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Management of Lettuce Downy Mildew with Fungicides

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Incited by the obligate parasite *Bremia lactucae*, downy mildew is one of the most devastating diseases of lettuce (*Lactuca sativa* L.) worldwide. Attempts to manage this fungal disease using host-plant resistance have frequently failed due to the development of new races of the pathogen. Therefore, chemical control is of the utmost importance in humid areas where environmental conditions are very favorable for disease development. Numerous fungicide field trials have been conducted in south Florida on both muck and sandy soils over the past several years with definitive results. Of currently registered compounds, mandipropamid (Revus) and fenamidone (Reason) have repeatedly provided the highest levels of control, with no significant difference between the two. Presidio (fluopicolide), dimethomorph (Forum), dimethomorph plus ametoctradin (Zampro), cyazofamid (Ranman), and propamocarb (Previcur Flex) have also provided significant control. With regard to new chemistries, the experimental compound V-10208 has looked very promising when applied foliarly. As a group, the aforementioned fungicides represent a wide array of different modes of action, meaning that they may be alternated or tank-mixed with other fungicides in a program to prevent fungicide resistance. This is indeed fortunate, as lettuce downy mildew has developed insensitivity in the past. With potassium phosphites and the broad spectrum EBDC fungicide mancozeb holding lettuce registrations, lettuce growers now have a wide selection of fungicides for managing this important disease. However, prevention and cultural practices, such as destroying old crop debris, should also be part of the program.

Florida currently ranks third nationally in the production of lettuce, trailing only California and Arizona in acreage, but at a considerable distance (Anonymous, 2012). Although Florida's lettuce acreage declined substantially during the 1990s, it has since recovered and again exceeds over 10,000 acres. Over 95% of Florida's commercial lettuce production is located on the histosols of the Everglades Agricultural Area centered near Belle Glade, with the bulk of the acreage being planted to a handful of varieties (Mossler and Dunn, 2011). Once dominated by iceberg or head lettuce, the domestic fresh market is now divided nearly 50/50 into head and Romaine lettuce types. Downy mildew, incited by the fungal parasite Bremia lactucae Regel, is widely considered to be the most important foliar disease of lettuce worldwide (Koike et al., 2007). One recommended management strategy for this disease has been the use of resistant varieties (Davies, 1994; Lebeda and Zinkernagel, 2003). However, host-plant resistance has not been stable due to the large number of B. lactucae isolates or pathotypes, some with uncharacterized genetics (van Bruggen and Scherm, 1997). To complicate matters, fungicide insensitivity has also been documented, particularly to the phenylamide fungicide metalaxyl, a former industry standard (Crute, 1987; Raid et al., 1990; Schettini et al., 1991). More recently, fosetyl-Al insensitive strains have been reported in California (Brown et al., 2003). Such difficulties mandate the use of integrated management programs utilizing fungicides offering diverse modes-of-action. Since the year 2000, a number of new fungicides targeting the Oomycetes, the class of fungi to which downy mildew belongs, have come to the market or are being considered for registration. It was the objective of these studies to investigate a select number of these for potential use in Florida for lettuce downy mildew control.

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Materials and Methods

Four fungicide trials were conducted during spring 2011 to evaluate the efficacy of various fungicides, alone and in combination, for their control of lettuce downy mildew. The first two experiments were conducted on a highly susceptible unnamed variety of sword leaf lettuce cultivated on sandy soil located 25 miles south of Clewiston, FL. The soil was classified as Immokalee fine sand with a soil pH of 7.4 and was fertilized according to soil test recommendations prior to planting. Lettuce was direct-seeded in four rows with a 10-inch row spacing on top of 8-inch raised beds formed on 6-ft centers on 20 Nov. 2010 and 28 Dec. 2010 for the first and second experiments, respectively. The crop was densely planted for leaf production, and final plant spacing within the row was approximately 1 inch. These sand location experiments used a randomized complete-block design with four replications of nine and ten treatments, respectively. Lettuce beds receiving fungicide treatment were bordered on each side by lettuce beds that were left unsprayed. These served as a natural source of inoculum. Experimental units consisted of 4-row, 10-ft bed sections, separated on the end by 5-ft alleys. Chemical treatments were applied using a CO_2 backpack sprayer. Two passes were made over each experimental unit, with the hand-held boom spraying two lettuce rows per pass. The boom was equipped with three TeeJet 11003 flat-fan nozzles (TeeJet Technologies, Springfield, IL). Foliar sprays were applied at 30 psi, delivering a final spray volume of 62 gal/acre. A nonionic surfactant (Induce) was added to all fungicide mixtures at a rate of 0.125% volume/volume.

