

Seed Treatment Application-Timing Options for Control of Fusarium Decay and Sprout Rot of Cut Seedpieces

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ABSTRACT

The efficacy of application timings of a commercially formulated mixture of fludioxonil plus mancozeb (Maxim MZ) applied prior to planting for the control of seedpiece decay and rotting of sprouts, caused by the dry rot pathogen *Fusarium sambucinum*, was evaluated over two years. Cut potato seedpieces were inoculated with a virulent strain of *F. sambucinum* and either treated with the fungicide mixture or not. Treatment applications were made 10, 5 or 2 days prior to planting. Seedpiece and sprout health were evaluated *in vitro* and agronomic impacts were evaluated *in vivo* in field experiments. Overall, the *in vitro* experiments indicated that inoculation with *F. sambucinum* did not have an effect on the mean number of sprouts per seedpiece but did affect the incidence of rotting sprouts and seedpiece decay. However, treatment of seedpieces with the fungicide mixture 10, 5 or 2 days before planting significantly reduced the percentage of diseased sprouts per seedpiece and seedpiece decay. Inoculated seedpieces treated with the fungicide mixture produced similar numbers of healthy sprouts as did the non-inoculated seedpieces. The experiment, conducted in 2003, showed that final plant stand, RAUEPC and RAUCCC were similar for non-inoculated seedpieces and inoculated fungicide-treated seedpieces. Overall, there were no significant differences among treatment timings, and these results suggest that applying a fungicide seed treatment up to 10 days prior to planting can provide effective control of both Fusarium seedpiece decay and sprout rot.

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ADDITIONAL KEY WORDS: *Solanum tuberosum*, *Fusarium sambucinum*, seedpiece decay, sprouts, rot, plant establishment

ABBREVIATIONS: RAUEPC = relative area under emergence progress curve; RAUCCC = relative area under canopy closure curve

RESUMEN

Durante dos años se evaluó el mejor tiempo de aplicación de una mezcla formulada comercialmente de fludioxonil mas mancozeb (Maxim MZ) aplicada antes de la siembra para el control de la descomposición de semilla y pudrición de brotes, causada por el patógeno de la pudrición seca *Fusarium sambucinum*. Semilla cortada de papa tratada y no tratada con la mezcla fungicida fue inoculada con un strain virulento de *F. sambucinum*. Las aplicaciones del tratamiento se hicieron 10, 5 o 2 días antes de la siembra. La sanidad de la semilla cortada y de los brotes fue evaluada *in vitro* y el impacto agronómico se evaluó *in vivo*. En términos generales, los experimentos *in vitro* indicaron que la inoculación con *F. sambucinum* no tuvo efecto sobre el promedio de brotes por semilla cortada, pero si afectó la incidencia de pudrición de brotes y de descomposición de la semilla. Sin embargo, el tratamiento de la semilla con la mezcla fungicida 10, 5 o 2 días antes de la siembra, redujo significativamente el porcentaje de brotes enfermos por semilla y la pudrición de la semilla. Las semillas tratadas con la mezcla fungicida produjeron un número similar de brotes sanos que la semilla no inoculada. El experimento hecho el 2003, mostró que el resultado final de plantas, RAUEPC y RAUCCC fueron similares entre las semillas inoculadas tratadas con el fungicida y las no inoculadas. En términos generales no hubo diferencia significativa entre el tiempo de aplicación de los tratamientos y estos resultados sugieren que aplicando un fungicida como tratamiento de semilla 10 días antes de la siembra puede proporcionar un control efectivo para Fusarium tanto para la descomposición de la semilla como para la pudrición del brote.

