Research Reports

Improving Sea Oats Seedling Production from Seed with Fungicides

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SUMMARY. In Louisiana, sea oats (*Uniola paniculata*) are incorporated into beach restoration projects to build and stabilize sand dunes. Unfortunately, sea oats seed yield, germination, and seedling survival are poor. The objectives of this study were to assess the impact of commercial fungicide(s) on sea oats germination, seedling survival, and seedling quality. Sea oats seed were planted into soilless media and grown in greenhouse conditions in Baton Rouge, LA. Four fungicide treatments at two rates were applied to seeded trays: mefenoxam, thiophanate-methyl, azoxystrobin, and iprodione. Two control treatments were included: a 15-minute seed soak in water before seeding and dry seed. Percentage germination, percentage survival, shoot height, and fresh weight were measured. Sea oats seed treated with thiophanate-methyl at twice the fungicide label's recommended rate [$2\times$ (23.0 oz/1000 ft² a.i.)] had the greatest mean germination and survival and were the tallest seedlings 8 weeks after seeding. These results strongly suggest that treating seed with thiophanate-methyl $2\times$ increased sea oats germination, survival, seedling quality, and profitability of sea oats production. The cost to apply thiophanate-methyl $2\times$ to 1000 sea oats seed was \$1.74. The additional revenue generated from greater germination, survival, and seedling quality when growing media was treated with thiophanate-methyl $2\times$ was \$37.72 per 1000 sea oats seeds. Therefore, the fungicide thiophanate-methyl was identified to be a practical and economical method to rapidly produce a large number of genetically diverse sea oats plants.

high wind velocities, sand movement, limited water or xeric situations, high evaporation rates, and extreme temperatures (Dahl and Woodard, 1977; Wagner, 1964; Woodhouse et al., 1968; Woodhouse and Hanes, 1967). Because of these characteristics and its ability to build and stabilize sand dunes, it is commonly used in beach restoration projects.

In Louisiana, most sea oats plants used in beach restoration projects are genetically identical. They are produced by vegetatively dividing and propagating clonal material in greenhouses and nurseries. Planting the same clone on a large scale reduces genetic diversity and threatens the success of the project (Kutner and Morse, 1996). A more desirable system would be to produce sea oats from seed (Knott et al., 2012). Production of sea oats plants from seed would not only increase genetic diversity of sea oats plants but would also reduce production costs (Nabukalu and Knott, 2013a).

Large-scale production of sea oats from seed has been limited in Louisiana for several reasons. First, limited seed production, possibly resulting from the majority of florets in a spikelet being sterile or incompletely developed or from aborted ovules, makes it difficult to acquire seed from natural ecosystems (Gould and Shaw, 1983; Wagner, 1964; Williams, 2007). Second, there is limited knowledge of seed storage conditions to prolong seed viability, which could compromise the integrity of the seed. Typically most seed are stored at 4 °C; however, recent research indicates sea oats seed storage should be at room temperature in sealed jars to maximize seed longevity (Nabukalu and Knott, 2013b). Finally, sea oats have extremely poor germination rates, typically around 30% to 40%. These limited germination rates have been

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Sea oats is a perennial grass native to the Gulf of Mexico and Atlantic coastal regions of the United States. It is adapted to withstand

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
407.4583	gal/1000 ft ²	L·ha ⁻¹	0.0025
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
28.3495	oz	g	0.0353
3.0515	oz/1000 ft ²	kg·ha ⁻¹	0.3277
0.4732	pt	L	2.1134
5.0932	pt/ft ²	L·m ⁻²	0.1963
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

attributed to seed dormancy and/or to pathogens, fungal or bacterial, that potentially reside internally, on the seed surface or in the immediate soil zone, which can reduce germination (Burgess et al., 2002; Hester and Mendelsohn, 1987; Nabukalu, 2013; Sharvelle, 1961). Additionally, these pathogens could parasitize the seed before or during germination, or revive later and attack the seedling as a latent infection (Arya and Perelló, 2010; Sharvelle, 1961). Fortunately, fungicide applications at seeding are a traditional and effective method of protecting seed from fungal pathogens, thereby aiding germination and improving seedling survival in field, nursery, and greenhouse conditions (Arya and Perelló, 2010). The objectives of this study were to assess the impact of commercial fungicides on sea oats germination, seedling survival, and seedling quality, such as shoot height and fresh weight.

