



This Journal of Environmental Horticulture article is reproduced with the consent of the Horticultural Research Institute (HRI – www.hriresearch.org), which was established in 1962 as the research and development affiliate of the American Nursery & Landscape Association (ANLA – <http://www.anla.org>).

HRI's Mission:

To direct, fund, promote and communicate horticultural research, which increases the quality and value of ornamental plants, improves the productivity and profitability of the nursery and landscape industry, and protects and enhances the environment.

The use of any trade name in this article does not imply an endorsement of the equipment, product or process named, nor any criticism of any similar products that are not mentioned.

Research Reports

Substrate pH Suppression Using Incorporated Sulfur-based Compounds in Nursery Container Production¹

Chad P. Giblin and Jeffrey H. Gillman²

University of Minnesota
Department of Horticultural Science
St. Paul, MN 55108

Abstract

Container production of ericaceous plants requires maintenance of a long-term substrate pH of 4.0 to 5.5. The objective of the study was to examine the effects of incorporated elemental sulfur, ferrous sulfate, and aluminum sulfate on long-term pH suppression in an acidic container substrate irrigated with highly alkaline water. 'Northcountry' blueberry liners were planted into a peat/pine bark based container substrate containing one of six different commercial amendments for pH reduction at three different rates of actual sulfur: 0.89 kg S/m³ (1.5 lb S/yd³), 1.78 kg S/m³ (3 lb S/yd³), and 2.67 kg S/m³ (4.5 lb S/yd³). After fourteen weeks, only one elemental sulfur treatment had a substrate pH significantly lower than untreated substrate pH. Elemental sulfur particle size played a role in ability to control substrate pH.

Index words: acidification, alkalinity, aluminum sulfate, container media, ferrous sulfate, substrate, sulfur, *Vaccinium*.

Species used in this study: *Vaccinium* x 'Northcountry' L.

Significance to the Nursery Industry

Maintenance of a low pH in container substrates is a concern for many nursery growers throughout the country. Nursery crops such as *Vaccinium* spp., *Rhododendron* spp., and *Hydrangea* spp. are often finished as container stock and require a low substrate pH for optimal growth. In the Upper Midwest container stock is often irrigated with water having a pH of 7.5 or greater and high levels of total carbonates which can result in increases in container substrate pH. Any

amendments that could offer long-term pH suppression, at a low cost, would be of significant importance to the nursery industry in the production of ericaceous nursery crops.

Introduction

The use of elemental sulfur and other soluble sulfur products to acidify soil in field production of blueberries has been well established (2, 8, 11). Similarly, in container production of blueberries, nursery growers require a low substrate pH with minimum inputs. Numerous studies have examined the effects of aluminum sulfate, ferrous sulfate, and wettable sulfur products on container substrates (3, 5, 6, 7, 12). Others have examined the effects of top-dressed elemental and sulfate materials (12). Few studies, however, have focused on incorporated elemental sulfur and sulfate compounds

¹Received for publication January 21, 2005; in revised form March 12, 2006. Minnesota Experiment Station #041210140. This research was funded in part by Bailey Nurseries, Inc. and the Minnesota Nursery and Landscape Association.

²Horticultural Research Scientist and Associate Professor, respectively.

Copyright 2006
Horticultural Research Institute
1000 Vermont Avenue, NW, Suite 300
Washington, DC 20005

Reprints and quotations of portions of this publication are permitted on condition that full credit be given to both the HRI *Journal* and the author(s), and that the date of publication be stated. The Horticultural Research Institute is not responsible for statements and opinions printed in the *Journal of Environmental Horticulture*; they represent the views of the authors or persons to whom they are credited and are not binding on the Institute as a whole.

Where trade names, proprietary products, or specific equipment is mentioned, no discrimination is intended, nor is any endorsement, guarantee or warranty implied by the researcher(s) or their respective employer or the Horticultural Research Institute.

