Optimizing fungicide application frequency and application interval relative to soybean maturity for improved white mold management in soybeans

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Introduction

Fungicide residual activity declines with time due to degradation of the active ingredient and the inability of fungicides to translocate into new plant growth that occurs after the fungicide application. The decline in fungicide residual activity can result in sharp declines in the effectiveness of fungicides; in field research conducted on dry beans in Brazil, the fungicide Omega (1.3 pt/ac, active ingredient = fluazinam) provided nearly 100% control of white mold 2 days after application as a foliar spray, approximately 60% control 8 to 12 days after application, less than 25% control 14 days after application, and nearly 0% control 16 days after application (**Figure 1**; Miorini et al. 2017). Similar results were observed in parallel studies conducted in soybeans (Miorini et al. 2016).

When fungicide residual activity declines below acceptable levels within the window that a crop is susceptible to the target disease, a second fungicide application is required to maintain satisfactory disease control. Soybeans are highly susceptible to new white mold infections from the R2 through late R4 growth stages, a period that often exceeds the 2-week interval for which acceptable fungicide residual activity is generally assumed.

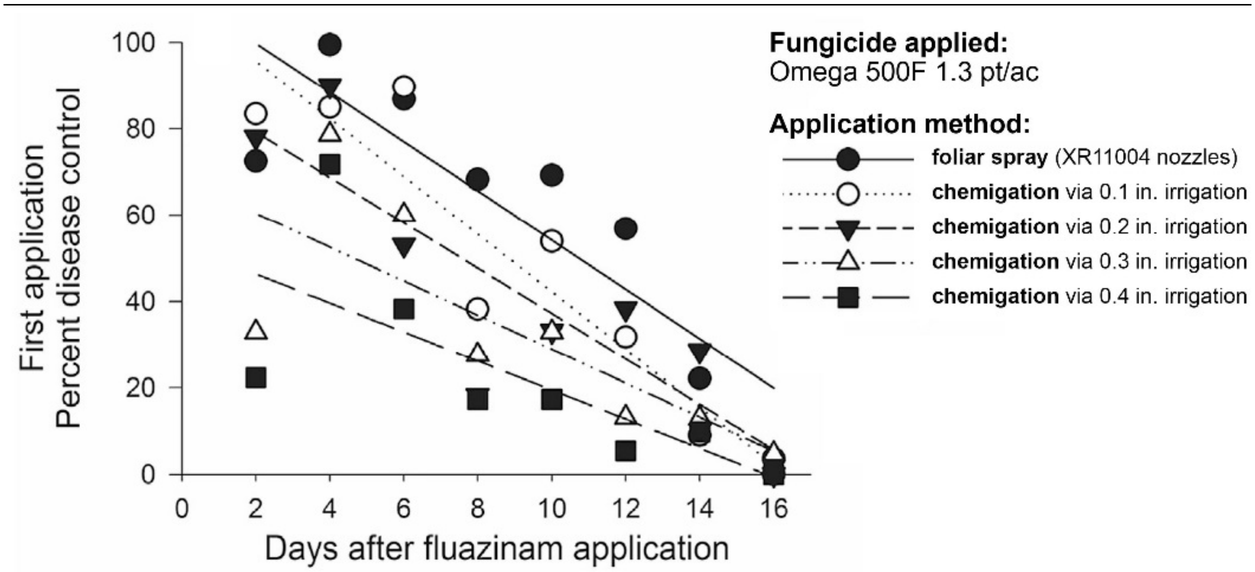

Figure 1. White mold control conferred by the fungicide Omega (active ingredient = fluazinam) 2 to 16 days after application to dry beans as a foliar spray or via chemigation; Pereiras, Brazil (2014). White mold control was assessed by collecting dry bean foliar samples from the field, placing them under controlled humid conditions in a laboratory and inoculating with *Sclerotinia sclerotiorum*, the fungal pathogen that causes white mold.