Materials and methods

FUNGICIDE APPLICATIONS. On 31 May and 14 June 2013, sea oats seed were planted under greenhouse conditions at Burden Museum and Gardens in Baton Rouge, LA. Seed used had been harvested on 26 Aug. 2011 from Long Beach, MS. Seed were placed into standard trays (11 × 21–3/8 inches, 1.6 ft²; T.O. Plastics, Clearwater, MN) containing 72-cell inserts (Standard Inserts 1206; T.O. Plastics) filled with an all-purpose soilless media mix (Sunshine Professional Growing Mix #8; Sun Gro Horticulture Canada, Agawam, MA). All watering was done by hand. About 0.5 to 1.5 L of water was added to each tray every 3 to 4 d when the tray holding water was empty and the growing media was beginning to dry. Additional plant nutrients were not used. Media was moistened 3 to 4 d before seeding. The greenhouse was maintained under natural photoperiod at ≈83 to 88 °F. A total of eight fungicide treatments, four fungicides at two rates, were examined. The two rates examined were the recommended rate based on the fungicide label (1×) and twice the recommended rate (2×). Two controls with no fungicide application consisted of soaked and dry sea oats seed. The soaked seed were submerged in tap water for 15 min before seeding. The dry seed were seeded without any seed preparation.

To prepare fungicide solutions, tap water was adjusted to pH of ≈6.0 with acid buffer (pH Down; GH, Sebastopol, CA) before addition of fungicides. Mefenoxam (SubdueMaxx; Syngenta, Greensboro, NC) was applied as a soil drench at 0.08 oz/1000 ft² a.i. (0.25 fl oz SubdueMaxx per 100 gal water applied at 1 pt/ft²) for the 1× rate and 0.16 oz/1000 ft² a.i. (0.50 fl oz SubdueMaxx per 100 gal water applied at 1 pt/ft²) for the 2× rate. Thiophanate-methyl (3336F; Cleary Chemicals, Dayton, NJ) was applied as a soil drench at 11.5 oz/1000 ft² a.i. (12 fl oz 3336F per 100 gal water applied at 0.25 pt/ft²) for the 1× rate and 23.0 oz/1000 ft² a.i. (24 fl oz 3336F per 100 gal water applied at 0.25 pt/ft²) for the 2× rate. Half of each soil-drench fungicide solution was applied to soilless media before seeding and remaining

solution was applied immediately after seeding.

Iprodione (Rovral; Bayer Crop Science, Research Triangle Park, NC) and azoxystrobin (Abound; Syngenta) were applied as surface spray fungicides with a 2.5-pt hand sprayer (Flo-Master model 4OTS; Root-Lowell Manufacturing Co., Lowell, MI). To ensure an even fungicide application, a 100 mL solution was prepared; however, only 50 mL of fungicide solution was applied to the soil surface of each 1.6-ft² tray. The 1× rate for iprodione was 0.37 oz/1000 ft² a.i. (1.5 pt Rovral per 40 gal water per acre) and the 2× rate was 0.54 oz/1000 ft² a.i. (3.0 pt Rovral per 40 gal water per acre). The 1× rate for azoxystrobin was 0.06 oz/1000 ft² a.i. (10.75 fl oz Abound per 100 gal water per acre) and 0.12 oz/1000 ft² a.i. (21.5 fl oz Abound per 100 gal water per acre).

Fig. 1. Mean sea oats seed germination percentages for 10 fungicide treatments applied at planting. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1×) and twice the recommended rates (2×) at Baton Rouge, LA, on 31 May and 14 June 2013 (1×, 2× in oz/1000 ft² a.i.): azoxystrobin (0.06, 0.12), iprodione (0.37, 0.54), mefenoxam (0.08, 0.16), and thiophanate-methyl (11.5, 23.0). Treatment means with different capitalized letters are significantly ($P < 0.05$) different according to Tukey–Kramer adjustment and pairwise tests; 1 oz/1000 ft² = 3.0515 kg·ha⁻¹.