The *Journal of Environmental Horticulture* (ISSN 0738-2898) is published quarterly in March, June, September, and December by the Horticultural Research Institute, 1000 Vermont Avenue, NW, Suite 300, Washington, DC 20005. Subscription rate is \$65.00 per year for scientists, educators and ANLA members; \$95.00 per year for libraries and all others; add \$25.00 for international (including Canada and Mexico) orders. Periodical postage paid at Washington, DC, and at additional mailing offices. POSTMASTER: Send address changes to *Journal of Environmental Horticulture*, 1000 Vermont Avenue, NW, Suite 300, Washington, DC 20005.

which may offer long-term acidification of container substrate with a one-time application at potting.

One potential benefit from the addition of a sulfur product is maintaining a low substrate pH. Blueberries and other ericaceous crops require a pH between 4.0 and 5.5 for optimal growth (3, 7, 11, 17). In the Upper Midwest, container nursery stock is often irrigated with well water having both high pH (>7.0) and large amounts of total carbonates (alkalinity or 'hardness'). This often results in substrate pH values rising above a target range of 4.0 to 5.5 within two months in container production (9, 14). Consequently, acid injection or repeated applications of an acidifying product are usually necessary to keep pH from rising to an unacceptable level over time (1, 13). Little research has explored the effects of incorporated sulfate and elemental sulfur materials on pH in a highly organic container substrate. Peterson *et al.* (11) found that blueberry growth in soil was significantly increased with the addition of sulfur products. This work, however, made use of a soil that was already considered unsuitable for blueberry production due to the addition of limestone. Most previous work has focused on the effects of sulfur and/or sulfate materials on substrates that already have a high pH.

The objective of this study was to critically examine the use of a one-time incorporation of various sulfur sources for season-long substrate pH suppression.

Materials and Methods

A growth substrate developed by a local nursery grower for use specifically with ericaceous plants was used as the base substrate in this study. The composition of this substrate was: 25% reed-sedge peat, 25% sphagnum peat, 30% composted red pine (*Pinus resinosa*) bark, and 20% composted plant materials amended with a complete, controlled-release fertilizer 18N–2P–10K (Harrell's 18–6–12, Pursell Technologies, Inc., Sylacauga, AL) at a rate of 5.93 kg/m³ (10 lb/yard³).

Six sulfur compounds were evaluated for their effectiveness at maintaining a low substrate pH:

- 1) prilled elemental sulfur (90% S) (Yellowstone Sulfur Granules, Montana Sulfur Co., Billings, MT)
- 2) flaked elemental sulfur (99.9% S) (Yellowstone High-Purity Flaked Sulfur, Montana Sulfur Co., Billings, MT)
- 3) ground elemental sulfur (90% S) (Agri-Sul, Caldwell Computer Corporation, Dallas, TX)
- 4) ground elemental sulfur (88% S) (Sol-U-Sul, National Sulfur Co., Midland, TX)
- 5) ferrous sulfate (25% S) (Iron-Sul, Duval Sales Co., Houston, TX)
- 6) aluminum sulfate (21% S) (Delta Corporation, Baltimore, MD).

These six sulfur compounds were manually incorporated into the base substrate prior to potting at three different rates of sulfur content (0.89 kg S/m³ (1.5 lb S/yard³), 1.78 kg S/m³ (3 lb S/yard³), and 2.67 kg S/m³ (4.5 lb. S/yard³), in a factorial arrangement (six products at three different rates) in a randomized complete block design. Twelve replications of untreated substrate were also randomized within the experiment to track temporal change in untreated substrate pH as affected by irrigation water.

All elemental sulfur products were sifted using a SS SandShaker mechanical sieve (Keck Instruments, Inc., Williamston, MI) to determine percentage and size of the various sulfur particles in each formulation (Table 1).

