

Effects of Fall Applications of Chemical Defoliant, Urea, and Gibberellic Acid on Defoliation in the Fall and Performance of Hydrangeas During Forcing

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Abstract. In two separate experiments, *Hydrangea macrophylla* (Thunb.) Ser. ‘Merritt’s Supreme’ plants were used to study the effects of foliar sprays of Def 6 (tributyl phosphorotrithioate, 2500, 5000, 7500, and 10,000 mg·L⁻¹), gibberellic acid (GA, 50 mg·L⁻¹), copper–EDTA (CuEDTA, 0.5% and 1.0%), Florel (2000 mg·L⁻¹), and urea (3%) on defoliation in the fall and growth and flowering performance during forcing. Compared with controls (plants sprayed with water only), spraying plants with urea or GA alone had no influence on defoliation or plant performance during forcing, and spraying plants with Florel alone had no influence on defoliation but decreased total flower dry weight during forcing. Combining urea with Florel sprays decreased the adverse effects of Florel on plant quality and combining GA with Florel improved defoliation. Increasing concentrations of Def 6 and CuEDTA increased defoliation. Compared with controls, plants sprayed with CuEDTA exhibited more defoliation, showed bud and leaf necrosis, and produced lower flower dry weight during forcing. Combining urea with CuEDTA sprays decreased the adverse effects of CuEDTA on plant quality. Compared with controls, spraying plants with Def 6 increased defoliation, caused no visible damage to plants, and had no adverse effects on plant quality during forcing. Adding urea to sprays containing Def 6 decreased or had no influence on the efficiency of defoliation and increased total flower dry weight during forcing compared with Def 6 alone. Adding GA to sprays containing lower concentrations of Def 6 (2500 and 5000 mg·L⁻¹) increased the efficiency of defoliation without adversely influencing plant quality.

During production of florists’ hydrangea, defoliation before cold storage is required for prevention of diseases such as botrytis bud rot (Bailey, 1989). Many hydrangea growers

manually remove leaves before natural leaf abscission. This practice is time-consuming, expensive, and can result in damage to stems and buds. An alternative to this practice is chemical defoliation. A wide variety of chemicals have been tested for their effectiveness in defoliation of hydrangeas, but all have some limitations (Bailey, 1989). Some chemicals such as ethephon (2-chloroethylphosphonic acid) adversely influence performance during forcing by retarding growth or reducing inflorescence size (Shanks, 1969; Tjia and Buxton, 1976). Application procedures for some chemicals such as Vapam (sodium N-methyldithiocarbamate) and ethylene require an air-tight storage unit. Some chemicals such as 2-butyne-1,4-diol (BD) are effective defoliant at high concentrations but are poisonous to humans and require special safety regulations for application. The influence of only a few combinations of chemicals on defoliation of hydrangea has been evaluated. Gibberellic acid (GA₃) has

been found to be able to enhance chemical [BD and TPTA (tributyl phosphorotrithioate)] defoliation of hydrangeas (Bailey, 1990).

During natural leaf senescence, deciduous plants can mobilize nutrients, including nitrogen (N), from leaves into storage tissues (Titus and Kang, 1982). Stored N is important for the initial growth of deciduous plants in spring, and there is a positive relationship between the amount of stored N and spring growth in many species (Cheng and Fuchigami, 2002; Cheng and Xia, 2004; Taylor, 1967; Taylor and May, 1967). The N mobilized from senescing leaves makes an important contribution to whole plant N economy (Chapin and Kedrowski, 1983; Taylor and May, 1967). For example, in apple, N mobilized during leaf senescence constitutes ≈25% of the total plant N (Cheng et al., 2002). Manual or chemical defoliation removes green leaves from plants before any significant N mobilization occurs. In *Hydrangea macrophylla* ‘Merritt’s Supreme’, ≈50% of total plant N was in leaves in early fall (Bi et al., 2008). Early defoliation could potentially decrease N storage and result in poor growth and flower development during forcing.

