the spore germination was decided by the sum of the following grades with 10 pieces of leaf:

1=spores fully germinated with developed mycelia.

0.5=spores germinated slightly.

0=no germinated spores.

The results are shown in Table 3. It indicates that the spore could not well germinate even on the leaves which had not touched at all the fungicide-impregnated net and this inhibitory efficiency was maintained fairly well about two months after the netting operation on the tree crowns (the total amount of rainfall during this period was 370 mm).

Table 3. Protective effect of redistributed active ingredient of fungicides dispersed by rain on the spore germination of the *Diaporthe citri*

Treatment	Dates of leaf collection				
	13/VII	27/VII	11/VIII	25/VIII	8/IX
Difolatan netting	5.0*	4.0	2.5	8.0	10.0
Delan netting	3.0	1.0	5.0	9.0	7.0
Control (no chemical, no net)	10.0	10.0	10.0	10.0	10.0
Days after netting	33	47	62	76	90
Amount of rainfall (mm)	283.6	363.4	373.9	500.2	532.1

* Grades of spore germination. Its maximum value was 10.0

This proved that the active ingredients of fungicides (Difolatan or Delan) deposited on the net were redistributed gradually by the rainfall and were newly deposited on the surfaces of inner leaves of trees as protective fungicide.

The fungicide application method to make use of the active ingredient of fungicide redistributed by rainfall

By the results described above, it has been proved theoretically that the traditional laborious method of protective fungicide application is not necessary and the newly exploited method should be more available in the fields.

After several tests practicing this new technique, it was decided that the most practical method of fungicide application is to cover the tree crown with the concentrated suspension of fungicide. Then we carried out some practical experiments in the fields to prove this idea.

1) Experiment on the inhibitory efficiency of the fungicide against the citrus scab

This experiment was carried out on the orchard of early ripening Satsuma oranges of 6 ages. Each experimental area was set with 5 areas of orchard which contained about 140 trees and these plots were triplicated to get accuracy.

Twelve liters of the suspension of Difolatan or of concentrated Delan (22 times dilution) were used per 10 ares to cover the tree crown surfaces. As regards controlling the experiment, 540 liters of the 1,000 times diluted suspension of the same fungicides were applied sufficiently to cover the upper and lower surfaces of leaves. The results are shown in Table 4.

Table 4. Effect of concentrated fungicides applide on the tree-crown by the surface spraying method against the citrus scab. (Okitsu branch, Hort. Res. Sta. 1965)

Application & chemicals	Disease percentage		
	Spring shoot (2/Ⅶ)	Fruit (3/Ⅸ)	Summer shoot (29/Ⅹ)
Surface spraying with conc. (fungicide) 12*l*/10a			
Difolatan × 22	0.5	18.9	4.9
Delan × 22	1.9	49.2	9.8
Control spraying 540*l*/10a			
Difolatan × 1,000	2.8	23.5	4.6
Delan × 1,000	3.7	52.8	16.1

Satsuma oranges (early var.) of 6 ages were subjected, 1 plot = 5a (about 140 trees), the plots were triplicated and the fungicide had been sprayed 4 times. (26/Ⅲ, 16/Ⅳ, 7/Ⅴ, 6/Ⅵ)

Here, the tree crown covering method with the concentrated fungicide showed a more excellent efficiency than the traditional method. This application method of concentrated fungicide is more rational and more labor-saving because the amount of used suspension is not much, the working hour is short and it is practically without any special technique.

2) Experiment on the inhibitory efficiency of the fungicide against the citrus melanose

(1) Application of concentrated solution of the fungicide by the sprayer

In this experiment the Dithane and Ziman Dithane were used as the fungicides to the Satsuma orange trees of about 30 ages and the effects of tree crown coverage with the concentrated chemicals were compared with those of control treatment. The results are shown in Table 5.