Twelve uniform *Vaccinium* x 'Northcountry' liners were randomly assigned to each treatment and rate combination and untreated substrate replications and planted into #1 nursery containers 16 cm wide × 17.5 cm tall (6.30 in wide × 6.89 in tall) (Nursery Supplies Inc., Chambersburg, PA) on June 19, 2002. Plants were irrigated using a drip irrigation system on an automatic timer set to deliver approximately 600mL (20 fl oz) of water two times daily every other day. Irrigation volume was decreased and frequency was increased on July 11, 2002, to deliver approximately 500 mL (17 fl oz) two times a day until the conclusion of the experiment. Beginning on July 17, 2002, irrigation water was collected every two weeks and analyzed for pH and total carbonates (CaCO₃ mg/liter).

Prior to containerization, five substrate samples from each treatment were collected for initial substrate pH analysis. Substrate samples were also collected bi-weekly to track changes in substrate pH as affected by the treatments. Final substrate samples from each container were collected on September 25, 2002. All substrate samples consisted of a 20 mm × 175 mm (0.79 in × 6.89 in) column representing the entire height of substrate in the container. Substrate pH was measured using a 1:1 v:v water extraction method using deionized water as the extractant (18) and measured in the supernatant as described by Elliott (6) and Thomas (16) using an Orion 290A meter and Orion model 9107BN gel filled pH electrode (Thermo Orion, Beverly, MA).

Dry shoot and root mass were measured to evaluate the effects of the different treatments on biomass production and root:shoot ratio. After fourteen weeks, shoots were removed at the soil line and the roots were washed of substrate to determine dry weight. Plants were dried at 60C (140F) for a minimum of 21 days before weighing. A final substrate sample was collected from each replicate to measure the level of soluble salts (EC) using a 3:1 v:v extraction with deionized water. Soluble salts were measured using an Agri-Meter

Table 1. Particle size distribution of elemental sulfur formulations based on percentage of total mass collected at each of nine screen sizes.

Sulfur formulation	Mesh opening (mm)								
	2.46	1.83	1.02	0.76	0.66	0.38	0.23	0.15	< 0.15
	(%)								
Prilled – 90% Sulfur	99.44 ^a	0.13	0.2	0.14	0	0	0	0	0
Flaked – 99.9% Sulfur	53.91	20.29	20.2	4.07	0.3	0.25	0.1	0.08	0.13
Ground – 90% Sulfur	32.61	26.25	26.63	11.96	1.36	0.81	0.08	0	0
Ground – 88% Sulfur	16.64	19.41	29.7	16.83	4.82	7.83	1.67	0.74	0.87

^aElemental sulfur compounds were collected at various sized mesh screens after shaking through Keck SS Sandshaker mechanical hand sieve.

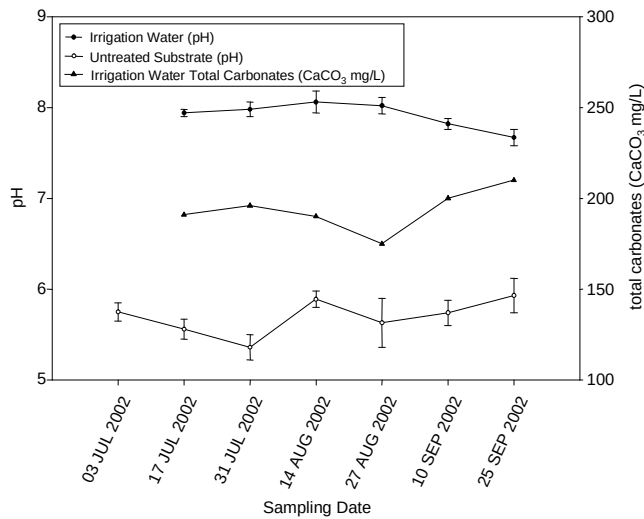


Fig. 1. Mean substrate pH of container grown 'Northcountry' blueberry and irrigation water pH and total carbonates sampled and tested every 2 weeks over a 14-week period. pH values are based on averages on each sampling date for irrigation water ($n = 4$) and untreated substrate ($n = 12$). Error bars indicate standard error (SEM).

(Myron L Co., Carlsbad, CA) to determine electrical conductivity in deciSiemens/meter (dS/m).

