Auburn University
Southern Forest Nursery
Management Cooperative

RESEARCH REPORT 12-03

HARDWOOD SEEDLING TOLERANCE TO PENDULUM® AQUACAP™ APPLICATIONS

by
D. Paul Jackson and Barry Brooks

INTRODUCTION

Pendulum® AquaCap™ (PAC) (pendimethalin) is a dinitroaniline herbicide registered for use in forest-tree nurseries that provides good prostrate spurge (*Chamaesyce maculate*) control. However, in some of our herbicide trials, PAC has caused herbicide galls to form on the stems of pine seedlings (South and Hill 2009; Jackson and South 2012). We speculated that factors such as heat, soil texture, and seedling genetics may contribute to gall formation when applied after pine germination (South and Hill 2009).

Prostrate spurge is a summer annual weed controlled by PAC with preemergence (to spurge) springtime applications. The herbicide's mode of action involves inhibiting root cell division of germinating prostrate spurge seeds and rendering their roots distorted, swollen and non-functional. By now, we have a general understanding of PAC behavior on pine seedlings, but the effects of using PAC on hardwood seedling beds to control prostrate spurge have yet to be determined. Some hardwood seedlings such as oaks (*Quercus* spp.) are sown in the fall. Due to prostrate spurge seed dormancy and herbicide decomposition in the soil, preemergence applications of PAC to hardwood seedbeds in the fall would not be effective for controlling the weed the next spring. A PAC application in the spring over fall-sown hardwoods would be considered a postemergence application, which has caused herbicide galls on loblolly pine (*Pinus taeda*).

A wide range of hardwood species are grown in forest-tree nurseries, with each having varying herbicide tolerances. Nursery managers have reported stem swellings from operational use of the following hardwood species and dinitroaniline herbicides: sugarberry (*Celtis laevigata*) with prodiamine (Barricade®) and pendimethalin, common apple (*Malus domestica*) with pendimethalin, and maple (*Acer* spp.) with oryzalin (Surflan®). Herbicide injury has not been reported on *Quercus* spp. from the use of pendimethalin.

In previous Nursery Cooperative trials, sycamore (*Platanus occidentalis*) seedlings have been negatively affected by both preemergence and postemergence applications of 12 herbicides (VanderSchaaf et al. 2003). Of those herbicides, preemergence applications of oryzalin, prodiamine and trifluralin (Treflan®) and postemergence applications of pendimethalin plus oxyfluorfen (Goal®) reduced sycamore seedling quality with no reports of stem swellings (VanderSchaaf et al. 2003). The PAC label states that applications are safe over-the-top of established sycamore, but the effects of applying PAC over sycamore seeds are unknown.

Past Nursery Cooperative research with PAC on pines at time of sowing are encouraging, and some nursery managers are beginning to incorporate PAC into their operational herbicide regime. However, research is needed to determine if PAC can be used in hardwood seedling beds. Therefore, the objective of these trials was to evaluate herbicide injury and overall seedling quality from applications of Pendulum® AquaCap™ to germinated *Quercus* spp. (postemergence) and sycamore at time of sowing (preemergence).

METHODOLOGY

Pendulum® AquaCap™ trials were conducted at time of sowing (preemergence) on sycamore and 10 weeks after sowing (postemergence) on black oak (*Quercus velutina*) seedlings at the Native Forest nursery in Chatsworth, GA (Table 1). Postemergence PAC trials were also done on cherrybark oak (*Quercus falcate v. pagodaefolia*) at 10 weeks post-sowing and sawtooth oak (*Quercus acutissima*) seedlings at 22 weeks post-sowing at the Tennessee state nursery in Delano, TN (Table 1). Pendulum® AquaCap™ was applied at rates of either 34 or 68 oz of product per acre (1 or 2 lb a.i./acre) using a CO_2 backpack sprayer calibrated to deliver 22 gallons per acre. Treatment plots were one seedling bed wide and 10 feet long and replicated three times.

Soil samples were collected from each plot to determine soil texture, pH, and organic matter levels (Table 2). The Tennessee nursery used Agrilock® soil stabilizer on treatment beds while the Chatsworth nursery used sawdust mulch on sycamore and bark mulch on the black oak seedling beds. All mulches were applied to seedling beds prior to herbicide treatments.

