Soil pH Effects on Growth and Foliar Nutrient Concentrations of *Spiraea alba* Du Roi and *Spiraea tomentosa* L.

Michael V. Mickelbart¹ and Michael J. Gosney

Department of Horticulture and Landscape Architecture, Purdue University, 625 Agriculture Mall Drive, West Lafayette, IN 47907

James Camberato

Department of Agronomy, Purdue University, 915 West State St., West Lafayette, IN 47907

Kelly M. Stanton

Department of Horticulture and Landscape Architecture, Purdue University, 625 Agriculture Mall Drive, West Lafayette, IN 47907

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Abstract. The North American native plants *Spiraea alba* and *S. tomentosa* have potential as landscape plants because they are small- to medium-sized shrubs with showy flowers that persist from early to late summer. However, the cultural requirements of these species are not well documented. Both species grow in slightly acidic soils in their native habitats. The objective of this work was to determine if the growth and/or appearance of these shrubs is affected by the neutral to slightly alkaline soils common throughout the Midwest. *Spiraea alba* grown from three seed sources and *S. tomentosa* grown from a single seed source were grown for 2 years in soils of different pH. Elemental sulfur (S) was incorporated into a Drummer silty clay loam with a pH of 7.2 to bring the pH to 5.8 and 6.4 2 years after incorporation, thus establishing plots with three pH levels for assessing growth and appearance. The soil pH increased to 6.4 and 6.8 in the amended plots between Years 2 and 3 after S incorporation. Soil concentrations of exchangeable magnesium (Mg) and calcium (Ca) were lowered with added S. Height and width varied among *S. alba* from different seed sources, and height and width of all plants were reduced when grown at the highest soil pH. Leaf greenness, specific leaf weight, and individual leaf area were unaffected by pH. Leaf concentrations of nitrogen, potassium, zinc, and manganese were higher in lower soil pH, whereas Mg was lowest at the lowest soil pH. These results suggest that *S. alba* and *S. tomentosa* can be grown in neutral pH soils without an effect on plant appearance, but plant size will be less than at pH levels closer to the native soils for these species. Although some micronutrients were present at lower concentrations at the neutral pH, leaf greenness was unaffected, again suggesting that these plants may perform suitably outside of their native habitat pH range.

The native shrubs *Spiraea alba* (meadowsweet) and *S. tomentosa* (hardhack or steeplebush) grow to be 1 to 1.5 m tall with long-lasting terminal inflorescences (white and pink flowers, respectively) present throughout most of the summer. Both species are native to the eastern United States and Canada and can be found growing from Canada to the Gulf states (U.S. Department of Agriculture, 2012). *Spiraea tomentosa* was used in the landscape as early as 1736 (Symes, 1983), but today both species

are mainly used in habitat restoration. *Spiraea alba* is also attractive to arthropod natural enemies and has been suggested as an important native species for habitat management (Fielder and Landis, 2007).

Soil pH greatly affects the availability of many plant nutrients (Tinus, 1980). Zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) can become deficient at high soil pH causing chlorosis (Thomas, 1955; Tinus, 1980). *Spiraea alba* and *S. tomentosa* will be more successful as landscape plants if they can tolerate the neutral to slightly alkaline soils that are common in many urban environments in the Midwest. Urban soils can become alkaline through the exposure and incorporation of lower limestone strata during construction, the addition of construction materials such as plaster or concrete, or the use of calcium chloride as a deicer in winter (Craul and Klein, 1980; Lehmann and Stahr, 2007).

The soil pH of the natural habitat usually, but not always, is the optimum soil pH for a species (Symonds et al., 2001). *Spiraea alba*

and *S. tomentosa* are typically found in wet acidic soils (Braun, 1936; Koning, 2005; Meilleur et al., 1997). *Spiraea tomentosa* has been found in soils with a pH as low as 4 or as high as 7 but it is rare above pH 6 (Baines, 1973; Gille, 1950), and *S. alba* is found in soils below pH 6 (Girardin et al., 2001; White, 1965).

