Auburn University
Southern Forest Nursery
Management Cooperative

RESEARCH REPORT 12-01

SCREENING OF PENDULUM® AQUACAP™ AND TOWER® HERBICIDES ON PINE SEEDBEDS

by
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INTRODUCTION

Pendulum® AquaCap™ (PAC) (pendimethalin) has been tested in Nursery Cooperative trials from 2007 to 2009 with good prostrate spurge (*Chamaesyce maculate*) control and no adverse effects on loblolly pine (*Pinus taeda*) seedling density, root collar diameter, or height when applied at time of sowing (South and Hill 2009; 2010b). However, PAC has caused herbicide galls to form at the seedling root collar. We speculated that factors such as heat, soil texture, and seedling genetics may contribute to gall formation when applied after germination (South and Hill 2009; 2010b).

Observations from Nursery Cooperative trials have indicated that the timing of PAC applications influences the formation of herbicide galls (South and Hill 2010b). Applying PAC before seeds germinate decreases the chance of gall formation compared to applying PAC after seed germination (South and Hill 2010b). In the 2008 and 2009 trials, 25% (665 of 2,625) of the examined seedlings had galls when PAC was applied 4 to 8 weeks post-sowing. When PAC was applied before germination, only 11 of 1,000 examined seedlings had herbicide galls. Nursery location (soils, temperature, etc.) may also impact the degree of gall formation on seedlings sprayed with PAC. Ten of the aforementioned 11 galls were discovered on seedlings from one nursery out of five trial locations.

Another herbicide, Tower® (dimethenamid) (WSSA-Group 15), is a preemergence herbicide that has activity on grasses and small-seeded broadleaves including prostrate spurge. Tower® has been tested in Nursery Cooperative trials as a postemergence application (> 6 weeks post-sowing) with a significant reduction in loblolly pine seedling height, root dry weight and density (South and Hill 2010a). Tower® has also been tested on one-year-old potted slash pine (*Pinus elliottii*) and caused a reduction in seedling diameter growth (Jackson et al. 2008). Although postemergence applications of Tower® have yielded poor seedling quality, effects on seedling tolerance have yet to be determined for applications at time of sowing.

The objectives of these trials were to evaluate herbicide gall formation and overall seedling quality after applications of Pendulum® AquaCap™ alone and tank mixes of Pendulum® AquaCap™ and Tower® at time of sowing (preemergence) in five nurseries and two weeks post-sowing at one nursery.

METHODOLOGY

Herbicide trials were conducted at time of sowing (preemergence) in Camden, AL, Elberta, AL, Flint River, GA, Shubuta, MS and Trenton, SC and 2 weeks post-sowing in Glennville, GA during the 2010 growing season (Table1). Slash pine (*Pinus elliottii*) was treated at the Flint River, GA nursery and loblolly pine at all the other nurseries. Pendulum® AquaCap™ was applied at rates of either 34 or 68 oz. of product per acre (1 or 2 lb a.i./acre), and Tower® treatments were applied as a tank mix at rates of either 21 or 42 oz. of product per acre (1 or 2 lb a.i./acre) along with each rate of Pendulum® AquaCap™ (Table 2). Herbicide treatments were applied using a CO_2 backpack sprayer calibrated to deliver 22 gallons per acre and replicated five times. Treatment plots were one seedling bed wide and 10 feet long.

Soil samples were collected from each plot to determine soil texture, pH, and organic matter levels (Table 3). All nurseries received an application of soil stabilizer with the exception of Flint River, GA. Pine bark mulch was applied to the trial beds by the nursery staff at Flint River, GA, Glennville, GA and Shubuta, MS. The herbicide treatments were applied under the bark at Shubuta, MS and over-the-top of the bark at Flint River, GA and Glennville, GA.

