2010

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Robert M. Harveson
University of Nebraska-Lincoln, rharveson2@unl.edu

James R. Steadman
University of Nebraska-Lincoln, jsteadman1@unl.edu

Carlos A. Urrea
University of Nebraska-Lincoln, currea2@unl.edu

Accepted for publication 8 May 2010. Published 1 July 2010.

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Robert M. Harveson, University of Nebraska, Panhandle Research and Extension Center, Scottsbluff, NE 69361; **James R. Steadman,** University of Nebraska, Department of Plant Pathology, Lincoln, NE 68588; and **Carlos A. Urrea,** University of Nebraska, Panhandle Research and Extension Center, Scottsbluff, NE 69361

Corresponding author: Robert M. Harveson. rharveso@unlnotes.unl.edu

Harveson, R. M., Steadman, J. R., and Urrea, C. A. 2010. Integrating planting dates and fungicide applications for managing white mold of dry beans in western Nebraska. Online. Plant Health Progress doi:10.1094/PHP-2010-0701-02-RS.

Abstract

White mold, caused by the soilborne fungus *Sclerotinia sclerotiorum*, is one of the most destructive diseases of common beans (*Phaseolus vulgaris* L.) and is greatly influenced by environmental conditions and certain agronomic practices. A 3-year study (2003 to 2005) evaluated planting date and thiophanate-methyl fungicide applications based on decision aids consisting of blue plate technique, sugar beet Cercospora leaf spot (CLS) disease forecasting model, and crop phenology (90% bloom). Overall yields were lower in 2003 and higher in 2005, and disease severity was greater in 2004. Planting dry beans in late June to early July resulted in higher levels of disease than planting in late May or mid-June in 2004. Late planting also resulted in lower yields and 100-seed weight in 2004 and 2005 than the early and mid-plantings. Compared to the control and CLS model, fungicide applications based on the blue plate and 90% bloom treatments reduced disease severity in 2004 and 2005, while also increasing 100-seed weight and yields in 2004.

Introduction

White mold, also known as Sclerotinia wilt, is one of the most important and destructive diseases of common bean (*Phaseolus vulgaris* L.) and numerous other oilseed and vegetable crops in temperate growing areas (1,17,20). The disease is caused by the soilborne fungus *Sclerotinia sclerotiorum* (Lib.) de Bary, and is widely distributed throughout the irrigated dry bean areas of western Nebraska and other bean production regions. Spread and development of white mold is highly dependent upon specific weather conditions needed for the pathogen. The disease generally occurs in localized areas and seldom spreads throughout entire fields (17,20). However, the disease can limit yield during cool wet periods or under heavy plant canopies with irrigation near the end of the season. When environmental conditions are conducive, yields and quality are reduced through total seed yield, and yield components such as numbers of seeds per plant, 100-seed weight, and number of pods per plant (5,6,22,26). Loss estimates in Nebraska from white mold have averaged as high as 20%, with several individual fields suffering up to 65% yield reductions (5,6).

The pathogen survives in the soil as mycelium in debris and as sclerotia that can remain viable for 5 or more years in soil, assuring a source of infection when a host crop is planted (5,17,19,20). Sclerotia are the most important means of initiating infections in bean (17,21,22,26). In Nebraska, these survival structures germinate to form mushroom-like apothecia beneath the canopy that release infective ascospores as initial inoculum (Fig. 1). Ascospores require an exogenous energy source to infect living tissues (17,20,21). Typically for dry beans in this region, old blossoms on soil or plant surfaces serve as this nutrient source. After blossom colonization, the mycelium can infect adjacent green

pods, leaves, or stems within 2 to 3 days (5,6,21), resulting in symptoms and signs consisting of bleached stems (Fig. 2), wilting, watery soft rot, and white fungal growth (1,17,19,20,21).

Fig. 1. *Sclerotinia sclerotiorum* apothecia arising from conditioned sclerotia. Close-up of apothecia showing cup-shaped structure that produces infective ascospores (inset).

