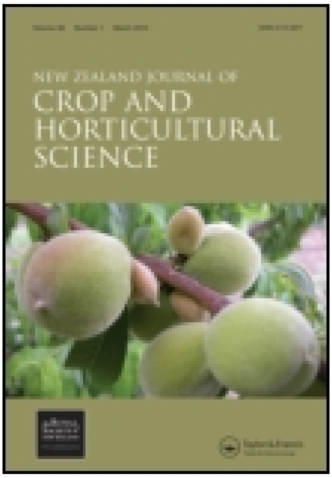

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RESEARCH ARTICLE

Fungicide use in processing tomatoes in New Zealand

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Fungicide use in processing (field) tomatoes from 1995 to 2009 on the East Coast of the North Island of New Zealand has been documented using data extracted from growers' annual spray diary records. During this period, 26 different fungicides—some of which are also used as bactericides—were used by growers to control a range of plant diseases. The number of fungicide applications to each crop ranged from 10 to 28, with fewer applications in very dry seasons. Inorganic copper (mainly copper hydroxide), applied to control both bacterial and fungal diseases, was the most commonly used material, followed by chemicals in the dithiocarbamate, chloro-nitrile and pyridinamine groups. These four multi-site 'protective' fungicide groups accounted for 90% of all disease-control products used during the 15-year period. Site-specific fungicides (e.g. benzimidazoles, phenylamides, dicarboximides, dimethomorph and strobilurins) were used much less frequently. The exclusive use of fungicides at risk from fungicide resistance development (most commonly the site-specific fungicides) was generally avoided and therefore overall risk of the development of fungicide resistance in processing tomatoes in Hawke's Bay is believed to be low. This study demonstrated that the number of fungicide applications per crop has increased about two-fold since 1995 while, during the same period, insecticide applications decreased.

Keywords: fungicide and bactericide use; processing tomatoes; fungicide resistance management; pesticide use records

Introduction

Processing, or field, tomatoes (*Solanum lycopersicum* L.) in New Zealand are grown mainly in Hawke's Bay and, to a lesser extent, Poverty Bay in the East Coast region of the North Island (approximately 177°E and 39°S). About 1000 ha are grown annually and the crop is machine harvested for local processing. Pest and disease control is usually regulated by the local processing company and, from 1995, applications of pesticides have been based on information from crop scouts using methods developed in an integrated pest management (IPM) programme (Herman 1995). The influence of that programme on insecticide use over time has already been examined (Cameron et al. 2009), and the same pesticide use database has provided the information to document fungicide use in this paper.

Research to support the development of the IPM programme for insect pests and diseases in processing tomatoes was initiated in 1989, mainly to reduce pesticide use. In addition to providing economic gains, the IPM programme aimed to reduce risks of pesticide (insecticide and fungicide) resistance, to increase natural pest controls, and to respond to public and market demands for more sustainable or environmentally

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friendly crop production (Campbell 1996). Disease control concentrated on the use of cultural control techniques (e.g. field selection, time of planting, crop rotation, clean cultivation), appropriate fungicide choice and application frequency based on tomato diseases noted during routine scouting. Access to pesticide use data from East Coast processing tomato growers from 1995 to 2009 provided an opportunity to document and analyse fungicide and bactericide use and to identify trends in the selection and quantity of fungicides used.

Currently, 26 products comprising 15 active ingredients (ai) are registered in New Zealand to control diseases of outdoor tomatoes (Young 2009) (Table 1). In the present paper we use the term fungicide to include those products (specifically the copper compounds) with both fungicidal and bactericidal properties. Fungicides were grouped according to the way in which fungal pathogens develop resistance to them (cross-resistance groups), rather than by the chemical structures of active ingredients (Beresford & Vanneste 2005). Fungicides used to control plant pathogens are mostly multi-site inhibitors with non-specific modes of action that are protective against broad spectra of diseases. Despite their widespread use, resistance of target pathogens to these compounds is rare (Beresford 2005). Non-specific fungicides used on crops of processing tomatoes in New Zealand include copper (copper hydroxide and copper oxychloride), dithiocarbamates (mancozeb), thiram, chlorothalonil and fluazinam (Table 1).