Seedlings were maintained per each nursery's cultural treatments during the growing season. At the end of the growing season, all seedlings were lifted from within a 9 x 48 inch counting frame centered in each plot. The seedlings were transported to Auburn University and placed in a cooler until processing. At the Nursery Cooperative laboratory, seedling densities (i.e. number of seedlings per square ft), the number of culls (< 3.2 mm root collar diameter (RCD)) and the number of plantable seedlings (≥ 3.2 mm RCD) were recorded. Seedling height and root collar diameter were measured on 25 plantable seedlings from each plot (rep), and oven dry weights of shoots and roots were recorded for each 25-seedling sample. The root dry weight ratio was calculated by dividing the weight of the roots by the weight of the entire seedling to provide an evaluation of overall root quality. The seedlings were also examined for herbicide galls (i.e. swellings) on the stem.

Data were analyzed using analysis of variance (ANOVA) and treatment effects were compared using orthogonal polynomial contrasts ($\alpha = 0.05$). These type of contrasts are used to compare treatment levels that are equally spaced (i.e. 34 and 68 oz of PAC). Linear functions indicate significant treatment effects in a linear fashion (for example, if RCD increases as the PAC rate increases). Quadratic functions indicate significance in a non-linear fashion (for example, if RCD decreases as the PAC rate increases).

RESULTS AND DISCUSSION

Herbicide applications at time of sowing. Herbicide galls were not detected on any of the 1,875 test seedlings that were sprayed with PAC or PAC+Tower® at time of sowing. Although there

was a 6-day gap between sowing and herbicide application at Trenton, SC, no galls formed on those seedlings. However, it is best to apply PAC immediately following sowing to reduce the chance of the herbicide coming into contact with germinated seeds and subsequent gall formation (Jackson 2012).

The PAC treatments without Tower® produced seedlings with similar density, height, root collar diameter, and shoot dry weight as non-treated seedlings at each nursery (Tables 4-8). The use of PAC alone did not significantly increase any of the aforementioned seedling characteristics. However, at Shubuta, MS, seedling root weight ratio was reduced by PAC at both the 34 and 68 oz/acre rates (Table 7), yet in contrast, PAC at 34 oz/acre increased seedling root weight ratio at Trenton, SC (Table 8).

At the Elberta, AL nursery, applying PAC at 68 oz/acre did not affect seedling density but reduced seed efficiency by producing fewer plantables seedlings when compared to non-treated seedlings (Table 5). The number of seedling culls and plantable seedlings produced at the other four nurseries was similar to non-treated plots for both rates of PAC. While the PAC label allows for the use of 68 oz. of product per acre in nurseries, and spurge control is better as the PAC rate increases (South and Hill 2008); the higher rates also increase the chance for gall formation (South and Hill 2009) and reduced seed efficiency at Elberta, AL.

Seedbeds at Camden, AL and Trenton, SC that received applications of PAC+Tower® did not have a single seed germinate (Figure 1). Because there were no seedlings to measure, the tank mix treatments were removed from the data when analyzed for those two nurseries. At Elberta, AL, PAC+Tower® applied at 34+21 oz/acre reduced stocking by 10 seedlings per square foot (Table 5). As a result of having less seedling competition, root collar diameter, root and shoot dry weight and root weight ratio significantly increased in the PAC+Tower® treatments.

PAC+Tower® treatments of 34+21 and 68+42 oz/acre reduced slash pine stocking levels by 6 and 18 seedlings per square foot, respectively, at Flint River, GA (Table 6) and 19 and 25 loblolly pine seedlings per square foot, respectively, at Shubuta, MS (Table 7 and Figure 2). At both nurseries, the tank mix treatments significantly reduced seedling height and root and shoot dry weights. However, reductions in seedling density did not result in an increase in root collar diameter. The reductions in seedling density were more severe with an increase in the tank mix rate at each nursery. The effect of Tower® on seedling growth is not surprising as previous trials at Shubuta, MS using dimethenamid (Outlook®) produced shorter seedlings with smaller RCDs when sprayed 9 weeks post-sowing (South and Hill 2005).