The third and fourth experiments were situated on the organic soils of the Everglade Agricultural Area and were planted to iceberg lettuce of the mildew susceptible variety 'Belle Glade'.

Located at the University of Florida's Everglades Research and Education Center, the soil was classified as Pahokee muck with a soil pH of 7.2. Lettuce at this site was direct-seeded on 6 Jan. 2011 in double rows located atop 6-inch raised beds formed on 3-ft centers. Both experiments were hand-hoed for weed control and thinned to produce a plant spacing of 12-inches within the row, the commercial standard. Experimental units in the third and fourth trials consisted of 2-row, 15-ft bed sections, separated on the ends by 5-ft alleys. These too were arranged in randomized complete blocks with four replications. Fungicide applications were made as above, with a single pass being made directly over the double rows. Soil types, planting dates, plant spacing information, and fungicide application details are listed in Table 1 for all four trials.

Downy mildew severity was visually assessed on a percentage basis by examining the entire canopy in a 2-ft^2 section of bed at two randomly selected locations per experimental unit on 10 and 15 Jan. for Trial 1, 1 and 11 Feb. for Trial 2, and 1 and 11 Mar. for Trials 3 and 4. Severity ratings represent the percentage of foliage visibly displaying chlorosis or necrosis. In the experiments on iceberg lettuce (Trials 3 and 4), percentages of marketable heads were obtained by harvesting 20 heads of lettuce per experimental unit and grading them for marketability. Heads were considered unmarketable if downy mildew symptoms were evident on foliage interior to the innermost wrapper leaf. Such infections cause rapid deterioration in shipment and storage following harvest. Observations were also made for the presence of phytotoxicity 48 h following each application.

A complete listing of fungicides tested, listed by common and trade names, formulation, and manufacturer, is presented in Table 2. Compounds are listed alphabetically by common name. In the first experiment on sand (Trial 1) eight fungicides used individually for downy mildew control were investigated. In the second experiment on sand (Trial 2) nine fungicides used in alternation with a potassium phosphite compound were examined. Phosphites belong to a class of compounds now commonly recognized for their activity against a wide range of downy mildews, including lettuce (Raid, 2009, 2011). In this trial, it is worth noting that the phosphite compound (Nutri-Phite Magnum 2–40–16) was used for the first, third, and fifth applications, and that the respective alternating fungicide treatments were applied for the second and fourth applications. In a third experiment (Trial 3), located on muck soil near Belle Glade (Trial 3), four of these fungicides were examined, alone at the full labeled rate, and in tank-mixture at ¾ rates with potassium phosphite (Nutri-Phite Magnum 2–40–16) at a reduced rate. And lastly, in a fourth experiment (Trial 4), the efficacy of a promising new numbered compound from Valent, V-10208, was investigated, alone and in combination or alterna-

Table 1. Soil type, location, lettuce type, planting dates, planting specifications, and spray specifications for four lettuce downy mildew fungicide trials conducted during spring 2011.

	Trial 1	Trial 2	Trial 3	Trial 4
Soil type	Sand	Sand	Muck	Muck
Location	Clewiston	Clewiston	Belle Glade	Belle Glade
Lettuce type	Sword Leaf	Sword Leaf	Iceberg	Iceberg
Planting date	20 Nov. 2010	28 Dec. 2010	6 Jan. 2011	6 Jan. 2011
Bed width	4 ft	4 ft	1.5 ft	1.5 ft
Rows per bed	4	4	2	2
Row spacing	10 inch	10 inch	12 inch	12 inch
In-row spacing	1 inch	1 inch	12 inch	12 inch
Plot size	10 ft (4 rows)	10 ft (4 rows)	15 ft (2 rows)	15 ft (2 rows)
Spray interval	7 days	5–7 days	7 days	7 days
Application no.	4	5	3	3
Spray volume	62 gal/acre	62 gal/acre	60 gal/acre	60 gal/acre

Table 2. Common chemical name, trade name, formulation, chemical manufacturer, and FRAC grouping of the fungicides used in these trials.

Common name	Trade name	Formulation[z]	Manufacturer	FRAC group[y]
Chlorothalonil + Potassium phosphite	Catamaran	F	Luxemburg	M5 & 33
Copper hydroxide	Kentan	DF	Isagro	M1
Cyazofamid	Ranman	SC	FMC	21
Dimethomorph	Forum	SC	BASF	40
Dimethomorph + Ametoctradin	Zampro	SC	BASF	40 & 45
Fenamidone	Reason	SC	Bayer	11
Fosetyl-Al	Aliette	WDG	Bayer	33
Fluopicolide	Presidio	F	Valent	43
Mandipropamid	Revus	SC	Syngenta	40
Maneb	Maneb	F	Griffin	M3
Mefenoxam + Chlorothalonil	Ridomil Bravo	F	Syngenta	4 & M5
Potassium phosphite (2–40–16)	Nutri-Phite	SL	Biagro	33
Propamocarb	Previcur Flex	EC	Bayer	28
Experimental unknown	V-10208	SC	Valent	M, U

[z]Fungicide formulation: DF, dry flowable; EC, emulsifiable concentrate; F, flowable; SC, soluble concentrate; SL, soluble liquid; WDG, wettable dispersible granule.

