Dikegulac Sodium Concentration and Application Number Affects Branching of Blackgum and Southern Sugar Maple during Container Production[1]

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Abstract

A study was conducted under nursery production conditions to evaluate multiple concentrations of dikegulac sodium (dikegulac) (0, 800, and 1,600 ppm) applied either once or twice as a foliar spray to blackgum grown at two locations in Alabama and to southern sugar maple grown at a single location. Mid-season and end-of-season shoot counts increased linearly in response to increasing dikegulac concentrations in both species and at both locations. Shoot counts also were greater when dikegulac was applied twice compared to a single application, except when 800 ppm dikegulac was applied to blackgum at one location. Both southern sugar maple and blackgum were visibly more branched and compact following treatments with dikegulac than nontreated control plants, although the branching response was much greater in blackgum. Effects of dikegulac application on plant height and caliper varied with species, concentration, application number, and time after application. Southern sugar maple exhibited temporary reddening of immature foliage that dissipated over time, while immature foliage of blackgum yellowed at one location and cupped and developed necrotic lesions at the second location. No phytotoxicity was evident 6 weeks after dikegulac application.

Index words: nursery production, plant growth regulators, branching agent.

Chemicals used in this study: Augeo (dikegulac sodium)[sodium salt of 2,3:4,6-Bis-O-(1-methylethylidene)-α-L-xylo-2-hexulofuranosonic acid].

Species used in this study: blackgum (*Nyssa sylvatica* Marsh.), southern sugar maple {*Acer barbatum* Michx. [*A. floridanum* (Chapm.) Pax]}.

Significance to the Horticulture Industry

Shade trees for high-end markets must be uniform and have dense, symmetrical canopies. To meet these demands, nurserymen prune the lateral shoots and the central leader multiple times throughout production. This is a labor-intensive process, especially when pruning requires working from lifts. The plant growth regulator dikegulac applied as 800 or 1,600 ppm foliar sprays can greatly increase the branching of southern sugar maple and blackgum without the removal of the central leader. With both species, early plus mid-season applications were more effective than only an early-season application. Although branching was greatly increased, some mechanical pruning would be necessary to both species to ensure that lateral branches are radially and vertically spaced along the central leader.

Introduction

High-end markets for shade trees require straight trunks and symmetrical canopies much denser than most species develop naturally. A common practice to promote canopy density in young trees with an excurrent growth form is to prune lateral and terminal shoots frequently to promote branching, leading to a decurrent form characterized by weak apical dominance. Removal of the terminal shoot or central leader requires reestablishment of a new central leader from a lateral shoot that may not be as strongly attached as the original shoot and more prone to failure in the landscape (Chalker-Scott 2010). Pruning trees multiple times during production to increase canopy density and reestablishing a central leader are labor-intensive practices, exacerbated when canopies cannot be worked from the ground (Bold Spring Nursery, Hawkinsville, GA, personal communication).

Apical dominance, the control that terminal buds and developing shoots exert over lateral buds on a plant stem (Cline 1998), is regulated by auxin, which diffuses basipetally from terminal buds and inhibits the outgrowth of lateral buds (Tamas 1995), often resulting in sparsely branched trees during production. Nurserymen overcome apical dominance by removing the terminal meristems, e.g. by pruning. Pruning removes viable tissue, reduces overall plant size, and results in a loss of a minimum of 3 weeks of active growth from each pruning (Vander Woude 2002). Plant growth regulators (PGRs) that may substitute or supplement mechanical pruning of woody landscape plants have been evaluated with mixed results, and only dikegulac is labelled for use as a branching agent and growth retardant on woody landscape plants. Dikegulac interferes with terminal growth areas by inhibiting DNA synthesis, which is required for new growth. Growth of the dominant shoot apexes of treated plants is suppressed, resulting in a breaking of apical dominance and enhancement of the growth of lateral shoots (Arzee et al. 1977). Dikegulac increased new shoot counts in dwarf yaupon holly (*Ilex vomitoria* Ait. 'Nana') (Banko and Stefani 1995), Goldflame honeysuckle (*Lonicera* ×*heckrottii* 'Goldflame') (Bruner et al. 2002), and ornamental pear (*Pyrus calleryana* Decne.) (Jacyna et al. 1994), but also reduced shoot length in all of the above and tree height in ornamental pear. Dikegulac has been shown to effectively suppress growth of established landscape plants (Banko and Stefani 1996, Norcini 1991), and is widely used in the landscape