Source: Miorini et al. (2017); Crop Protection 94:192-202.

The likelihood that a second fungicide application targeting white mold is needed increases with soybean maturity length. Longer-maturity soybean varieties have a longer bloom period than early-maturity varieties: They take longer to progress from the R2 to the late R4 growth stage, and thus they exhibit a longer period of heightened susceptibility to white mold. Preliminary findings from ND Soybean Council funded research confirm this relationship. In field trials conducted in Carrington and Oakes, ND in 2018 and 2019 evaluating the return to zero, one or two sequential applications of the fungicide Endura (5.5 oz/ac) across a large number of soybean varieties in the 00, 0, and 1 maturity groups, making two sequential fungicide applications was often more profitable than a single application, with the profitability of a second fungicide application increasing with soybean maturity (**Figure 2**).

When making a second fungicide application, the second fungicide application must be made before disease control from the first application drops below acceptable levels. The standard recommendation for making sequential fungicide applications for white mold and other fungal diseases is to apply fungicides 10 to 14 days apart, but the difficulty of achieving satisfactory fungicide deposition to the soybean tissues where most white mold infections develop suggests that this interval may not be optimal when targeting white mold in soybeans. White mold develops primarily on dead blossoms on the lower stem and lower branches of soybeans, and it is difficult to achieve high levels of fungicide deposition to these tissues even with optimal application methods with standard boom-mounted nozzles. Only a small proportion of the fungicide applied to the crop successfully penetrates the canopy and is deposited on the lower stems and branches. As a result, the concentration of the active ingredient present in the target tissues in the lower canopy is relatively low even shortly after a fungicide is applied, and disease control would be expected to decline below acceptable levels in a shorter time period than for other foliar diseases that infect primarily in the upper canopy where fungicide deposition levels are higher.

The recommendation of applying fungicides 10 to 14 days apart when targeting white mold in soybeans is not based on empirical data and differs from standard practice in other regions of the world. In Brazil, where white mold is a serious constraint for soybean production and fungicides are widely utilized for white mold management, fungicides targeting white mold are applied twice sequentially on a target 10-day interval.

Optimizing the interval between successive fungicide applications has the potential to facilitate satisfactory white mold control with the low-cost, off-patent fungicide thiophanate-methyl (Topsin and generics). While Topsin and generics (applied at the registered rate of 20 fl oz/ac) have not consistently provided satisfactory control of white mold in soybeans when applied in sequential applications 10 to 14 days apart, Topsin (20 fl oz/ac) performed equivalently to Endura (5.5 oz/ac) in two separate field trials conducted in Carrington in 2019 in which two sequential fungicide applications were made 7 days apart.

This project seeks to identify the optimal interval between sequential fungicide applications (7-8, 10-11, or 13-14 days) in soybeans of early, mid and late 0-maturity; to assess the profitability of a single versus two sequential fungicide applications targeting white mold; and to evaluate whether the low-cost, off-patent fungicide thiophanate-methyl (Topsin and generics) might consistently confer acceptable levels of white mold control with an optimized interval between sequential applications.

Methods:

Planting was conducted May 12 in Oakes and May 14 in Carrington. Experimental design was a randomized complete block with a split-plot arrangement (main factor = soybean variety, sub-factor = fungicide treatment) and eight replicates. The varieties Golden Harvest '0145X' (0.1 maturity), Golden Harvest '0543X' (0.5 maturity), and Peterson '14R09N' (0.9 maturity) were planted in rows 14 inches apart at 165,000 pure live seeds/ac. Plots consisted of four rows, 25 feet long at seeding and approximately 20 feet long at harvest. To facilitate overspray of fungicides, all treatment plots were separated by four-row unharvested plots.

