Florists' Hydrangea Blueing with Aluminum Sulfate Applications during Forcing

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Abstract. The Al content was determined in roots, buds, and stems of dormant florists' hydrangeas [*Hydrangea macrophylla* subsp. *macrophylla* var. *macrophylla* (Thunb.) 'Mathilda Gutges' and 'Brestenburg'] that were or were not treated in the field with aluminum sulfate. During the greenhouse forcing stage, previously nontreated plants were subjected to four successive weekly subirrigated applications of aluminum sulfate totalling 4, 8, 12, or 16 g/pot. Applications were early (weeks 2, 3, 4, 5) or late (weeks 6, 7, 8, 9), using the start of forcing as week = 0. The Al contents in stems and buds of dormant plants were about five to six times higher in field-treated than in nontreated plants. Roots were the primary location of Al accumulation ($\approx 70\%$). Aluminum sulfate applications of 12 to 16 g/pot during greenhouse forcing provided commercially acceptable blue plants. Maximum foliar Al concentration was 50% higher in early than in late-treated plants and calculated to occur with 14.5 and 12.2 g aluminum sulfate/pot for early and late-treated plants, respectively. There was a positive correlation ($r = 0.74$) between blueness ranking and the Al foliar concentration of the two uppermost expanded leaves taken from flowering plants.

Chenery (1937) and Allen (1943) showed that availability of Al in soil and/or application of Al ions to the sepals strongly influenced the blueing of florists' hydrangeas. Robinson and Robinson (1932) showed that both Al and anthocyanin (delphinidin-3-monoglucoside) were involved in blueing of

hydrangea sepals. Takeda et al. (1985) reported that the blueing of hydrangea sepals was mainly due to the delphinidin-3-glucoside-aluminum-3-caffeoylquinic acid complex, with Al serving as the stabilizer.

Florists' hydrangeas are normally grown from spring-rooted cuttings in pots placed outside during the summer (Bailey, 1989). At the end of summer (August-September), Al is applied to plants scheduled to be forced with blue sepals. This is normally done by manual drenching the substrate two to four times with aluminum sulfate (AS) at 12 to 20 g-liter⁻¹. Besides the additional labor of applying the drenches, this decision commits the field producer to the number of plants to be forced as blue, since AS-treated plants are

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Fig. 1. (A) Effect of early (top row) and late (bottom row) applications of aluminum sulfate (4, 8, 12, or 16 g/pot) on blueing of hydrangea 'Brestenburg' during the greenhouse forcing stage only. Treatments 12E and 16E (the two plants in northeast corner) were considered commercially acceptable (blue) plants. (B) Plant on left was treated in the field only, while control plant was not treated with aluminum sulfate (0 AS/pot). Neither was considered commercially acceptable (as blue).

difficult to force as true pink (personal observation). Following cold storage, AS is further applied during the forcing (greenhouse) stage to guarantee the "true" blue of the flowers.

We found no published reports describing where Al is stored in the plant and/or its availability during forcing. Moreover, quantitative information is difficult to interpret due to the method of AS application (overhead). In this regard, the subirrigation technique that allows negligible leaching from the pots (Blom and Piott, 1990) permits a more quantitative approach to the application of AS.

This study was initiated to determine: 1) the distribution of Al in dormant plants previously treated with AS in the field during the summer vegetative growth stage; and 2) whether blue hydrangeas could be produced by applying AS solely during the greenhouse forcing stage using subirrigation.

In early Oct. 1990, AS-treated and non-treated (control) 'Mathilda Gutges' or 'Brestenburg' hydrangeas grown in 15-cm-diameter (1.6-liter) pots from three producers were defoliated and placed into 4 to 5°C dark storage. These producers represented the three replications of the experiment confounding the effect of cultivars, as two growers provided 'Mathilda Gutges' and one grower 'Brestenburg'. Plants field-treated (pre-forced) by growers received three applications of AS with overhead irrigation at 15 g-liter⁻¹ during August and September.

In early Dec. 1990, two field-treated and control plants from each producer were removed from cold storage and divided into roots, stems, and buds. Roots were washed extensively to remove substrate particles. Samples of each plant part were air-dried at 70°C, weighed, ground to pass through a 2-mm mesh screen, and analyzed for total N by a Kjeldahl method (with copper sulfate

as the catalyst) and for Ca, Mg, Fe, Mn, Zn, and Al by flame emission or atomic absorption spectrophotometry (Varian SpectraAA-300, Varian Techtron Pty., Mulgrave, Victoria, Australia). Aluminum was measured at a wavelength of 309.3 nm in a nitrous oxide + acetylene flame. Aluminum content for each plant part was calculated by multiplying dry weight and Al concentration. Acidity (pH) and soluble salts of the substrate, expressed as electrical conductivity (EC), also were determined using the pour-through method (Yeager et al., 1983).