The bark mulch used at Flint River, GA and Shubuta, MS could have acted as a buffer from Tower® (South and Hill 2006), making the effects of the herbicide less severe compared to the Camden, AL and Trenton, SC nurseries where no seeds germinated. In addition, applying Tower® to the seedbeds before bark mulch at Shubuta, MS may explain why seedling density was lower than densities at Flint River, GA. Using bark mulch on seedbeds has shown to increase seed efficiency by as much as 3 plantable seedlings per square foot (Jackson and South 2011). Evidently, the benefits of bark mulch were lost in these trials by treating seedlings with Tower® at time of sowing.

Herbicide applications two weeks post-sowing. Germination was underway and some seedlings had reached the "matchstick" stage of growth at the time herbicide treatments were applied 2 weeks post-sowing at Glennville, GA. At lifting, herbicide galls were not detected on non-treated seedlings but were found on all treatments that received herbicides. The number of galls on seedlings increased with the amount of herbicide applied (Table 9). However, instead of forming at the ground-line, as in previous PAC trials (South and Hill 2009), galls were higher on the stem at the point of the cotyledon scar (Figure 3). One possible explanation for this gall location is that after treatment, the herbicide flowed down the cotyledons and collected in the "umbrella" area of the seedling that later becomes the main stem. Seedlings without main stem galls may have yet to cast off their seed coat, thus, minimizing their exposure to PAC.

Seedling density and height was reduced by the PAC+Tower® treatments (Table 9). Seed efficiency was also reduced with the number of plantable seedlings decreasing and cull seedlings increasing with an increase in tank mix rate. Applications of PAC alone at 68 oz/acre also reduced seed efficiency.

MANAGEMENT IMPLICATIONS

1. These trials indicate that applying Pendulum® AquaCap™ at time of sowing (before seeds germinate) can produce seedlings without herbicide galls. Applying Pendulum® AquaCap™ at 2 weeks post-sowing (seedling "matchstick" stage) can cause herbicide galls to form at the point of the cotyledon scar.

2. Prior to Pendulum® AquaCap™ being implemented into herbicide regimes to combat prostrate spurge over the entire nursery, it is important to set up watch trials in small seedling plots using the herbicide. This will indicate the herbicide's behavior in that climate, soil type and using certain nursery cultural practices. For instance, PAC reduced the root weight ratio at Shubuta, MS and increased it at Trenton, SC. Testing PAC at different rates may indicate the level at which the herbicide can be used at a nursery without reducing seedling quality or producing galls.

3. Tower® (dimethenamid) should not be used in forest-tree nurseries as a method to control prostrate spurge. First, it is not labeled for use in tree seedling nurseries. Second, applying the herbicide to seedbeds has prevented seed germination and reduced seedling density in some nurseries. Third, postemergence applications in all previous Tower® trials have shown detrimental effects to seedling quality.

REFERENCES

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Table 1. The date of sowing, herbicide treatment, and seedling lifting at each nursery in 2010.

Nursery	Species	Sow date	App. date	Lift date
Camden, AL	Loblolly	4/20	4/20	11/8
Elberta, AL	Loblolly	4/22	4/26	12/1
Flint River, GA	Slash	5/10	5/10	10/5
Glennville, GA*	Loblolly	4/14	4/29*	10/20
Shubuta, MS	Loblolly	4/22	4/23	10/6
Trenton, SC	Loblolly	4/6	4/12	11/15

*Postemergence application (2 weeks post-sowing); all others were applied preemergence to seedlings (less than 7 days from day of sowing).

Table 2. Herbicide treatments and the nursery location where treatments were applied in 2010.

Herbicide	Product/acre (oz)	Active Ingredient/Acre (lb)	Nursery*
Control	0	0	C, E, FR, G, S, T
Pendulum AquaCap	34	1	C, E, FR, G, S, T
Pendulum AquaCap	68	2	C, E, FR, G, S, T
Pendulum AquaCap + Tower**	34 + 21	1 + 1	C, E, FR, G, S, T
Pendulum AquaCap + Tower**	68 + 42	2 + 2	FR, G, S

*C = Camden, AL; E = Elberta, AL; FR = Flint River, GA; G = Glennville, GA; S = Shubuta, MS; T = Trenton, SC
**Tank mix treatment

Table 3. Soil pH, texture, and organic matter (OM) at each nursery in 2010.