Since the introduction of site-specific fungicides (a fungicide affecting a single well-defined

Table 1 Fungicides and bactericides registered in New Zealand for control of diseases in processing tomato crops (adapted from Young 2009).

Fungicide chemical group	Active ingredient	Diseases controlled
DMI (demethylation inhibitor)[2]	Triforine	Leaf mould
MBC (methyl benzimidazole carbamates)[2]	Carbendazim Thiophanate methyl	*Sclerotinia Botrytis*, *Sclerotinia*
Chloro-nitrile[1]	Chlorothalonil	*Botrytis*, early blight, late blight
Chloro-nitrile[1] + MBC[2]	Chlorothalonil + thiophanate methyl	*Botrytis*, late blight, *Sclerotinia*
Chloro-nitrile[1] + phenylamide[2]	Chlorothalonil + metalaxyl	Early blight, late blight
Dicarboximide[2]	Procymidone	*Botrytis*, *Sclerotinia*
Dithiocarbamate[1]	Mancozeb	Early blight, late blight, leaf mould, Septoria leaf spot
Disulphide[1]	Thiram	Early blight, late blight, leaf mould, Septoria leaf spot
Pyridinamine[1]	Fluazinam	*Botrytis*, early blight, late blight, *Sclerotinia*
Inorganic copper[1]	Copper ammonium acetate, copper hydroxide, copper oxychloride, cuprous oxide	Bacterial diseases, early blight, late blight, Septoria leaf spot
Phenylamide[2] + dithiocarbamate[1]	Metalaxyl + mancozeb	Early blight, late blight
Qo inhibitor (QoI)[2]	Azoxystrobin	Early blight, late blight, black mould

[1] Fungicide activity not site-specific.
[2] Fungicides with site-specific activity.
QoI, quinone outside inhibitors.

biochemical process within the pathogen) in the late 1960s, strategies to avoid resistance by some fungal pathogens to these fungicides have become important considerations in the design of crop protection programmes (Beresford & Vanneste 2005). The repeated use of 'at-risk' (site-specific) fungicides may lead to the selection of fungicide-resistant strains from the pathogen population. Fungicide groups and their respective compounds that have experienced fungicide resistances both overseas and in New Zealand (Martin et al. 2005) include benzimidazoles (e.g. benomyl, carbendazim, and thiophanate-methyl), phenylamides (e.g. metalaxyl), dicarboximides (e.g. procymidone, iprodione and vinclozolin), and quinone outside inhibitors (QoIs) (e.g. azoxystrobin), all of which are registered for use on tomatoes (Table 1).

This study details the use of fungicides used on processing tomato crops on the East Coast of the North Island of New Zealand. The study examines changes in fungicide use over time (1995–2009), compares multi-site and site-specific fungicide groups, and discusses and reasons for the continuing high rates of fungicide use compared with insecticide use in processing tomatoes.

Methods

Pesticide use records

Spreadsheets prepared from a database of growers' spray diary records for processing tomatoes, over the period 1995 to 2009, were the principle sources of information for this report. All crops were grown on the East Coast of the North Island with four crops in the Gisborne region (one in 2001 and three in 2004), and the remainder in the Hawke's Bay. The data comprised fungicide use by 109 growers (farms) on a total of 586 tomato crops (fields or blocks) with data taken from 47 to 67 crops per year. The spreadsheets (Microsoft™ Excel pivot tables) contained individual pesticide use data on separate fields, and details such as the product (trade name), active ingredient rate (kg ai/ha), water rate, season and tomato cultivar. Each product was identified by a unique product number, and the active ingredient(s) were listed by the CAS Registry Number (HortPlus 2009) and trends in the number of applications per crop over years were analysed using regression statistics from Microsoft Excel 2010. When fungicides were applied as a mixture, for example ManKocide® DF, it was recorded as two applications—in this example as one of copper hydroxide and one of mancozeb.

Crops

The crops grown during the period for which spray diaries were analysed were transplanted in the field as seedlings, using cultivars such as 'Morse', 'Nortico', 'H225' and 'H3402', and were grown without support structures. Irrigation was mainly applied through large overhead sprinkler 'guns'. Tomato plants were treated with the fruit ripening promoter Ethephon (2-chloroethylphosphonic acid), and crops were machine-harvested, producing 70–100 tonnes/ha. Tomato fields varied in size from 5 to 20 ha with the total regional production of processing tomatoes ranging from 500 to 1000 ha per year, averaging approximately 600 ha per year. Weather data from the National Institute of Water and Atmosphere, Flag Range Road, Hastings site in Hawke's Bay were obtained from the HortPlus™ website http://www.hortnet.co.nz/weather-data.htm to identify seasonal variations in weather.