INTRODUCTION

Fusarium dry rot is one of the most important diseases of potato (*Solanum tuberosum* L.), affecting tubers in storage and whole seed or seedpieces after planting (Hanson et al. 1996). *Fusarium sambucinum* Fuckel (teleomorph *Giberella pulicaris*) is the most common pathogen causing dry rot of stored tubers in North America (Secor and Salas 2001). Fusarium dry rot of seed tubers can reduce crop establishment by killing developing potato sprouts (Wharton et al. 2006), with crop losses up to 25% (Chelkowski 1989), while more than 60% of tubers can be infected in storage (Theron and Holtz 1991). All the commonly grown potato cultivars in North America are susceptible to the pathogen, although some are more susceptible than others (Leach and Webb 1981) and several breeding lines have been reported to have a higher degree of resistance to dry rot (Ray and Hammerschmidt 1998).

There are two main opportunities in the potato crop cycle for the control of Fusarium dry rot. The first is the post-harvest control of seedpiece decay in the seed crop in the fall, and the second is the control of seedpiece decay prior to planting the crop in the spring (Nolte et al. 2003). In crops intended for use as seed for the following season, the dry rot pathogen enters tubers mainly through wounds produced during harvest and transportation to storage facilities. Potato seed tubers are maintained at 3 to 4 C, which is approximately the temperature at which *F. sambucinum* is dormant, and consequently there is minimal development of dry rot in storage (O'Brien et al. 1983; Lui and Kashalappa 2002). During the pre-planting phase of potato production, seed tubers are warmed to about 12 C and then cut into seedpieces prior to planting (Chase et al. 1988). Seedpieces infected with *F. sambucinum* may develop seedpiece decay and rot completely before planting, and up to 50% of sprouts developing on infected seedpieces may become diseased and may be killed outright before emergence (Wharton et al. 2006). Damage at this stage can result in non-emergence, delayed emergence, and poor or uneven stands, sometimes with weakened plants. During recent seasons in the potato-growing regions of the north central states of the US, three factors have enhanced dry rot problems: 1) lack of information on effective fungicides for both post-harvest and pre-planting use against *F. sambucinum*, 2) an increase in the area of potatoes grown by fewer growers (MPIC Pesticide Surveys, 1995-1999), leading to management issues such as appropriate timing of pre-cutting of seed and 3) climatic factors such

as increased rainfall events during the planting phase of the season (Andresen et al. 2001; Baker et al. 2005). In combination, these factors can delay planting and increase the impact of Fusarium seedpiece decay and sprout rot during the early portion of the growing season and subsequently may affect the yield and quality of the crop.

There is little information on the use and effectiveness of seed treatments for control of Fusarium seedpiece decay, the pre-planting phase of dry rot, or sprout rot, the post-planting phase of the disease (Nolte et al. 2003; Wharton et al. 2006). Much of the research that has been carried out on the use of fungicide seed treatments for control of seedborne *Fusarium* spp. on seed tubers was conducted in Europe during the latter part of the 20th century on whole seed (Hide and Cayley 1985; Carnegie et al. 1998). Thus, the objectives of this investigation were twofold: first, to evaluate *in vitro* the effectiveness of fungicidal seed treatments applied at various times prior to planting for controlling Fusarium seedpiece decay and rotting of sprouts, and second, to conduct field experiments to evaluate the agronomic effects of fungicidal seed treatments applied at various times prior to planting on crop health.

MATERIALS AND METHODS

Fungal Cultures and Inoculation

A virulent single-spore isolate of *Fusarium sambucinum*, which produces dry rot symptoms in potato tuber tissue, was used. Conidia of the isolate were maintained at 4 C in the dark on filter paper and axenic cultures of the isolate were produced by placing a 1 mm² section of filter paper containing conidia of the stored culture on potato dextrose agar (PDA). For inoculum production, cultures of *F. sambucinum* were grown on PDA in the dark at 8 C for 14 days prior to the date of inoculation. Conidia were harvested by flooding the surface of the Petri dish with sterile distilled-deionized water (5 ml) and gently scraping the surface of the media with an L-shaped glass rod to dislodge the conidia. The conidial suspension was stirred with a magnetic stirrer for 1 h and strained through four layers of cheesecloth to remove mycelial fragments. The concentration was then adjusted to 1 x 10⁵ conidia ml⁻¹ using a hemacytometer.