Foliar sprays of urea in the fall after terminal bud set can increase reserve N in deciduous plants without stimulating new growth late in the season (Cheng et al., 2002; Sanchez et al., 1990; Tagliavini et al., 1998). Increased N from urea sprays can compensate for the N lost from early defoliation and improve plant growth and development during the next growing season (Bi et al., 2005; Guak et al., 2001). Spraying florists’ hydrangea with urea before manual defoliation has the potential to improve growth and increase the number of flowers and flower size during forcing (Bi et al., 2008). At present, there is no available information on whether spraying hydrangea with urea ameliorates the effects of chemical defoliants on growth and flowering performance during forcing.

This article presents the results of two studies assessing the effects of foliar sprays with chemical defoliants and urea on defoliation in the fall and plant performance during forcing in florists’ hydrangea. Our objective was to determine if the combination of urea with defoliant applications promotes early defoliation and maintains or improves growth and flowering performance during forcing.

Materials and Methods

Expt. 1. A study was conducted at the Truck Crops Branch Experiment Station in Crystal Springs, MS (lat. 31°59′ N, long. 90°21′ W). Rooted *Hydrangea macrophylla* (Thunb.) Ser. ‘Merritt’s Supreme’ cuttings were potted into Elite/Ultra Azalea pots (17.8 cm o.d., 12.7 cm height, 2100 cm³ volume; ITML Horticultural Products, Inc., Brantford, Ontario, Canada) containing Sun Gro

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#4 (Sun Gro Horticulture, Bellevue, WA) in late May 2006. Each pot contained two cuttings that were pinched (leaving two nodes per shoot) in early June. Starting in early June, plants were fertigated two times per week with 200 mg·L⁻¹ N (20N-4.4P-16.6K; TotalGro 20-10-20; SDT Industries, Inc., Winnsboro, LA) for 6 weeks followed by 150 mg·L⁻¹ N for the next 4 weeks and 100 mg·L⁻¹ N for another 4 weeks. Plants were grown outdoors under shade cloth (40% shade) and drip-irrigated as needed throughout the growing season. Plants were sprayed twice in July and once in August with 5000 mg·L⁻¹ daminozide [B-9, butanedioic acid mono (2,2-dimethylhydrazide); Crompton Manufacturing Company, Inc., Middlebury, CT] to control plant height.

On 31 Oct. 2006, plants were selected for uniformity and eight plants were randomly assigned to each of 19 treatments (Table 1). Def (Def 6; Bayer CropScience, Research Triangle Park, NC) contains 6 lb S,S,S-tributyl phosphorotrithioate per gallon. Florel (Southern Agricultural Insecticides, Inc., Hendersonville, NC) contains 3.9% ethephon. ProGibb T&O (Valent U.S.A. Corporation, Walnut Creek, CA) contains 4.0% GA. Applications were made using a backpack sprayer and plants in the control treatment were sprayed with water only. Plants were sprayed to the point of runoff on leaves to assure complete spray coverage of the foliage for best results. Leaf color was observed visually after spray applications and any color change was recorded. Defoliation on each plant was recorded 7 d and 14 d after treatment. Defoliation was determined by estimating the

number of leaves abscised as a percentage of the total leaves on each plant. On 25 Nov. 2006, any leaves remaining on plants were manually removed, and plants were placed into a dark cooler (4.4 to 5.5 °C). After 8 weeks, plants were removed from the cooler and placed into a greenhouse (15.4 °C night temperature/23.7 °C vent temperature) for forcing using conventional nursery practices.

After bud break, plants were fertigated with 200 mg·L⁻¹ N using 20N-4.4P-16.6K fertilizer (TotalGro 20-10-20) two times per week from February to mid-Apr. 2007. All plants received one spray application of B-9 (2500 mg·L⁻¹) after three to five pairs of leaves had unfolded to control plant height. In late April, plant height (measured from top of the pot to top of the inflorescence) was recorded and the inflorescences were harvested from each plant. Inflorescences were dried at 60 °C in a forced-air oven and total flower dry weight was recorded for each plant.

