Impact of White Mold Incidence on Dry Bean Yield Under Nonirrigated Conditions

L. E. del Río, J. R. Venette, and H. A. Lamey, Department of Plant Pathology, North Dakota State University, Fargo 58105

ABSTRACT

del Río, L. E., Venette, J. R., and Lamey, H. A. 2004. Impact of white mold incidence on dry bean yield under nonirrigated conditions. *Plant Dis.* 88:1352-1356.

Studies on chemical control of white mold, conducted between 1994 and 2001 at several locations in North Dakota, resulted in diverse levels of white mold incidence and severity. Navy bean cultivars were evaluated in on-farm trials between 1994 and 1996, while pinto bean cultivars were used between 1997 and 2001. The relationship between yield and white mold incidence in these trials was examined using correlation and regression analysis. White mold incidence was correlated to severity using a second-degree polynomial equation ($R^2 = 0.90$, $P = 0.0001$) in pinto bean experiments. For every percent unit increase in white mold incidence, yield was reduced by 12 kg/ha (range 7 to 19 kg/ha) in pinto bean and by 23 kg/ha (range 19 to 26 kg/ha) in navy bean. In both instances, the coefficients of determination were significant ($P < 0.04$) for most locations or years, and ranged from 0.42 to 0.87 for pinto bean and from 0.98 to 0.99 for navy bean. Fungicide-protected plots had an average white mold incidence of 34 and 50% compared with 76 and 73% in nonprotected plots for pinto and navy bean, respectively. Fungicide applications increased yields by 33 and 26% ($P \leq 0.05$) for pinto and navy bean, respectively.

North Dakota is the number one producer of dry edible beans (*Phaseolus vulgaris* L.) in the United States, with an estimated production of 4.83×10^5 tons in 2002 valued at over \$157 million (11). Surveys conducted among dry bean producers in North Dakota and Minnesota in the past several years indicated that white mold, caused by the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary, is the most important disease affecting dry bean production in the region (15–17).

White mold can be especially severe when wet and cool conditions are prevalent during the crop's early reproductive stages (1). Airborne ascospores, considered the primary source of inoculum (28), colonize senescent tissues, especially petals, and subsequently invade the main stem and branches of plants. Infected plants wither and die within several days after inoculation. Yield losses due to this disease in the past 10 years have been estimated at several million dollars. Characterization of the relationship between white mold and yield on dry bean is necessary not only to better estimate losses due to this disease, but also to help in the selection of control measures and determine when control is possible or cost

effective. This article presents one approach to address this issue.

MATERIALS AND METHODS

Field data were collected in eight replicated experiments conducted between 1997 and 2001 at the North Dakota State University Experimental Centers in Oakes and Carrington, and in on-farm trials con-

ducted at five locations in Grand Forks County, ND between 1994 and 1996.

Replicated experiments. White mold-susceptible pinto bean cultivars were planted for all replicated experiments. 'Topaz' was planted in 1997 and 1998, 'Hatton' in 1999, and 'Buster' in 2000 and 2001. All pinto bean cultivars were planted at a density of 190,000 seed/ha. Experimental plots consisted of four rows, each 6 m in length and spaced every 76 cm. Treatments were replicated four times at each location using a randomized complete-block design. The herbicides trifluralin and metolachlor were applied prior to planting at a rate of 1.2 and 1.7 liters/ha, respectively, followed by postemergence application of bentazon at a rate of 2.3 liters/ha. Between 1997 and 2000, the experimental plots were exposed to ascospores produced in the fields. In 2001, a suspension of laboratory-produced ascospores (10^4 ascospores/ml) was sprayed on each experimental plot at R1 stage, when there was at least one open flower on each plant (18). All experiments included positive and negative controls, treated with benomyl or thiophanate-methyl at 0.5 to 1.2 kg a.i./ha or untreated, respectively. Additional treat-

Table 1. Fungicide treatments applied to replicated experiments at two locations in North Dakota between 1997 and 2001