Fungicides were applied in 15 gal/ac with a hand-held boom equipped with four AIXR110015 air-induction flat-fan nozzles spaced 19 inches apart (Spraying Systems Co.;

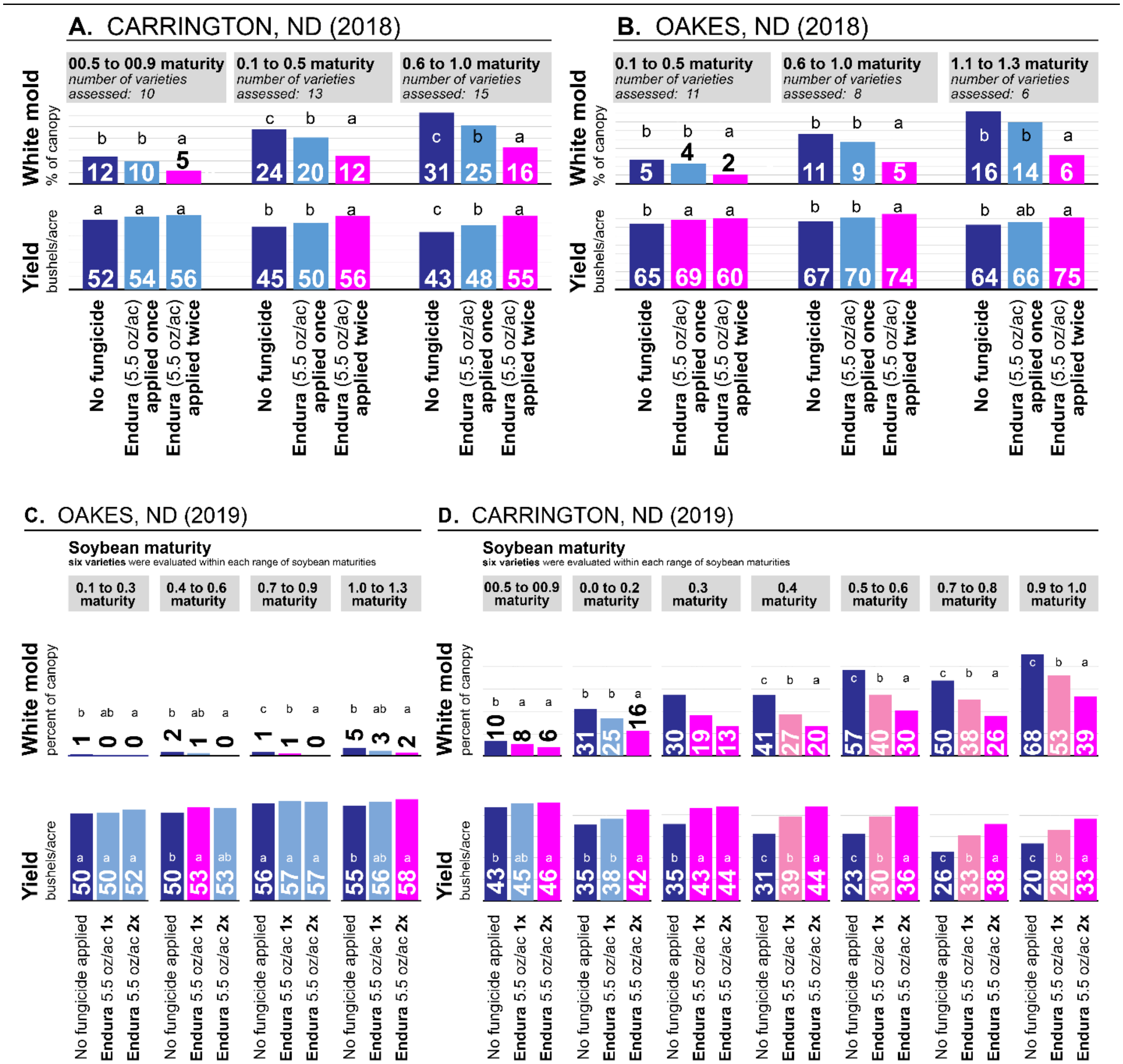

Figure 2. Response to one versus two applications of the fungicide Endura (5.5 oz/ac; active ingredient = boscalid) for management of white mold relative to soybean maturity; Carrington and Oakes, ND (2018). Studies were established as randomized complete block designs with a split-plot arrangement with variety as the main factor and fungicide as the sub-factor. Fungicides were applied at the R2 growth stage (single application) or 10-12 days apart at the R2 and R3 growth stages (two applications).