			%			
Nursery	pH	Texture	Sand	Silt	Clay	OM
Camden, AL	4.8	sandy loam	68	18	14	1.3
Elberta, AL	5.3	sandy loam	77	16	7	2.0
Flint River, GA	5.4	loamy sand	85	11	4	2.0
Glennville, GA	4.9	loamy sand	87	7	6	2.3
Shubuta, MS	5.0	sand	96	3	1	1.6
Trenton, SC	5.1	sand	89	9	2	1.9

Table 4. The number of culls and plantable seedlings and seedling density, height, root collar diameter (RCD), root dry weight, shoot dry weight and root weight ratio (RWR) for loblolly pine seedlings at Camden, AL; Analysis of variance for loblolly pine seedlings as affected by the herbicide treatments.

Treatment	Product/ Acre (oz)	Culls (ft^2)	Plantable (ft^2)	Density (ft^2)	Height (cm)	RCD (mm)	Root Wt (g)	Shoot Wt (g)	RWR (%)
Control	0	6.4	14.9	21.3	26.2	4.72	0.84	4.36	16.1
Pendulum AquaCap	34	6.5	15.4	21.9	26.0	4.77	0.83	4.07	16.9
Pendulum AquaCap	68	5.7	15.1	20.7	27.5	4.96	0.97	4.47	18.1
LSD*		*(1.8)*	*(3.1)*	*(3.2)*	*(2.1)*	*(0.45)*	*(0.17)*	*(0.80)*	*(3.2)*
Source	**df****					**P > F**			
Replication	4	0.0014	0.5652	0.0421	0.0045	0.1206	0.0372	0.0215	0.9548
Treatment	2	0.5239	0.9402	0.6997	0.2743	0.4517	0.1698	0.5244	0.3890
PAC-linear	(1)	0.3792	0.9245	0.6770	0.2047	0.2496	0.1113	0.7589	0.1840
PAC-quadratic	(1)	0.4846	0.7436	0.4756	0.3153	0.6537	0.2942	0.2872	0.9016
Error	8								

*Least significant differences in parentheses are italicized; **Degrees of freedom

Table 5. The number of culls and plantable seedlings and seedling density, height, root collar diameter (RCD), root dry weight, shoot dry weight and root weight ratio (RWR) for loblolly pine seedlings at Elberta, AL; Analysis of variance for loblolly pine seedlings as affected by the herbicide treatments.

Treatment	Product/ Acre (oz)	Culls (ft^2)	Plantable (ft^2)	Density (ft^2)	Height (cm)	RCD (mm)	Root Wt (g)	Shoot Wt (g)	RWR (%)
Control	0	1.1	17.0	18.1	26.1	4.60	0.88	3.51	20.1
Pendulum AquaCap	34	2.0	17.4	19.4	26.3	4.65	0.81	3.72	18.1
Pendulum AquaCap	68	2.4	14.9	17.3	26.3	4.65	0.88	3.41	20.5
Pendulum AquaCap+Tower	34+21	0.3	7.7	8.0	26.9	5.92	1.29	4.38	23.0
LSD*		*(1.3)*	*(2.5)*	*(3.0)*	*(1.8)*	*(0.64)*	*(0.25)*	*(0.99)*	*(2.2)*
Source	**df****					**P > F**			
Replication	4	0.0811	0.1623	0.7918	0.3016	0.5027	0.8251	0.6947	0.5888
Treatment	3	0.0170	0.0001	0.0001	0.8011	0.0017	0.0048	0.1921	0.0029
PAC-linear	(1)	0.0416	0.0948	0.6047	0.8653	0.8726	0.9609	0.8160	0.6922
PAC-quadratic	(1)	0.6080	0.1720	0.1802	0.9219	0.9262	0.5123	0.5199	0.0239
Control vs PAC+Tower	(1)	0.2336	0.0001	0.0001	0.3776	0.0008	0.0039	0.0807	0.0126
Error	12								

*Least significant differences in parentheses are italicized; **Degrees of freedom

Table 6. The number of culls and plantable seedlings and seedling density, height, root collar diameter (RCD), root dry weight, shoot dry weight and root weight ratio (RWR) for slash pine seedlings at Flint River, GA; Analysis of variance for slash pine seedlings as affected by the herbicide treatments.