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maintenance industry to promote compactness and branching, but it is used much less in nursery production. Recently, dikegulac was labeled as a branching agent for use in commercial field and container nurseries as Augeo (OHP Inc., Mainland, PA), and in a recently-published study at Auburn University, a single foliar application of 800 to 3,200 ppm effectively promoted branching of red maple (*Acer rubrum* L.), Japanese maple (*Acer palmatum* Thunb.), redbud (*Cercis canadensis* L.), green ash *Fraxinus pennsylvanica* Marsh.), bald cypress (*Taxodium distichum* L. Rich.), and blackgum (*Nyssa sylvatica* Marsh.) without hand pruning (Miller et al. 2014). Of the six species evaluated, blackgum was the most responsive. Within 3 to 5 weeks of treatment, plant height was suppressed, numerous new shoots were rapidly developing, and the treated canopies were visibly fuller than those of nontreated controls. However, the effects on canopy density dissipated over the subsequent 3 to 4 weeks. Several of the new shoots on each plant regained apical dominance and elongated vigorously, which accounted for a lack of dikegulac effect on plant height at the end of the growing season. However, the upper canopies formed by these vigorous shoots lacked the density seen earlier in the growing season that is sought by growers. Multiple applications of PGRs are common due to the transient nature of most of these materials (Holland et al. 2007, Keever and Morrison 2003, Oates et al. 2004 and 2005), and blackgum in our study (Miller et al. 2014), while dense and compact at mid-season (4 to 8 weeks after treatment), would have required additional hand or chemical pruning to be marketable at season's end. The objective of this study was to evaluate multiple concentrations of dikegulac applied either once or twice to two woody landscape tree species during production.

Materials and Methods

Auburn, AL. Dormant, bare-root liners of blackgum and southern sugar maple were potted into 12.4 L (3.3 gal) containers (EconoGrip, GL 1400, Nursery Supplies, Inc., Chambersburg, PA) on March 5, 2013. The pine bark:sand (7:1, by vol) substrate was amended per m^3 (yd^3) with 9.5 kg (16 lb) of 17N-2P-9K [PolyOn 17-5-11 (Pursell Industries, Sylacauga, AL)], 0.9 kg (1.5 lb) Micromax (Everris NA, Dublin, OH) and 3.0 kg (5 lb) dolomitic limestone. Plants were placed pot-to-pot in a nursery area in full sun on Auburn University's main campus in Auburn, AL (USDA cold hardiness zone 8a; 32.6° N, 85.5° W) and irrigated as needed by overhead impact heads until shoot growth began, after which pots were spaced 1.2 m (4 ft) on center and irrigated twice-daily, receiving about 2.6 cm (1.0 in) of water per day.

On May 28, 2013, trees were selected for uniformity and staked; leaves from the lower 30 cm (12 in) of the trunks were removed; and tree height, caliper 30 cm (12 in) above the substrate, and shoots longer than 2 cm (0.8 in) were quantified. Between 5:45 A.M. and 6:30 A.M. on May 31, 2013, at which time foliage from the spring flush of growth had matured, a foliar spray treatment of 800 ppm or 1,600 ppm dikegulac was applied to 20 plants each of both species by making four passes over each plant using a CO_2 sprayer with a flat spray nozzle (TeeJet 8004VS, TeeJet Technologies, Wheaton, IL) at 1.4 $kg \cdot cm^{-2}$ (20 psi), which wetted all foliage to the point of runoff. Temperature and relative humidity during treatment application were 20.6 C (69 F) and 95%, respectively. In addition to the dikegulac treatments, a nontreated control replicated with 10 single plants was included. On July 8, 2013, plant height and caliper and shoot counts were recorded on all trees. The next day, 800 ppm or 1,600 ppm dikegulac was reapplied to one-half of the plants that had previously been treated with the same concentration of dikegulac. Temperature and relative humidity during treatment application were 25.6 C (78 F) and 92%, respectively. Final plant height, caliper, and shoot counts were recorded on October 10, 2013.