Diseases

Thirty-six fungi and 10 bacteria have been recorded as pathogens of tomato in New Zealand (Pennycook 1989). The main fungal diseases and pathogens of processing tomatoes in Hawke's Bay are black mould (*Alternaria alternata*), grey mould (*Botrytis cinerea*), leaf mould (*Fulvia fulva*), corky root (*Pyrenochaeta lycopersici*), damping off (*Phytophthora* spp., *Pythium* spp. and *Rhizoctonia* spp.), early blight (*Alternaria solani*), fusarium wilt (*Fusarium oxysporum*), late blight (*Phytophthora infestans*), phytophthora root rot (*Phytophthora* spp.), sclerotinia rot (*Sclerotinia* spp.), southern blight (*Sclerotium rolfsii*) and verticillium wilt (*Verticillium* spp.) (Herman 1995). The main bacterial diseases are bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*), bacterial speck (*Pseudomonas syringae* pv. *tomato*) and bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) (Herman 1995).

Crop monitoring

The rigour of crop monitoring to identify and record the incidence of pests, diseases and weeds in processing tomato crops varied widely among growers and years. Prior to 2000, crops were monitored by growers or representatives from local horticultural suppliers but it was not done in a systematic manner. Recommendations for systematic monitoring of diseases in tomatoes started in 1995 in association with a new IPM programme implemented for insect pests (Herman 1995). From 2000, a commercial crop monitoring service was started in the Hawke's Bay region (Crop Monitoring Services, Fruitfed Supplies) using methods outlined in the tomato IPM programme. Although the monitoring system used action thresholds for insecticide applications for key insect pests, no action thresholds were established for tomato diseases, and no weather-based disease forecasting methods were used. During routine crop scouting, the incidence, severity and prevalence of diseases present in each surveyed field were noted. These notes were not an accurate record of the diseases present and were not recorded in the database, therefore this information is not available. Individual growers used this information to refine their fungicide programmes in those crops, i.e. product choice and timing (T. Herman, pers. comm.).

Results

The mean number of fungicide applications per crop per year in the Hawke's Bay–Gisborne region between 1995 and 2009 ranged from 10.3 in 1997–98 to 27.7 in 2007–08 (Fig. 1). These data showed a significant upward trend ($P < 0.001$) in fungicide use over the 15 years analysed. The relatively low number of applications in 1997–98 and 1998–99 was associated with hot, dry El Niño conditions (Wratt et al. 2008), where rainfall from October 1997 to

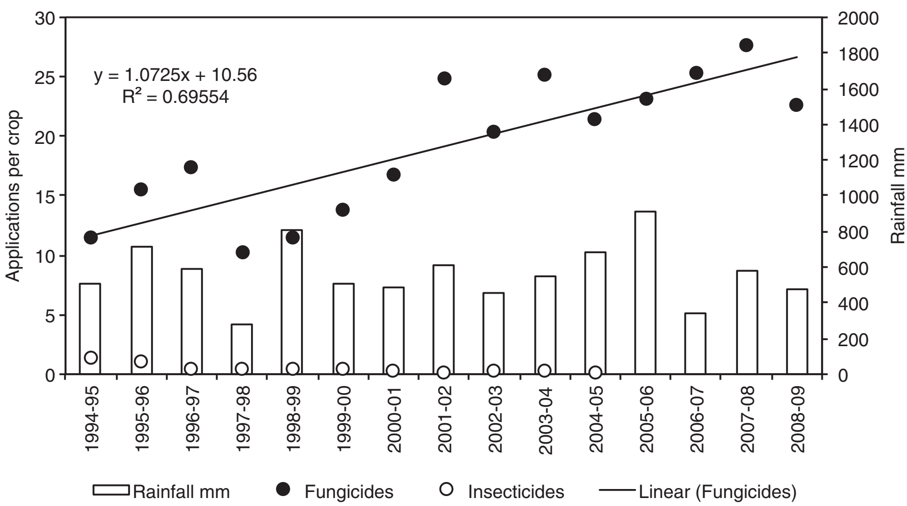

Figure 1 Applications per crop of fungicide and bactericide (copper) applied annually to processing tomatoes in the Hawke's Bay and Gisborne regions, and rainfall (mm) from October to April between 1995 and 2009, with comparative insecticide data from Cameron et al. (2009).