Descriptive statistics, univariate analysis of variance, and significant differences in substrate pH, substrate soluble salts, and dry mass between treatments were determined using the general linear model function of SPSS (19). Data recorded in pH units collected from irrigation water, untreated substrate, and all treatments were transformed prior to statistical analysis using the equation $x = 10^{-\text{pH}}$. Untransformed pH data from treated substrate were compared to untransformed

pH data from the untreated substrate using Dunnett's t-test function in SPSS with a levels of significance at $P = 0.05$ and $P = 0.01$ (19). After statistical analysis, data was transformed back into pH units for reporting using the equation $\text{pH} = -\log(x)$.

Results and Discussion

All plants survived for the duration of the experiment and did not exhibit any foliar symptoms indicating a nutrient deficiency. The lack of chlorosis or other pH related foliar symptoms would suggest that high pH stress had not occurred.

The irrigation water used for this study was considered generally unsuitable for nursery production. Water pH values ranged from 7.67 to 8.06 and total carbonates ranged from 175 to 210 mg/liter CaCO_3 over the course of the study (Fig. 1). Bailey *et al.* (1) and Robbins and Evans (13) suggest keeping irrigation water pH between 5.5 and 7.0 and total carbonates less than 100 mg/liter CaCO_3 for general nursery production.

After fourteen weeks, substrate soluble salts varied significantly depending on treatment (Table 2). Prilled elemental sulfur, ground elemental sulfur (90% S), and ground elemental sulfur (88% S) treatments all at the two highest rates had significantly higher soluble salts than untreated substrate at the end of the experiment (Table 2). Swanson *et al.* (15) suggest keeping soluble salts for water extraction below 1.00 dS/m for salt-sensitive plants. In these treatments, soluble salts ranged from 0.41 to 0.66 dS/m over that recommendation. However, there were no observed symptoms of excessive salt buildup over the course of this study.

Mean dry shoot and root mass and root:shoot ratio in treated plants did not differ significantly from untreated plants (Table 2).

There was significant interaction between treatment and rate in initial mean substrate pH at $P = 0.05$. Aluminum sulfate and ferrous sulfate treatments at the high rate (2.69 kg S/

Table 2. Mean initial substrate pH, final substrate soluble salts (EC), final shoot and root dry weights, and final root:shoot ratio in 'Northcountry' blueberry after 14 weeks as affected by various incorporated sulfur treatments.

Treatment	Sulfur content	Rate	Initial substrate pH	Final substrate Ec	Final shoot dry weight	Final root dry weight	Final root:shoot ratio
	(%)						
Prilled Elemental Sulfur	90	0.89	4.37 ^z	1.24	30.49	25.71	0.8877
Prilled Elemental Sulfur	90	1.78	4.68	1.44**	31.87	34.66	1.1295
Prilled Elemental Sulfur	90	2.67	4.69	1.56**	27.14	20.57	0.7665
Flaked Elemental Sulfur	99.9	0.89	4.59	1.01	29.35	20.92	0.7134
Flaked Elemental Sulfur	99.9	1.78	4.48	1.22	26.23	19.64	0.7355
Flaked Elemental Sulfur	99.9	2.67	4.46	1.08	28.49	28.97	1.0216
Ground Elemental Sulfur	90	0.89	4.52	0.83	30.72	23.69	0.7732
Ground Elemental Sulfur	90	1.78	4.53	1.41**	26.16	23.86	1.0136
Ground Elemental Sulfur	90	2.67	4.24	1.66**	30.37	27.06	0.9547
Ground Elemental Sulfur	88	0.89	4.54	1.12	28.49	22.12	0.7996
Ground Elemental Sulfur	88	1.78	4.37	1.52**	27.20	26.63	1.0188
Ground Elemental Sulfur	88	2.67	4.27	1.66**	28.00	27.58	1.0377
Iron Sulfate	25	0.89	4.31	0.80	30.45	33.51	1.1175
Iron Sulfate	25	1.78	4.41	1.07	28.52	35.62	1.3060
Iron Sulfate	25	2.67	3.98**	1.04	26.71	24.43	0.8749
Aluminum Sulfate	21	0.89	4.16	0.55	25.54	28.60	1.0373
Aluminum Sulfate	21	1.78	4.19	0.65	31.71	32.82	1.0604
Aluminum Sulfate	21	2.67	3.97**	0.59	28.41	24.86	0.9263