Fig. 2. Mean total survival percentage of sea oats seedlings following 10 fungicide treatments at planting. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1×) and twice the recommended rates (2×) at Baton Rouge, LA, on 31 May and 14 June 2013 (1×, 2× in oz/1000 ft² a.i.): azoxystrobin (0.06, 0.12), iprodione (0.37, 0.54), mefenoxam (0.08, 0.16), and thiophanate-methyl (11.5, 23.0). Treatment means with different capitalized letters are significantly ($P < 0.05$) different according to Tukey–Kramer adjustment and pairwise tests; 1 oz/1000 ft² = 3.0515 kg·ha⁻¹.

About 24 h after fungicide applications, all seeded trays were watered by hand to prevent desiccation and in accordance with the label for surface spray fungicides (iprodione and azoxystrobin). Trays were subsequently watered by hand about every 3 to 4 d for the first 2 to 3 weeks followed by about every 7 d for remaining weeks. If media appeared dry and the tray was empty then water was added by hand (≈ 0.5 to 1.5 L), if water remained in the tray then watering was delayed. Insecticides were sprayed to control pests on 21 June [acephate (Hi-Yield Acephate; VPG, Bohnam, TX) at 0.05 oz/1000 ft² a.i. (3 fl oz Hi-Yield Acephate per 10 gal water per acre)] and 17 July [spinosad (Lawn & Garden Spray Spinosad₂; Green Light, San Antonio, TX) at 0.03 oz/1000 ft² a.i. (2 fl oz Lawn & Garden Spray Spinosad₂ per gallon water applied at 3 gal/1000 ft²)].

DATA COLLECTION. Every 7 d after planting sea oats seed, germination was measured. A seed was considered germinated if the coleoptile or radicle was visible. Germination percentage was calculated as (observed germinations/total seed of each tray) $\times$ 100. Beginning 14 d after seeding, seedling mortality was measured every 7 d; a seedling was considered dead if it had no visible green color or became completely separated at the crown. Seedling survival was calculated as [(germinated seed – dead seedlings) $\div$ germinated seed] $\times$ 100. Fifty-six days (8 weeks) after seeding, seedling shoot height and fresh weight were measured. Shoot height was measured as the distance from media surface to the end of the longest leaf. Seedlings were then removed from trays and rinsed thoroughly in water to remove media. Total fresh weight was measured for

each sea oats seedling using a balance (PC4400; Mettler-Toledo International, Columbus, OH).

STATISTICAL ANALYSIS. The experiment was designed as a randomized complete block design with three replications and two blocks. Each replication was a tray that consisted of 52 sea oats seed. Each block consisted of 30 trays, three replications of 10 treatments. Block 1 was initiated on 31 May and Block 2 was initiated on 14 June 2014. Percentage germination and survival data were analyzed using analysis of variance (ANOVA) with logistic regression [PROC GLIMMIX (SAS version 9.3 for Windows; SAS Institute, Cary, NC)]. Treatment and week were specified as fixed effects; block and replicates were considered random effects. Means were adjusted with Tukey–Kramer adjustment and separated using pdmix800 (Saxton, 1998) at $P < 0.05$ level. Full model analysis found week by treatment interaction was not significant; therefore, data were combined for all weeks and a reduced model of main effects (week and treatment only) was used.

Odds ratios were used to obtain the likelihood of germination of one treatment vs. another. An odds ratio is the ratio of two odds, each of a different treatment. The odds were obtained from probabilities, in this case germination. The odds of an event occurring is a ratio [$P/(1 - P)$], where P is probability of success or in this case germination. If success or germination of a seed is more likely, then the odds are >1 , if failure is more likely, odds are <1 . By comparing odds of two treatments with a ratio, the likelihood of germination success of one treatment to another can be found.

Seedling shoot height and fresh weight data were analyzed with ANOVA as randomized complete block designs [PROC MIXED (SAS version 9.3 for Windows)]. Treatment was specified as fixed effect; block, replicate, and sea oats seedling were considered random effects. LSMEANS were separated using pdmix800 at $P < 0.05$ level. Contrasts were also performed with SAS to compare groups of treatments.