April 1998 totalled 274 mm, the lowest for the 15-year period (Fig. 1). This low rainfall pattern continued into the 1998–99 season except for a period of rain in mid-January 1999 which increased the seasonal total. Although there were fewer fungicide applications in these two seasons, there was no relationship over years between fungicide use and rainfall (Fig. 1). For example, from 2002 onwards, seasons that received >550 mm of rain between October and April occurred slightly more often (five seasons) than in seasons prior to 2001 (three seasons), but there was no correlation ($R^2 = 0.008$) between the number of fungicide applications and rainfall.

Inorganic copper (mainly copper hydroxide), used to control both fungal and bacterial diseases, was the most commonly applied active ingredient, followed by mancozeb (dithiocarbamate), chlorothalonil (chloro-nitrile) and fluazinam (pyridinamine) (Fig. 2). These four active ingredients, all 'protective' in action, accounted for 90% of all fungicide products used from 1995 to 2009, and that relative proportion of the total fungicide use was similar for all 15 years, although fluazinam was only used after 1996. Thiram (disulphide) was the least-used of the five multi-site group fungicides, being utilized in only 6 of the 15 years, and accounting for only 129 (0.8%) of the total 16,228 fungicide applications that were made during the study period.

The average number of applications of multi-site fungicide applications applied annually increased significantly ($P<0.001$) between 1995 and 2009 ($y=1.041x+9.14$; $R^2=0.79$) and varied according to active ingredient (Fig. 2). Copper and mancozeb were used on more occasions than the other multi-site group fungicides—except in 1995, when mancozeb was ranked behind chlorothalonil. The mean number of copper and mancozeb applications per crop per season increased significantly after 2001 with three to six applications of copper and mancozeb per crop in each of the years from 1995 to 2001, compared with seven to 10 applications per crop from 2002 to 2009 (Fig. 2). This was partly due to the introduction of Mankocide® DF (a combination of copper hydroxide and mancozeb) in November 2001. Mankocide® DF immediately became popular with growers in Hawke's Bay as it targeted both bacterial and fungal diseases. Chlorothalonil, fluazinam and thiram were usually applied between one and four times a year throughout

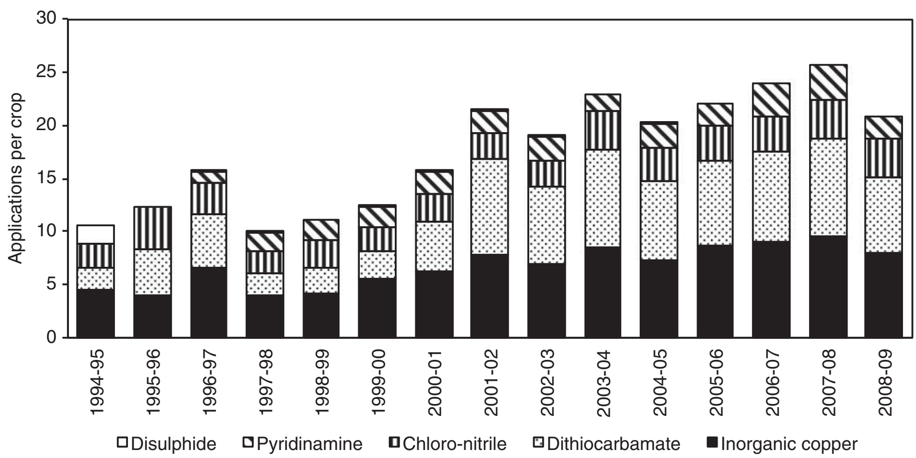

Figure 2 Applications per crop of multi-site fungicide and bactericide (copper) applied annually to processing tomatoes, grown in the Hawke's Bay and Gisborne regions between 1995 and 2009. For total applications per crop over years (x), $y=1.041x+9.14$; $P<0.001$; $R^2=0.79$

the whole 15-year period, except that no thiram use was recorded during the last 4 years.