Wheaton, IL). Application pressure was set relative to canopy closure to deliver fungicides with medium droplets when the soybean canopy was open and coarse droplets when the soybean canopy was at or near closure. The first application was made at the early to late R2 growth stage. Application details are presented in Table 1.

Table 1. Fungicide application timing; soybean growth stage and canopy canopy closure when fungicides were applied; and fungicide application pressure and droplet size.

	Carrington, ND (2020)			Oakes, ND (2020)		
Soybean variety	GH '0145X'	GH '0543X'	PFS '14R09N'	GH '0145X'	GH '0543X'	PFS '14R09N'
1st application	July 6	July 8	July 10	July 1	July 8	July 8
Growth stage	24% R2, 75% R3	78% R2, 20% R3	11% R1, 89% R2	6% R1, 94% R2	65% R2, 35% R3	79% R2, 21% R3
Canopy closure	69%	88%	87%	68%	91%	87%
Applic. pressure	70 psi	60 psi	60 psi	70 psi	60 psi	60 psi
Droplet size	medium	medium	medium	medium	medium	medium
2nd application	July 13	July 15	July 17	July 8	July 15	July 15
Canopy closure	95%	97%	96%	84%	95%	94%
Applic. pressure	40 psi	40 psi	40 psi	60 psi	40 psi	40 psi
Droplet size	coarse	coarse	coarse	medium	coarse	coarse
3rd application	July 16	July 18	July 20	July 11	July 18	July 18
Canopy closure	94%	99%	98%	93%	94%	94%
Applic. pressure	40 psi	40 psi	40 psi	50 psi	40 psi	40 psi
Droplet size	coarse	coarse	coarse	coarse	coarse	coarse
4th application	July 20	July 22	July 24	July 15	July 22	July 22
Canopy closure	98%	99%	99%	93%	99%	99%
Applic. pressure	40 psi	40 psi	40 psi	40 psi	40 psi	40 psi
Droplet size	coarse	coarse	coarse	coarse	coarse	coarse

Disease establishment: The research studies were planted on land with a prior history of Sclerotinia epidemics and received supplemental overhead irrigation. In Oakes, irrigation was delivered with a linear irrigator; to facilitate disease pressure, a second pass with the irrigator delivering an extra 0.25 inches of water was made a day after the normal scheduled irrigation. In Carrington, irrigation was applied with micro-sprinklers established on a 20-foot offset grid, with 6.8 inches of water applied across 8 days from July 3 (R1 growth stage) to August 5 (R4/R5).

White mold was assessed Aug. 26-28 (0.1- and 0.5-maturity varieties; R7 growth stage) and Sept. 25 (0.9-maturity variety; R8) in Oakes and Oct. 8-15 (R8 growth stage) in Carrington. Each plant in the middle two rows of each plot was individually assessed for Sclerotinia stem rot severity using a 0 to 5 scale representing the percentage of the plant impacted by Sclerotinia stem rot, where 0 = 0% of the plant impacted by Sclerotinia, 1 = 1-25%, 2 = 26-50%, 3 = 51-75%, 4 = 76-99%, 5 = 100%. Plant tissue was considered to be impacted by Sclerotinia stem rot if it exhibited symptoms of Sclerotinia and/or bore poorly filled or unfilled pods caused by one or more Sclerotinia lesions that girdled stem tissue below the pods.

The studies were harvested on October 8-9 in Oakes and October 15-16 in Carrington.