Fig. 2. White mold symptoms of bleached white stems (left) vs. healthy yellow-green color (right).

White mold has been a production problem for more than 50 years, yet cultural and chemical management methods developed to date have had varying degrees of success (17,19,21). In fact, many cultural strategies to reduce white mold such as reduced plant vigor, fertilizer, and irrigation also can reduce yield potential (20). The life cycle of the pathogen and complex environmental conditions needed for conditioning sclerotia, production of ascospores, and infection make predictive methods very difficult to implement (19). No single practice will completely prevent infection and limit yield losses. Thus disease management based on integrating multiple techniques provides the best approach for reducing white mold in dry beans while maintaining yield potential. This study was conducted over a 3-year period to evaluate effects of planting dates and fungicide applications based on the use of decision aids, including the blue plate test (23) and a forecasting model originally developed for the sugar beet fungal foliar disease, Cercospora leaf spot (CLS) (7,25). These treatments were compared with a standard application made at 90% bloom, and an untreated control.

Decision Aids

The blue plate technique assessed the presence and relative density of *S. sclerotiorum* ascospores in fields over a certain time. Petri dishes containing a semi-selective medium were placed under bean canopies for 3 h during late morning to early afternoon, coinciding with peak spore release and deposition (20,23,26). Airborne ascospores land and germinate on plates, producing colonies that induce a medium color change from blue to yellow within the agar due to oxalic acid production by the pathogen, which is a primary determinant for infection and pathogenicity. The medium contains bromophenol blue, a pH indicator that changes from blue to yellow at pH ≤ 4.7. The medium promotes germination of *S. sclerotiorum* ascospores while also suppressing the growth of other common fungal and bacterial contaminants (23). For the blue plate decision aid treatment, 12 blue plates with lids removed were placed within rows on the soil surface between plants under plant canopies (two plates per plot, one in each of the two middle rows 3 m from each end) (Fig. 3). This was performed approximately 1 week after 50% bloom (50% of plants have at least one open flower). After 3 h, plates were covered, removed from the field, brought into the laboratory and incubated in the dark at 22 ± 2°C for 3 days. Colonies with yellow zones surrounding them were considered to be positive for *S. sclerotiorum* (Fig. 4).

Fig. 3. Open blue plate placed under a dry bean canopy to monitor *Sclerotinia sclerotiorum* ascospore deposition.

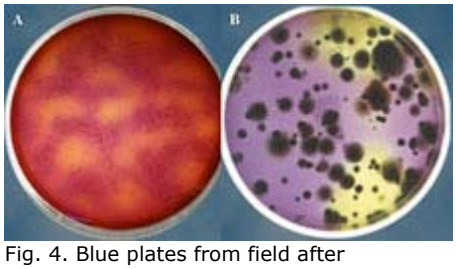

Fig. 4. Blue plates from field after incubation (note yellow spots on media): (**A**) more than ten *Sclerotinia sclerotiorum* colonies without contaminants; (**B**) two *S. sclerotiorum* colonies with other fungal contaminants.

The germination rate of *S. sclerotiorum* ascospores on this medium is relatively high (91 to 94%) (23). Resulting colonies on plates from the field were verified as *S. sclerotiorum* when black sclerotia were produced in plates 8 to 10 days later. Less than 5% of putative colonies could not be verified (*unpublished data*), thus validating the blue plate technique for accurately identifying *S. sclerotiorum*. Temperatures less than 30°C (optimal 25°C) with 12 to 16 h of leaf wetness are prerequisites for white mold development (3,5,6,20,26).