Overall, site-specific fungicides from groups with site-specific activity (benzimidazoles, phenylamides, dicarboximides, dimethomorph and strobilurins [QoIs]) were used much less frequently than protective fungicides (Fig. 3). Compared with a total of 16,228 applications of all fungicides carried out during the study period, the relatively low use of site-specific fungicides in processing tomatoes is evident. Phenylamides and dicarboximides were the most used site-specific fungicides, with 583 (3.6% of all applications) and 560 (3.5%) applications, respectively, during the 15-year period. Very few applications of QoI fungicides (73 applications), dimethomorph (46) and benzimidazoles (37) were made. Applications of site-specific fungicides per crop showed no trend over time ($P = 0.6$) and were more variable (Fig. 3) than non-site-specific fungicides. Numbers of applications were particularly low during the drier seasons of 1997–98 and 1998–99 (Figs. 2–3). The dicarboximides, vinclozolin and procymidone, used to control *Sclerotinia* and *Botrytis*, were the only site-specific fungicides used in all of the years studied, and their use was lowest in the dry period from 1997 to 1999. A QoI fungicide (azoxystrobin) was first used in 1999–2000 to control early blight. Forty-five applications of azoxystrobin were made that year in Hawke's Bay, but this 'new' fungicide was used sparingly thereafter (< 10 applications per year for the entire region). The average number of applications of the site-specific groups of fungicides ranged annually from 1 to 2.1 applications per crop per season.

Discussion

The database of growers' spray diary records compiled from all Hawke's Bay and Gisborne processing tomato growers between 1995 and 2009 allowed an analysis of total fungicide (and bactericide) and comparisons between pesticide groups. These data provide a baseline against which future pesticide use trends can be measured. The analysis has shown that fungicide use in New Zealand was high (10–28 applications per crop) in comparison with the 10–15 applications per crop in fresh market tomatoes in Alabama (Sikora et al. 2002) and the eight to 14 applications per crop in processing crops in California (NASS 2007). This high use rate in New Zealand is consistent with the recommendation (Young 2009) of multiple fungicide applications at 7–14-day intervals to processing tomatoes. Dithiocarbamates and copper

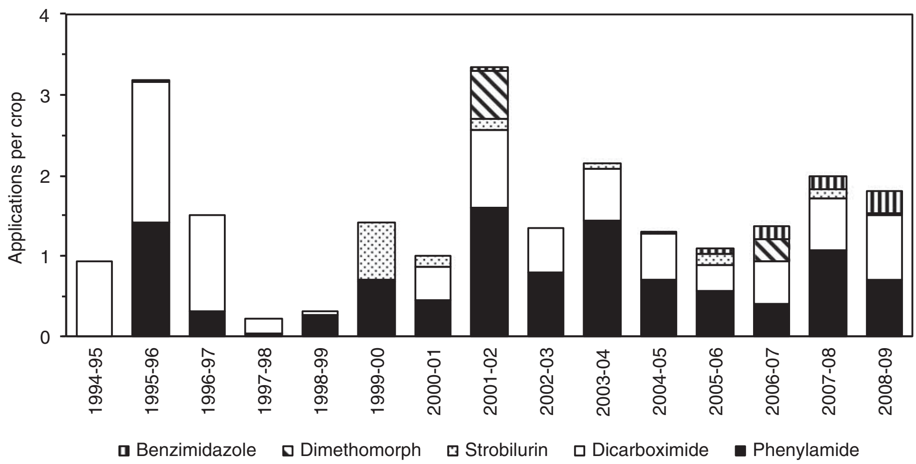

Figure 3 Applications per crop of the site-specific group of fungicides and bactericides (copper) applied annually to processing tomatoes grown in the Hawke's Bay and Gisborne regions between 1995 and 2009.

remained the most important fungicide classes because growers considered that calendar applications of these multi-site group compounds were the most cost-effective option to control diseases caused by a wide range of bacterial and fungal pathogens (Chaurasia 2005; Damicone 2009; Fernández-Northcote et al. 2000).