Data were evaluated with analysis of variance. (1) The assumption of constant variance was assessed with Levene's test for homogeneity of variances and visually confirmed by plotting residuals against predicted values. (2) The assumption of normality was assessed the Shapiro-Wilk test and visually confirmed with a normal probability plot. (3) The assumption of additivity of main-factor effects across replicates (no replicate-by-treatment interaction) was evaluated with Tukey's test for nonadditivity. All data met model assumptions. *Combined analyses in studies with a split-plot design*: Combined analyses of treatment effects across fungicide treatments were conducted with replicate and fungicide as main-factor effects and application timing/method as a sub-factor and controlling for replicate by main-factor and main-factor by treatment interactions. F-tests for the combined analysis of the main factor (fungicide) and the sub-factor (application timing & method) were conducted utilizing replicate-by-main-factor interaction for the error term. *Treatment contrasts:* Single-degree-of-freedom contrasts were performed for all pairwise comparisons of treatments; to control the Type I error rate at the level of the experiment, the Tukey multiple comparison procedure was employed. Analyses were implemented in PROC UNIVARIATE and PROC GLM of SAS (version 9.4; SAS Institute, Cary, NC).

Results:

Susceptibility to white mold increased with soybean maturity, and significant disease pressure was observed only in the 0.9-maturity variety at the Carrington study location (**Table 2**). In this variety in Carrington, white mold control and soybean yield were optimized when sequential applications were made 10 days apart. Follow-up research will be needed to confirm this result; consistent trends were observed across when fungicides were applied 7, 10 or 14 days apart, with disease control and soybean yield maximized with applications 10 days apart, but differences were not statistically significant. At the Oakes study location and in the shorter-maturity varieties in Carrington, disease pressure was insufficient to evaluate the impact of fungicide application interval.

The fungicide Topsin applied at 20 fl oz/ac was consistently less effective than Endura irrespective of application frequency or application interval (**Table 2**). The label for Topsin was recently changed to permit a single application to soybeans at 40 fl oz/ac, and future testing will evaluate applying 40 fl oz/ac Topsin followed by Endura. In dry beans, the efficacy of Topsin improves with increased application rate, and applying Topsin at 40 fl oz/ac followed by Endura has improved white mold management relative to two sequential applications of Endura.

Conclusions and Discussion:

The increase in white mold pressure that was observed in longer maturity soybeans is consistent with previous research. The return to fungicides targeting white mold increases with soybean maturity, with two fungicide applications most likely to be profitable in longer maturity varieties.

Making sequential applications 10 days apart optimized white mold management in this study. While follow-up research is needed to confirm this finding, this interval is consistent with standard practice in Brazil, where fungicide applications targeting white mold in soybeans are typically made 10 days apart.

Literature cited:

Miorini et al. 2016. Evaluation of fungicide residual activity in soybean leaves using analytical chemical quantification and Sclerotinia sclerotiorum bioassay. Phytopathology 106:S4.189.

Miorini et al. 2017. Control of white mold of dry bean and residual activity of fungicides applied by chemigation; Crop Protection 94:192-202.

Table 2. Impact of fungicide application frequency and application interval on white mold management and soybean yield; Carrington and Oakes, ND (2020).