Seedlings were maintained per each nursery's cultural treatments during the growing season. At Chatsworth, GA, sycamore seedling density was determined based on the number of seedlings per 3.7 m^2 (40 ft^2) plot at the end of the growing season. Due to the size and number of oak seedlings per plot, seedling densities were not calculated at either nursery. Approximately 30 seedlings (if available) of each hardwood species per plot in each herbicide treatment were lifted and transported to Auburn University for processing. At the Nursery Cooperative laboratory, seedling height, root collar diameter (RCD) and oven dry weights of shoots were measured. 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 ($\alpha = 0.10$). 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 decreases as the PAC rate

increases). Quadratic functions indicate significance in a non-linear fashion (for example, if RCD initially increases and then decreases as the PAC rate increases).

RESULTS AND DISCUSSION

Herbicide galls were detected on the stem near the ground-line of sycamore seedlings from the Chatsworth, GA nursery (Figure 1). Seedlings treated with 34 oz of PAC per acre had more total galls than those that received 68 oz of PAC per acre resulting in a significant quadratic relationship (Table 3). However, this relationship is misleading as only 12 sycamore seedlings were in the 68 oz per acre treatment plots compared to 31 seedlings in the 34 oz per acre plots. A higher percentage of galls were found on sycamore treated with 68 oz per acre (Table 4). Applications of pendimethalin (0.5 and 1 lb a.i./acre) plus oxyfluorfen have caused reductions in sycamore seedling quality (VanderSchaaf et al. 2003), but these trials are the first to indicate gall formation on sycamore seedlings with preemergence applications of pendimethalin.

As the PAC rate increased, sycamore seedling density was reduced (Figure 2) resulting in a significant linear relationship (Table 3). The number of sycamore seedlings decreased by an average of 20 seedlings as the PAC rate increased from 0 to 68 oz per acre. PAC treatments did not affect sycamore seedling RCD, height or shoot dry weight (Table 3). It is possible that small seeded species such as sycamore may be intolerant to PAC applications. PAC is labeled to control some small-seeded (< 2 mm) broadleaf weeds by disrupting root cell division and ceasing root and shoot growth after contacting the herbicide in the soil. The embryo portion of a sycamore seed is only about 3 mm (Bonner 1974) and may not provide enough energy to push the germinating radicle passed the PAC zone in the soil. Sycamore and loblolly pine average 160,000 and 18,000 seeds per pound (Bonner 1974), respectively, but unlike sycamore, loblolly pine seedling density is unaffected by PAC applications at time of sowing (Jackson and South 2012). Loblolly pine seeds may have larger embryos and more energy to germinate passed the PAC zone in the soil.

The PAC treatments did not produce herbicide galls or affect black oak seedling RCD, height or shoot dry weight at Chatsworth, GA (Table 5). Black oak seedlings were top-pruned four times during the growing season with the last pruning being one month prior to lifting. Because of the more uniform crop, it is not surprising that there were no differences in seedling height or shoot dry weight.

Herbicide galls were not found on any cherrybark oak or sawtooth oak seedlings sampled at the Tennessee nursery. Because neither oak species were top-pruned during the growing season, morphological differences as a result of herbicide treatments could be measured. Cherrybark oak seedling RCD and shoot dry weight were not affected by PAC, but seedling height decreased linearly as the PAC rate increased (Table 6). PAC treatments did not affect sawtooth oak seedling RCD, height or shoot dry weight (Table 7).

MANAGEMENT IMPLICATIONS

1. These trials indicate that applying Pendulum® AquaCap™ to sycamore at both 34 and 68 oz of product per acre at time of sowing (before sycamore seeds germinate) can produce herbicide

galls on the stem near the ground-line and significantly reduce sycamore seedling density. More research is needed to learn the effects of preemergence Pendulum® AquaCap™ applications to other small-seeded hardwood species like sycamore.

2. Applying Pendulum® AquaCap™ postemergence to black oak, sawtooth oak, and cherrybark oak at both 34 and 68 oz of product per acre in the spring (after oak leaf emergence) did not produce herbicide galls or affect seedling root collar diameter or shoot dry weight. Pendulum® AquaCap™ applied at 68 oz of product per acre can reduce cherrybark oak seedling height. However, if nursery managers top-prune their hardwood seedlings, the reduction in height would likely go undetected.