Whereas applications of fungicides have generally increased since 1995, insecticide applications have decreased (Fig. 3). This decline has been attributed to the implementation of IPM procedures such as crop monitoring and pest action thresholds (Cameron et al. 2009). The general trend of increasing annual fungicide use indicates that the lower number of spray operations initiated by the reduced need for insecticides did not influence decisions on disease control. In contrast to reports on changes in insecticide use, no report on trends in fungicide use in IPM programmes for processing tomatoes could be found. For example, IPM programmes in New Zealand (Herman & Cameron 1993), Australia (McDougall 2006), Mexico (Trumble & Alvarado-Rodriguez 1993) and Brazil (Picanço et al. 2007) emphasize reductions in insecticide use even though diseases may be key causes of production losses (Picanço et al. 2007). Where pesticide use has been analysed in experimental IPM programmes, savings resulting from reduced fungicide use have approximately equalled savings associated with reduced insecticide use (Sikora et al. 2002). Although trends in fungicide use have not often been reported in IPM studies, they are documented in some pesticide use reporting systems (California Department of Pesticide Regulation 2006; NASS 2007). Over a similar period to our study (1994–2006), the California databases report decreased use of copper compounds and mancozeb in dry seasons.

Reductions in the use of fungicides on tomato in North America and Australia have been associated with the use of forecasting techniques that identify disease risk periods based on weather measurements. For example, Madden et al. (1978), Minchinton et al. (2006) and Sikora et al. (2002) used computer programs such as TOMCAST to predict the need for fungicide applications for early blight, Septoria leaf spot and anthracnose fruit spot. In New Zealand, where vegetable production areas tend to be wetter and have less predictable weather, forecasting is considered to be less useful than in continental climates (Cameron 2007). For example, in potatoes, Hartill & Young (1985) considered that when susceptible cultivars of potatoes are grown in humid climates, growers must rely almost entirely on fungicide applications to control late blight. In addition, Australian and Californian growers often reduce leaf wetness by using buried drip tape rather than overhead sprinklers for irrigation. In 1994, TOMCAST was used in processing tomatoes in Hawke's Bay (Gleason et al. 1995). However, while predictions of disease were accurate, the model simply confirmed that the environmental conditions were not conducive to a reduction in fungicide applications and the use of this warning system has not continued (A. Hodson, unpubl. data).

The relatively low use of site-specific fungicides in processing tomatoes in Hawke's Bay is attributed partly to pesticide resistance management recommendations made by the New Zealand Committee on Pesticide Resistance (Beresford et al. 2009), and also to their cost compared with multi-site fungicides. Procymidone is the only dicarboximide currently registered for use on processing tomatoes in New Zealand following the deregistration of vinclozolin in 1996. In addition to agronomic factors, strategies to help prevent the development of fungicide resistance problems have focused on limiting the number of applications per season and tank-mixing them with protective fungicides (Beresford & Vanneste 2005). The analysis of grower spray diaries confirmed that the exclusive use of at-risk fungicides is generally avoided, so the overall risk of fungicide resistance problems in processing tomatoes in the Hawke's Bay–Gisborne region is small.

This study demonstrates that fungicides are used far more often than insecticides and, unlike insecticides, the annual number of applications of fungicide in processing tomatoes in the Hawke's Bay–Gisborne region is increasing. This suggests that current field observations of disease incidence and knowledge of environmental conditions do not identify opportunities to reduce applications of fungicides. The exception to this pattern was the decline in fungicide use in 1998 (and early 1999) when extreme hot, dry, weather prevailed during the El Niño season (Wratt et al. 2008). More recently (2002–09), there have been no significant climate-related reductions in application of fungicides. It is unclear if this is because disease incidence is high or if crop monitoring is insufficient to identify opportunities for reductions. Studies of weather-induced infection periods in relation to disease incidence are needed to determine if it is possible to use disease forecasting systems to reduce fungicide use. It is possible that reductions in fungicide (and bactericide) use in processing tomatoes, as well as other vegetable crops, are limited by the generally wet and mild climate in New Zealand. The economic cost of disease control failure may be too high to justify the small reductions in numbers of fungicide and bactericide applications that disease prediction systems would achieve. However, insufficient research has been carried out to fully determine whether the fungicides being applied to control diseases are being used in optimal ways.

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