There are a number of methods for decreasing the pH of field soils (Mickelbart et al., 2012). Elemental S has been successfully used to lower soil pH provided the carbonate levels in the soil are not too high (Camberato, 1999). We used elemental S to lower the pH of field soil with a pH of ≈ 7.2 . The objective of this study was to determine if *S. alba* and *S. tomentosa* growth and appearance are affected by soil pH higher than that found in their natural range. The growth, appearance, and leaf nutrient content of *S. alba* (grown from seed of three different geographical origins) and *S. tomentosa* (grown from seed of a single geographical origin) plants grown under several soil pH levels were evaluated to determine the landscape potential of these plants.

Materials and Methods

Field plots. The experiment was conducted at the Meigs Farm of the Throckmorton Purdue Agricultural Center in Tippecanoe County, IN (lat. 40.29° N, long. 86.88° W). The soil type is Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls) with a pH of 7.2. Elemental S (90% Pastille S; Agrilience LLC, St. Paul, MN) was incorporated in Apr. 2009 to a depth of 15 cm at rates of 0.27 and 0.11 kg·m⁻² S to achieve target pH values of 6.0 and 6.5, respectively. Plots with a target pH of 7.0 were not amended with S. Plots were mulched with ≈ 8 cm pine bark. Weeds were manually removed and spot-sprayed with glyphosate. The plots were irrigated with drip tape as required to avoid water stress. Plants were fertilized in April of 2010 and 2011 with 15 g of Scotts 33-3-6 (33% N, 3% P₂O₅, 6% K₂O) field fertilizer derived from 0.6% ammoniacal nitrogen and 32.4% urea nitrogen (The Scotts Company LLC, Marysville, OH).

Plant materials. Plants grown from three *S. alba* and one *S. tomentosa* seed sources were germinated and grown in 40-cm³ plugs (Table 1). Plants were transplanted to 2-L containers in Sept. 2008 and planted in the field on 31 Aug. 2009. All plants were pruned to 20 cm at planting. Each seed source was given a unique designation: the first letter indicates species and the next two letters are the postal code for the state or province of each seed source (Table 1). Two different Michigan accessions of *S. alba* (A-MI1 and A-MI2) were grown. Seed source A-MI1 was supplied from the National Plant Germplasm System Germplasm Resources Information Network (GRIN; accession number PI 564841) and seed source A-MI2 was supplied from Wildtype Nursery (Mason, MI). Possibility Place Nursery (Monee, IL) supplied seed of *S. alba* (A-IL) and *S. tomentosa* (T-IL), both collected from Will County, IL.

Measurements. Soil samples were collected before (Oct. 2008) and 1 (July 2010)

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¹To whom reprint requests should be addressed; e-mail mickelbart@purdue.edu.

and 2 (July 2011) years after S incorporation. Each time, a soil probe (2.5 cm diameter) was used to remove nine cores 15 cm deep from between plants in each plot. The top 1 cm was removed from each core to avoid contamination from vegetative material and the cores were combined, air-dried, and ground to pass a 2-mm sieve. Soil pH was determined in a 1:1 (soil:water) slurry (Watson and Brown, 1998). Soil phosphorus (P), Ca, potassium (K), and Mg were extracted by the Mehlich 3 method (Mehlich, 1984) and measured with inductively coupled plasma atomic emission spectroscopy.

On 8 July 2011, plant height, plant width, and leaf greenness were determined and leaves were collected for measurements of leaf area (LA), specific leaf weight (SLW), and foliar nutrient concentrations. Plant height was determined as the vertical distance from the ground to the highest portion of the plant. The width of each plant was determined by averaging the north-south and east-west width. A SPAD 502 meter (Minolta, Osaka, Japan) was used to determine relative chlorophyll content of leaves (Netto et al., 2005). Measurements were made on three individual recently matured, fully expanded leaves and the mean of these measurements was recorded for each plant. Fifteen to 20 recently matured, fully expanded leaves were removed from each plant. The leaves were photographed and LA was determined from the photograph using Image J 1.38x (National Institutes of Health, Bethesda, MD). Leaves were then washed in reverse-osmosis water and dried to a constant weight at 70 °C to obtain leaf dry weight (DW). Specific leaf weight was calculated as $SLW = DW/LA$. Leaves were ground to a fine powder using a coffee grinder. Nitrogen (N) was analyzed using the Dumas combustion procedure (Simonne et al., 1994). Leaf tissue was digested with 1 mL of HNO_3 (Mallinckrodt, AR Select grade) at 110 °C for 4 h and concentrations of all other elements were quantified by inductively coupled plasma spectrometry on a PerkinElmer Elan DRc ICP-MS (PerkinElmer SCIEX, Shelton, CT).