Table 5. Effect of concentrated fungicides applied on the tree-crown by the surface spraying method against the citrus melanose (Okitsu branch, Hort. Res. Sta. 1970)

Applications & chemicals		Disease percentage of fruit (7/Ⅺ)
Surface spraying with conc. (fungicide)		
Ziman dithane × 300	20*l*/3 trees	7.1
Ziman dithane × 120	8*l*/3 trees	9.4
Dithane × 250	20*l*/3 trees	9.3
Dithane × 100	8*l*/3 trees	7.5
Control spraying		
Ziman dithane × 600	40*l*/3 trees	9.5
Dithane × 500	40*l*/3 trees	9.7
Control (no application)		43.0

Satsuma orange trees of 30 ages were subjected, 1 plot = 3 trees, fungicides had been sprayed 3 times. (11/Ⅵ, 10/Ⅶ, 3/Ⅸ)

The entire applicated fungicide revealed a high inhibitory efficiency against the disease, and no significant difference could be seen among all the examined groups. The effect of concentrated chemicals was the same as that of the traditional method.

(2) Fungicide application by sprinklers

This experiment was carried out on the Satsuma orange orchard of 15 ages. Four sprinklers were set at the four corners of each experimental area (12 m×12 m), and each of these sprinklers had sprayed to cover the plot area at an angle of 90°.

The fungicide used was Ziman Ditane (600 times dilution) and the sprayed solution amounted to 500, 750, 1,000 l per 10 a. Two control plots were set near by, one of them had been sprayed with the fungicide of 500 l/10a by the sprayer according to the traditional laborious method, and the other had no fungicide application. The results are shown in Table 6.

Table 6. The amount of fungicide sprayed by sprinkler and its deposition on the plant inrespect of the effect on the citrus melanose control (Okitsu branch, Hort. Res. Sta. 1971)

Method of spraying	Amount of sprayed fungicide per 10a	Fungicide deposits on the leaf surface		Disease percentage of fruit (10/XI)
		upper	lower	
Sprinkler	1,000 l	7.73	1.89	17.1
〃	750	8.17	1.60	15.2
〃	500	6.41	1.41	15.6
Control spraying	500			11.1
Control (no spraying)				45.6

The nozzle of sprinkler=M—IIp, pressure=3kg/cm².

The fungicide used was Ziman dithane, sprayed 3 times (11/VI, 13/VII, 26/VIII) with 600 times dilution

Every experimental plot applied with fungicide revealed high efficiency upon disease control compared with the non-applied plot, and any significant difference was not recognized between the sprinkler method and the traditional one. Therefore, from this result, it seemed that the traditional application of fungicide is not always necessary.

Summary

As the melanose and scab, the main citrus diseases in Japan, are rainfall dispersal diseases, the author has investigated the possibility of making use the active ingredients of sprayed fungicide deposits which were redistributed on the plants by rain, on the rationalization and labor-saving of fungicide applications for controlling the disease. The results are as follows:

Copper-8-quinolinolate and Difolatan had a strong protective fungicidal effect on the pathogenic fungi and the active ingredient of these two fungicides redistributed by rainfall revealed not only the effect as the contact fungicide against the pycnospore germination of melanose but also the inhibitory efficiency against the conidia formation of scab as the eradicant fungicide.

Difolatan and Delan were recognized as protecting the plants from pathogens by covering them with the sprayed fungicide deposits. And their effects did not quickly disappear even after ample rain.

Consequently, it is not necessary for these fungicides to form the direct cover of sprayed deposits on plants as the traditional idea for protective fungicide applications but it could be practically useful to deposit the fungicide on the surfaces of the tree crown and let the rain redistribute them on the plants.

The most suitable and promising procedure for this purpose is the "surface spraying" method (a small amount of concentrated fungicide should be applied to the top of plant only), and against the melanose, Ziman Dithane, Dithane, Delan and copper oxyquino line are suitable. Against the citrus scab, Difolatan and Delan are suitable.

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