Foliar Application of Dikegulac Sodium Increases Branching of ‘Merritt’s Supreme’ Bigleaf Hydrangea

Youping Sun¹, Guihong Bi², Genhua Niu^{1,4}, and Christina Perez³

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SUMMARY. The goal of this experiment was to evaluate the efficiency of foliar application of dikegulac sodium on increasing the lateral branching of ‘Merritt’s Supreme’ bigleaf hydrangea (*Hydrangea macrophylla*). Plants were grown in greenhouses at two locations including El Paso, TX and Kosciusko, MS. Two weeks before application of dikegulac sodium, half of plants were hand-pinched leaving two nodes. Foliar spray of dikegulac sodium at 400, 800, or 1600 mg·L⁻¹ was then applied to pinched and unpinched plants. There were two additional control treatments: pinched or unpinched without application of dikegulac sodium. Data were collected at 2 weeks, 6 weeks, 80 days, and 10 months after treatments. Bigleaf hydrangea plants exhibited severe phytotoxicity including interveinal chlorosis or bleaching of new growth at 2 weeks after application of dikegulac sodium with more pronounced symptoms at higher dikegulac sodium concentrations. The severity of phytotoxicity symptoms became less significant at 6 weeks after treatment. The effect of dikegulac sodium on bigleaf hydrangea plant growth, number of branches, and number of flowers depended on both locations and dosages. In El Paso, TX, dikegulac sodium at 800 or 1600 mg·L⁻¹ inhibited bigleaf hydrangea plant growth at 6 weeks and 80 days after treatment, and this effect disappeared at 10 months after treatment. Dikegulac sodium at all tested dosages doubled or tripled the number of branches of pinched or unpinched bigleaf hydrangea, respectively, at 80 days after treatment. At 10 months after treatment, the number of branches and flowers of bigleaf hydrangea plants tended to increase, but was insignificant. In Kosciusko, MS, dikegulac sodium at 1600 mg·L⁻¹ reduced the plant growth at 6 weeks after treatment. This treatment increased the number of branches and flowers of unpinched plants by 196% and 95% and pinched plants by 53% and 31%, respectively, at 10 months after treatment. Dikegulac sodium application could be used to increase number of branches and flowers and produce compact ‘Merritt’s Supreme’ bigleaf hydrangea. However, the efficacy varied with environmental conditions.

Hydrangeas (*Hydrangea* sp.) are popular ornamental plants due to their enormous, round flower heads blooming in white, pink, red, purple, or blue in spring and summer. It was listed as

the third most used plant in a 2011 survey of 4000 landscape professionals (GIE Media, 2011). There are at least 70 hydrangea species native to southern and eastern Asia and the Americas (Wikipedia, 2014). In the United States, only five hydrangea species are widely cultivated (U.S. National Arboretum, 2005), and an estimated \$73 million hydrangea plants were sold annually (U.S. Department of Agriculture, 2009).

Bigleaf hydrangea is one of the most widely grown hydrangea species in the United States with over 1000 cultivars (Dirr, 2012). Some cultivars are best pruned or pinched on an annual basis to prevent them from being “leggy” and to promote lateral branching.

Pruning or pinching is a common technique in hydrangea production to reduce plant size, stimulate lateral branching, improve overall appearance, and enhance flower development. But hand pruning or pinching is labor intensive and costly. If done improperly, it can also reduce flowering in hydrangea plants (U.S. National Arboretum, 2005). Alternatively, a wide range of plant growth regulators (PGRs) with diverse modes of action, sites of absorption and activity are available to control height and promote lateral branching. Their use varies with plant species, chemical concentration, time of application, and environmental conditions. For example, ethephon has been reported to effectively reduce the height of ‘Sonora Jingle’ poinsettia (*Euphorbia pulcherrima*) by 33% and ‘Sonora White’ poinsettia by 31% when 700 mg·L⁻¹ ethephon was sprayed three times on 29 Aug., 20 Sept., and 13 Oct. 2005, respectively (Sun et al., 2011). Ethephon acts via release of ethylene, which is absorbed by the plant and causes cells to limit elongation and increase in width (Taiz and Zeiger, 2010). Unlike ethephon, most PGRs inhibit the biosynthesis of gibberellins within plants and therefore function as antigibberellins to suppress stem elongation (Bailey and Whipker, 1998). For example, seashore mallow (*Kosteletzkya virginica*) plants treated with chlormequat chloride at 750, 1000, or 1500 mg·L⁻¹ or paclobutrazol at 60 mg·L⁻¹ were effective for height control and lateral branching (Hilgers et al., 2005).