Treatment	Product/ Acre (oz)	Culls (ft^2)	Plantable (ft^2)	Density (ft^2)	Height (cm)	RCD (mm)	Root Wt (g)	Shoot Wt (g)	RWR (%)
Control	0	5.3	21.4	26.7	26.9	3.23	0.36	2.50	12.7
Pendulum AquaCap	34	4.5	23.0	27.5	28.6	3.22	0.37	2.35	13.9
Pendulum AquaCap	68	7.0	20.1	27.1	26.8	3.20	0.35	2.43	12.6
Pendulum AquaCap+Tower	34+21	11.1	9.3	20.4	21.5	3.05	0.23	1.69	12.1
Pendulum AquaCap+Tower	68+42	5.5	3.6	9.1	18.0	3.12	0.11	0.71	13.4
LSD*		*(3.2)*	*(2.5)*	*(3.0)*	*(2.5)*	*(0.18)*	*(0.07)*	*(0.43)*	*(1.5)*
Source	**df****					**P > F**			
Replication	4	0.5691	0.0455	0.5593	0.1373	0.0133	0.0273	0.0132	0.0091
Treatment	4	0.0031	0.0001	0.0001	0.0001	0.2227	0.0001	0.0001	0.1544
PAC-linear	(1)	0.2642	0.2957	0.7433	0.9078	0.7636	0.8062	0.7445	0.9256
PAC-quadratic	(1)	0.2172	0.0428	0.6467	0.1087	0.9254	0.5401	0.5452	0.0599
PAC+Tower-linear	(1)	0.8609	0.0001	0.0001	0.0001	0.2140	0.0001	0.0001	0.3604
PAC+Tower-quadratic	(1)	0.0004	0.0057	0.0559	0.3651	0.1255	0.9090	0.6409	0.1580
Error	16								

*Least significant differences in parentheses are italicized; **Degrees of freedom

Table 7. The number of culls and plantable seedlings and seedling density, height, root collar diameter (RCD), root dry weight, shoot dry weight and root weight ratio (RWR) for loblolly pine seedlings at Shubuta, MS; Analysis of variance for loblolly pine seedlings as affected by the herbicide treatments.

Treatment	Product/ Acre (oz)	Culls (ft^2)	Plantable (ft^2)	Density (ft^2)	Height (cm)	RCD (mm)	Root Wt (g)	Shoot Wt (g)	RWR (%)
Control	0	12.4	15.3	27.7	26.4	3.78	0.45	3.39	11.7
Pendulum AquaCap	34	12.7	12.8	25.5	25.1	3.70	0.36	3.22	10.1
Pendulum AquaCap	68	10.9	14.4	25.3	26.5	3.79	0.38	3.35	10.2
Pendulum AquaCap+Tower	34+21	3.6	5.3	8.9	21.2	3.79	0.26	1.99	11.8
Pendulum AquaCap+Tower	68+42	1.1	1.3	2.4	16.4	3.75	0.07	0.52	13.1
LSD*		*(3.6)*	*(3.4)*	*(2.7)*	*(1.9)*	*(0.25)*	*(0.09)*	*(0.48)*	*(1.5)*
Source	**df****					**P > F**			
Replication	4	0.4898	0.2955	0.0974	0.0052	0.2335	0.7933	0.8099	0.0900
Treatment	4	0.0001	0.0001	0.0001	0.0001	0.9356	0.0001	0.0001	0.0046
PAC-linear	(1)	0.3746	0.5713	0.0740	0.8970	0.9732	0.1093	0.8800	0.0551
PAC-quadratic	(1)	0.4875	0.1588	0.3689	0.0956	0.4205	0.1553	0.4542	0.2287
PAC+Tower-linear	(1)	0.0001	0.0001	0.0001	0.0001	0.8144	0.0001	0.0001	0.0759
PAC+Tower-quadratic	(1)	0.0467	0.0434	0.0001	0.7939	0.8616	0.9234	0.8447	0.3891
Error	16								