^zMean separations in columns by Dunnett's t-test at $P = 0.05$ (*) or $P = 0.01$ (**) indicating treatments that resulted in mean value that is significantly different from untreated substrate mean value.

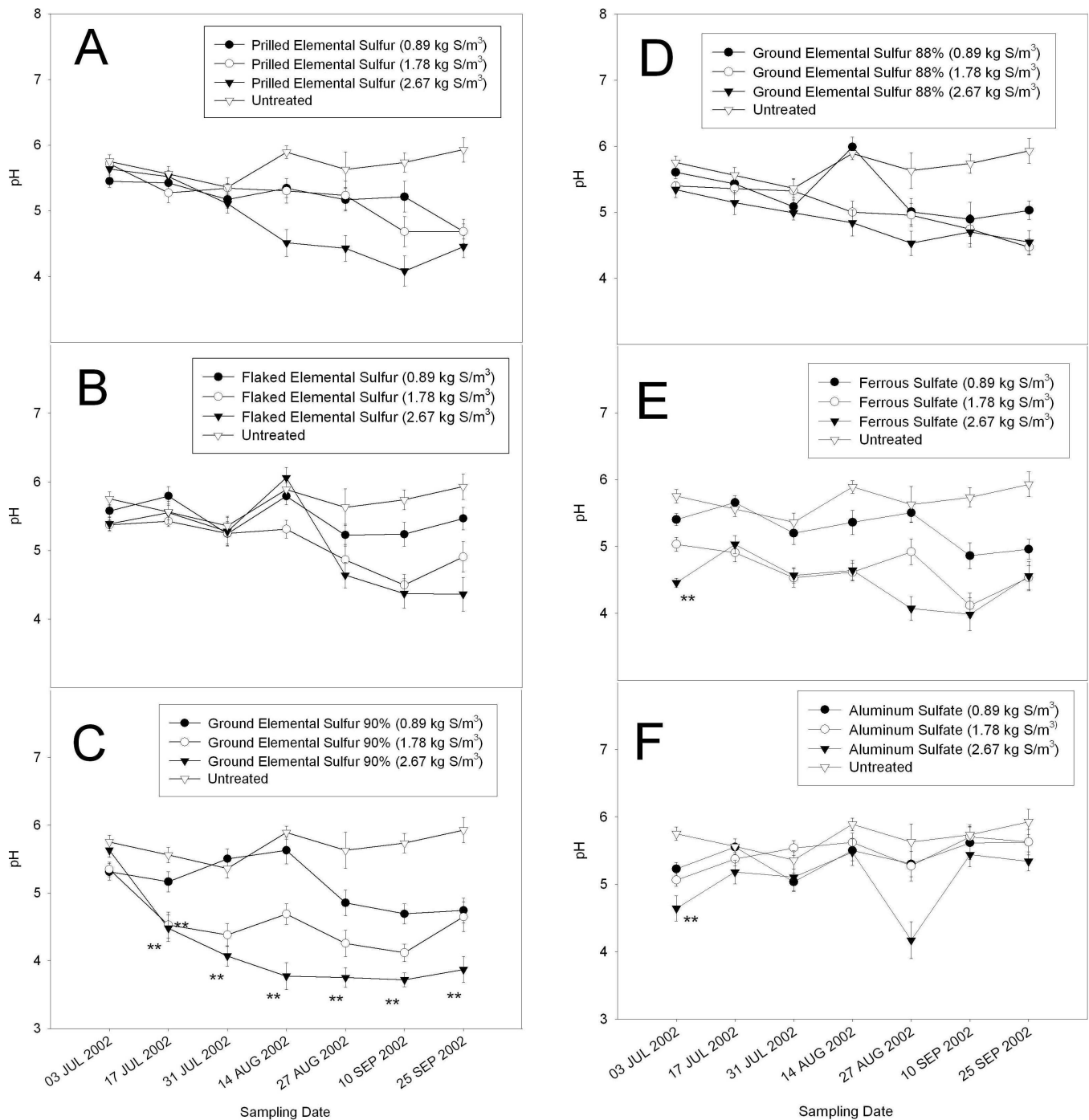


Fig. 2. Mean substrate pH of container grown 'Northcountry' blueberry treated with six different sulfur-based compounds at three different rates. Substrate samples were collected every 2 weeks over a 14-week period. Mean separations within dates by Dunnett's t-test at $P = 0.05$ (*) or $P = 0.01$ (**) indicating treatments that resulted in substrate pH that is significantly different from untreated substrate pH. Error bars indicate standard error (SEM).

m³) had significantly lower initial substrate pH than untreated substrate pH, remaining significantly lower until July 17, 2002. Initial pH was not significantly different from untreated substrate pH in any of the other treatments (Table 2). Poor initial suppression of substrate pH in the elemental sulfur treatments may have been due to a lack of small sulfur particles (Table 1), allowing the highly alkaline irrigation water to cause initial increases in substrate pH. Beverly and Anderson (4) and Janzen and Bettany (8) both noted that smaller sulfur particle sizes increased the overall surface area of reactivity for oxidation in elemental sulfur amendments. As

the experiment progressed, the elemental sulfur compounds were most likely slowly oxidized, thus suppressing substrate pH increases more effectively while ferrous sulfate and aluminum sulfate treatments were fully solubilized and ineffective in suppressing substrate pH for extended periods of time (Table 2). This trend was noted in substrate pH samples collected on July 3, 2002, two weeks after starting the experiment, where substrate pH in all elemental sulfur treatments had risen to a pH range of 5.40 to 5.80 (Figs. 2A to 2D). Conversely, substrate pH in ferrous sulfate and aluminum sulfate treatments, especially at the two highest sulfur rates