[y]FRAC grouping represents the mode-of-action as determined by the Fungicide Resistance Action Committee (Anonymous, 2011).

tion with the companion fungicide fluopicolide. It is important to note that some of the fungicide treatments described herein are experimental and are therefore not currently registered for legal use on lettuce in Florida. Their use in these trials is for the sake of comparison and does not constitute an endorsement.

Results and Discussion

Favored by cool to moderate temperatures and long periods of leaf wetness (Scherm et al., 1995), environmental conditions were very conducive for downy mildew development. Disease was severe in all four trials, providing for a good evaluation of the relative efficacy of the various treatments. In Trial 1 on sword leaf lettuce, all fungicide treatments resulted in significantly lower downy mildew severities than the untreated check (Table 3). Fenamidone and mandipropamid provided the most efficacious control, with these two compounds being significantly better than all other treatments as determined by Fisher's Least Significant Difference Test at the $P < 0.05$ significance level. Copper hydroxide provided the least amount of control of all fungicides tested, with the remaining treatments being intermediate. In this particular trial, disease severity averaged 86% in the untreated check and although yield was not determined, it was readily apparent that only lettuce in the top two treatments would have been considered marketable. All other treatments displayed considerable leaf necrosis due to the disease.

Featuring eight fungicides used in alternation with potassium phosphite, disease pressure in Trial 2 on sandy soil was somewhat less than that which occurred in the first trial, topping out at 62% severity in the untreated check (Table 4). Again, all fungicide treatments provided for significant reductions in disease. As in Trial 1, mandipropamid and fenamidone performed well, as did alternations with propamicarb and a mefenoxam/chlorothalonil premixture.

In Trial 3, conducted on iceberg lettuce, four fungicides (mandipropamid, dimethomorph, maneb, and fenamidone) were investigated alone and in tank-mixture with potassium phosphite. Applied on a 7-d schedule, all treatments provided for significant reductions in disease severity with mandipropamid, maneb, and fenamidone all providing significantly better control than dimethomorph (Table 5). Although there were no significant differences in comparing each fungicide alone with its respective potassium phosphite tank-mixture, disease severities with the tank-mixtures were consistently lower than with each respective fungicide applied solo. Likewise, the percentages of marketable heads were consistently higher with tank-mixtures, although not significantly so. Using rates that were 75% of the high labeled rates, tank-mixtures with a phosphite may prove to be an economical alternative to full labeled rates, as well as serving as a resistance management tool. However, the relatively low level of control observed in Trial 3 with the phosphite alone should be a warning to growers not to rely solely on this class of compounds.

The experimental Valent compound, V-10208, provided significant downy mildew control in Trial 4 (Table 6), comparable to that of fluopicolide and mandipropamid, which are already registered. Mixtures or alternations at full and ¾ rates showed no significant difference and displayed no phytotoxicity, suggesting that this experimental compound, reportedly displaying a unique

Table 3. Fungicide treatment, rate of product per acre, and downy mildew severity on indicated dates in Trial 1 conducted on sword leaf lettuce on sand.

Fungicide treatment	Rate/acre	% Downy mildew severity 10 Jan	15 Jan
Untreated check	---	85 a[z]	86 a
Mandipropamid	8 fl oz	5 ef	9 f
Fenamidone	8 fl oz	1 f	2 f
Propamocarb	2 pt	13 d	28 cde
Dimethomorph + Ametoctradin	14 fl oz	20 c	34 c
Chlorothalonil + Potassium phosphite	4 pt	13 d	23 de
Potassium phosphite	3 pt	9 de	20 e
Fosetyl-Al	4 lb	19 c	32 cd
Copper hydroxide	1.25 lb	59 b	65 b

[z]Numbers in a column followed by a letter in common are not significantly different as determined by Fisher's LSD, $P \leq 0.05$.

Table 4. Fungicide treatment, rate of product per acre, and downy mildew severity on indicated dates in Trial 2 conducted on sword leaf lettuce on sand.