Inoculation and Seed Treatment

Chip processing potato cultivars 'Pike' (Plaisted et al. 1998) and FL1879 were used in all experiments. Whole tubers

were harvested in October from certified seed crops grown in northern Michigan in 2001 and 2002. Tubers free from symptoms of Fusarium dry rot (and other diseases) were selected for the experiments. The tubers were stored in the dark at 3 C and 95% RH until the spring of the following year. Tubers were removed from storage, warmed from 4 C in 2 C increments, every two days, up to 12 C over a period of eight days and maintained at 12 C for a further two days in the dark in a controlled-environment chamber with forced-air ventilation at 5950 l min⁻¹ until cutting and treatment. Tubers were cut in half longitudinally with a sterile knife, ensuring that viable sprouts were present on both halves. Treatments applied to seedpieces were 1) not inoculated, 2) inoculated with *F. sambucinum* or 3) inoculated with *F. sambucinum* and treated with the commercial seed protectant Maxim[®] MZ (active ingredients: fludioxonil 5 g kg⁻¹ + mancozeb 96 g kg⁻¹; Syngenta Crop Protection Inc., Greensboro, NC, USA) at the manufacturer's recommended rate (500 g per 100 kg potato seed). The non-inoculated treatment consisted of cut seedpieces which were sprayed with sterile distilled water only. Inoculated seedpieces were produced by spraying 200 ml of conidial suspension (1 x 10⁵ conidia ml⁻¹) over the entire cut surface to give a final dosage of about 1 ml per seedpiece. Care was taken to limit inoculum spray to the cut surface only. Fungicide-treated seedpieces were inoculated as described and treated with seed protectant Maxim[®] MZ. The fungicidal seed treatment was applied to the cut seedpieces 30 minutes after inoculation using a Gustafson revolving drum seed treater. To determine the effectiveness of fungicidal seed treatments applied at various times prior to planting for controlling Fusarium seedpiece decay and rotting of sprouts, identical treatments were made at 10, 5, and 2 days prior to planting. After treatment, seedpieces were placed in sterilized plastic crates and returned to dark, controlled-environment chambers set at 12 C, with forced-air ventilation at 5950 l min⁻¹ until planting. Sufficient tubers were treated to give a total of 160 seedpieces per treatment for the field experiment and 25 for the *in vitro* experiment.

In Vitro Evaluation of Seed Treatment Timing on Fusarium Seedpiece Decay and Sprout Rot

To evaluate the effect of seed treatment on the development of dry rot on the seedpieces and infection of sprouts, 25 seedpieces were removed from each treatment on the day of planting. These seedpieces were re-incubated at 18 C (95% RH)

in a controlled-environment chamber for 14 days after the scheduled time of planting. Data were collected on the total number of healthy and infected sprouts, and the percentage of infected sprouts was calculated. The percentage of decay per seedpiece was scored by cutting each seedpiece into four transverse sections and estimating subjectively the percentage of surface area covered by darkening. The maximum length, width, and depth of both the seedpiece and the lesion were measured and multiplied to give an approximate volume of the seedpiece and amount of decay, respectively. The estimated volume of decay was expressed as a percentage of the estimated volume of the seedpiece. The experiment was carried out in 2002 and repeated in 2003. Data from both years were analyzed together by five-way analysis of variance using the statistical analysis software package JMP (SAS Institute, Cary, NC). Treatment means were compared using the Tukey Multiple Comparison test ($P = 0.05$).