*Least significant differences in parentheses are italicized; **Degrees of freedom

Table 8. The number of culls and plantable seedlings and seedling density, height, root collar diameter (RCD), root dry weight, shoot dry weight and root weight ratio (RWR) for loblolly pine seedlings at Trenton, SC; Analysis of variance for loblolly pine seedlings as affected by the herbicide treatments.

Treatment	Product/ Acre (oz)	Culls (ft^2)	Plantable (ft^2)	Density (ft^2)	Height (cm)	RCD (mm)	Root Wt (g)	Shoot Wt (g)	RWR (%)
Control	0	1.4	22.1	22.4	28.6	4.83	1.15	3.62	24.1
Pendulum AquaCap	34	1.7	20.1	21.9	27.4	4.90	1.37	3.70	27.1
Pendulum AquaCap	68	2.3	18.9	21.7	28.2	5.00	1.24	3.86	24.2
LSD*		*(1.9)*	*(5.4)*	*(5.3)*	*(1.7)*	*(0.37)*	*(0.21)*	*(0.34)*	*(2.6)*
Source	**df****					**P > F**			
Replication	4	0.9915	0.5496	0.6502	0.2282	0.1085	0.0841	0.0201	0.1993
Treatment	2	0.5475	0.4103	0.9543	0.3107	0.5890	0.1153	0.3257	0.0533
PAC-linear	(1)	0.2932	0.1988	0.7792	0.5919	0.3215	0.3510	0.1522	0.9531
PAC-quadratic	(1)	0.8574	0.8604	0.9225	0.1597	0.9059	0.0609	0.7764	0.0187
Error	8								

*Least significant differences in parentheses are italicized; **Degrees of freedom

Table 9. The number of culls and plantable seedlings and seedling density, height, root collar diameter (RCD), root dry weight, shoot dry weight, root weight ratio (RWR) and number of galls for loblolly pine seedlings at Glennville, GA; Analysis of variance for loblolly pine seedlings as affected by the herbicide treatments.

Treatment	Product/ Acre (oz)	Culls (ft^2)	Plantable (ft^2)	Density (ft^2)	Height (cm)	RCD (mm)	Root Wt (g)	Shoot Wt (g)	RWR (%)	Galls (#)*
Control	0	1.8	19.8	21.6	29.7	4.37	0.74	3.72	16.6	0.0
Pendulum AquaCap	34	2.7	17.2	19.9	28.7	4.46	0.75	3.75	16.7	2.4
Pendulum AquaCap	68	4.5	15.5	20	28.4	4.46	0.78	3.91	16.6	3.6
Pendulum AquaCap+Tower	34+21	4.8	14.4	19.2	27.1	4.44	0.79	3.84	17.1	3.0
Pendulum AquaCap+Tower	68+42	5.7	11.7	17.4	27.1	4.58	0.79	3.90	16.7	4.2
LSD**		*(2.3)*	*(2.8)*	*(2.2)*	*(1.7)*	*(0.22)*	*(0.13)*	*(0.52)*	*(1.4)*	*(2.5)*
Source	**df*** **					**P > F**				
Replication	4	0.3900	0.0660	0.0197	0.0606	0.0001	0.2258	0.4485	0.2331	0.2188
Treatment	4	0.0153	0.0002	0.0133	0.0211	0.4026	0.8295	0.9065	0.9270	0.0273
PAC-linear	(1)	0.0230	0.0044	0.1371	0.1413	0.4023	0.4824	0.4590	0.9673	0.0086
PAC-quadratic	(1)	0.6515	0.7074	0.3421	0.5758	0.6414	0.8681	0.7621	0.9251	0.5725
PAC+Tower-linear	(1)	0.0026	0.0001	0.0008	0.0051	0.0597	0.3853	0.4677	0.8419	0.0030
PAC+Tower-quadratic	(1)	0.2739	0.2457	0.7391	0.075	0.6804	0.5598	0.8869	0.4602	0.4002
Error	16									