Mobile, AL. The experiment was repeated at the Ornamental Horticulture Research Center in Mobile, AL (USDA cold hardiness zone 8b; 30.7° N, 88.2° W) using similar methodology unless otherwise noted. Dormant bare-root liners of blackgum were transplanted into 11.4 L (3 gal) pots containing a milled pine bark:peat (3:1, by vol) substrate on February 4, 2013. The substrate was amended per m^3 (yd^3) with 8.3 kg (14 lb) 17N-3P-10K (Osmocote 17-7-12), 3.6 kg (6 lb) dolomitic limestone, 1.2 kg (2 lb) gypsum, and 0.9 kg (1.5 lb) Micromax. Tree height, caliper and shoot counts were recorded and treatments applied on May 31, 2013 [27.8 C (82 F) and 84% relative humidity]. Tree heights, calipers and shoot counts were recorded on July 10, 2013, and the second dikegulac applications were made on July 12, 2013 [30.6 C (87 F) and 77% relative humidity]. Final plant height, caliper, and shoot counts were recorded on January 14, 2014.

Analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). At both locations, species were analyzed as separate experiments, and the data were analyzed as completely randomized designs. The treatment design for final data was an augmented factorial of dikegulac application number and concentration. Initial plant height, shoot count, and caliper recorded just before the first dikegulac applications were included in the model as a covariate when a significant linear trend was found between the covariate and the response. Where residual plots and a significant covariance test for homogeneity indicated heterogeneous variance, a RANDOM statement with the GROUP option was used in the analysis. Shoot counts were analyzed using the normal, Poisson, and negative binomial probability distributions, and the model that gave the degrees of freedom value for Pearson Chi-square closest to 1.0 was chosen. Single degree of freedom orthogonal contrasts were used to test linear and quadratic trends over the dikegulac concentrations. Differences in least squares means between application numbers were determined using Bonferroni's test in the cases of a significant interaction or by the main effect F-test if only the main effect was significant. All significances were at $\alpha = 0.05$.

Results and Discussion

Auburn, AL. By 1 week after treatment (WAT), the youngest foliage on southern sugar maple was visibly redder than that of the nontreated control. The enhanced redness of the foliage dissipated over the following 2 to 3 weeks, but reappeared for several weeks following the second application of dikegulac in July 2013. By mid- to late August, foliage color of treated and nontreated control plants was indistinguishable. Temporary foliar discoloration, and in some cases necrotic shoot terminals, has frequently been reported following application of dikegulac (Arzee 1977, Banko and Stefani 1995 and 1996, Miller et al. 2014, Norcini 1991), and has often been viewed by growers as an indication that the product has been absorbed. Numbers of new

Table 1. Effects of dikegulac concentration after one application on growth and branching of container-grown southern sugar maple (*Acer floridanum*) and blackgum (*Nyssa sylvatica*) in nursery production trials at Auburn and Mobile, AL.

	Auburn, AL[z]				Mobile, AL		
	Southern sugar maple		Blackgum		Blackgum		
Dikegulac (ppm)	Plant height (cm)[y]	Shoot counts	Plant height (cm)	Shoot counts	Plant height (cm)	Shoot counts	Trunk caliper (mm)[x]
0	109.7	8	115.6	35	105.0	25	11.7
800	105.4	9	120.1	70	94.4	55	10.6
1,600	97.8	14	107.6	124	88.0	64	10.3
Sign.[w]	L*	L**	Q***	L***	L***	L***	L**

[z]Data recorded on July 8, 2013, in Auburn, AL, and on July 10, 2013, in Mobile, AL.

[y]Plant height was measured from the root-shoot junction to the uppermost point on the plants.

[x]Trunk caliper was measured 15.2 cm (6 in) above the root-shoot junction.

[w]Significant (Sign.) linear (L) or quadratic (Q) trends over dikegulac concentration using orthogonal polynomials at α = 0.05 (*), 0.01 (**) or 0.001 (***).

shoots in maple increased linearly in response to increasing dikegulac concentration and were 13% (800 ppm) and 75% (1,600 ppm) higher than those of nontreated control plants by mid-July (Table 1). These linear responses in shoot counts are consistent with those previously reported for red maple and Japanese maple following a single dikegulac application (Miller et al. 2014).

Dikegulac concentration and application number, but not their interaction, were significant for shoot counts at the end of the growing season (Table 2). Numbers of new shoots in maple at the end of the growing season increased linearly in response to increasing dikegulac concentration and were 10% (800 ppm) and 100% (1,600 ppm) greater than those of nontreated control plants. Shoot counts of maple receiving two dikegulac applications were 58% greater than those of plants that were treated only once. These results indicated a transient branching response of southern sugar maple to 800 ppm, a season-long increased branching effect from 1,600

Table 2. Effects of dikegulac concentration and application number on growth and branching of container-grown southern sugar maple (*Acer floridanum*) and blackgum (*Nyssa sylvatica*) in nursery production trials at Auburn and Mobile, AL.