The CLS forecasting system was developed in the late 1980s specifically for western Nebraska (7,25). This model is well known and has been routinely implemented by growers and consultants as a management tool for another yield-limiting fungal disease in the Central High Plains for more than 15 years (4). It was included as a comparison to the blue plate test since environmental conditions favorable for both diseases are similar (high humidity, wet, closed plant canopies, and moderate temperatures) (3,4,19,25,26). The pathogen, *Cercospora beticola*, requires 11 to 12 h of leaf wetness and day temperatures of 25 to 35°C with night temperatures above 16°C for infection and growth (4,7,25). The CLS model determines daily infection values (DIV) based on the number of hours of leaf wetness or high relative humidity (> 90%) and concurrent average temperature during this period. If the 2-day sum of the DIV's is seven or greater, the conditions over that previous 48-h period are assumed to have been conducive for infection and further disease development (4), and a fungicide application for this treatment was made the first time this model estimated DIVs greater than seven.

Evaluating Planting Date and Decision Aid Treatments

Tests were conducted from 2003 to 2005 at the Panhandle Research and Extension Center in Scottsbluff, NE, on land with a history of *S. sclerotiorum* infestation. This site had been continually cropped with dry beans or sunflowers (*Helianthus annuus* L.), another known host, for several years prior to initiation of the experiment.

The study consisted of three planting dates (late May, mid-June, and late June/early July) (Table 1) utilizing the great northern dry bean cultivar 'Harris' (2) and four treatments timed with decision aids. The experimental design was a split plot with six replications per treatment. Planting dates were assigned to the main plots, and decision aid treatments to sub-plots. Each subplot consisted of four rows on 55-cm centers, each 12 m in length.

The four subplot treatments included: (i) untreated control; (ii) fungicide application when blue plate count thresholds reached ≥ 5 positive colonies per plate, or when 80% of plates had at least one positive colony (23); (iii) fungicide application based on optimal conditions for disease development for *C. beticola* as estimated by the CLS forecasting model (7,25); and (iv) fungicide application at 90% bloom. A single fungicide application per treatment was performed with a back pack sprayer utilizing thiophanate-methyl at 1.7 kg/ha.

Table 1. Dry bean planting dates, rainfall amounts, and number of days with temperature above 35°C before and after flowering (when 50% of the plants have at least one open flower) in Nebraska from 2003 to 2005.

Planting date[z]		Rainfall (mm)			Days maximum T>35°C		
		Before flowering	After flowering	Total	Before flowering	After flowering	Total
2003	Early	47	54	101	6	16	22
	Mid	24	56	80	12	9	21
	Late	23	48	71	17	4	21
2004	Early	34	120	154	2	7	9
	Mid	88	82	170	6	2	8
	Late	58	98	156	8	1	9
2005	Early	132	56	189	3	14	17
	Mid	48	51	99	13	4	17
	Late	39	87	126	13	2	15

[x] 28 May, 10 June, and 24 June 2003; 28 May, 15 June, and 2 July 2004; and 27 May, 15 June, and 28 June 2005.

Furrow irrigation was used initially for emergence and stand establishment, after which sprinkler irrigation was applied every 3 days in July, August, and early September, regardless of rainfall, to total approximately 3.75 cm of water via irrigation per week. Environmental conditions were recorded at a near-by weather station (approximately 10 to 15 m from test site) and reported by the High Plains Climate Center, Lincoln, NE, www.hprcc.unl.edu) (Table 1).

Disease severity was estimated at harvest in late September to early October as percentage of above-ground symptomatic plant canopy with wilting and/or plants exhibiting white, bleached stems (Fig. 2). All plants from 6 m of the two center rows were rated for disease severity, pulled by hand, air dried in the greenhouse, and later threshed with a stationary dry bean combine. Plot yields and 100-seed weight in grams (seed size) were estimated.

Statistical Analysis

Data were analyzed using PROC MIXED (PC SAS Version 9.1, SAS Institute Inc., Cary, NC) (Table 2). A combined analysis was conducted after running a test for homogeneity of variance using Barlett's χ^2 test (24). Means were separated using an F-protected LSD. All tests were considered significant at $P \leq 0.05$.

Table 2. Mean squares from analysis of variance for dry bean disease severity, 100-seed weight, and yield due to white mold for three years, three planting dates, and four decision aid treatments.