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¹Texas A&M AgriLife Research and Extension Center at El Paso, Texas A&M University System, El Paso, TX 79927

²Department of Plant and Soil Sciences, Mississippi State University, Mississippi State, MS 39762

³El Paso Community College, El Paso, TX 79925

⁴Corresponding author. E-mail: gniu@ag.tamu.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
29.5735	fl oz	mL	0.0338
7.8125	fl oz/gal	mL·L ⁻¹	0.1280
2.54	inch(es)	cm	0.3937
16.3871	inch ³	cm ³	0.0610
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Symptoms of phytotoxicity are a known issue with most plant growth retardants. The severity of phytotoxicity depends on plant species or cultivar and the chemical concentration. Foliar application of ethephon to 'Sonora Jingle' and 'Sonora White' poinsettia exhibited phytotoxicity as indicated by reduced biomass accumulation (Sun et al., 2011). Leaf chlorosis appeared on seashore mallow plants immediately after application of paclobutrazol, chlormequat chloride, and chlormequat chloride/daminozide, and disappeared 8 weeks after treatments (Hilgers et al., 2005). This phytotoxicity would reduce plant marketability and should be avoided by choosing an optimized concentration of PGR for producing compact plants.

Dikegulac sodium [18.5% dikegulac sodium (Augeo®; OHP, Mainland, PA)] is a PGR labeled to reduce or break apical dominance in plant shoots and to enhance lateral branching by disrupting cell wall integrity. Dikegulac sodium could be used to produce more compact plants with an increased number of flowers. It can also be used to enhance the overall structure and appearance of ornamentals including bedding plants, herbaceous plants, perennials, woody ornamentals and trees. Dikegulac sodium sprayed between 4000 and 6000 mg·L⁻¹ to mock orange (*Murraya paniculata*) hedge decreased apical dominance among lateral shoots and enhanced uniform regrowth without causing visible damage (Kawabata and Criley, 1996). Norcini et al. (1993) recommended that a foliar spray of dikegulac sodium at 1600 mg·L⁻¹ could potentially reduce the amount of pruning required during 'Barbara Karst' bougainvillea [*Bougainvillea × buttiana* (*B. glabra* × *B. peruviana*)] production. However, many factors including species, ingredient dosage, cultural and environmental conditions affect the efficacy of dikegulac sodium on plant growth and development. For example, foliar application of dikegulac sodium at 500, 1000, or 1500 mg·L⁻¹ did not control the height and increase the number of branches of seashore mallow (Hilgers et al., 2005). However, Grossman et al. (2013) reported that the application of dikegulac sodium to herbaceous perennial liners ['Autumn Joy'

butterfly stonecrop (*Sedum spectabile*), 'Bright Eyes' garden phlox (*Phlox paniculata*), 'Walker's Low' dwarf catmint (*Nepeta racemosa*)] before transplanting increased branching, with higher rates of dikegulac sodium being more effective in liners. Carter et al. (1996) observed that dikegulac sodium at 250, 500, or 750 mg·L⁻¹ increased shoot number without decreasing frond length of boston fern (*Nephrolepis exaltata*). Al-Juboory and Williams (1991) observed that dikegulac sodium not only stimulated branching, but also reduced branch length in golden pothos (*Scindapsus aureus*). Dikegulac sodium has also been reported to reduce the stem length of 'Enchantment' and 'Joan Evans' midcentury hybrid lily (*Lilium × hybrida*), but prevent the development of flower buds and plant senescence (Hanks and Menhenett, 1980). Norcini et al. (1993) observed that dikegulac sodium stimulated profuse flowering of both 'Barbara Karst' and 'Rainbow Gold' bougainvillea during middle spring to early summer. Symptoms of phytotoxicity such as yellow and narrow leaves were also present in finished plants of 'Autumn Joy' butterfly stonecrop, 'Bright Eyes' garden phlox, 'Walker's Low' dwarf catmint, 'Moonshine' yarrow (*Achillea filipendulina*) that were treated with 1600 mg·L⁻¹ dikegulac sodium (Grossman et al., 2013).