Dikegulac (ppm)	Shoot counts[z], Auburn		Height (cm)[y], Mobile		Shoot counts, Auburn		Height (cm), Mobile
	Maple[x]	Blackgum	Blackgum	Applications	Maple	Blackgum	Blackgum
0	10	67	137.0	1	12b[w]	104b	120.6a
800	11	100	103.9	2	19a	134a	102.1b
1,600	20	136	118.8				
Sign.[v]	L**	L***	Q**				

	Auburn[u]				Mobile	
	Blackgum height (cm)		Blackgum caliper (mm)[t]		Blackgum shoot counts	
	Applications				Applications	
Dikegulac (ppm)	1	2	1	2	1	2
0	145.2		18.7		51	
800	139.0a[s]	125.6b	20.1a	17.9b	68ns	72
1,600	128.1ns	135.3	17.4ns	17.8	74b	98a
Sign.[r]	L**	Q**	Q**	NS	L***	L***

[z]Data recorded on October 10, 2013, in Auburn, AL, and on January 14, 2014, in Mobile, AL. Only the dikegulac concentration and application number main effects were significant at α = 0.05.

[y]Plant height was measured from the root-shoot junction to the uppermost point on the plants.

[x]Southern sugar maple.

[w]Least square means comparisons between application numbers (in columns) using Bonferroni's test α = 0.05; ns = not significant.

[v]Significant (Sign.) linear (L) or quadratic (Q) trends over dikegulac concentration using orthogonal polynomials at α = 0.01 (**) or 0.001 (***).

[u]There were dikegulac concentration by application number interactions at α = 0.05.

[t]Trunk caliper was measured 15.2 cm (6 in) above the root-shoot junction.

[s]Least square means comparisons between application numbers (in rows) using Bonferroni's test at α = 0.05.

[r]Non-significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends over dikegulac concentration using orthogonal polynomials at α = 0.01 (**) or 0.001 (***). The nontreated control was included in the orthogonal polynomial for both application numbers.

ppm dikegulac, and a further increase in branching following a second application. Increased branching from multiple applications of dikegulac agrees with previous results with other branching agents (Holland et al. 2007, Keever and Morrison 2003, Oates et al. 2005). Plant height decreased linearly, up to 11%, with increasing dikegulac concentration (Table 1), while plant caliper (data not shown) was not affected by dikegulac concentration in mid-July. Neither plant height nor caliper at the end of the growing season was affected by treatments (data not shown). Increased branching without adversely affecting height or caliper should aid in the development of marketable shade trees. However, not all of the new shoots were in desirable locations or formed wide crotch angles with the main trunk. Additional hand-pruning would be needed for these trees to be considered of high quality.

Immature foliage of blackgum treated with dikegulac in May and July became off-color to chlorotic within a week of treatment. In both cases, the abnormal coloration dissipated within 2 weeks. Similar to southern sugar maple, numbers of new shoots in blackgum increased linearly in response to increasing dikegulac concentration and were 126% (800 ppm) and 303% (1,600 ppm) higher than those of nontreated control plants by mid-July (Table 1). Dikegulac concentration and application number, but not their interaction, were significant for blackgum shoot counts at the end of the growing season (Table 2). New shoot counts in blackgum increased linearly in response to increasing dikegulac concentration and were 49% (800 ppm) and 103% (1,600 ppm) higher than those of nontreated control plants. Shoot counts of blackgum receiving two dikegulac applications were 29% higher than those of plants that were treated only once. Plants treated with dikegulac were visibly more branched and compact than nontreated control plants at mid-season and at the end of the growing season. Although not compared statistically, blackgum naturally developed more branching than maple (35 vs. 8 new shoots in mid-July) and percentage increases, relative to nontreated plants, were higher following dikegulac application. Shoot counts were likewise much higher in blackgum than in maple at the end of the season. Based on the extensive branching induced by dikegulac application, treated blackgum were of higher quality than nontreated controls, and trees receiving two applications of either concentration or 1,600 ppm dikegulac were of higher quality than those receiving only one application of either concentration or 800 ppm dikegulac, respectively. Even with the numerous new shoots that developed in response to dikegulac application, hand-pruning would have been necessary to ensure well-spaced lateral shoots radially and vertically along the central leader.