Design and analysis. The three *S. alba* and one *S. tomentosa* ecotypes (Table 1) and three soil elemental S incorporation rates (main plots) were arranged in a split plot design on a randomized complete block with eight blocks and species/seed source randomized within each S incorporation plot. Each block contained three rates of S incorporation and each plot contained one plant of each ecotype. Each plot was 4.6 m long and 1.5 m wide and plots were separated by 2.7 m of buffer space between rows and 1.8 m between plots within a row. The data were analyzed using the PROC GLIMMIX procedure in SAS 9.1 (SAS Institute Inc., Cary, NC) with soil pH and year were considered fixed effects and block as a random effect. For soil measurements, soil pH and year were considered fixed effects and block as a random effect. Correlation analysis was performed with the PROC CORR procedure in SAS. Transformations of measured variables were used as needed to correct for variance and normality. The transformations used are given in the tables where the data are

presented. All of the values presented are averages of the untransformed data.

Results and Discussion

Sulfur was used to decrease the soil pH of plots in which *S. alba* and *S. tomentosa* were grown to determine their adaptability to pH conditions. Incorporation of elemental S into soils results in a lowering of pH as a result of the oxidation of S to H_2SO_4 by microorganisms (Lindemann et al., 1991). Plots were amended in the spring of 2008, plants were planted in the plots in late Summer 2009, and soil characteristics were determined before amendments and 1 and 2 years after planting. Organic matter (OM) did not vary over years or among pH plots and the average OM overall plots and years was 3.8%.

Incorporation of 0.27 and 0.11 $kg\cdot m^{-2}$ elemental S was effective in lowering the soil pH from an average value of 7.2 to 5.8 and 6.4, respectively, 22 months after incorporation (Fig. 1). However, 2 years after S incorporation, pH values had risen to 6.4 and 6.8, respectively (Fig. 1). Throughout the experiment, the average soil pH of the three treatments were all significantly different from each other. Incorporation of elemental S is effective for reducing pH in many soils, but the reduction may be temporary (Janzen and Bettany, 1987) as was the case in our study (Fig. 1). Reaction of acidity generated with residual calcium carbonate may explain the increase in pH over time in our study.

Soil P and K increased over the 3 years of the study but were not different among pH plots, indicating that the availability of these nutrients was not increased by S incorporation (Table 2). Seasonal fluctuations in soil test P levels are typically of low magnitude but could account for the relatively small $7\text{-mg}\cdot kg^{-1}$ increase in soil test P seen in our study in the first 2 years after S incorporation (Murdock and Call, 2006). Soil test K levels can vary substantially with time as a result of wetting and drying and freezing and thawing effects on fixation of K in the interlayer of 2:1 clays (Sparks, 2012), crop K uptake (Fernández et al., 2008), and/or return of K to the soil from crop residues (Oltmans and Mallarino, 2011), among other factors. Unfortunately, the net effects of these factors over time on soil test K are difficult to predict (Mallarino et al., 2011). The differences in soil test K in our study with time could reflect the influence of any combination of these factors.