Dikegulac sodium has been used to successfully control height of Little Lime™ hardy hydrangea [*H. paniculata* 'Jane' (Cochran and Fulcher, 2013)] and 'Limelight' hardy hydrangea (Cochran et al., 2013). Both hydrangea cultivars set flower buds on current season wood. However, 'Merritt's Supreme' bigleaf hydrangea produces blooms on old wood. Therefore, the timing of foliar application and dosage of dikegulac sodium might be different for hardy hydrangea and bigleaf hydrangea. The objectives of this project were to investigate the efficacy of dikegulac sodium on lateral branching applied as a foliar spray and possible phytotoxicity on 'Merritt's Supreme' bigleaf hydrangea in two greenhouse experiments at two locations, El Paso, TX, and Kosciusko, MS.

Materials and methods

PLANT MATERIALS, CULTURE, AND TREATMENTS. The study was conducted

at two locations: Texas AgriLife Research Center at El Paso, TX (lat. 31°41'47.31"N, long. 106°16'55.07"W) and Natchez Trace Greenhouse, Kosciusko, MS (lat. 33°02'27.39"N, long. 89°34'53.54"W). Softwood cuttings of 'Merritt's Supreme' bigleaf hydrangea were received on 3 May 2012 from Oregon Hydrangea Company (Brookings, OR). At both locations, bigleaf hydrangea cuttings were treated as quick-dip with 1000 mg·L⁻¹ indole-3-butyric acid (IBA) [1.0% IBA, 0.5% 1-naphthaleneacetic acid, 98.5% inert ingredients (Dip'N Grow® liquid rooting concentrate; Dip'N Grow®, Clackamas, OR)]. All cuttings were stuck into propagation cells (6.5 × 6.5 × 7.5 cm) filled with a mixture of perlite : commercial medium (Sunshine Mix No. 4; Sun Gro Horticulture, Bellevue, WA) at a 1:1 volume ratio and kept on a mist bench until they were well-rooted.

In El Paso, TX, rooted cuttings were transplanted on 19 June to plastic containers [14.5 cm diameter, 13.5 cm height, 2600 cm³ volume (Poly-Tainer No-1P; Nursery Supplies, Orange, CA)] filled with commercial medium (Sunshine Mix No. 4). In Kosciusko, MS, rooted cuttings were transplanted on 12 June to 6-inch round plastic pots [15 cm diameter, 11 cm height, 1327 cm³ volume (ITML Horticultural Products, Brantford, ON, Canada)] filled with potting mix of pine bark, peatmoss, and sand at a ratio of 5:4:1 by volume. They were irrigated with reverse osmosis water containing 1 g·L⁻¹ of 15N-2.2P-12.5K [nutrient solution (Peters 15-5-15; Scott-Sierra Horticultural Products Co., Marysville, OH)]. The electrical conductivity (EC) and pH of the nutrient solution were (mean ± SD) 1.1 ± 0.1 dS·m⁻¹ and 6.2 ± 0.2, respectively. Micronutrients (Micromax® Micronutrients; Scott, Marysville, OH) were added to each pot at 4 g/pot. During the experiment, abamectin at 0.08 fl oz/gal [2% abamectin (AVID® 25% EC; Syngenta Crop Protection, Greensboro, NC)] was sprayed as needed to control western flower thrips (*Frankliniella occidentalis*) and/or melon aphids (*Aphis gossypii*).

Greenhouse temperature was controlled via pad-and-fan cooling and gas heating systems. In El Paso, TX, the temperature in the greenhouse

Fig. 1. Photos of 'Merritt's Supreme' bigleaf hydrangea plants from Mississippi taken 2 weeks [(A) unpinched, (B) pinched] and 80 d after treatment (C). From left to right (A, B, and C): application rate of dikegulac sodium at 0 (water), 400, 800, and 1600 mg·L⁻¹ (ppm). Bottom photo: front row: unpinched; back row: pinched.

over the experimental period was measured using T thermocouples (Omega Engineering, Stamford, CT) connected to a data logger (21X; Campbell Scientific, Logan, UT). Photosynthetic

photon flux was recorded with a quantum sensor (Apogee Instruments, Logan, UT). The average air temperatures in the greenhouse were (mean $\pm$ SD) 28.0 ± 3.4 °C during the day

and 25.4 ± 2.4 °C at night from 19 June to 1 Oct. 2012, and 25.5 ± 3.0 °C during the day and 22.2 ± 1.6 °C at night from 8 Mar. to 7 May 2013. The daily light integral photo-synthetically active radiation was 17.9 ± 3.3 and 22.3 ± 4.0 mol·m⁻²·d⁻¹ from 19 June to 1 Oct. 2012 and from 8 Mar. to 7 May 2013, respectively. In Kosciusko, MS, the day and night temperatures in the greenhouse were 29.0 ± 3.0 °C and 21.0 ± 3.0 °C, respectively, over the period of experiment in 2012 and 23.0 ± 2.0 °C and 18.0 ± 2.0 °C in 2013.