Results and discussion

Efficient production of sea oats seedlings from seed is very important to ensure the success of coastal restoration efforts. We examined four

fungicides at two rates and two control treatments to determine whether fungicide treatments would increase sea oats seedling survival from seed. When compared with the untreated dry seed control, sea oats germination was greatest when sea oats growing media was treated with azoxystrobin 1× and thiophanate-methyl 2× (Fig. 1), and least for mefenoxam 2× (Fig. 1). Sea oats seedling survival was also greatest for thiophanate-methyl 2× (Fig. 2). Although mean germination was similar for thiophanate-methyl 2× and the untreated sea oats seeds that were soaked in water before germination, mean survival was greatly reduced for both the dry seed control and the soaked seed control (Fig. 2). The greater mean survival for sea oats seeds treated with thiophanate-methyl 2× indicates that fungi controlled by thiophanate-methyl, such as ascomycetes, basidiomycetes, or deuteromycetes, may be reducing sea oats seedling survival. Previous research has reported sea oats seed to be infected by pathogens at germination with some studies reporting 13% to 49% pathogen incidence (Burgess et al., 2002; Hester and Mendelsohn, 1987; Nabukalu and Knott, 2013b). A previous study using seed from the same location but a different year identified fungal pathogens affecting germinating seed as belonging to the fungal phylum Ascomycota (Nabukalu, 2013).

Application rate was also a factor. Significant differences were observed in germination percentages of azoxystrobin and mefenoxam 1× rates vs. 2× rates (Fig. 1). Likewise, the treatment mefenoxam 2× had a mean germination significantly less than both untreated controls. It should be noted that an embryo viability test was performed in laboratory conditions in July 2013 using a 1% solution of 2,3,5-triphenyltetrazolium chloride and found seed viability to be ≈65% (Barrios, 2013). We also determined the likelihood percentages, based on odds ratios, for 1× and 2× rates for azoxystrobin and mefenoxam. We found that sea oats seed germination was 39% more likely for azoxystrobin 1× than azoxystrobin 2× and 48% more likely for mefenoxam 1× than mefenoxam 2× (data not shown). These data suggest higher fungicide concentrations may be phytotoxic thereby reducing seed germination. Another explanation could be that

the fungicide destroyed a fungal symbiont conferring some advantage to the seed as with an endophyte. Many grasses worldwide have been reported to host endophytes that either parasitize their host plant or form a mutualistic relationship conferring some advantage to the host under adverse

conditions (Carroll, 1988; Paracer and Ahmadjian, 2000). This is commonly seen with tall fescue grass that is tolerant of abiotic stresses, such as drought conditions, high temperatures, and low soil fertility, and is attributed to the highly specific endophyte–grass symbiosis (Bush et al., 1997; Cheplick and

Fig. 3. Mean sea oats seed germination percentages following 10 fungicide treatments at planting by week after seeding at Baton Rouge, LA, on 31 May and 14 June 2013. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1×) and twice the recommended rates (2×) in oz/1000 ft² a.i.: azoxystrobin (0.06, 0.12), iprodione (0.37, 0.54), mefenoxam (0.08, 0.16), and thiophanate-methyl (11.5, 23.0). Weekly means with different capitalized letters are significantly ($P < 0.05$) different according to Tukey–Kramer adjustment and pairwise tests; 1 oz/1000 ft² = 3.0515 kg·ha⁻¹.

Fig. 4. Mean survival percentage for sea oats seedlings following 10 fungicide treatments at planting by week after seeding at Baton Rouge, LA, on 31 May and 14 June 2013. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1×) and twice the recommended rates (2×) in oz/1000 ft² a.i.: azoxystrobin (0.06, 0.12), iprodione (0.37, 0.54), mefenoxam (0.08, 0.16), and thiophanate-methyl (11.5, 23.0). Weekly means with different capitalized letters are significantly ($P < 0.05$) different according to Tukey–Kramer adjustment and pairwise tests; 1 oz/1000 ft² = 3.0515 kg·ha⁻¹.

Faeth, 2009; West, 1994). Because of the exceptional performance of sea oats in the harsh coastal environment, the possibility exists that they are host to an unknown mutualistic endophyte.