Expt. 2. A study was conducted at a commercial greenhouse in Kosciusko, MS (lat. 33°06' N, long. 89°59' W). Plant cultivar, growing conditions, fertigation, and B9 treatment were the same as described for Expt. 1. Plants were selected for uniformity on 27 Nov. 2007. Fifteen plants were randomly assigned to each of 12 treatments (Table 1). Treatments and evaluations of leaf color were performed as described for Expt. 1. All treatments were applied on 27 Nov. 2007. Defoliation was evaluated 7 d after treatment as described for Expt. 1. On 4 Dec. 2007, any leaves remaining on plants were manually removed. Plants were stored and

forced as described for Expt. 1. In late Apr. 2008, plant heights were recorded.

Experimental design and statistical analyses. Treatments were set up in a completely randomized design with each experimental unit (pot) replicated eight times for Expt. 1 and 15 times for Expt. 2. Data were analyzed by one-way analysis of variance. The effects of Def concentration on response variables were evaluated using a priori polynomial contrasts based on the concentrations of Def in sprays. Specific a priori contrasts were used to compare means between control and other treatments and to assess the effects of copper concentration and addition of urea and GA to sprays. Defoliation data were arcsine-transformed before analysis and back-transformed for data presentation. All analyses were performed using Statistica® (Statsoft, Inc., Tulsa, OK).

Results and Discussion

The chemical Def 6 is an effective defoliant for use with florists' hydrangeas. At the concentrations tested (2500, 5000, 7500, and 10,000 mg·L⁻¹), we observed no visible injury to plants (data not shown), and plant quality during forcing (e.g., flower dry weight and plant height) was not adversely influenced by sprays with Def 6 during the previous fall (control versus Def 6; Tables 2 and 3). Although spraying plants with 10,000 mg·L⁻¹ Def 6 significantly reduced plant height compared with controls, the reduction in height is not considered a negative influence on plant performance because hydrangeas normally require height control during forcing. In both Expt. 1 and Expt. 2, spraying plants with Def 6 promoted earlier defoliation compared with control plants and increasing the concentration of Def 6 in the spray improved defoliation (Def 6 linear contrasts; Tables 2 and 3). Seven days after spraying plants with Def 6 at 7500 and 10,000 mg·L⁻¹, plants were 90% to 98% defoliated. Similarly, Bailey (1990) reported spraying hydrangeas with 7500 to 15,000 mg·L⁻¹ tributyl phosphorotrithioate (TPTA) resulted in 93% to 100% defoliation after 7 d and defoliation increased linearly with increasing concentration of TPTA from 2500 up to 7500 mg·L⁻¹.

Our results indicate copper-EDTA (CuEDTA) can also promote early defoliation of florists' hydrangeas (control versus copper; Table 2) and 1.0% CuEDTA is more effective than 0.5% CuEDTA on promoting early defoliation (Table 2); however, at the concentrations tested (0.5% and 1.0%), we observed some necrosis on leaves and buds after spraying (data not shown) and 1.0% CuEDTA had a negative effect on plant quality during forcing (Table 2). CuEDTA has been used as a defoliant for nursery plants (Bi et al., 2005; Guak et al., 2001; Knight, 1983; Larsen and Fritts, 1986). Using apple and cherry rootstocks, substantial defoliation was achieved by spraying trees with 2.1% CuEDTA with little or no damage to plants (Knight, 1983). Using apple, cherry, and pear

Table 1. Chemical combinations used in foliar sprays in two experiments assessing the effects of different chemical combinations on defoliation and plant growth and flowering performance of *Hydrangea macrophylla* 'Merritt's Supreme' during forcing.

Expt. ²	Treatment ¹	Chemicals ³				
		Def 6 (mg·L ⁻¹)	Florel	CuEDTA (%)	Urea	GA
1, 2	Control	-	-	-	-	-
1, 2	U	-	-	-	+	-
1, 2	GA	-	-	-	-	+
1	0.5Cu	-	-	0.5	-	-
1	1.0Cu	-	-	1.0	-	-
1	0.5Cu+U	-	-	0.5	+	-
1	1.0Cu+U	-	-	1.0	+	-
1	Def2500	2,500	-	-	-	-
1, 2	Def5000	5,000	-	-	-	-
1, 2	Def7500	7,500	-	-	-	-
2	Def10000	10,000	-	-	-	-
1, 2	Def2500 + GA	2,500	-	-	-	+
1, 2	Def5000 + GA	5,000	-	-	-	+
1	Def7500 + GA	7,500	-	-	-	+
1	Def2500 + U	2,500	-	-	+	-
1, 2	Def5000 + U	5,000	-	-	+	-
1, 2	Def7500 + U	7,500	-	-	+	-
2	Def2500 + U+GA	2,500	-	-	+	+
2	Def5000 + U+GA	5,000	-	-	+	+
1	F	-	+	-	-	-
1	F+U	-	+	-	+	-
1	F+GA	-	+	-	-	+