On 28 June 2012, 'Merritt's Supreme' bigleaf hydrangea plants were divided into two groups: pinched or unpinched. Pinched plants were hand-pinched to leave two nodes. Two weeks later (i.e., 12 July), dikegulac sodium application was made as a foliar spray to both pinched and unpinched plants at both locations at a rate of 400, 800, or 1600 mg·L⁻¹ according to the IR-4 protocol (IR-4 Project, 2012). There were two control treatments: plants hand-pinched leaving two nodes (pinched) and unpinched plants sprayed with tap water (EC = 0.8 dS·m⁻¹, pH = 7.4). Foliar spray was made to runoff (≈ 2.5 fl oz/plant) using a backpack sprayer at both locations.

To determine the blooming responses, plants were moved to a cooler at 4 °C on 4 Dec. 2012 and moved back to the greenhouse on 8 Mar. 2013 in El Paso, TX, whereas in Kosciusko, MS, plants were moved into a cooler (4.5 ± 1 °C) in mid-Nov. 2012 and stayed in the cooler for 8 weeks before moving them back to the greenhouse for forcing. Plants were manually defoliated before being placed into the coolers.

DATA COLLECTION. Initial growth data including plant height (centimeters), two perpendicular widths (centimeters), and the number of branches were recorded. Height was measured from pot rim to the tallest point of the plant. Growth index was calculated as (height + width 1 + width 2)/3. Phytotoxicity symptoms, reflected as curled leaves, and/or interveinal chlorosis, or bleaching of new growth were evaluated 2 weeks (i.e., 26 July) and 6 weeks after dikegulac sodium application on a 0 to 10 visual

Table 1. Effect of dikegulac sodium applied as a foliar spray to ‘Merritt’s Supreme’ bigleaf hydrangea on phytotoxicity assessed at 2 and 6 weeks and visual quality assessed at 6 weeks after treatments (WAT) in El Paso, TX (TX), and Kosciusko, MS (MS).

Pinch treatment	Dikegulac sodium (mg·L ⁻¹) ^z	Phytotoxicity (0–10 scale) ^y				Visual quality (1–7 scale) ^x	
		TX		MS		TX	MS
		2 WAT	6 WAT	2 WAT	6 WAT	6 WAT	6 WAT
Unpinched	0	0.0 e ^w	0.0 d	0.0 d	0.0 c	4.0 ab	4.0 b
Unpinched	400	5.2 c	0.0 d	0.4 c	0.0 c	3.9 ab	4.0 b
Unpinched	800	7.4 b	2.0 b	0.9 b	0.0 c	3.3 c	4.0 b
Unpinched	1,600	8.0 ab	3.8 a	2.0 a	1.9 a	2.8 c	1.1 d
Pinched	0	0.0 e	0.0 d	0.0 d	0.0 c	4.2 a	6.7 a
Pinched	400	2.0 d	0.3 cd	0.2 c	0.0 c	4.0 ab	6.9 a
Pinched	800	7.3 b	1.5 bc	0.6 b	0.0 c	3.4 bc	6.7 a
Pinched	1,600	9.1 a	4.0 a	2.0 a	0.4 b	2.8 c	1.5 c
Pinch		NS ^v	NS	*	***	NS	***
Dikegulac sodium		***	***	***	***	***	***
Pinch × Dikegulac sodium		*	NS	NS	***	NS	***

^z1 mg·L⁻¹ = 1 ppm.

^y0 = no phytotoxicity, 10 = complete kill.

^x1 = significantly worse than unpinched without application of dikegulac sodium (untreated), 2 = moderately worse than untreated, 3 = slightly worse than untreated, 4 = no difference from untreated, 5 = slightly better than untreated, 6 = moderately better than untreated, 7 = significantly better than untreated.

^wMeans followed with same letters within column are not significantly different among treatments by Tukey’s honest significant difference test at $P < 0.05$.