On 15 Jan. 1991, 45 control and five field AS-treated plants from each replicate were removed from cold storage (after a total of 9 weeks), completely randomized in groups of five plants (experimental unit), and placed in a greenhouse (week 0) on subirrigation troughs. Two weeks later, all plants were pruned leaving four shoots per plant. The control plants were subjected to one of the following nine treatments: 1) nontreated controls; 2-5) four early, and 6-9) four late applications of 4, 8, 12, or 16 g AS/pot. The early applications of AS were timed during weeks 2, 3, 4, and 5; the late ones during weeks 6, 7, 8, and 9. The late timing was completed before the sepals of the hydrangeas showed color. For each AS application (controls received no AS), each plot (five plants) was transferred from the troughs to a separate subirrigation tray containing 1 liter of solution with an AS concentration of 5, 10, 15, or 20 g-liter⁻¹, providing AS doses of 1, 2, 3, or 4 g/pot at each application for a four-application cumulative total of 4, 8, 12, or 16 g/pot, respectively. After absorbing the solution, treated plants were returned to the troughs, and all plants were subirrigated with water. On days that AS was not applied and plants required irrigation, all plants were subirrigated with a solution at the following concentration (mM): 7.8 NO₃⁻, 2.4 NH₄⁺, 1.7 K⁺, 2.4 Ca²⁺, and 0.7 Mg²⁺ with an electrical conductivity of 1.0 to 1.2 mS-cm⁻¹. The heating setpoint in the greenhouse was 18/16C (day/night) for the first 2 weeks followed by 18/18C for the remainder of the forcing period.

At flowering (full color), the degree of blueness of sepals on plants was judged by three people, and the plots were given a numerical ranking according to the purity of the blue pigmentation (lack of pink). The two uppermost expanded leaves of shoots on all plants per plot were collected, air-dried, and analyzed for nutrients as described above. Substrate samples also were taken and analyzed using the saturated medium extraction (SME) method.

Statistical analysis. After cold storage, the nutrient levels of the plants with and without field AS applications were subjected to a factorial analysis of variance (ANOVA) for each plant part separately, since the Al content of the different plant parts might be interdependent.

During the forcing stage, the experiment followed a completely randomized design with three replicates, four doses of AS per pot, and two timings, plus a common nontreated

Fig. 2. Effect of aluminum sulfate applied during greenhouse forcing on foliar Al content of florists' hydrangeas. The regression curves represent early (weeks 2, 3, 4, 5) and late (weeks 6, 7, 8, 9) applications. Data are means of three replicates of five plants (pooled). $R^2 = 0.85$, $SE_e = 71.1$, and $SE_e = 4.3$.

Table 1. Tissue analysis of various plant parts of dormant hydrangeas that were treated in the field with aluminum sulfate.

Field trt ^z Al ₂ (SO ₄) ₃	Al (ppm)	Fe (ppm)	Mn (ppm)	Percent dry matter					Dry wt (g)
				N	P	K	Ca	Mg	
<i>Root</i>									
—	1430	800*	110	2.8	0.39	2.0	0.52	0.46	18.0
+	1890	530*	124	3.7	0.39	1.8	0.44	0.40	17.6
<i>Bud</i>									
—	93***	83	78	3.2	0.39	2.1	0.92	0.32	5.6
+	453***	90	105	3.3	0.39	2.4	0.91	0.31	5.2
<i>Stem</i>									
—	77***	104	66	1.9	0.21	0.79	0.36	0.20	21.5
+	446***	144	97	2.1	0.20	0.85	0.45	0.21	23.1

^aField treatment consisted of three applications of aluminum sulfate at 15 g·liter⁻¹. No significant interaction of AS treatment by producer was evident.

***Elemental concentration of the tissue is significant at $P = 0.05$ or 0.005 , respectively. Data are averages of two plants from three producers.

control. The initial model for the various nutrient contents of the foliage was $Y_{ijk} = \mu + r_i + a_jX_j + \beta_jX_j^2 + e_{ijk}$, where Y_{ijk} = the response from the i -th timing (early and late) at AS concentration j ($j = 0, 1, 2, 3, 4$), μ represented the mean response without any AS applications, and r_i was the effect of the producer ($\approx$ cultivar). The terms a_jX_j and $\beta_jX_j^2$ represented a quadratic polynomial response, respectively, from AS dose ($X_0 = 0$, $X_1 = 4$, $X_2 = 8$, $X_3 = 12$, $X_4 = 16$), and e_{ijk} the random error term. Graphically, the model represents two curves, one for each timing, radiating from a common intercept representing plants that received no AS (Cochran and Cox, 1955). Multivariate ANOVA was used to determine the error correlation coefficient (r) between the foliar Al concentration and the blueness ranking. Micro-SAS (SAS Institute Inc., Cary, N.C.) was used for the analysis.