Source	df	Mean squares		
		Disease severity	100-seed weight	Yield
Year (Y)	2	9750.1[x]	341.2[x]	30453829.7[x]
Rep (Y)	15	348.3	6.9	670740.7
Planting date (Pd)	2	3883.8[x]	354.8[x]	3863179.2[x]
Y x Pd	4	1746.6[x]	162.2[x]	1800134.6[x]
Pooled error a	30	105.1	3.3	84030.5
Treatment (Trt)	3	1292.8[x]	3.3ns[z]	192434.3[y]
Y x trt	6	393.4[x]	8.0[x]	161618.5[y]
Pd x Trt	6	72.4ns	1.2ns	42669.6ns
Y x Pd x Trt	12	54.8ns	2.3ns	44181.9ns
Pooled error b	135	54.8	2.7	57895.2

[x] = statistically significant at $P \leq 0.01$.
[y] = statistically significant at $P \leq 0.05$.
ns = statistically non-significant.

Planting Date and Decision Aid Treatment Results

In general, yields were lower in 2003 compared to 2004 and 2005, and higher in 2005 compared to 2003 and 2004 (Table 3). Additionally disease severity overall was significantly higher in 2004 than the other 2 years (Tables 3 and 4), resulting in conditions more conducive for proper evaluation of decision aid treatments.

Table 3. Interaction of year and planting date on dry bean disease severity, 100-seed weight, and yield due to white mold in Nebraska from 2003 to 2005.

Planting date[y]	Disease severity (%)[x]			100-seed weight (g)			Yield (kg/ha)		
	2003	2004	2005	2003	2004	2005	2003	2004	2005
Early	4.9	17.6	9.6	31.7	34.9	36.8	1084	1758	2601
Mid	8.9	20.6	5.2	32.2	31.8	36.1	1344	1662	2693
Late	10.3	48.2	13.1	32.7	25.6	32.2	1323	959	2106
LSD	2.1	11.8	8.2	0.8	1.8	1.1	464	234	267

[x] Disease severity = percent infected plant canopy.
[y] 28 May, 10 June, and 24 June 2003; 28 May, 15 June, and 2 July 2004; and 27 May, 15 June, and 28 June 2005.

Significant interactions were additionally observed between years with both planting date and decision aid treatment (Table 2), thus these data are presented separately. Disease severity was unaffected by planting date in 2005. However, the late planting date resulted in significantly higher disease levels than the early date in 2003, and both mid- and early planting dates in 2004 (Table 3). The early planting date resulted in greater 100-seed weight compared to the mid-planting date in 2004 only. The late planting date also resulted in lower 100-seed weight in 2004 and 2005 than both the early and mid-planting dates (Table 3). In 2003, planting date had no effect on either 100-seed weight or yields, but planting late resulted in significantly lower yields compared to the other two planting dates in both 2004 and 2005 (Table 3).

Few differences were observed between decision aid treatments in 2003, although the control treatment did result in significantly higher disease severity levels than any of the other treatments (Table 4). In 2004 and 2005, both the blue plate and the 90% bloom treatments had significantly less disease than control and CLS model (Table 4). 100-seed weight was different among treatments only in 2004, when the 90% bloom treatment produced better results than the CLS model, and the blue plate resulted in significantly higher weights than both the control and CLS model results. Yield results were unaffected by various decision aids in 2003 and 2005, but in 2004 significantly better yields were obtained from the blue plate and 90% bloom treatments compared to both the CLS and controls.

Table 4. Interaction of year and decision aid treatments on white mold disease severity, 100-seed weight, and dry bean yield in Nebraska from 2003 to 2005.

	Disease severity (%)[x]			**100-seed weight** (g)			**Yield** (kg/ha)		
Treatment	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**
Control	11.3	36.4	12.8	32.3	30.4	35.2	1277	1326	2440
Blue plate	7.3	18.3	7.0	32.2	31.9	34.6	1161	1598	2478
CLS model[y]	6.4	37.3	13.4	32.5	29.7	34.8	1261	1260	2430
90% bloom	7.2	23.3	4.0	31.9	31.1	35.5	1303	1555	2520
LSD	2.4	6.6	4.9	1.0	1.3	0.9	185	132	223

[x] Disease severity = percent infected plant canopy.