¹Expt. 1: Plants sprayed on 31 Oct. 2006. Expt. 2: Plants sprayed on 27 Nov. 2007.

²Def 6 = S,S,S-tributyl phosphorotrithioate at 0 (-) and 2500, 5000, 7500, and 10,000 mg·L⁻¹; Florel = ethephon (2-chloroethylphosphonic acid) at 0 (-) and 2000 mg·L⁻¹ (+); CuEDTA = Copper EDTA at 0 (-) and 0.5% and 1.0%; urea = 0 (-) and 3% urea (+); GA = 0 (-) and 50 mg·L⁻¹ gibberellic acid from ProGibb T&O (+).

³U = urea; Cu = CuEDTA; Def = Def 6; F = Florel.

Table 2. Defoliation in the fall of 2006 and plant height and flower dry weight of *Hydrangea macrophylla* 'Merritt's Supreme' in the spring of 2007 after being sprayed with different combinations of chemical defoliant, urea, and GA in the fall of 2006.

Treatment ^z	Defoliation (%)		Flower dry wt (g)	Plant ht (cm)
	7 d	14 d		
Control	0	0	25.5	36.6
U	0	0	27.0	37.7
GA	0	0	24.7	34.5
0.5Cu	27* ^y	38*	24.1	36.0
0.5Cu+U	8	14	25.6	38.3
1.0Cu	60**	72**	17.8**	33.3
1.0Cu+U	43**	60**	24.3	33.5
Def2500	63**	72**	22.7	35.5
Def2500 + U	40**	56**	27.2	35.6
Def2500 + GA	82***	90***	25.0	36.6
Def5000	82***	91***	23.0	35.7
Def5000 + U	66**	80***	27.6	41.7
Def5000 + GA	97***	100***	21.8	30.9**
Def7500	97***	100***	22.6	34.5
Def7500 + U	90***	98***	26.9	33.8
Def7500 + GA	100***	100***	24.9	38.4
F	8	10	19.1**	35.5
F+U	5	5	25.0	32.3
F+GA	35**	50**	21.4*	30.0**
<i>Def concentration responses^x</i>				
Def	L	L	NS	NS
Def+U	L	L	NS	NS
Def+GA	L	L	NS	NS
<i>Cu comparisons^x</i>				
Cu: 0.5 versus 1.0Cu	**	**	***	*
Cu+U: 0.5 versus 1.0Cu	**	**	*	*
<i>Urea comparisons^x</i>				
Def versus Def+U	**	**	***	NS
Cu versus Cu+U	**	**	***	NS
F versus F+U	NS	NS	***	NS
<i>GA comparisons^x</i>				
Def 2500: Def versus Def+GA	**	**	NS	NS
Def 5000: Def versus Def+GA	**	**	NS	NS
Def 7500: Def versus Def+GA	NS	NS	NS	NS
F versus F+GA	**	**	NS	**

^zSpray treatment combinations as outlined in Table 1. Control = sprayed with water; U = 3% urea; GA = 50 mg·L⁻¹ gibberellic acid from ProGibb T&O; Cu = CuEDTA at 0.5% (0.5Cu) and 1.0% (1.0Cu); Def = 2500 (Def2500), 5000 (Def5000), and 7500 (Def7500) mg·L⁻¹ Def 6; F = 2000 mg·L⁻¹ Florel.

^yMeans within a column denoted by asterisk(s) are significantly different from control plants $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***) (n = 8).