Field Experiments

In both years all the treated cut seedpieces were planted on the same day at the Michigan State University Montcalm Potato Research Farm, Edmore, MI into single-row plots 9 m long (with approximately 22 cm between seedpieces to give an intended population of 40 plants at 86 cm row spacing) replicated four times in a randomized complete block design. Fertilizer was formulated according to results of soil tests and drilled into plots before planting. Additional nitrogen (final N

TABLE 1—*Summary of the analysis of variance of the main effects of seed treatment application and inoculation with Fusarium sambucinum on in vitro sprout development, and sprout and seedpiece health in two cultivars of potato stored for 14 days in controlled environments after the scheduled time of planting.*

Source	P value ^b		
	Mean sprout number	Diseased sprouts	Seedpiece decay
Year	<0.0001	0.4031	<0.0001
Variety (Var)	0.0017	0.1088	0.6875
Seed Treatment (ST)	<0.0001	<0.0001	<0.0001
Inoculation (Inoc)	<0.0001	<0.0001	<0.0001
Treatment Timing (Time) ^a	0.0116	0.0023	0.3269
Year × Var × ST × Inoc × Time	0.0544	0.0012	0.3212

^aTreatment timing = fludioxonil + mancozeb applications applied to the seedpieces 10, 5 or 2 days prior to planting on a common date.

^bSignificance indicated by $P \leq 0.05$.

TABLE 2—Effect of timing of seed treatment application and inoculation with *Fusarium sambucinum* on sprout development, and sprout and seedpiece health in two cultivars of potato stored for 14 days in controlled environments after the scheduled time of planting.

Year ^a /Cultivar	Timing ^b (days)	Inoculation ^c	Fungicide treatment ^d	Mean sprout number ^e	Diseased sprouts ^f (%)	
2002	FL1879	2	+	+	2.4 ab ^g	6.7 def
			+	-	2.5 ab	22.7 bcde
			-	-	2.1 abc	0.0 f
		5	+	+	2.4 ab	10.3 cdef
			+	-	1.6 c	25.3 bcd
			-	-	1.9 bc	0.0 f
	Pike	2	+	+	2.2 ab	30.3 b
			+	-	2.6 a	39.7 b
			-	-	2.6 a	0.0 f
		5	+	+	2.6 x ^h	2.7 f
			+	-	2.4 xy	38.0 b
			-	-	1.9 z	28.0 bc
	10	+	+	2.6 x	4.0 ef	
		+	-	2.7 x	32.3 b	
		-	-	2.7 x	0.0 f	
		+	+	2.4 xy	2.3 f	
		+	-	2.6 x	63.0 a	
		-	-	2.6 x	0.0 f	
2003	FL1879	2	+	+	3.7 bcd	0.0 c
			+	-	4.7 a	47.3 ab
			-	-	4.2 abc	0.0 c
		5	+	+	3.0 d	11.1 c
			+	-	4.4 abc	44.9 ab
			-	-	3.9 abc	0.0 c
	Pike	2	+	+	3.9 abc	0.0 c
			+	-	4.6 a	57.9 a
			-	-	3.5 cd	0.0 c
		5	+	+	3.0 d	11.1 c
			+	-	4.4 abc	35.9 b
			-	-	4.0 abc	0.0 c
	10	+	+	4.2 abc	0.0 c	
		+	-	4.6 ab	57.1 a	
		-	-	3.8 abcd	4.0 c	
		+	+	4.4 ab	4.8 c	
		+	-	4.5 ab	50.9 ab	
		-	-	4.1 abc	0.0 c	

^aData from each year were analyzed separately for all variables.

^bFludioxonil + mancozeb applications were applied to the seedpieces 10, 5 or 2 days prior to planting on a common date.

^cSeedpieces inoculated with *Fusarium sambucinum* = "+"; seedpieces not inoculated = "-"; seedpieces were inoculated immediately after cutting 10, 5 or 2 days prior to planting.

^dSeedpieces were treated with a fludioxonil + mancozeb seed treatment 30 min after inoculation.

^eMean sprout number for each cultivar.

^fSprout rot was symptomatic of *Fusarium sambucinum*.

^gNumbers followed by the same letter within a column are not significantly different at $P = 0.05$ (Tukey multiple comparison method).