	Sclerotinia incidence (percent of plants)				**Sclerotinia incidence** (percent of plants)			
	OAKES, ND (2020)				**CARRINGTON, ND** (2020)			
Soybean variety:	**GH0145X**	**GH0543X**	**14R09N**	Combined analysis	**GH0145X**	**GH0543X**	**14R09N**	Combined analysis
Soybean maturity:	**0.1**	**0.5**	**0.9**		**0.1**	**0.5**	**0.9**	
Non-treated control	**0.4** a*‡‡	**4** c*‡	**2** cde*‡‡	**2** d*‡‡	**0.5** a*‡‡	**2** a*‡	**18** bcd*	**7** de*
Topsin 20 fl oz/ac **(R2 growth stage)**	**0.7** a	**4** c	**4** e	**3** d	**0.5** a	**2** a	**25** d	**9** e
Topsin 20 fl oz/ac **(R2 + 7 days)**	**0.9** a	**3** bc	**3** de	**2** d	**0.2** a	**3** a	**22** cd	**8** de
Topsin 20 fl oz/ac **(R2 + 10 days)**	**0.5** a	**2** bc	**3** de	**2** d	**0.0** a	**2** a	**11** ab	**5** bcd
Topsin 20 fl oz/ac **(R2 + 14 days)**	**0.4** a	**2** abc	**3** b-e	**2** abc	**0.5** a	**2** a	**18** bcd	**7** de
Endura 5.5 oz/ac **(R2 growth stage)**	**0.2** a	**2** bc	**2** a-e	**1** bcd	**0.1** a	**1** a	**12** abc	**5** a-d
Endura 5.5 oz/ac **(R2 + 7 days)**	**0.1** a	**1** ab	**0** a	**0** ab	**0.0** a	**1** a	**9** ab	**3** abc
Endura 5.5 oz/ac **(R2 + 10 days)**	**0.0** a	**0** a	**1** abc	**0** a	**0.0** a	**1** a	**6** a	**2** a
Endura 5.5 oz/ac **(R2 + 14 days)**	**0.0** a	**1** a	**1** ab	**0** a	**0.0** a	**1** a	**7** a	**2** ab
Topsin 20 fl oz/ac **(R2 growth stage) +** **Endura** 5.5 oz/ac **(7 days later)**	**0.2** a	**1** ab	**1** a-d	**1** abc	**0.2** a	**3** a	**14** abc	**6** cde
F:	2.07	6.81	6.76	13.57	2.13	2.31	8.58	11.33
P>F:	0.0461	<.0001	<.0001	<.0001	0.0404	0.0260	<0.0001	<0.0001
CV:	147.2	55.1	45.6	57.4	185.6	67.2	43.5	37.1

	Sclerotinia severity index (percent of canopy)				**Sclerotinia severity index** (percent of canopy)			
	OAKES, ND (2020)				**CARRINGTON, ND** (2020)			
Soybean variety:	**GH0145X**	**GH0543X**	**14R09N**	Combined analysis	**GH0145X**	**GH0543X**	**14R09N**	Combined analysis
Soybean maturity:	**0.1**	**0.5**	**0.9**		**0.1**	**0.5**	**0.9**	
Non-treated control	**0.2** a*‡‡	**2.3** d*‡‡	**0.7** cde*‡‡	**1.1** d*‡‡	**0.5** a*‡‡	**2** a*‡‡	**11** b-e*	**4** de*‡‡
Topsin 20 fl oz/ac **(R2 growth stage)**	**0.4** a	**1.9** d	**1.5** e	**1.3** d	**0.5** a	**2** a	**17** e	**6** d
Topsin 20 fl oz/ac **(R2 + 7 days)**	**0.6** a	**1.1** bcd	**1.2** de	**0.9** d	**0.1** a	**2** a	**13** de	**5** cd
Topsin 20 fl oz/ac **(R2 + 10 days)**	**0.4** a	**1.2** cd	**1.0** de	**0.9** d	**0.0** a	**2** a	**7** a-d	**3** abc
Topsin 20 fl oz/ac **(R2 + 14 days)**	**0.3** a	**0.9** a-d	**0.9** b-e	**0.7** cd	**0.4** a	**2** a	**12** cde	**5** cd
Endura 5.5 oz/ac **(R2 growth stage)**	**0.2** a	**0.9** bcd	**0.5** a-e	**0.5** bcd	**0.1** a	**1** a	**7** a-d	**3** abc
Endura 5.5 oz/ac **(R2 + 7 days)**	**0.1** a	**0.3** abc	**0.1** a	**0.1** ab	**0.0** a	**1** a	**5** abc	**2** ab
Endura 5.5 oz/ac **(R2 + 10 days)**	**0.0** a	**0.1** a	**0.1** abc	**0.1** a	**0.0** a	**0** a	**3** a	**1** a
Endura 5.5 oz/ac **(R2 + 14 days)**	**0.0** a	**0.2** ab	**0.1** ab	**0.1** a	**0.0** a	**0** a	**3** ab	**1** ab
Topsin 20 fl oz/ac **(R2 growth stage) +** **Endura** 5.5 oz/ac **(7 days later)**	**0.1** a	**0.2** abc	**0.2** a-d	**0.2** abc	**0.1** a	**2** a	**8** a-d	**3** bc
F:	1.86	7.24	7.04	13.09	2.21	2.22	7.97	10.83
P>F:	0.074	<.0001	<.0001	<.0001	0.0333	0.0320	<0.0001	<.0001
CV:	154.2	45.9	48.8	63.8	190.6	55.6	53.0	39.0