Lindemann et al. (1991) demonstrated that although S incorporation did reduce pH, it did not result in increased availability of P. Soil pH can affect K availability by altering cation exchange capacity and the concentration of ions Ca, Mg, aluminum (Al), and hydrogen (H) competing for those cation exchange sites (Mikkelsen and Camberato, 1995). Although a decrease in pH resulted in an increased concentration of Mg and Ca, no decrease in K occurred (Table 2). Increasing acidity (lower pH) typically decreases exchangeable Mg and Ca by replacement of these basic

Table 1. Seed sources of *S. alba* and *S. tomentosa* used in this study.^z

ID	Species	Supplier	Seed collection site
A-IL	<i>S. alba</i>	Possibility Place Nursery	Will Co., IL
A-MI1	<i>S. alba</i>	NPGS	Kent Co., MI
A-MI2	<i>S. alba</i>	Wildtype Nursery	Jackson Co., MI
T-IL	<i>S. tomentosa</i>	Possibility Place Nursery	Will Co., IL

^zThe ID given to each seed source indicates species (A = *S. alba*, T = *S. tomentosa*) and the postal code of the state of each source (MI = Michigan, IL = Illinois). Plants were supplied as seed from the National Plant Germplasm System (NPGS) or as plugs from two commercial nurseries (Possibility Place and Wildtype Nursery). State and county where seed was collected are indicated (seed collection site).

Fig. 1. Change in soil pH of three pH treatments over 3 years. Symbols represent the mean of eight plots (blocks) in each year. Bars are SE. Significant differences among treatments within a year are indicated above the data points for each year (ns = nonsignificant; *** $P \leq 0.001$). The year $\times$ treatment interaction was significant ($P \leq 0.001$), indicating that soil pH changed over years. Symbols with the same upper case letter within a year and symbols with the same lower case letter within a pH treatment are not different based on Tukey's honestly significant difference test ($P \leq 0.05$). Sulfur incorporation occurred in 2009 and soil samples were collected in Oct. 2008 (before treatment initiation), July 2010, and July 2011. Plants were transplanted into plots in 2009.

cations with acidic cations (Al and H) (Darusman et al., 1991; Finn et al., 1993; McCoy and Webster, 1977; Schwab et al., 1989), although effects are not always detected (Peterson et al., 1987). Soil Ca also increased by 8.5% from 2010 to 2011, which may be the result of dissolution of residual calcium carbonate (U.S. Department of Agriculture, 1954). The value of soil Mg was 3% higher in 2011 than 2008, but there were no significant differences between the years.

Genotypic differences in growth response to soil or media pH have been documented in several woody species including *Dirca palustris* (Peterson and Graves, 2009), *Vaccinium corymbosum* (Austin and Bondari, 1992), and *Acer rubrum* (Boyce and Sydnor, 1983). The Illinois seed source of *S. alba* generally was shorter than the Michigan seed source plants (Table 2), similar to what was previously reported for these genotypes (Stanton et al., 2010a). All plants were larger when grown in lower pH soils (Table 3). There were no seed source $\times$ pH effects, suggesting that genotype growth response to changes in soil pH was similar. However, because the number of genotypes used in this experiment

was small, it is possible that variation in growth response to pH may exist in these species. Although overall growth was reduced when plants were grown at neutral pH, individual leaf size was unaffected by soil pH in either species (Table 3), suggesting that lower annual shoot extension is the reason for reduced height and width.

Leaf chlorophyll concentration or greenness is often higher when acidic soil-adapted species are grown on slightly acidic as opposed to neutral soils (Anderson and Ladiges, 1978; Peterson and Graves, 2009). *Spiraea tomentosa* has thicker, darker green leaves than *S. alba* (Table 3; Stanton et al., 2010b), but soil pH did not affect either of these traits in either species (Table 3). Leaf greenness is sometimes correlated with leaf nutrient concentrations other than N such as Ca (Fernández-Falcón et al., 2006), but in this study, it was not correlated with any differences in foliar nutrient concentrations (data not shown) although concentrations of several nutrients were different at various soil pH levels (Table 4).