^vns, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

scale; 0 representing no phytotoxicity and 10 representing complete kill. Six weeks after treatment (i.e., 22 Aug.), plant height and two perpendicular widths were measured. Visual quality was recorded based on a scale of 1 to 7, where 1 = significantly worse than unpinched without application of dikegulac sodium (untreated), 2 = moderately worse than untreated, 3 = slightly worse than untreated, 4 = no difference from untreated, 5 = slightly better than untreated, 6 = moderately better than untreated, and 7 = significantly better than untreated. Eighty days after treatment (i.e., 2 Oct.), 10 plants per treatment were harvested in El Paso, TX. Plant height, two perpendicular widths, number of branches, leaf area (square centimeters), and dry weight (gram) were measured. On 7 May 2013, plant height, two perpendicular widths, number of branches and flowers, and diameter of flowers (centimeters) were measured.

EXPERIMENTAL DESIGN AND DATA ANALYSIS. A randomized complete block design with three blocks, eight plants per block, and a total of 24 plants per treatment was used at both locations. A two-way analysis of variance procedure was used to test the effects of pinching and dikegulac sodium on bigleaf hydrangea plant growth. Means separation among treatments was conducted using

Tukey’s honest significant difference multiple comparison. Phytotoxicity ratings and visual scores were analyzed by PROC NPARIWAY, which was designed for nonparametric tests. All statistical analyses were performed using SAS (version 9.1.3; SAS Institute, Cary, NC).

Results and discussion

Two weeks after treatment, all bigleaf hydrangea plants sprayed with dikegulac sodium exhibited phytotoxicity with more pronounced symptoms on plants treated with dikegulac sodium at higher concentrations at both locations (Fig. 1; Table 1). The symptoms included curled new leaves (in some plants), and/or interveinal chlorosis, or bleaching of new growth. Six weeks after treatment, bigleaf hydrangea plants had many fewer phytotoxicity symptoms. There were little or no curled leaves and/or interveinal chlorosis or bleaching of new growth for bigleaf hydrangea plants treated with dikegulac sodium at 400 mg·L⁻¹ at both locations (Table 1). In El Paso, TX, bigleaf hydrangea plants sprayed with dikegulac sodium at 800 or 1600 mg·L⁻¹ experienced more pronounced symptoms with phytotoxicity ratings ranging from 1.5 to 4.0. Unpinched and pinched plants showed similar patterns of phytotoxicity symptoms. In Kosciusko, MS, only bigleaf hydrangea plants treated with dikegulac sodium at 1600 mg·L⁻¹

showed phytotoxicity symptoms with a phytotoxicity rating of 1.9 for unpinched plants and 0.4 for pinched ones. Bigleaf hydrangea plants treated with dikegulac sodium at 0 or 400 mg·L⁻¹ had better visual quality than those with dikegulac sodium at 800 or 1600 mg·L⁻¹ in El Paso, TX. Pinching did not affect whole plants’ visual quality. In Kosciusko, MS, bigleaf hydrangea plants treated with dikegulac sodium at 0, 400, or 800 mg·L⁻¹ had better visual quality than those treated at 1600 mg·L⁻¹. Pinched bigleaf hydrangea plants were better than unpinched ones in term of visual quality. Phytotoxicity is a concern with dikegulac sodium application (Sansberro et al., 2006). Similar to previous reports (Cochran et al., 2013), phytotoxicity symptoms of ‘Limelight’ hardy hydrangea were more pronounced as the concentrations of dikegulac sodium increased. The severity of phytotoxicity symptoms usually decreases over time as seen in this study. In another study, phytotoxicity of Little Lime™ hardy hydrangea disappeared 16 weeks after treatment (Cochran and Fulcher, 2013).

Six weeks after treatment, both pinching and dikegulac sodium significantly impacted bigleaf hydrangea plant growth at both locations (Table 2). In El Paso, TX, unpinched or pinched bigleaf hydrangea plants were shorter with smaller growth

index values when they were sprayed with dikegulac sodium at 800 or 1600 mg·L⁻¹. Compared with unpinched plants without dikegulac sodium treatment, height was reduced by 52% or 58% and growth index values decreased by 69% or 62% when plants were treated with dikegulac sodium at 800 or 1600 mg·L⁻¹, respectively. Pinched plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ were 62% or 90% shorter with 80% or 90% smaller growth index values than pinched plants without dikegulac sodium treatment, respectively. In Kosciusko, MS, unpinched or pinched bigleaf hydrangea plants were similar except those sprayed with dikegulac sodium at 1600 mg·L⁻¹. When unpinched bigleaf hydrangea plants were treated with dikegulac sodium at 1600 mg·L⁻¹, their height and growth index values decreased 82% and 62%, respectively, compared with unpinched plants without dikegulac sodium treatment. Height of pinched bigleaf hydrangea plants treated with dikegulac sodium at 1600 mg·L⁻¹ decreased 70% and growth index values decreased 80%, compared with pinched plants without dikegulac sodium treatment. Dikegulac sodium has been documented to effectively control height of Little Lime™ hardy hydrangea (Cochran and Fulcher, 2013) and liner and finished herbaceous perennial plants (Grossman et al., 2013). The results reported here suggested that dikegulac sodium is an ideal plant growth regulator for height control and for producing compact ‘Merritt’s Supreme’ bigleaf hydrangea.