Fungicide treatments ^b	Years ^a				
	1997	1998	1999	2000	2001
Untreated control	+	+	+	+	+
Calcium sulfate	+	+	+	+	–
Calcium sulfate + thiophanate-methyl	+	–	+	+	–
Calcium sulfate + benomyl	–	+	+	+	–
Calcium sulfide	–	+	–	–	–
Calcium sulfide + benomyl	–	+	–	–	–
Calcium nitrate	+	–	–	–	–
Calcium nitrate + thiophanate-methyl	+	–	–	–	–
Calcium chelate	+	–	–	–	–
Calcium chelate + thiophanate-methyl	+	–	–	–	–
Calcium chloride	–	+	–	+	+
Calcium chloride + thiophanate-methyl	–	–	–	+	+
Calcium chloride + benomyl	–	+	–	+	–
Crop Booster NutriCal	–	+	–	–	–
Crop Booster Super Cal	–	+	–	–	–
Calcium EDTA 3%	–	+	–	–	–
Flo-Gyp	–	–	–	–	+
Thiophanate-methyl	+	–	+	+	+
Benomyl	–	+	+	+	–

^a Compound evaluated (+) or not evaluated (–) that year. Experiments were conducted at single locations in 1997 and 1998, and at two locations from 1999 through 2001. Experiments at each location had four replications.

^b Rate of compounds as follows: calcium sulfate, 0.04 to 4.5 kg/ha; calcium chloride, 9.3 liters/ha; all other calcium compounds, 1.1 to 3.3 kg/ha; thiophanate-methyl, 0.4 to 1.2 kg/ha a.i.; benomyl, 0.3 to 0.8 kg/ha a.i. These compounds and fungicides were applied separately or in combination in several proportions for white mold control at flowering time (R1 stage).

Corresponding author: L. del Río
E-mail: Luis.delRio-Mendoza@ndsu.nodak.edu

Accepted for publication 13 August 2004.

Publication no. D-2004-1015-01R
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Table 2. Impact of fungicide application on white mold incidence and yield of pinto beans in replicated experiments between 1997 and 2001 at two North Dakota locations^a

Location	Year	White mold incidence (%)					Yield increase	
		Not protected		Fungicide protected		Probability	Percent	Probability
		Mean	Range	Mean	Range			
Carrington	1997	97	95–100	44	36–59	0.0001	39	0.0001
Carrington	1998	12	5–23	6	0–9	0.2586	14	0.3600
Carrington	1999A	66	45–95	10	5–15	0.0019	58	0.0102
Carrington	1999B	80	50–100	43	20–90	0.1062	33	0.0019
Carrington	2000	44	35–55	5	0–15	0.0004	3	0.6569
Oakes	2000	74	65–90	29	10–65	0.0173	22	0.0195
Carrington	2001	83	70–90	58	45–65	0.0082	14	0.0231
Oakes	2001	91	80–100	46	15–85	0.0282	11	0.1925

^a Means based on four replications per experiment and year.

ments included mixtures of diverse calcium compounds (Table 1) with either one of these fungicides applied once or twice at flowering time. White mold incidence and severity were estimated simultaneously in the two central rows of each plot when the plants were at the R7 stage. At this stage, no more pods are formed in type I (determinate) bean and only a few flowers may still be produced on the vines of type III (indeterminate) bean (18). Ten plants in each of the two central rows of each plot were examined visually for disease incidence and severity. Disease incidence was calculated as the percentage of symptomatic plants. Severity ratings were estimated in the field by adopting a scale of 0 to 5, where 0 = 0%, 1 = 5%, 2 = 15%, 3 = 40%, 4 = 65%, and 5 = 85% of the plant affected by the pathogen. Means for severity were calculated from plants showing white mold symptoms. Severity ratings later were transformed into percentages. At harvest time, a 3-m-long section was marked in the center two rows of each plot. All plants within the section were collected in burlap bags. Bags were stored in forced-air driers at 49°C for 2 to 5 days, and threshed using a Seedburo stationary belt thresher (Seedburo Equipment, Chicago, IL). Yields were estimated and expressed at 8% seed moisture content.