Overall, the Illinois seed source of *S. alba* had lower concentrations of N, P, K, S, Mn,

and Cu than the other *S. alba* ecotypes (Table 4). Foliar N concentrations are often higher at soil or media pH below 7.0 in a wide range of species (Peterson et al., 1987; Silber et al., 2000; Smith et al., 2004), and this was true in this experiment (Table 4). Foliar P varied among species and accessions but was unaffected by soil pH, whereas foliar K was slightly lower in plants growing in amended soils (Table 4), although neither P nor K was apparently more available in the amended soils (Table 2). Despite differences in soil Ca concentrations (Table 2), foliar Ca was not different in plants growing at different pH levels (Table 4). Furthermore, there was no genetic variation for foliar Ca (Table 3). Soil Mg was only slightly higher in amended soils (Table 2) and this was reflected in slightly higher foliar Mg concentrations (Table 4). Although soil-available S was not measured, it is likely that S was available at higher concentrations to plants growing in the amended soils (Lindemann et al., 1991). However, sulfate derived from incorporation of elemental S may be depleted quickly after application as a result of leaching or immobilization (Janzen and Bettany, 1987). This may account for the fact that foliar S was not higher in any plants grown in amended soils (Table 4).

The micronutrients Fe, Mn, and Cu were all present in higher concentrations in leaves of plants growing in the S-amended soils (Table 4). This was most dramatic for leaf Mn concentrations: foliar Mn concentrations at soil pH of 6.5 and 7.0 were 41% and 14% that of Mn concentrations at pH 6.0. Foliar Mn concentrations often decline with increases in soil pH in plants adapted to acidic soils such as blueberry (Finn et al., 1993; Peterson and Graves, 2009). There were no pH $\times$ seed source interactions for leaf nutrient concentrations except for Zn (Fig. 2), indicating that all genotypes responded similarly to changes in soil pH. Foliar Zn concentrations declined with an increase in pH in A-IL and T-IL, but not in the Michigan *S. alba* seed sources (Fig. 2). We did not measure soil Zn, but S incorporation to reduce soil pH can result in increased Zn availability (Wang et al., 2006). If Zn was more available at lower soil pH, the A-MI2 genotype did not respond to this increase with higher foliar Zn concentrations as the other genotypes did (Fig. 2). There were no symptoms that suggested higher concentrations of Zn, Mn, or Cu at lower soil pH were toxic. Soil pH also did not affect the foliar concentrations of Fe, Cu, boron, or Al (Table 4).

In conclusion, plants of *S. alba* and *S. tomentosa* were generally smaller and had lower foliar concentrations of some nutrients when grown in the neutral pH soil of the experimental field site. However, leaf size and greenness did not differ with soil pH. Taken together, this suggests that these species can be grown in more neutral landscape soils typical of many parts of the Midwest. However, they may benefit from some reduction in soil pH either through incorporation of sulfur or organic material or by the use of acidic fertilizers.

Table 2. Main effect (pH and year) values for the soil properties pH and nutrient concentrations.^z

	Phosphorus (mg·kg ⁻¹)	Potassium (mg·kg ⁻¹)	Magnesium (mg·kg ⁻¹)	Calcium (mg·kg ⁻¹)
pH (P) ^y	NS	NS	*	**
Year (Y)	***	***	NS	***
P $\times$ Y	NS	NS	NS	NS
pH				
6.0	30	107	387 b	2200 b
6.5	31	111	398 ab	2260 ab
7.0	30	107	414 a	2335 a
Year				
2008	25 b	93 c ^x	392	2229 b
2010	32 a	105 b	404	2190 b
2011	33 a	126 a	403	2377 a

^zElemental sulfur was added to plots to obtain soil pH levels of 6.0, 6.5, and 7.0. Sulfur incorporation occurred in 2009 and soil samples were collected in Oct. 2008 (before treatment initiation), July 2010, and July 2011. Plants were transplanted into plots in 2009. Means are of 24 soil samples: eight blocks and 3 years for pH main effects; eight blocks and three pH levels for year main effects.

^yNS, *, **, or ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

^zMeans within each column followed by the same letter are not different at $P \leq 0.05$ based on Tukey's honestly different significance test.