Eighty days after treatment, both pinching and dikegulac sodium significantly affected bigleaf hydrangea plant height, growth index, and number of branches (Fig. 1; Table 3). Unpinched bigleaf hydrangea plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ were 31% or 21% shorter than unpinched ones without dikegulac sodium treatments, respectively. Pinched bigleaf hydrangea plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ were 19% or 28% shorter than pinched ones without dikegulac sodium treatments, respectively. Unpinched bigleaf hydrangea plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ had 24% or 27% smaller growth index values than unpinched ones without

Table 2. Effect of dikegulac sodium applied as a foliar spray to ‘Merritt’s Supreme’ bigleaf hydrangea on the increases in plant height and growth index assessed at 6 weeks after treatments in El Paso, TX (TX) and Kosciusko, MS (MS).

Pinch treatment	Dikegulac sodium (mg·L ⁻¹) ^z	Ht (cm) ^z		Growth index (cm) ^z	
		TX	MS	TX	MS
Unpinched	0	10.3 a ^y	10.6 a	10.3 b	10.1 ab
Unpinched	400	10.6 a	11.3 a	8.9 b	11.1 a
Unpinched	800	5.0 b	10.5 a	3.2 d	10.0 ab
Unpinched	1,600	4.3 bc	1.9 b	4.0 d	3.8 c
Pinched	0	5.3 b	8.8 a	13.0 a	9.0 ab
Pinched	400	4.6 bc	9.6 a	6.0 c	9.1 ab
Pinched	800	2.0 cd	8.1 a	2.6 de	8.0 b
Pinched	1,600	0.5 d	2.6 b	1.4 e	1.8 c
Pinch		***	**	*	***
Dikegulac sodium		***	***	***	***
Pinch × Dikegulac sodium		NS	NS	***	NS

^z1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch, growth index = (height + width + perpendicular width)/3.

^yMeans followed with same letters within column are not significantly different among treatments by Tukey’s honest significant difference test at $P < 0.05$.

^zNS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 3. Effect of dikegulac sodium applied as a foliar spray to ‘Merritt’s Supreme’ bigleaf hydrangea on plant height (H), growth index (GI), number of branches (NB), leaf area (LA), and dry weight (DW) assessed on 1 Oct. 2012 (80 d after treatments) in Texas.

Pinch treatment	Dikegulac sodium (mg·L ⁻¹) ^z	H (cm) ^z	GI (cm) ^z	NB	LA (cm ²) ^z	DW (g) ^z
Unpinched	0	12.9 bc ^y	13.4 bc	1.3 bc	1,633 abc	22.1 a
Unpinched	400	15.1 a	14.3 bc	4.8 a	1,913 ab	22.9 a
Unpinched	800	9.0 e	10.2 de	4.9 a	1,469 bc	15.4 b
Unpinched	1,600	10.2 de	9.7 de	5.5 a	1,352 c	12.9 b
Pinched	0	14.5 ab	18.8 a	0.7 c	2,103 a	24.8 a
Pinched	400	14.8 ab	15.8 b	2.0 bc	1,908 ab	21.4 a
Pinched	800	11.8 cd	11.9 cd	2.2 b	1,552 bc	14.1 b
Pinched	1,600	10.4 de	8.5 e	1.8 bc	1,177 c	9.8 b
Pinch		***	***	***	NS	NS
Dikegulac sodium		***	***	***	***	***
Pinch × Dikegulac sodium		NS	***	***	*	NS

^z1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch, 1 cm² = 0.1550 inch², 1 g = 0.0353 oz, growth index = (height + width + perpendicular width)/3.

^yMeans followed with same letters within column are not significantly different among treatments by Tukey’s honest significant difference test at $P < 0.05$.