On-farm trials. All trials were conducted on navy bean cultivars. Commercial plantations of nonidentified navy cultivars

Table 3. Percent yield difference between nonprotected and fungicide-protected plots in on-farm trials with navy beans between 1994 and 1996 at four North Dakota locations

Location	Year	Cultivar ^a	White mold incidence (%)			Yield reduction (%)
			Protected	Not protected	Probability ^b	
Northwood	1994	...	69	92	0.05	45
Hatton	1995	...	9	45	0.05	21
Cummings	1996	Envoy	47	78	0.05	21
Cummings	1996	Schooner	13	32	0.05	24
Buxton	1996	Norstar	76	95	0.05	24
Buxton	1996	Schooner	58	73	0.05	21
Buxton	1996	Upland	77	95	0.05	26

^a ... Indicates navy bean cultivars not identified.

^b Probability based on Student *t* test with 15 observations per location and (protected versus nonprotected) strips.

were used in 1994 and 1995, whereas cvs. Envoy, Schooner, and Norstar were used in 1996. Nonreplicated field strips, 1.3 to 3.1 ha in size, were established at several commercial bean fields in North Dakota between 1994 and 1996 to compare the impact of different spraying systems on white mold control. In 1994 and 1995, strips were established near Northwood and Hatton, respectively; whereas, in 1996, strips were established at Cummings, Mayville, and Buxton. At each location, one strip was left untreated (control) while the other was sprayed at the same growth stage as the replicated experiments, with either benomyl or thiophanate-methyl at 1.1 or 1.6 kg a.i./ha, respectively, using commercial ground sprayers or aerial applicators. The strips were managed in

the same way as the rest of the commercial field. White mold incidence was estimated at the R7 stage following the procedure described for the replicated experiments. A total of 15 sampling sites, spaced every 40 m, were made within each strip and the average incidence calculated. Strips were harvested using commercial combines. Yields were estimated in the field.

Data analysis. An analysis of variance using the General Linear Model procedure of SAS (SAS Institute, Cary, NC) was conducted to discriminate between yield of protected and unprotected plots in replicated experiments. Bartlett's test for homogeneity of variances also was conducted to evaluate the possibility of combining data from experiments con-

Table 4. Relationship between white mold incidence and dry bean yields in replicated field trials in North Dakota between 1997 and 2001

Year	Location	Market class	Cultivar ^a	Intercept	Slope	R ² value	Probability
On-farm trials							
1994	Northwood	Navy	...	3550	−18.99	0.99	0.0003
1995	Hatton	Navy	...	2739	−7.46	0.25	0.2109
1996	Cummings	Navy	Envoy	2390	−15.40	0.78	0.1182
1996	Cummings	Navy	Schooner	2246	−26.44	0.98	0.0096
1996	Buxton	Navy	Norstar	3545	−22.38	0.76	0.1272
Replicated experiments							
1997	Carrington	Pinto	Topaz	4638	−19.07	0.87	0.0002
1998	Carrington	Pinto	Topaz	2786	−6.72	0.06	0.4800
1999	Carrington A	Pinto	Hatton	3160	−14.23	0.70	0.0014
1999	Carrington B	Pinto	Hatton	3337	−11.46	0.55	0.0089
2000	Carrington	Pinto	Buster	3054	−5.68	0.24	0.1249
2000	Oakes	Pinto	Buster	4123	−7.04	0.42	0.0322
2001	Carrington	Pinto	Buster	4278	−10.57	0.53	0.0070
2001	Oakes	Pinto	Buster	3725	−10.99	0.43	0.0208

^a ... Indicates navy bean cultivars not identified.

Fig. 1. Correlations between white mold incidence and dry bean yields from **A**, a single location at Carrington in 1997, **B**, a combined analysis of two Carrington locations in 1999, and **C**, a combined analysis of two locations, Carrington and Oakes, in 2001. Each data point represents the average of four observations (1997), and eight observations (1999 and 2001). All coefficients of determination were significant at $P < 0.001$.

ducted in the same year. Data from on-farm trials was analyzed using a Student t test where each sampling site was considered an observation. The association between yield and disease level generated by fungicide application in both replicated and on-farm trials was examined through regression and correlation analysis with the Correlation and Regression procedures of SAS.