When germination percentages for each week were examined, it was found that all weeks were statistically similar except for week 1 (Fig. 3). Mean germination overall treatments at week 1 was 12% and then increased to 31% at week 2, after which weekly mean germinations increased gradually to 33% by week 8 (Fig. 3). This is interesting because previous observations from 6 years of sea oats germination (C.A. Knott, unpublished data) as well as a published account by Nabukalu and Knott (2013b) reported largest germination occurring 3 weeks after seeding. One possible explanation for this difference in week of peak germination could be age of seed. Previous research was conducted with seed harvested ≈ 6 months before being germinated. This study used 2-year-old seed because there was no seed available from the previous year due to coastal destruction from Hurricane Isaac in Aug. 2012. Fresher seed has been observed to exhibit a degree of dormancy for a few months after harvest. Because seed used in these experiments appeared to germinate more readily, it could be attributed to possessing a lesser degree of dormancy. Another factor could be the temperature at germination. Mean greenhouse temperatures for this study ranged from ≈ 83 to 88°F depending on week of study. Highest temperatures ranged from 95 to 102°F and lowest were ≈ 74 to 77°F . Nabukalu and Knott (2013b) germinated sea oats seed in controlled conditions in an incubator where temperatures alternated from 35°C for 7 h followed by 18°C for 17 h. Hence, ranges of temperatures differed some between this study and previous studies. In this study, greenhouse conditions reached higher temperatures and did not reach the low temperatures at which incubator conditions were maintained, which could account for differences in germination rates between previous research and results from this experiment and high seed viability in laboratory, based on tetrazolium chloride test, and low seed germination in greenhouse.

Sea oats seedling survival significantly decreased from week 1 to week 8 (Fig. 4). Although the final mean survival percentage was still greater

than expected, this could be important to growers in case they are expecting a specific or standard survival percent. One possible explanation for the significant decline could be degradation of the fungicides and influx or growth of fungal pathogens due to higher temperatures experienced later in summer. This may be remedied by reapplication of fungicide. Further research into determining whether survival could be improved on by reapplication of fungicides would be worthwhile.

High-quality seedlings are typically defined as healthy vigorous plants with tall shoots. Therefore, seedlings with increased shoot height and fresh weight were considered the best quality seedlings. At the termination of this 8-week experiment, shoot height ($P < 0.001$) and fresh weight ($P < 0.033$) were significantly different for

fungicide treatments. The tallest sea oats plants were produced when treated with thiophanate-methyl 1 $\times$ and 2 $\times$ (Fig. 5). These results are similar to those for germination and seedling survival, which also found greatest percentages with thiophanate-methyl 2 $\times$. Thiophanate-methyl 2 $\times$ imparted an advantage not only at germination but also throughout the growth and development of the surviving sea oats seedlings.

Fungicide treatment was found to be significant for fresh weight ($P < 0.033$), although using Tukey–Kramer adjustment and pairwise tests, no significant differences among means were found (Table 1). However, by comparing collective means of groups of treatments using contrasts, some differences were observed. It was found that the fresh weight overall mean of

Fig. 5. Mean sea oats seedling shoot height (cm) for 10 fungicide treatments 8 weeks after seeding at Baton Rouge, LA, on 31 May and 14 June 2013. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1 $\times$) and twice the recommended rates (2 $\times$) in oz/1000 ft² a.i.: azoxystrobin (0.06, 0.12), iprodione (0.37, 0.54), mefenoxam (0.08, 0.16), and thiophanate-methyl (11.5, 23.0). Treatment means with different capitalized letters are significantly ($P < 0.05$) different according to Tukey–Kramer adjustment and pairwise tests; 1 oz/1000 ft² = 3.0515 kg·ha⁻¹, 1 cm = 0.3937 inch.

Table 1. Mean fresh weights of sea oats seedlings 8 weeks after seeding and application of fungicide treatments. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1×) and twice the recommended rates (2×) at Baton Rouge, LA, on 31 May and 14 June 2013.

Fungicide treatment (rate active ingredient) ^z	Mean sea oats seedling fresh wt (g) ^z
Azoxystrobin 1× (0.06 oz/1000 ft ²)	1.4 A ^y
Azoxystrobin 2× (0.12 oz/1000 ft ²)	1.3 A
Iprodione 1× (0.37 oz/1000 ft ²)	1.0 A
Iprodione 2× (0.54 oz/1000 ft ²)	1.2 A
Mefenoxam 1× (0.08 oz/1000 ft ²)	1.1 A
Mefenoxam 2× (0.16 oz/1000 ft ²)	1.1 A
Thiophanate-methyl 1× (11.5 oz/1000 ft ²)	1.5 A
Thiophanate-methyl 2× (23.0 oz/1000 ft ²)	1.4 A
Untreated dry sea oats seed	1.2 A
Untreated soaked sea oats seed	1.1 A

^z1 oz/1000 ft² = 3.0515 kg·ha⁻¹, 1 g = 0.0353 oz.