^zNS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

dikegulac sodium treatments, respectively; whereas pinched bigleaf hydrangea plants treated with dikegulac sodium at 400, 800, or 1600 mg·L⁻¹ were 16%, 37%, or 55% smaller than pinched ones without dikegulac sodium treatments, respectively. These data indicate that both unpinched and pinched bigleaf hydrangea plants sprayed with dikegulac sodium at 800 or 1600 mg·L⁻¹ were more compact than those sprayed with 0 or 400 mg·L⁻¹. Dikegulac sodium at all concentrations significantly increased the number of branches of unpinched bigleaf hydrangea

plants, while only dikegulac sodium at 800 mg·L⁻¹ increased the number of branches of pinched bigleaf hydrangea plants. In addition, pinching did not increase number of branches. Unpinched bigleaf hydrangea plants treated with dikegulac sodium at 400, 800, or 1600 mg·L⁻¹ had 270%, 276%, or 326%, respectively, more branches than unpinched plants without dikegulac sodium treatment, whereas pinched bigleaf hydrangea plants treated with dikegulac sodium at 400, 800, or 1600 mg·L⁻¹ had 186%, 214%, or 157%, respectively, more branches than pinched

Table 4. Effect of dikegulac sodium applied as a foliar spray to ‘Merritt’s Supreme’ bigleaf hydrangea on the increase in plant height, increase in growth index, number of branches, number of flowers, and average diameter of flowers assessed on 7 May 2013 (10 mo. after treatment) in El Paso, TX (TX) and Kosciusko, MS (MS).

Pinch treatment	Dikegulac sodium (mg·L ⁻¹) ^z	Ht (cm) ^z	Growth index (cm) ^z	Branches (no.)	Flowers (no) ^y	Flower diam. (cm)
TX						
Unpinched	0	18.5 a ^x	27.5 a	4.4 abc	2.4 b	13.6 a
Unpinched	400	20.7 a	30.0 a	6.7 a	3.7 ab	13.2 a
Unpinched	800	18.0 a	31.7 a	6.9 a	4.4 ab	12.5 a
Unpinched	1,600	17.0 a	30.8 a	5.3 ab	4.0 ab	13.0 a
Pinched	0	17.1 a	28.9 a	2.0 c	4.1 ab	13.4 a
Pinched	400	19.5 a	32.1 a	5.0 ab	4.3 ab	13.1 a
Pinched	800	18.9 a	31.3 a	4.7 abc	4.8 a	11.6 a
Pinched	1,600	14.6 a	25.5 a	3.5 bc	2.5 b	12.0 a
Pinch		NS ^w	NS	***	NS	NS
Dikegulac sodium		NS	NSS	NS	NS	*
Pinch × Dikegulac sodium		NS	*	NS	**	NS
MS						
Unpinched	0	34.5 a	32.7 a	2.4 c	2.2 c	20.6 a
Unpinched	400	36.2 a	31.5 a	2.3 c	2.2 c	21.3 a
Unpinched	800	26.3 b	31.5 a	2.3 c	2.3 c	20.6 a
Unpinched	1,600	28.3 b	30.8 a	7.1 a	4.3 a	17.3 b
Pinched	0	34.7 a	32.9 a	4.3 b	3.2 b	21.0 a
Pinched	400	34.8 a	31.1 a	4.4 b	3.2 b	19.9 a
Pinched	800	35.6 a	31.6 a	5.0 b	3.1 b	20.1 a
Pinched	1,600	37.3 a	32.4 a	6.6 a	4.2 a	17.9 b
Pinch		NS ^w	NS	***	***	NS
Dikegulac sodium		***	NS	***	***	***
Pinch × Dikegulac sodium		NS	NS	***	***	NS

^z1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch, growth index = (height + width + perpendicular width)/3.

^yFlower was counted only if the diameter > 8 cm.

^xAt each location, means followed with same letters within column are not significantly different among treatments by Tukey’s honest significant difference test at *P* < 0.05.

^wNS, *, **, ***Nonsignificant or significant at *P* < 0.05, 0.01, or 0.001, respectively.

ones without dikegulac sodium treatment. These results indicated that dikegulac sodium application could be used as a substitute for hand pinching of bigleaf hydrangea plants to save labor. In a previous study, foliar spray of dikegulac sodium at 1600 mg·L⁻¹ could potentially reduce the amount of pruning required during ‘Barbara Karst’ bougainvillea production in hanging baskets (Norcini et al., 1993).