RESULTS

The impact of fungicide applications on white mold incidence varied from year to year and location to location in both replicated and on-farm trials; in general, fungicide application reduced white mold incidence and increased yield significantly. The mean white mold incidence across experiments was 34% on fungicide-protected plots compared with 76% in nonprotected plots (Table 2). Fungicide-protected plots also had significantly higher yields at all sites and years, except at Carrington in 1998 and 2000 and at Oakes in 2001. Significant yield increments ranged from 14 to 58%, with a mean of 33%.

In on-farm trials, significant differences were detected for white mold incidence and yield between nonprotected and fungicide-protected strips at all sites and years (Table 3). White mold incidence for nonprotected strips ranged from 32 to 95%, with an overall mean of 73%, whereas the incidence in fungicide-protected strips ranged from 9 to 77%, with an overall mean of 50%. Yield in nonprotected strips ranged from 21 to 45% ($P = 0.05$) less than that of fungicide-protected strips. The mean yield reduction across trials was 26%.

White mold incidence was negatively correlated with dry bean yield in most of the replicated trials and in two of five on-farm trials (Table 4). Yield losses ranged from 7 to 19 kg/ha for each percent unit increment in white mold incidence in replicated trials and from 19 to 29 kg/ha in on-farm trials. Coefficients of determination (R^2) that were significant ($P < 0.05$) ranged from 0.42 to 0.87 for replicated trials and 0.91 to 0.98 for on-farm trials. Data from locations in the year 2000 could not be pooled according to Bartlett's test for homogeneity of variances, but those from years 1999 and 2001 were pooled. The combined analysis for both 1999 and 2001 improved the coefficients of determination (R^2) to 0.75 and 0.79, respectively (Fig. 1). The average yield reductions per incidence unit for both years were 13.2 and 13.0, respectively. A nonlinear association, explained by a second-degree polynomial equation ($R^2 = 0.90$, $P = 0.0001$), was identified between disease incidence and disease severity assessments made on replicated trials (Fig. 2).

DISCUSSION

White mold is a difficult disease to manage with fungicide applications alone.

Plant infection usually starts after ascospores released from apothecia have colonized senescent floral tissues (2). The disease progresses rapidly when cool and wet weather is present (29), and closed, dense canopies extend plant surface wetness for prolonged periods of time (4). The efficacy of fungicide applications to control this disease may be influenced by a number of factors, such as timing of fungicide application (22), fungicide penetration to lower parts of the canopy (22), presence of strains of the pathogen with enhanced tolerance for the fungicides applied (9,23), and fungicide degradation by alkaline hydrolysis (6). Current recommendations in North Dakota suggest to spray when the crop is at full bloom using drop nozzles and high pressure (14). A second application 7 to 10 days later is recommended if conditions are favorable for disease development. However, the use of drop nozzles has been abandoned by many growers that plant bean cultivars in rows 55 cm apart because they get tangled with the crop canopy and break. And even though compounds like thiophanate methyl, the most popular fungicide for white mold control in North Dakota (15), have systemic activity, their limited mobility through the apoplast (20) is an indication that good canopy penetration is still required to achieve adequate control levels. In this study, high disease pressure resulted in white mold incidence ranging from 44 to 97% in nonprotected plots, and a mean incidence for fungicide-protected plots of >29%. It is possible that white mold levels in commercial fields treated with fungicides could be even higher with poorer application coverage or penetration.