^hMean sprout number for each cultivar in 2002 were analyzed separately and were followed by letters^h starting at "a" for FL1879 and "x" for Pike. In 2003, data for both cultivars were analyzed together. Mean sprout rot incidence was analyzed separately for 2002 and 2003. The dotted lines in the table delimit the analyses.

31 kg ha⁻¹) was applied to the growing crop with irrigation 45 days after planting (DAP). To control potato late blight, the fungicide Bravo WS 6SC[®] (active ingredient: chlorothalonil) was applied at 1.75 l ha⁻¹ on a seven-day interval (eight applications) to all treatments, starting when the canopy was about 50% closed. A permanent irrigation system was established prior to the commencement of fungicide sprays, and the fields were maintained at about 80% soil moisture capacity throughout the season by frequent (minimum 5 day) irrigations delivering about 1.5 cm H₂O ha⁻¹ per irrigation. Weeds were controlled by hilling and with the herbicides metolachlor (Dual 8E[®]) at 2.3 l ha⁻¹ 10 DAP, and sethoxydim (Poast[®]) at 1.8 l ha⁻¹ 40 DAP. Insects were controlled with the insecticides imidacloprid (Admire 2F[®]) at 1.4 l ha⁻¹ at planting, carbaryl (Sevin 80S[®]) at 1.4 kg ha⁻¹ 31 and 55 DAP, permethrin (Pounce 3.2EC[®]) at 0.56 l ha⁻¹ 48 DAP, and endosulfan (Thiodan 3 EC[®]) at 2.7 l ha⁻¹ 65 and 87 DAP.

In both years, data were collected on emergence, canopy closure, plant stand, and yield. After harvest tubers were sorted into two size classes: marketable grade tubers (US1, >6.5 cm and <12.5 cm in any plane) and B grade tubers (4 to 6.5 cm). Due to environmental variability, each year's data were analyzed separately by four-way analysis of variance using the statistical analysis software package JMP (SAS Institute, Cary, NC). Emergence was rated as the cumulative number of plants breaking the soil surface. The number of emerged plants was recorded over a 22-day period after planting. The final plant stand was expressed as the percentage of emerged plants divided by the expected number based on the planting rate. Emergence progress over time was calculated initially as the area under the plant emergence progress curve (AUEPC; max=100). From this, the relative area under the emergence progress curve (RAUEPC) was calculated by modification of the method used to calculate the relative area under the disease progress curve (RAUDPC; Kirk et al. 2001), using the following equation:

$$\text{RAUEPC} = \frac{\sum(t_{i+1} - t_i) * \left(\frac{E_{i+1} + E_i}{2}\right)}{T_{\text{total}} * 100}$$

where t was the time in days after planting and E was the percentage of plant emergence. As plant emergence was assessed at various time intervals, the area under emergence progress curve (AUEPC) was calculated by adding the area under the linear progression of the number of emerged plants between consecutive estimations of emergence from planting to full emergence. The RAUEPC was calculated by dividing the sum of individual AUEPC values by the maximum AUEPC ($100 \times$ duration of emergence period, from planting to full emergence). Progress of canopy development was measured as the relative area under the canopy closure curve (RAUCCC), calculated from day of planting to a key reference point taken at 58 DAP (about 100% canopy closure; max = 100). RAUCCC was calculated by modification of the method used to calculate RAUEPC as described above. Treatment means were compared using the Tukey Multiple Comparison test in JMP ($P = 0.05$).

RESULTS AND DISCUSSION

Potato seedpiece treatments are useful for the control of seed-borne diseases and have been used to control diseases such as black scurf and stem canker (*Rhizoctonia solani* Kuhn), silver scurf (*Helminthosporium solani* Durieu & Mont) and dry rot [*Fusarium* spp. (Hide and Lapwood 1982; Frazier et al. 1998; Nolte et al. 2003)]. This is the first systematic study to investigate the optimal timing and effectiveness of fungicidal seed treatments prior to planting to control *Fusarium* seedpiece decay and sprout rot in potato.