Like other PGRs, such as daminonide (Reiss-Bubenheim and Lewis, 1984) and paclobutrazol (Bailey and Whipker, 1998), dikegulac sodium has inhibitory effects on biomass accumulation. Dikegulac sodium significantly affected plant leaf area and shoot dry weight (Table 3). Compared with unpinched bigleaf hydrangea plants without dikegulac sodium treatments, dikegulac

sodium at 800 or 1600 mg·L⁻¹ reduced the leaf area of unpinched bigleaf hydrangea plants by 10% or 17%, respectively. The leaf area of pinched bigleaf hydrangea plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ were 26% or 44% smaller than pinched ones without dikegulac sodium treatments, respectively. Compared with unpinched bigleaf hydrangea plants without dikegulac sodium treatments, unpinched plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ produced 31% or 42% less dry biomass, respectively. Pinched plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹ accumulated 43% or 60% less dry biomass than pinched ones without dikegulac sodium treatments, respectively. These results indicated that dikegulac sodium might have significant side effects such as phytotoxicity.

Ten months after treatment, the effects of pinching and dikegulac sodium application on bigleaf hydrangea plants were less obvious (Table 4). In El Paso, TX, no difference existed among treatments in terms of plant height, growth index, and flower size. Foliar application of dikegulac sodium at all tested dosages tended to increase the number of branches and flowers of unpinched plants, but their effects were insignificant. Compared with pinched plants without dikegulac sodium treatment, dikegulac sodium at 400 mg·L⁻¹ increased the number of branches of pinched plants by 150% but did not increase their number of flowers. Dikegulac sodium at 800 or 1600 mg·L⁻¹ tended to increase the number of branches and flowers of pinched plants, but their effects were insignificant. In Kosciusko, MS, all

bigleaf hydrangea plants had similar height with the exception of unpinched plants treated with dikegulac sodium at 800 or 1600 mg·L⁻¹. Compared with unpinched plants without dikegulac sodium treatment, dikegulac sodium at 800 or 1600 mg·L⁻¹ reduced unpinched plant height by 24% or 18%, respectively. Neither pinching nor dikegulac sodium affected the growth index of bigleaf hydrangea plants, but both significantly impacted the number of branches and flowers. For unpinched bigleaf hydrangea plants, those treated with dikegulac sodium at 1600 mg·L⁻¹ had 196% more branches and 95% more flowers than those without dikegulac sodium treatment. For pinched bigleaf hydrangea plants, dikegulac sodium at 1600 mg·L⁻¹ increased the number of branches by 53% and number of flowers by 31%, compared with those without dikegulac sodium treatments. Application of dikegulac sodium at 400 or 800 mg·L⁻¹ on pinched or unpinched plants did not increase the number of branches and flowers. All bigleaf hydrangea plants had similar flower size with the exception of unpinched or pinched plants treated with dikegulac sodium at 1600 mg·L⁻¹. Compared with unpinched or pinched plants without dikegulac sodium treatment, dikegulac sodium at 1600 mg·L⁻¹ reduced the flower size of unpinched or pinched plants by 16% or 15%, respectively. Dikegulac sodium has been reported previously to prevent the development of flower buds of midcentury hybrid lily 'Enchantment' and 'Joan Evans' (Hanks and Menhenett, 1980). In our study, the undesirable side effect of dikegulac sodium on flower number and flower size was minimal.

In conclusion, 'Merritt's Supreme' bigleaf hydrangea plants exhibited severe phytotoxicity 2 weeks after application of dikegulac sodium with more severe symptoms at higher concentrations of dikegulac sodium. The phytotoxicity symptoms became less severe 6 weeks after treatment. The effect of dikegulac sodium on bigleaf hydrangea plant growth, number of branches, and number of flowers depended on location and dosage. In El Paso, TX, dikegulac sodium at 800 or 1600 mg·L⁻¹ inhibited bigleaf hydrangea plant growth at 6 weeks and 80 d after

treatment, and this effect disappeared at 10 months after treatment. Dikegulac sodium at all tested dosages doubled or tripled the number of branches of pinched or unpinched bigleaf hydrangea, respectively, at 80 d after treatment. At 10 months after treatment, the number of branches and flowers of bigleaf hydrangea plants tended to increase, but was not significant. In Kosciusko, MS, dikegulac sodium at 1600 mg·L⁻¹ reduced the plant growth at 6 weeks after treatment. This treatment increased the number of branches and flowers of unpinched plants by 196% and by 95% and pinched plants by 53% and 31%, respectively, 10 months after treatment. Dikegulac sodium application could be used to increase number of branches and flowers and produce compact 'Merritt's Supreme' bigleaf hydrangea. However, environmental conditions related to locations should be considered in deciding the application concentration of dikegulac sodium.

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