3. Prior to Pendulum® AquaCap™ being implemented into herbicide regimes to combat prostrate spurge in hardwood seedling beds, it is important to set up watch trials in small seedling plots using the herbicide with a wide variety of hardwood species that differ in herbicide tolerance. This will indicate the herbicide's behavior in that climate, soil type, using certain nursery cultural practices and across many hardwood genotypes.

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Table 1. Hardwood species tested, mulch type and date of sowing, herbicide treatment and seedling lifting at each nursery in 2011.

Nursery	Species	Mulch	Sow date	App. date	Lift date
Chatsworth, GA	Sycamore	sawdust	5/3/2011	5/4/2011	10/11/2011
Chatsworth, GA	Black oak	bark	2/17/2011	5/4/2011	10/11/2011
Delano, TN	Cherrybark oak	Agrilock	2/14/2011	5/4/2011	10/12/2011
Delano, TN	Sawtooth oak	Agrilock	11/23/2010	5/4/2011	10/12/2011

Table 2. Soil pH, texture, and organic matter (OM) at each nursery in 2011.

			%			
Nursery	**pH**	**Texture**	**Sand**	**Silt**	**Clay**	**OM**
Chatsworth, GA	6.5	loam	42	42	16	2.5
Delano, TN	5.5	sandy loam	69	24	7	1.3

Table 3. Mean seedling density, root collar diameter (RCD), height, shoot dry weight and number of herbicide galls for sycamore seedlings at Chatsworth, GA; analysis of variance for sycamore seedlings as affected by herbicide treatments.

Treatment	Product/acre (oz)	Seedlings/density (per plot[x])	RCD (mm)	Height (cm)	Shoot Wt (g)	Galls (#)
Control	0	45.0	9.70	134.4	17.2	0
Pendulum AquaCap	34	18.0	8.73	127.2	18.8	4.7
Pendulum AquaCap	68	3.7	9.75	133.5	11.0	2.7
LSD[y]		*(26.9)*	*(2.31)*	*(24.7)*	*(12.8)*	*(4.0)*
Source	**DF[z]**		**P > F**			
Replication	2	0.4573	0.6495	0.3546	0.2685	0.8711
Treatment	2	0.0310	0.4544	0.7000	0.3088	0.0754
PAC-linear	(1)	0.0130	0.9550	0.9241	0.2480	0.1377
PAC-quadratic	(1)	0.4928	0.2370	0.4296	0.3063	0.0557
Error	8					

[x] = plot size is 3.7 m^2 (40 ft^2)
[y] = Least significant differences in parentheses are italicized
[z] = Degrees of freedom

Table 4. Total number and percentage of herbicide galls on sycamore seedlings for each Pendulum® AquaCap™ treatment at Chatsworth, GA in 2011.

Treatment	Product/acre (oz)	Sample size (#)	Galls (#)	Galls (%)
Control	0	30	0	0
Pendulum AquaCap	34	31	14	45
Pendulum AquaCap	68	12	8	67

Table 5. Mean root collar diameter (RCD), height and shoot dry weight for black oak seedlings at Chatsworth, GA; analysis of variance for black oak seedlings as affected by herbicide treatments.

Treatment	Product/acre (oz)	RCD (mm)	Height (cm)	Shoot Wt (g)
Control	0	7.23	42.4	10.5
Pendulum AquaCap	34	7.18	43.3	10.1
Pendulum AquaCap	68	7.37	43.2	10.2
LSD[y]		*(1.04)*	*(8.1)*	*(4.3)*
Source	**DF[z]**		**P > F**	
Replication	2	0.2441	0.3846	0.1809
Treatment	2	0.8730	0.9518	0.9714
PAC-linear	(1)	0.7207	0.8063	0.8583
PAC-quadratic	(1)	0.7330	0.8677	0.8885
Error	8			

[y] = Least significant differences in parentheses are italicized
[z] = Degrees of freedom

Table 6. Mean root collar diameter (RCD), height and shoot dry weight for cherrybark oak seedlings at Delano, TN; analysis of variance for cherrybark oak seedlings as affected by herbicide treatments.