There were no significant differences between varieties in the *in vitro* storage experiments in terms of the percentage of diseased sprouts and seedpiece decay (Table 1). Overall there was no significant effect of inoculation on the mean number of sprouts per tuber, even though inoculation of seedpieces with *F. sambucinum* caused disease in up to 57% of sprouts on inoculated seedpieces not treated with the fungicide mixture (Table 2). *Fusarium sambucinum* was reisolated from all decaying seedpieces and infected sprouts. There was a significant difference between treatment timings in terms of the percentage of diseased sprouts (Table 1). However, treatment of inoculated seedpieces with fludioxonil + mancozeb at 10, 5 or

TABLE 3—Effect of timing of seed treatment application and inoculation with *Fusarium sambucinum* on seedpiece health in two cultivars of potato stored for 14 days in controlled environments after the scheduled time of planting.

Cultivar ^a	Timing ^b (days)	Fungicide treatment ^b	Inoculation ^c	Seedpiece decay ^d (%)
FL1879	2	+	+	0.7 c
		-	+	8.2 b
		-	-	0.2 c
	5	+	+	0.5 c
		-	+	9.3 ab
		-	-	0.1 c
	10	+	+	0.7 c
		-	+	12.6 a
		-	-	0.4 c
Pike	2	+	+	0.2 c
		-	+	9.4 ab
		-	-	1.6 c
	5	+	+	0.8 c
		-	+	10.9 ab
		-	-	0.4 c
	10	+	+	0.8 c
		-	+	9.6 ab
		-	-	0.4 c

^aData from each cultivar and year were analyzed together for all variables.

^bFludioxonil + mancozeb applications were applied to the seedpieces 10, 5 or 2 days prior to planting on a common date 30 min after inoculation; "+" = seedpieces treated and "-" = seedpieces not treated after cutting and inoculation.

^cSeedpieces inoculated with *Fusarium sambucinum* = "+"; seedpieces not inoculated = "-"; seedpieces were inoculated immediately after cutting 10, 5 or 2 days prior to planting.

^dSeedpiece decay was symptomatic of *Fusarium sambucinum*.

^eNumbers followed by the same letter are not significantly different at $P = 0.05$ (Tukey multiple comparison method).

2 days before planting significantly reduced the percentage of diseased sprouts per seedpiece, and inoculated seedpieces treated with the fungicide mixture produced similar numbers of healthy sprouts to the non-inoculated seedpieces (Table 2). There was no significant effect among treatment timings on the levels of seedpiece decay (Table 1). Seed treatment with fludioxonil + mancozeb at 10, 5 or 2 days before planting provided very effective control of the disease (Table 3).

There was no significant effect in the field experiments among treatment timings on RAUEPC, RAUCCC, final plant stand or yield in both years (Table 4). In 2003, application of the commercial seed treatment mixture fludioxonil + mancozeb to inoculated seedpieces appreciably enhanced emergence of sprouts, RAUCCC and the final plant stand (Table 5). Inoculation with *F. sambucinum* did not have an effect on the

TABLE 4—Summary of the analysis of variance of the main effects of seed treatment and application timing on potato seedpieces in the presence and absence of *Fusarium sambucinum* on final plant stand, RAUEPC, RAUCCC and yield in field experiments.

Year ^a / Source	P value ^b					
	Final plant stand	RAUEPC ^c	RAUCCC ^d	Yield (US1)	Yield (B)	
2002	Variety (Var)	<0.0001	0.0006	0.3226	0.3194	0.8020
	Seed Treatment (ST)	<0.0001	<0.0001	<0.0001	0.0408	0.6888
	Inoculation (Inoc)	<0.0001	<0.0001	0.0002	0.0005	0.7894
	Treatment Timing (Time)	0.2858	0.2617	0.3443	0.4669	0.4348
	Var × ST × inoc × time	0.0485	0.0481	0.7965	0.4981	0.3874
2003	Variety (Var)	0.7804	0.6179	0.0005	0.5216	0.8492
	Seed Treatment (ST)	<0.0001	<0.0001	<0.0001	<0.0001	0.4095
	Inoculation (Inoc)	<0.0001	<0.0001	<0.0001	<0.0001	0.7356
	Treatment Timing (Time)	0.7427	0.9775	0.0118	0.2024	0.4637
	Var × ST × inoc × time	0.3416	0.2657	0.3987	0.1492	0.7348

^aData from each year were analyzed separately for all variables as there were significant differences in the effect of year of the field experiments.