^xDef concentration responses: significant ($P < 0.05$) linear (L) a priori polynomial contrasts based on the concentrations of Def in sprays. Cu comparisons, urea comparisons, and GA comparisons: specific a priori contrasts to assess the effects of Cu concentrations; adding urea to sprays containing Def, Cu, or F; and adding GA to sprays containing Def or F at $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***) (n = 8); NS = nonsignificant ($P > 0.05$).

trees, Larsen and Fritts (1986) obtained 80% or more defoliation 14 d after spraying plants with concentrations of 0.5% CuEDTA or greater; however, they also observed some bud and bark damage in trees sprayed with CuEDTA. Our results suggest CuEDTA at the concentrations tested is a less effective defoliant for florists' hydrangea than Def 6 (5000 mg·L⁻¹ and above) and may also potentially have adverse effects on plant quality during forcing (Table 2).

In general, combining 3% urea with the defoliant Def 6 or CuEDTA decreased or had no influence on defoliation of florists' hydrangea compared with plants sprayed only with defoliant (Def versus Def+U and Cu versus Cu+U; Tables 2 and 3). In Expt. 1, adding urea to the Def 6 or CuEDTA sprays decreased the defoliation effect of the defoliant and generally improved flower dry

weight during forcing. In Expt. 2, adding urea to Def 6 sprays had no influence on defoliation and increased plant height during forcing. Differences in defoliation response to using urea with the defoliant between the two experiments may be a result of the differences in the timing of the sprays in the fall. In Expt. 1, plants were sprayed at the end of October when their physiological status may have allowed for urea retention in the leaves to support leaf metabolism. This altered metabolism could decrease defoliant efficiency. In Expt. 2, plants were sprayed in late November, closer to when their leaves naturally abscise. Urea absorbed by the leaves at this time would be exported to storage tissues and have less of an influence on leaf metabolism and defoliant efficiency.

Our results indicate adding urea to sprays containing Def 6 has the potential to improve

plant quality of florists' hydrangea during forcing. Similarly, combining urea with defoliant sprays on young apple nursery trees can improve plant N reserves and result in better tree growth during establishment the next spring (Guak et al., 2001). This suggests urea sprays may compensate for the N lost as a result of early defoliation, and combining urea with appropriate defoliant sprays may be considered a strategy to promote earlier defoliation without reducing plant quality, especially for plants with low N status. This theory is also supported by our results using urea with CuEDTA on florists' hydrangea. Adding urea into sprays containing CuEDTA may have decreased the efficiency of defoliation; however, our results suggest the effects of urea mitigated some of the negative effects of CuEDTA, mentioned previously, on plant quality during forcing. This type of compensatory response of adding urea to CuEDTA sprays is similar to the effects of combining urea and CuEDTA in sprays to defoliate bare-root apple and almond nursery trees (Bi et al., 2005; Guak et al., 2001). If cost or availability issues cause growers to choose CuEDTA over Def 6 as a defoliant for use with florists' hydrangeas, then adding urea to CuEDTA sprays may decrease the adverse effect of CuEDTA on plant quality during forcing.

The results from Expt. 1 suggest Florel (ethephon) is not an effective defoliant for use with florists' hydrangeas. At the concentration tested (2000 mg·L⁻¹), spraying plants with Florel in late October did not promote early defoliation and, although we observed no visible injury to plants (data not shown), plant quality during forcing (e.g., flower dry weight) was decreased by sprays with Florel during the previous fall (control versus Florel; Table 2). Bailey (1990) also reported ethephon did not promote early defoliation of hydrangea. Adding urea to Florel sprays had no influence on the defoliation effects of Florel but mitigated some of the negative effects of Florel on plant quality during forcing (F versus F+U; Table 2).

Adding GA (50 mg·L⁻¹) to sprays containing Def 6 (2500 and 5000 mg·L⁻¹) and Florel increased the efficiency of defoliation of florists' hydrangea (Def versus Def+GA and F versus F+GA; Tables 2 and 3). Bailey (1990) also reported combining GA with TPTA at lower concentrations (2500 and 5000 mg·L⁻¹) increased defoliation of hydrangea over that obtained from sprays containing only TPTA. Interestingly, using sprays of only GA on florists' hydrangea had no influence on either defoliation in the fall or performance during forcing and the synergistic effects of combining GA with Def 6 at lower concentrations or Florel on defoliation did not result in any negative influence on plant performance during forcing compared with Def 6 or Florel alone, although plants were shorter when treated with a combination of Florel and GA compared with Florel alone. This suggests the influence of GA on defoliation may not influence factors related to plant performance during the next growing cycle.