[y] CLS model = disease forecasting model based on conditions conducive for development of Cercospora leaf spot in sugar beet.

Discussion and Conclusions

Low yield in 2003 was not due exclusively to white mold as disease levels were not severe (Table 3). The 2003 season was characterized by unusually dry and warm conditions during the season with more than 20 days with temperatures exceeding 35°C (Table 1). Temperatures above 28°C near 50% bloom often cause excessive blossom drop and abortion of fertilized ovules (15). Even though irrigation was consistent among years, the lower amount of rainfall experienced in 2003 (Table 1) still contributed to reduced yields, as drought can reduce yield, quality, and often the market value of dry beans (18).

The cooler and wetter conditions in 2004 (Table 1) also resulted in lower yields due primarily to higher disease levels, but these environmental conditions additionally may contribute to delayed plant maturity and seed development. Later maturity prolongs conditions conducive for disease infection and development, while also increasing probability of plant damage due to early frost (5,6). Both factors were likely responsible for the greater disease levels and yield reductions suffered in 2004. Later planted crops were also observed to produce lower yields and 100-seed weight in 2004 and 2005 (Table 3).

The blue plate test adequately indicated pathogen presence, illustrated the benefits of scheduling fungicide sprays in a year like 2004 when disease severity was high in controls, and also demonstrated that the failure to treat under those conditions could easily result in yield loss. It was additionally determined from these studies that decision aid fungicide treatments imposed using blue plate counts had similar or less disease than treatments utilized at arbitrary crop growth stages, e.g., 90% bloom. Therefore, the blue plates may also be particularly useful in a low disease year like 2003, showing that profitability would be enhanced if producers avoided unnecessary fungicide application treatments based on calendar dates or crop phenology. In 2004, the blue plate and 90% bloom decision aids provided superior results related to all measured variables compared with the control and CLS model (Tables 3 and 4). Although white mold and CLS have similar environmental requirements for disease progression, we cannot explain why the CLS model did not adequately predict conditions conducive for white mold.

This report presents the first published data that supports the value of the blue plate in verifying that *S. sclerotiorum* has been active in a field, and how it complements fungicide application timing. The predictive value was informally evaluated for pathogen detection (23) or when blue plates were distributed over a 2-year period to growers and other potential users in Nebraska to use as outlined in: plantpath.unl.edu/faculty/Steadman/Blueplate/blueplate.html and generalizations of satisfaction with use of the plates were verbalized. Commercialization awaits development of a smaller, dry-storage blue plate equivalent that would require hydration prior to usage.

A number of different methods for white mold disease management have been evaluated. Disease resistance is the most cost effective strategy for management of plant diseases for the grower. However, for bean and other hosts, including oil seed crops, resistance is only partial. Quantitative trait loci (QTLs) for *S. sclerotiorum* have been reported for sunflower, common bean, soybean [*Glycines max* (L.) Merr.] and oilseed rape (*Brassica napus* L.) (8,14). Some common bean QTLs were associated with disease avoidance in the field, while others suggested that physiological resistance was involved (9,10,12). Recent multi-site field screening (11) and standard greenhouse tests (13) confirmed moderate levels of resistance in common bean, but fungicide use is appropriate when conditions favor the pathogen.

In addition to chemical control strategies utilizing thiophanate-methyl, several cultural practices have additionally been demonstrated to reduce losses from white mold, including reducing irrigations late in the season, and planting cultivars with more upright architecture to allow better air circulation through the canopy (3,6,16,19). This study further showed that delaying planting until late June or early July resulted in reduced seed yields and 100-seed weight in two of the three years the study was conducted, even when disease severity was low to moderate (Table 3). Therefore, adjusting the planting date for bean cultivars with earlier or later maturity dates should provide a similar yield and white mold risk outcome.

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