Preforcing. The Al concentration in the roots was similar in field-treated and corresponding nontreated plants (Table 1). However, the Al concentration in buds and stems in field-treated plants was five to six times

that of nontreated plants. The reason(s) for the lack of redistribution of Al ions to the buds or stems in the control plants, unlike in the AS-treated plants, is unclear. The substrate pH of AS-treated plants (5.1 ± 0.4) was lower than that for nontreated plants (6.0 ± 0.5) and may have influenced the redistribution of Al within the plant. The source of Al for the control plants likely was the vermiculite, perlite, baked clay, or compost in the producers' growing substrate. There appeared to be an antagonistic effect of uptake between Fe and Al, as the Fe concentration in the roots was lower in AS-treated than in nontreated plants, but there was no effect from AS treatment in Fe content in either bud or stem. The concentrations of the other elements (N, P, K, Ca, Mg, and Mn) were not affected in any of the plant parts by AS treatment (Table 1). Since the dry weight ratio of roots : buds : stems of dormant plants was $\approx 3:1:4$ (Table 1), the roots were the primary location ($\approx 70\%$) of stored Al, followed in order by stems and buds. The total amount of Al absorbed per plant was calculated to be ≈ 28 and 46 mg for

nontreated and AS-treated plants, respectively.

Forcing. Increasing the amount of AS applied during forcing to previously nontreated plants increased the blueness of the flower sepals (Fig. 1). Early treated plants were generally ranked more blue than late-treated plants (data not shown). Commercially acceptable blue plants were obtained with 12 and 16 g AS/pot applied early (1.1 and 1.4 g Al, respectively).

Foliar Al content of the flowering plants showed a quadratic response to both early and late AS applications (Fig. 2). The initial slope (linear coefficient) for the early one was steeper than that of the late one, while the curvature (quadratic coefficient) was similar for the two timings. The maximum Al concentration of the foliage was calculated to be 14.5 and 12.2 g AS/pot for early and late timing, respectively. As a consequence, the maximum Al content of leaves from the early treated plants was higher than that of the late-treated plants (1960 vs. 1250 ppm, respectively), showing a more favorable response from the early applications. The blueness of field-treated plants receiving no AS during forcing was intermediate between those receiving 4 and 8 g AS/pot of early or late applications. However, the Al concentration (1460 ppm) was slightly higher than the maximum level of the late applications. These results indicate the importance of the timing of Al availability in relation to forcing stage.

The error correlation between the blueness ranking and foliar content of Al in the leaves (data not shown) was $r = 0.74$ ($P = 0.0001$). There were also positive correlations between Al and Mn ($r = 0.71$, $P = 0.0001$) and Fe ($r = 0.52$, $P = 0.008$) in the foliage. The positive character of the latter two r values was expected, as AS applications to the substrate lower the pH, thereby increasing the availability of Mn and Fe. Similar correlations were also found between Al and Mn ($r = 0.63$, $P = 0.009$) and Al and Fe ($r = 0.84$, $P = 0.009$) on the dormant plants (data not shown).

Substrate analysis. The pH, EC, Ca, and Mg levels in the substrate at the time of flowering were affected by the rate of AS but not by the timing of its applications (data not shown). The pH decreased from 6.0 to 4.5, while EC increased from 1.5 to 3.8 mS·cm⁻¹ with increasing doses of AS. The Mg and Ca concentrations increased similarly with the EC. All changes were a direct result of the acidic reaction and salt content of AS, respectively, or an indirect result (Ca and Mg) from a higher solubility in the substrate at lower pH levels. The N, P, and K concentrations were not affected by AS applications.

The results of these experiments show that Al had been absorbed into the roots of dormant plants and partially translocated into stems and buds in plants treated with AS in the field at the time of forcing. However, roots remained the primary location of Al in dormant, field-treated plants. Commercially acceptable blue plants were obtained with

AS applications made during the early greenhouse forcing period using subirrigation. Blueing florists' hydrangeas required ≈ 12 g AS or 1.1 g Al/pot. Overhead irrigation systems would normally require higher doses, i.e., >20 g AS/1.6-liter pot due to leaching. These results provide field producers more flexibility in determining the number of plants that are to be treated with AS. Greenhouse forcers will have to apply the AS at the early stages of growth to allow uptake and redistribution of Al within the plant.

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