*Average number out of 25 seedlings analyzed; ** Least significant differences in parentheses are italicized; ***Degrees of freedom

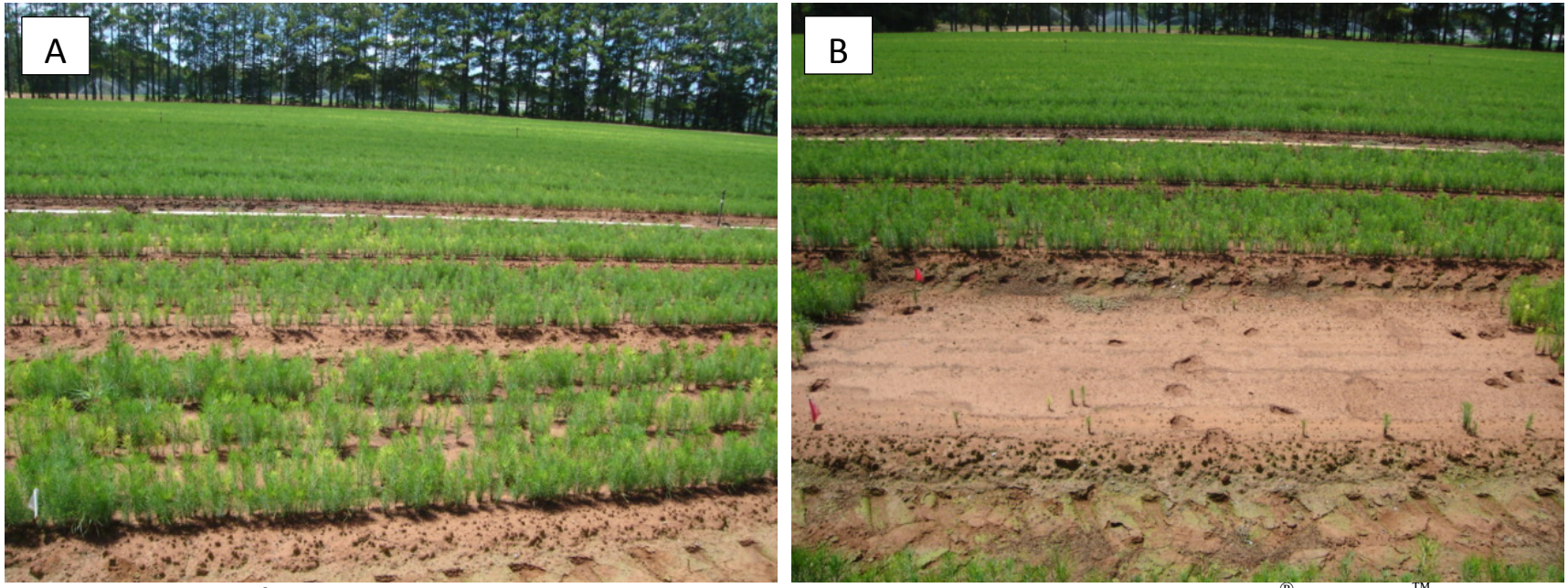

Figure 1. (A) A plot of non-treated loblolly pine seedlings and (B) a plot that was sprayed with the Pendulum® AquaCap™ and Tower® tank mix at time of sowing on April 20, 2010 at Camden, AL indicating no seedlings present. Pictures were taken August 8, 2010.