^bSignificance indicated by $P \leq 0.05$.

^cRAUEPC (relative area under the plant emergence progress curve) calculated from the day of planting to full emergence 22 days after planting (max = 100).

^dRAUCCC (relative area under the canopy closure curve) calculated from day of planting to a key reference point taken at 58 days after planting [(about 100% canopy closure) max = 100].

mean number of sprouts per tuber but did increase the incidence of diseased sprouts per tuber. RAUEPC was lower in treatments from inoculated seedpieces not treated with fungicide, which suggests that sprouts were becoming infected and killed prior to emerging from the soil. This indicates that the fungicide seed treatment not only prevented seedpiece decay but also protected the developing sprouts from infection. In 2002, there were no significant differences in the RAUEPC, RAUCCC, final plant stand or yield among treatments (Table 5). This suggests that the seedpieces were able to compensate for the loss of sprouts by stimulating the development of dormant sprouts. It has been suggested that seedpiece decay may be of little consequence if the soil moisture and temperature are suitable for rapid sprout growth and emergence (Secor and Salas 2001). Thus, the lower RAUEPC in 2003 may have enabled the fungus to become more established, resulting in higher mortality of developing sprouts from non-treated/inoculated seedpieces. A reduction in the RAUEPC may have an indirect effect on canopy closure (RAUCCC) and final plant stand. Climatic factors that influence early crop development appear to have at least as great an effect on subsequent crop development as seed health factors. In 2003, there were no significant differences between cultivars in the yield of US1 grade tubers (Table 5). However, there were significant differences among treatments, with the inoculated, non-treated treat-

ments having the lowest US1 yield and the non-inoculated, non-treated treatments having the highest US1 yield in general (Table 5). There were no significant differences among seedpieces inoculated and treated with fungicides or seedpieces not inoculated and not treated with fungicide in terms of yield of US1 grade tubers (Table 5).

Bacterial pathogens such as *Pectobacterium* spp. are known to frequently invade through dry rot lesions and cause soft rot decay, and plants developing from dry rot infected seedpieces are known to have a high risk of developing black leg (Secor and Salas 2001). Thus, by protecting

seedpieces from dry rot infection and promoting rapid sprout growth and emergence, fungicide treatment may indirectly provide protection from bacterial pathogens.

Some level of *Fusarium* dry rot is almost always present in commercially available seed tubers (Leach 1985). Even though it is not possible at present to be completely certain that a seed lot is free of dry rot, it is good practice to plant seed that meets established seed certification standards. Although it may not seem cost effective to apply fungicide seed treatments to healthy tuber pieces, these results suggest that applying a fungicide at the time of cutting up to 10 days prior to planting can provide effective control of dry rot and increase RAUEPC, RAUCCC and final plant stand.

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TABLE 5—Effect of seed treatment and application timing on potato seedpieces in the presence and absence of *Fusarium sambucinum* on final plant stand, RAUEPC, RAUCCC and yield in field experiments.