Table 3. Defoliation in the fall of 2007 and plant height of *Hydrangea macrophylla* 'Merritt's Supreme' in the spring of 2008 after being sprayed with different combinations of chemical defoliant, urea, and GA in the fall of 2007.

Treatment ^z	Defoliation (%) 7 d	Plant ht (cm)
Control	5	40.9
U	0	40.5
GA	5	39.0
Def2500 + GA	75**y	39.8
Def2500 + U + GA	55*	40.7
Def5000	77**	36.5
Def5000 + U	85***	42.3
Def5000 + GA	93***	37.6
Def5000 + U + GA	89***	38.9
Def7500	90***	38.3
Def7500 + U	92***	39.3
Def10000	98***	35.4*
<i>Def concentration responses^x</i>		
Def	L	NS
Def + U	L	NS
Def + GA	L	NS
<i>Urea comparisons^x</i>		
Def versus Def + U	NS	**
Def2500: Def + GA versus Def + GA + U	*	NS
Def5000: Def + GA versus Def + GA + U	NS	NS
<i>GA comparisons^x</i>		
Def versus Def + GA	*	NS
Def + U versus Def + GA + U	NS	NS

^zSpray treatment combinations as outlined in Table 1. Control = sprayed with water; U = 3% urea; GA = 50 mg·L⁻¹ gibberellic acid from ProGibb T&O; Def = 2500 (Def2500), 5000 (Def5000), 7500 (Def7500), and 10,000 (Def10000) mg·L⁻¹ Def 6.

^yMeans within a column denoted by asterisk(s) are significantly different from control plants $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***) (n = 15).

^xDef concentration responses: significant ($P < 0.05$) linear (L) a priori polynomial contrasts based on the concentrations of Def in sprays. Urea comparisons and GA comparisons: specific a priori contrasts to assess the effect of adding urea and GA to sprays containing Def at $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***); NS = nonsignificant ($P > 0.05$).

Results from Expt. 1 showed adding GA to lower concentrations of Def 6 sprays increased the efficiency of defoliation of florists' hydrangea and adding urea to Def 6 sprays improved plant performance during forcing and decreased the effectiveness of defoliation by Def 6. Based on these results, in Expt. 2, we sprayed plants with a combination of Def 6, urea, and GA to determine whether the three compounds would act synergistically to improve both the effectiveness of defoliation (GA effects on Def 6) and plant performance during forcing (urea effects on Def 6). Adding urea to sprays containing 2500 mg·L⁻¹ Def 6 and GA decreased the effectiveness of Def 6 and GA on defoliation and adding urea to sprays containing 5000 mg·L⁻¹ Def 6 and GA had no influence on the defoliation effects of Def 6 and GA. Adding GA to sprays containing Def 6 (5000 mg·L⁻¹) and urea also had no influence on the defoliation effects of Def 6 and urea. Together, these results suggest that any synergism among these three compounds in a spray might be dependent on the concentration of the defoliant.

In conclusion, our results indicate Def 6 is an effective defoliant for use on florists' hydrangea at different times in the fall. Increasing the concentration of Def 6 from 2500 up to 10,000 mg·L⁻¹ can increase defoliation without visible injury to plants and adverse effects on plant quality during forcing. Our results also suggest adding GA to lower concentrations of Def 6 sprays can improve defoliation activity of Def 6 and adding urea to Def 6 sprays has the potential to improve plant performance during forcing. The response of plants to defoliant is affected by many variables such as temperature, humidity and precipitation, species and cultivar, timing, chemical concentrations, soil moisture, nutrition, age of the plant, spray pressure and droplet size, adjuvant, water pH, and so on (Larsen, 1973); therefore, it is important for hydrangea producers to conduct proper testing before adopting defoliation methods into production practices.

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