The nature of the association between yield loss and plant disease has been studied using simple or multiple regression and correlation analysis and through surface-response associations between yield and disease severity or disease incidence (3,7,19,21,24,25,30). In this study, a negative linear relationship between yield and white mold incidence was detected. Other researchers have found a similar relationship for these variables on soybean (30). For every percent unit increase on white mold incidence, yield of pinto bean (replicated experiments) was reduced by an average of 12 kg/ha (range of 7 to 19 kg/ha), while the yield of navy bean (on-farm trials) was reduced an average of 23 kg/ha (range of 19 to 26 kg/ha). The coefficients of determination (R^2) were highly significant and, in general, explained more than 50 and 90% of the variability observed in replicated experiments and on-farm trials, respectively. However, these associations only apply to conditions where high disease pressure prevail. No significant yield differences were detected between fungicide-protected and nonprotected plots when the average disease incidence (Carrington 1998) or disease sever-

ity (Carrington 2000) was low. Other researchers have found similar results (8,27). Thus, using the numbers described above to estimate yield losses under low disease pressure could result in overestimation of the damage.

The second-degree polynomial equation that described the association between disease incidence and severity showed sharp increments in disease severity when incidence was higher than 50%; whereas, at incidences lower than 40%, disease severity readings were under 10%. Kerr et al. (12), working on irrigated dry bean cultivars, determined that the relationship between yield and white mold severity, based on observations of individual plants, also was explained by a second-degree polynomial equation; however, they indicated that disease severity lower than 40% did not have an impact on yield. In this study, the mean for disease severity in nonprotected and fungicide-protected plots was 34 and 10%, respectively (*data not shown*), but yields on average were 33% higher in the latter. It is possible that infected plants compensate better for the impact of the disease when irrigation is provided. Measuring white mold severity is more difficult and subjective than measuring its incidence. The polynomial that described their association in this article accounted for 90% of the variation observed in the field and is an indication that, under low disease pressure, taking data on disease incidence should be enough to describe an epidemic and its potential impact on yield.

The data suggest that pinto bean tolerated white mold infection better than navy bean. In this study, all pinto cultivars had an indeterminate growth habit type III, whereas the navy bean cultivars had either an indeterminate type II or a determinate type I. The ability of type III bean cultivars

to continue producing more lateral branches after the reproductive stage has started may be an indication that they also can compensate better for yield than the more upright type I bushy navy bean, which stop growing once the flowering stage sets in (13). Further, the upright plant architecture found in most of the indeterminate cultivars has not been correlated with increased disease escape (26) under varying production systems and conditions.

Genetic factors aside, the ability of plants to tolerate disease also is related to their nutritional condition as influenced by soil fertility, fertilization practices, and plant population at the sampling site. The foliar application of calcium compounds alone or in combination with reduced fungicide doses in the experiments analyzed in this study did not increase yield significantly when compared with nontreated plots or with plots treated with a similar fungicide dose, respectively (5). Incidence of diseases other than white mold was negligible at all locations and years. The relationship between disease and yield also is affected by the timing of initial infection and by environmental conditions prevalent after the infection process has started (30), which explains why data from multiple locations and years usually are required to reach sound conclusions. In this study, data for navy bean analysis was produced in commercial farms over a period of 3 years in four locations in North Dakota.

The association found in this article between white mold incidence and yield confirms the importance of this disease as a limiting problem for the dry bean industry. The average disease incidence in replicated experiments was 33%; therefore, we decided to use that value as the cutoff point to extrapolate yield losses. A field survey that scouted over 90 fields in the

Fig. 2. Relationship between white mold incidence and severity at experiments conducted between 1997 and 2001 in North Dakota. Each data point represents the mean of four replications. The coefficient of determination was significant at $P = 0.0001$.

main dry bean-producing areas of North Dakota (10) indicated that 19% of the fields had an average white mold incidence of 43%. Considering a grower price for dry beans at \$0.34/kg as published by the USDA-CO Department of Agriculture Market News for 9 March 2004, a simple calculation would place yield losses for 2003 at about 120 kg/ha or \$53.04/ha. If the pinto bean acreage harvested in North Dakota in 2003 is similar to that of 2002 (1.86×10^5 ha) (11), yield losses attributed to white mold could have approached \$1.9 million without considering the cost of the fungicide and its application.

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