Fungicide treatment (application no.)[z]	Rate/acre	% Downy mildew severity 1 Feb	11 Feb
Untreated check	---	54 a[y]	62 a
Dimethomorph + Ametoctradin (2,4) alt. w/Pot. phos (1,3,5)	14 fl oz/3 pt	1 d	16 bc
Mandipropamid (2,4) alt. w/Pot. phos. (1,3,5)	8 fl oz/3 pt	0 d	5 f
Cyazofamid (2,4) alt. w/ Pot. phos. (1,3,5)	4 fl oz/3 pt	1 d	17 bc
Propamocarb (2,4) alt. w/ Pot. phos. (1,3,5)	2 pt/3 pt	10 b	8 ef
Fenamidone (2,4) alt. w/ Pot. phos. (1,3,5)	8 fl oz/3 pt	0 d	7 ef
Mefenoxam + chlorothalonil (2,4) alt. w/Pot. phos. (1,3,5)	1.5 lb/3 pt	1 d	9 de
Maneb (2, 4) alt. w/ Pot. phos. (1,3,5)	1.5 qt/3 pt	4 d	15 bc
Copper hydroxide (2, 4) alt. w/Pot. phos. (1,3,5)	1.25 lb/3 pt	8 bc	19 b
Potassium phosphite (1,2,3,4,5)	3 pt	5 bcd	19 b

[z]Numbers in parentheses represent the order of application for which the respective compounds were applied.
[y]Numbers in a column followed by a letter in common are not significantly different as determined by Fisher's LSD, $P \leq 0.05$.

Table 5. Fungicide treatment, rate of product per acre, downy mildew severity on indicated dates, and percent marketable heads in Trial 3 conducted on iceberg lettuce on muck.

Fungicide treatment	Rate/acre	% Downy mildew severity 1 March	% Downy mildew severity 11 March	% Heads marketable
Untreated check	---	21 a[z]	56 a	44 f
Potassium phosphite	3 pt	8 b	33 b	69 e
Mandipropamid	8 fl oz	3 de	9 de	91 abc
Mandipropamid + Potassium phosphite	6 fl oz/2 pt	1 e	4 e	96 ab
Dimethomorph	6 fl oz	5 bcd	23 bc	71 de
Dimethomorph + Potassium phosphite	4.5 fl oz/2 pt	4 cde	20 cd	79 cde
Maneb	1.5 qt	6 bc	9 e	84 bcd
Manab + Potassium phosphite	1.12 qt/2 pt	3 de	5 e	89 abc
Fenamidone	8 fl oz	4 cde	5 e	90 abc
Fenamidone + Potassium phosphite	6 fl oz/2 pt	3 de	3 e	98 a

[z]Numbers in a column followed by a letter in common are not significantly different as determined by Fisher's LSD, $P \leq 0.05$.

Table 6. Fungicide treatment, rate of product per acre, downy mildew severity on indicated dates, and percent marketable heads in Trial 4 conducted on iceberg lettuce on muck.

Fungicide treatment	Rate/acre	% Downy mildew severity 1 March	% Downy mildew severity 11 March	% Heads marketable
Untreated check	---	36 a[z]	68 a	46 c
Fluopicolide	4 fl oz	5 b	9 b	84 b
Fosetyl-Al	4 lb	4 bc	4 bc	93 ab
V-10208	10 fl oz	10 b	2 c	96 ab
V-10208 alt. w/ Fluopicolide	10 fl oz/4 fl oz	3 bc	4 bc	88 ab
V-10208 + Fluopicolide	10 fl oz + 4 fl oz	3 bc	2 c	97 a
V-10208 + Fluopicolide	7.5 fl oz + 3 fl oz	0 c	4 bc	93 ab
Mandipropamid	8 fl oz	3 bc	4 bc	96 ab

[z]Numbers in a column followed by a letter in common are not significantly different as determined by Fisher's LSD, $P \leq 0.05$.

mode of action, may be a good candidate for a pre-mixture with fluopicolide in the future.

In summary, results of these trials reveal a number of different fungicides of dissimilar modes of action as efficacious in managing lettuce downy mildew. Of those investigated, mandipropamid (FRAC group 40) and fenamidone (FRAC group 11) consistently provided for high levels of control. Fluopicolide (FRAC group 43), dimethomorph (FRAC group 40), dimethomorph plus ametoctradin (FRAC groups 40 & 45), cyazofamid (FRAC group 21), and propamocarb (FRAC group 28) also provided significant control. With the majority of these fungicides already being labeled or close to being labeled on lettuce, it would appear that lettuce growers now have a wide array of efficacious downy mildew fungicides with differing modes of action from which to choose. This is a far cry from the situation that existed during 1989, when the EBDC fungicides were being threatened with cancellation and metalaxyl insensitivity was becoming widespread (Raid and Datnoff, 1990; Raid et al. 1990). While costs and returns must certainly be a part of the decision making process, growers should also focus on efficacy and resistance management. This information should be useful in making those decisions.

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