^yMeans followed by the same letter are statistically the same according to Tukey–Kramer adjustment and pairwise tests at $P < 0.05$.

Table 2. Significant ($P < 0.05$) treatment group contrasts, based on pairwise tests, of average sea oats seedling fresh weight 8 weeks after seeding and fungicide applications of 10 treatments. Treatments consisted of two untreated controls (untreated dry sea oats seed and untreated sea oats seed soaked for 15 min in water) and four commercial fungicides at recommended label rates (1×) and twice the recommended rates (2×) at Baton Rouge, LA, on 31 May and 14 June 2013 (1×, 2× in oz/1000 ft² a.i.): azoxystrobin (0.06, 0.12), iprodione (0.37, 0.54), mefenoxam (0.08, 0.16), and thiophanate-methyl (11.5, 23.0); 1 oz/1000 ft² = 3.0515 kg·ha⁻¹.

Significant treatment group contrasts for sea oats seedling fresh weight 8 wk after seeding and fungicide treatment ^z	F value	$P > F$
Thiophanate-methyl 1× and 2× vs. untreated controls	10.46	0.004
Thiophanate-methyl + azoxystrobin 1× and 2× rates vs. all other treatments (including untreated controls)	19.43	<0.001
Thiophanate-methyl 1× and 2× rates vs. all other treatments	14.24	0.001
Thiophanate-methyl + azoxystrobin + mefenoxam 1× and 2× rates + iprodione 2× rate vs. all other treatments	6.49	0.019
Thiophanate-methyl + azoxystrobin 1× and 2× rates vs. untreated controls	8.73	0.008

treatments thiophanate-methyl 1× and 2× were significantly different from the two untreated controls (Table 2). In addition, thiophanate-methyl 1× and 2× were significantly different from all other treatments (Table 2). Fresh weight means of thiophanate-methyl 1× and 2× were 1.5 and 1.4 g, respectively (Table 1). The mean fresh weight of all other treatments ranged from 1.0 to 1.4 g (Table 1). These findings provide additional evidence that thiophanate-methyl 2× applied at seeding enhanced germination and benefited seedling growth by increasing height and the corresponding biomass of the seedling.

Application of additional inputs, in this case fungicides, must be economically feasible in order for them to

be useful in seedling production systems. The increased germination over the mean of untreated dry seed control (28%) was 3% for thiophanate-methyl 2×. The increased survival of quality seedlings over the mean of untreated dry seed control (95%) for thiophanate-methyl 2× was 3%. Current market value of 1-gal-size sea oats plant is \$5 to \$6, which takes ≈1 year to produce in Louisiana. However, recent research found 2- to 3-month-old seedlings to be acceptable for restoration work and would cost less to produce (Nabukalu, 2013). At the 2-month stage, seedlings have an estimated value of \$0.92. Assuming 1000 seed are sown for each treatment, the benefit in gross sales after 2 months of growth using thiophanate-methyl

2× would be \$37.72. These estimated dollar amounts were found using germination and survival percentages to calculate how many resultant seedlings would be produced from 1000 seed multiplied by market value of 2-month-old seedling (\$0.92) compared with mean estimated sales of untreated seed. When the current prices of fungicides are calculated, it would cost \$1.74 for thiophanate-methyl 2× to treat 1000 seed. From these calculations, it appears that thiophanate-methyl at twice the recommended rate would confer an economic advantage when producing sea oats seedlings by increasing the amount of seedlings produced.

Conclusion

When sea oats seedlings were germinated in growing media treated with twice the recommended rate of thiophanate-methyl (23.0 oz/1000 ft² a.i.), sea oats germination, survival, and plant height were improved 8 weeks after planting. These results strongly suggest that treating sea oats seed with twice the recommended rate of thiophanate-methyl (23.0 oz/1000 ft² a.i.) increases germination, survival, and seedling quality. The additional revenue generated 8 weeks after the thiophanate-methyl application was \$37.72 for each 1000 sea oats seeds planted. These estimated revenue increases provide an economic incentive for fungicide application at sea oats seeding.

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