	Yield (bushels/acre)				**Yield** (bushels/acre)			
	OAKES, ND (2020)				**CARRINGTON, ND** (2020)			
Soybean variety:	**GH0145X**	**GH0543X**	**14R09N**	Combined analysis	**GH0145X**	**GH0543X**	**14R09N**	Combined analysis
Soybean maturity:	**0.1**	**0.5**	**0.9**		**0.1**	**0.5**	**0.9**	
Non-treated control	**72** a*	**77** a*	**76** a*	**75** a*	**52** a*	**58** a*	**53** ab*	**54** ab*
Topsin 20 fl oz/ac **(R2 growth stage)**	**72** a	**79** a	**76** a	**76** a	**54** a	**58** a	**50** b	**54** b
Topsin 20 fl oz/ac **(R2 + 7 days)**	**74** a	**79** a	**76** a	**76** a	**53** a	**57** a	**53** ab	**54** ab
Topsin 20 fl oz/ac **(R2 + 10 days)**	**72** a	**79** a	**76** a	**76** a	**53** a	**59** a	**55** ab	**56** ab
Topsin 20 fl oz/ac **(R2 + 14 days)**	**74** a	**80** a	**77** a	**77** a	**53** a	**58** a	**50** b	**54** b
Endura 5.5 oz/ac **(R2 growth stage)**	**75** a	**77** a	**79** a	**77** a	**52** a	**57** a	**54** ab	**55** ab
Endura 5.5 oz/ac **(R2 + 7 days)**	**73** a	**77** a	**79** a	**76** a	**54** a	**58** a	**56** ab	**56** ab
Endura 5.5 oz/ac **(R2 + 10 days)**	**73** a	**78** a	**78** a	**76** a	**55** a	**60** a	**57** a	**58** a
Endura 5.5 oz/ac **(R2 + 14 days)**	**73** a	**79** a	**77** a	**76** a	**57** a	**60** a	**56** ab	**57** a
Topsin 20 fl oz/ac **(R2 growth stage) +** **Endura** 5.5 oz/ac **(7 days later)**	**72** a	**79** a	**77** a	**76** a	**54** a	**57** a	**52** ab	**54** ab
F:	1.14	0.96	1.06	1.09	1.52	0.61	3.49	3.23
P>F:	0.3491	0.4781	0.4018	0.369	0.1601	0.7852	0.0015	0.0011
CV:	3.9	3.5	3.8	3.7	6.4	6.4	6.8	6.5

* Within-column means followed by different, non-overlapping ranges of letters are significantly different (P<0.05; Tukey multiple comparison procedure).

To meet model assumptions of normality and/or homoskedasticity, analysis of variance was conducted on data subjected to a systematic natural-log transformation (‡) or cube-root transformation (‡‡). For ease of interpretation, treatments means are presented for the non-transformed data.