Plant height recorded in mid-July changed quadratically in response to increasing dikegulac concentrations. Height growth was enhanced 4% by 800 ppm dikegulac and suppressed 7% by 1,600 ppm dikegulac, but these effects were not of horticultural significance. Mid-season caliper was not affected by dikegulac treatments. The interaction of dikegulac concentration and application number was significant for plant height and caliper at the end of the growing season (Table 2). Height of blackgum receiving a single dikegulac application decreased linearly in response to increasing dikegulac concentration and was 4% (800 ppm) and 12% (1,600 ppm) less than that of nontreated control plants. Height of plants treated twice with dikegulac changed quadratically in response to increasing concentrations, increasing 13% and decreasing 7% when 800 ppm and 1,600 ppm dikegulac were applied, respectively. Caliper of plants treated once with dikegulac changed quadratically in response to increasing concentrations, increasing 7% and decreasing 7% when 800 ppm and 1,600 ppm dikegulac were applied, respectively. Caliper was not affected by two applications of dikegulac. Height and caliper of plants treated twice with 800 ppm dikegulac, but not 1,600 ppm, were about 10% less than those of plants treated only once.

Mobile, AL. In contrast to blackgum in the Auburn experiment, injury to blackgum from dikegulac in Mobile was more severe, possibly due to foliage being at a different stage of development or to higher temperatures during treatment applications, 7.2 C (13 F) higher during the first application and 5 C (9 F) higher during the second application. Marginal and tip necrosis, strapping, and downward cupping of the youngest foliage developed on dikegulac-treated plants following the May application. As with blackgum in the Auburn experiment, new shoot counts in blackgum increased linearly in response to increasing dikegulac concentration and were 120% (800 ppm) and 156% (1,600 ppm) higher than those of nontreated control plants by mid-July (Table 1). At the end of the growing season the interaction between dikegulac concentration and application number for shoot counts was significant (Table 2). New shoot counts in blackgum increased linearly in response to increasing dikegulac concentration and were 34% (800 ppm) and 46% (1,600 ppm) higher than those of nontreated control plants following a single dikegulac application and 41% (800 ppm) and 92% (1,600 ppm) higher following two applications. Shoots counts of plants receiving two 1,600 ppm dikegulac applications were 32% higher than those of plants treated once; however, shoot counts were not affected by application number when plants were treated with 800 ppm dikegulac. Mid-July recordings of blackgum height and caliper decreased linearly, up to 16 and 12%, respectively, with increasing dikegulac concentration (Table 1). Dikegulac concentration and application number, but not their interaction, were significant for blackgum height at the end of the growing season (Table 2). Height of blackgum changed quadratically in response to increasing dikegulac concentration and plants were 24% (800 ppm) and 13% (1,600 ppm) shorter than nontreated control plants. Blackgum receiving two dikegulac applications were 15% shorter than plants that were treated only once. Plant caliper at the end of the growing season was not affected by treatments (data not shown).

In summary, mid-season and end-of-season shoot counts increased linearly in response to increasing dikegulac concentrations in both species and at both locations. Shoot counts also were greater when dikegulac was applied twice compared to a single application, except when 800 ppm dikegulac was applied to blackgum in Mobile. Both southern sugar maple and blackgum were visibly more branched and compact following treatment with dikegulac than nontreated control plants, although the branching response was much greater in blackgum. Based on the branching response in blackgum, and to a lesser extent in southern sugar maple, we would expect the use of 800 ppm or 1,600 ppm dikegulac foliar sprays to reduce the amount of hand pruning necessary to develop marketable canopies. Effects of dikegulac application on plant height and caliper varied with species, concentration, application number, and time after application. For example, mid-season height of maple in Auburn and blackgum in Mobile decreased linearly in response to increasing dikegulac concentration, whereas height of blackgum in Auburn increased following the application of 800 ppm dikegulac but decreased when 1,600 ppm was applied. Likewise, mid-season caliper decreased linearly in blackgum (Mobile) with increasing dikegulac concentration, but caliper of blackgum or maple in Auburn was not affected by treatments. Similar variability in height and caliper occurred at the end of the season, and is consistent with the variability observed when six tree species were treated with a single foliar application of dikegulac (Miller et al. 2014).

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