Table 3. Main effect (pH and year) values for plant growth (height and width) and leaf greenness (SPAD), specific leaf weight (SLW), and individual leaf area (LA).^z

	Ht (cm)	Width (cm)	SPAD	SLW (mg·cm ⁻²)	LA (cm ⁻²)
pH (P) ^y	***	***	NS	NS	NS
Seed source (S)	***	***	***	***	***
P $\times$ S	NS	NS	NS	NS	NS
pH					
6.0	88.0 a ^x	61.0 a	34.6	7.07	4.39
6.5	87.3 a	51.5 a	35.6	7.42	4.02
7.0	74.0 b	39.9 b	33.9	7.37	3.60
Seed source					
A-IL	66.4 c	59.3 a	31.5 b	7.58 b	3.96 ab
A-MI1	94.1 b	43.9 b	32.6 b	6.16 d	3.32 b
A-MI2	110.7 a	62.8 a	33.5 b	6.76 c	4.02 ab
T-IL	61.2 c	37.2 b	41.1 a	8.66 a	4.72 a

^zElemental sulfur was added to plots to obtain soil pH levels of 6.0, 6.5, and 7.0. Sulfur incorporation occurred in 2009 and soil samples were collected in Oct. 2008 (before treatment initiation), July 2010, and July 2011. Plants were transplanted into plots in 2009. Values are the averages of eight blocks and four seed sources (n = 32) for pH or eight blocks and three pH levels (n = 24) for seed source main effect.

^yNS, *, **, or ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

^zMeans within each column followed by the same letter are not different at $P \leq 0.05$ based on Tukey's honestly different significance test.

Table 4. Leaf nutrient concentrations of *Spiraea alba* (A-IL, A-MI1, and A-MI2) and *Spiraea tomentosa* after 2 years growing in field soils of pH 6.0, 6.5, or 7.0.^z

	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Manganese ^y	Iron	Copper	Boron	Aluminum
	(mg·g ⁻¹)						(μg·g ⁻¹)				
pH (P)	***	NS	**	NS	**	NS	***	NS	*	NS	NS
Seed source (S)	***	***	***	NS	NS	***	**	***	***	***	***
P × S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
pH											
6.0	2.05 a ^w	0.41	1.03 a	0.93	0.15 b	0.15	364 a	72	7.3	23	29
6.5	1.95 ab	0.46	1.03 a	0.91	0.17 ab	0.15	150 b	68	7.2	24	25
7.0	1.89 b	0.41	0.92 b	0.91	0.19 a	0.14	51 c	66	6.6	22	30
Seed source											
A-IL	1.75 b	0.32 c	0.93 b	0.94	0.17	0.14 b	132 b	60 b	5.3 c	24 a	25 b
A-MI1	2.14 a	0.46 ab	1.13 a	0.93	0.17	0.16 a	211 a	63 ab	7.3 b	25 a	22 b
A-MI2	2.12 a	0.51 a	1.08 a	0.93	0.18	0.16 a	207 a	73 a	7.0 b	25 a	29 ab
T-IL	1.82 b	0.42 b	0.83 b	0.87	0.16	0.13 b	204 ab	76 a	8.5 a	18 b	37 a

^zElemental sulfur was added to plots in spring of 2009 to obtain soil pH levels of 6.0, 6.5, and 7.0, plants were transplanted into plots in 2009, and leaves were sampled in July 2011. Values are the averages of eight blocks and four seed sources (n = 32) for pH or eight blocks and three pH levels (n = 24) for seed source main effect.

^yLog values were analyzed to correct for non-normal distribution of data.

^{*}NS, *, **, or ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

^wMeans within each column followed by the same letter are not different at $P \leq 0.05$ based on Tukey's honestly different significance test.

Fig. 2. Foliar zinc (Zn) concentration of *Spiraea alba* (A-IL, A-MI1, and A-MI2) and *S. tomentosa* (T-IL) plants in July after 2 years growth in soils with pH levels of 6.0, 6.5, or 7.0. Sulfur incorporation occurred in Spring 2009 and soil samples were collected in Oct. 2008 (before treatment initiation), July 2010, and July 2011. Plants were transplanted into plots in 2009. Columns are the means of eight blocks and bars represent SEM.

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