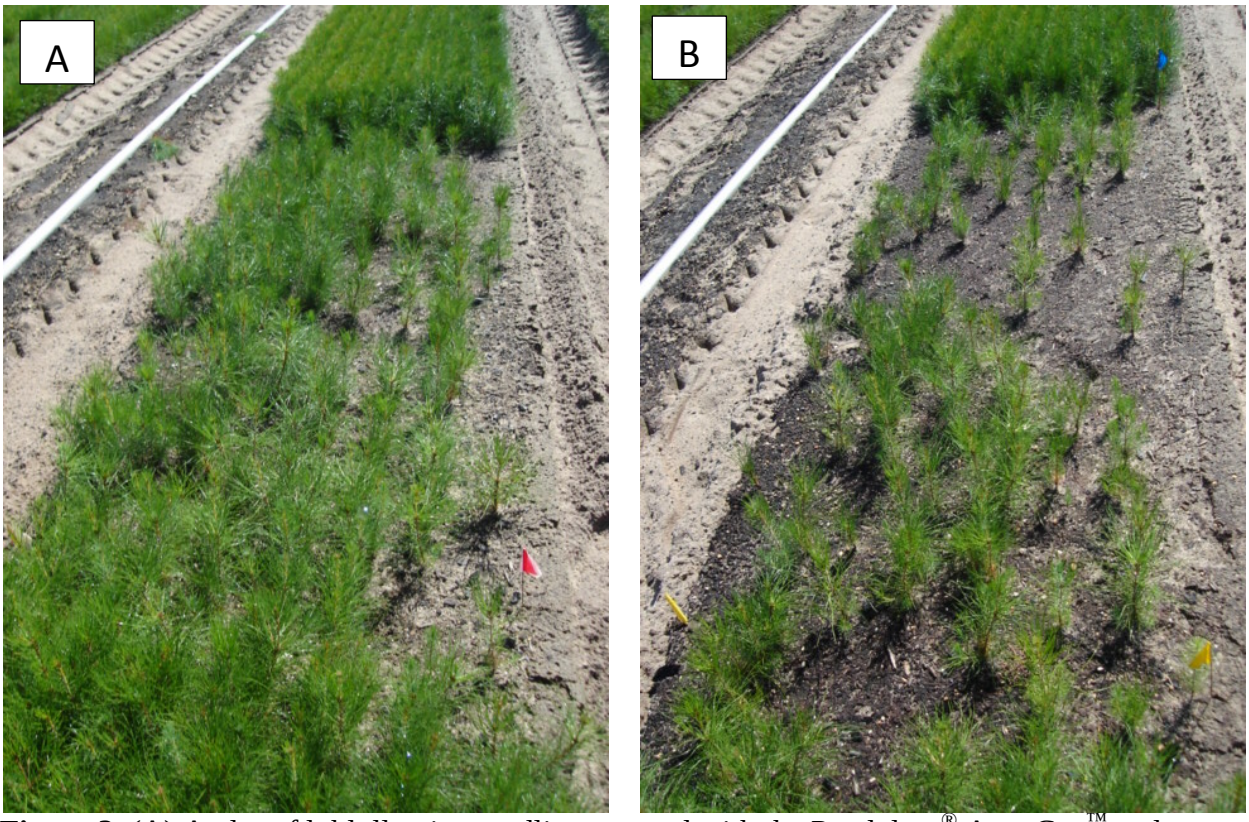

Figure 2. (A) A plot of loblolly pine seedlings treated with the Pendulum® AquaCap™ and Tower® tank mix at 34+21 oz/acre with reduced stocking and (B) a plot of seedlings treated with the Pendulum® AquaCap™ and Tower® tank mix at 68+42 oz/acre with even more reduction in stocking. Treatments took place one day following sowing on April 23, 2010 at Shubuta, MS. Pictures were taken October 6, 2010.

Figure 3. Herbicide gall at the point of the cotyledon scar (circled) from herbicide treatments 2 weeks post-sowing on April 29, 2010 at Glennville, GA. Picture was taken October 26, 2010.