Year ^a and Cultivar	Fungicide treatment timing (days) ^b and inoculation ^c			Final plant stand (%)	RAUEPC ^d	RAUCCC ^e	Yield (t/ha)		
	(US1)	B-size							
2002 FL1879	2 ^b	+	+	99 a ^f	7.64 ab	32.9 ab	38.7 a	0.04 a	
		-	+	94 a	6.53 abc	31.7 ab	36.1 a	0.04 a	
		-	-	97 a	7.33 ab	36.1 ab	42.5 a	0.04 a	
	5	+	+	91 ab	6.03 abc	36.0 ab	38.8 a	0.04 a	
		-	+	91 ab	5.94 abc	28.1 ab	39.0 a	0.03 a	
		-	-	95 a	7.47 ab	38.0 ab	41.2 a	0.04 a	
	10	+	+	100 a	7.95 a	38.6 a	38.3 a	0.04 a	
		-	+	87 abc	5.53 bc	31.3 ab	36.4 a	0.04 a	
		-	-	98 a	7.37 ab	35.7 ab	38.1 a	0.04 a	
	Pike	2	+	+	92 ab	6.03 abc	32.9 ab	36.8 a	0.04 a
			-	+	88 abc	6.03 abc	31.0 ab	33.9 a	0.03 a
			-	-	85 abc	6.12 abc	31.7 ab	39.2 a	0.04 a
		5	+	+	94 a	7.01 ab	39.6 a	41.1 a	0.04 a
			-	+	73 c	4.48 c	31.4 ab	34.9 a	0.04 a
			-	-	92 ab	6.56 abc	35.0 ab	40.2 a	0.04 a
	10	+	+	94 a	7.02 ab	35.4 ab	37.2 a	0.04 a	
		-	+	75 bc	4.81 c	26.4 b	33.9 a	0.03 a	
		-	-	96 a	6.99 ab	35.3 ab	42.0 a	0.04 a	
	2003 FL1879	2	+	+	93 a	6.17 a	36.5 ab	38.7 abc	0.04 a
			-	+	61 b	3.28 c	10.8 c	34.2 bc	0.01 a
			-	-	91 a	6.30 a	38.6 a	43.9 ab	0.04 a
		5	+	+	89 a	6.46 a	33.7 ab	39.2 abc	0.04 a
			-	+	54 b	3.75 c	13.8 c	36.4 abc	0.02 a
			-	-	93 a	6.82 a	32.9 ab	36.8 abc	0.04 a
10		+	+	92 a	6.63 a	33.6 ab	38.9 abc	0.04 a	
		-	+	66 b	4.31 bc	13.8 c	34.0 bc	0.02 a	
		-	-	98 a	5.77 ab	32.9 ab	38.1 abc	0.04 a	
Pike		2	+	+	95 a	6.56 a	33.6 ab	40.8 abc	0.04 a
			-	+	57 b	3.76 c	15.5 c	33.9 bc	0.02 a
			-	-	96 a	6.61 a	31.3 ab	40.3 abc	0.04 a
		5	+	+	93 a	6.32 a	29.0 b	41.7 ab	0.03 a
			-	+	65 b	3.07 c	11.9 c	34.0 bc	0.01 a
			-	-	94 a	6.46 a	28.2 b	44.9 a	0.03 a
10		+	+	93 a	6.57 a	29.2 b	37.2 abc	0.03 a	
		-	+	56 b	2.93 c	11.8 c	31.0 c	0.01 a	
		-	-	92 a	6.43 a	28.2 b	42.0 ab	0.03 a	

^aData from each year were presented separately in the analyses for all variables as there were significant differences in the effect of year on the field experiments due to environmental differences between years.

^bFludioxonil + mancozeb applications were applied to the seedpieces 10, 5 or 2 days prior to planting on a common date 30 min after inoculation; "+" = seedpieces treated and "-" = seedpieces not treated after cutting and inoculation.

^cSeedpieces inoculated with *Fusarium sambucinum* = "+"; seedpieces not inoculated = "-"; seedpieces were inoculated immediately after cutting 10, 5 or 2 days prior to planting.

^dRAUEPC (relative area under the plant emergence progress curve) calculated from the day of planting to full emergence 22 days after planting (max = 100).

^eRAUCCC (relative area under the canopy closure curve) calculated from day of planting to a key reference point taken at 58 days after planting [(about 100% canopy closure) max = 100].

^fNumbers followed by the same letter within a column are not significantly different at $P = 0.05$ (Tukey multiple comparison method).

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