Treatment	Product/acre (oz)	RCD (mm)	Height (cm)	Shoot Wt (g)
Control	0	8.89	111.4	28.0
Pendulum AquaCap	34	8.28	104.1	33.9
Pendulum AquaCap	68	7.36	97.3	27.0
LSD[y]		*(2.23)*	*(11.0)*	*(16.3)*
Source	**DF[z]**		**P > F**	
Replication	2	0.5520	0.0855	0.1356
Treatment	2	0.2724	0.0583	0.5111
PAC-linear	(1)	0.1301	0.0239	0.8643
PAC-quadratic	(1)	0.8328	0.9384	0.2795
Error	8			

[y] = Least significant differences in parentheses are italicized
[z] = Degrees of freedom

Table 7. Mean root collar diameter (RCD), height and shoot dry weight for sawtooth oak seedlings at Delano, TN; analysis of variance for sawtooth oak seedlings as affected by herbicide treatments.

Treatment	Product/acre (oz)	RCD (mm)	Height (cm)	Shoot Wt (g)
Control	0	9.70	134.4	45.3
Pendulum AquaCap	34	8.73	127.2	39.4
Pendulum AquaCap	68	9.75	133.5	44.7
LSD[y]		*(2.31)*	*(24.7)*	*(14.9)*
Source	**DF[z]**		**P > F**	
Replication	2	0.6495	0.3546	0.3285
Treatment	2	0.4544	0.7000	0.5333
PAC-linear	(1)	0.9550	0.9241	0.9096
PAC-quadratic	(1)	0.2370	0.4296	0.2931
Error	8			

[y] = Least significant differences in parentheses are italicized
[z] = Degrees of freedom

Figure 1. Herbicide galls on sycamore seedlings from the Chatsworth, GA nursery. Preemergence Pendulum® AquaCap™ treatments took place May 4, 2011 and pictures were taken October 13, 2011.

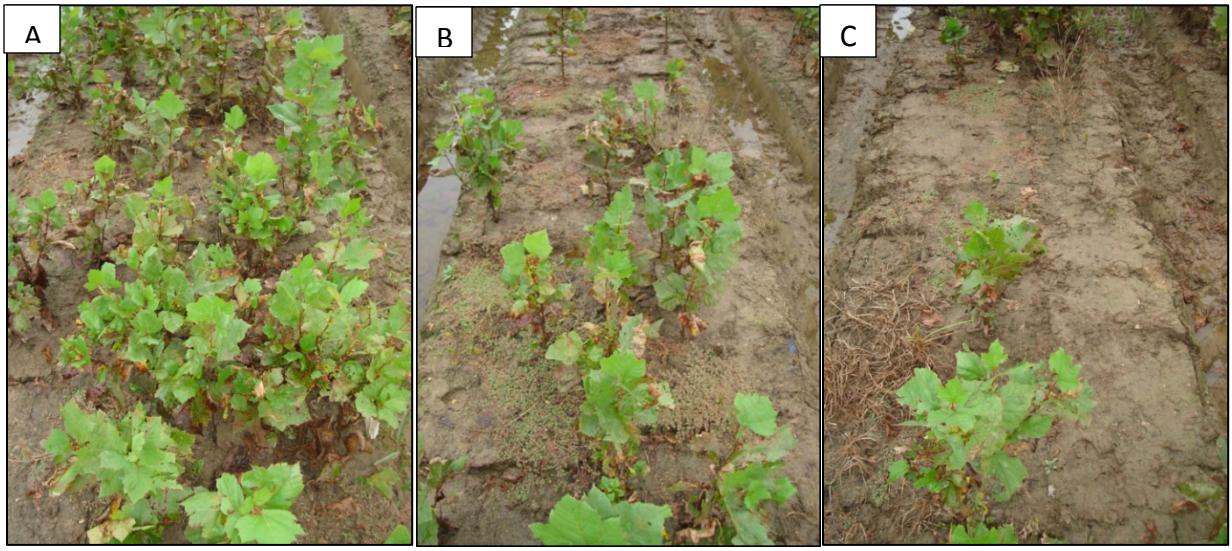

Figure 2. Differences in sycamore seedling density for plots that received (A) no herbicide, (B) 34 oz per acre of Pendulum® AquaCap™ and (C) 68 oz per acre of Pendulum® AquaCap™. Preemergence Pendulum® AquaCap™ treatments took place May 4, 2011 and pictures were taken October 11, 2011.