(1.78 kg S/m³ and 2.67 kg S/m³) had risen only slightly, ranging from pH 4.40 to 5.30 (Figs. 2E and 2F). From July 3, 2002, until experiment termination on September 25, 2002, elemental sulfur treatments at the two highest sulfur rates (1.78 kg S/m³ and 2.67 kg S/m³) showed a steady drop in substrate pH. Elemental sulfur treatments at the lowest rate (0.89 kg S/m³) offered some substrate pH suppression but not to the extent offered by the two higher rates. Beginning on July 17, 2002, the ground elemental sulfur treatment (90% S) at the highest rate (2.67 kg S/m³) had a significantly lower substrate pH than untreated substrate pH until the end of the experiment. Substrate pH in ferrous sulfate treatments held relatively stable or rose just slightly throughout the experiment (Fig. 2E). Aluminum sulfate treatments showed a general rise in substrate pH (Fig. 2F).

At termination of the experiment, tests of between-subject effects showed that there was still an interaction between treatment and rate at $P = 0.05$. Untreated substrate pH had increased about 1.75 units to 5.93 (Fig. 1). All treatments except the aluminum sulfate treatment at the two lowest rates had a mean substrate pH that fell within the acceptable range (pH 4.0 to 5.5) as described by Hall *et al.* (7), and Townsend (17). One of the ground elemental sulfur treatments (90% S) at the highest rate had a final substrate pH of 3.87, slightly lower than the acceptable range. This was also the only treatment that had a substrate pH significantly lower than untreated substrate at the end of the experiment (Table 2). Ferrous sulfate and aluminum sulfate treatments, while having good initial substrate pH depression, offered no long-term substrate pH control (Table 2).

Lindeman *et al.* (10) state that many commercial formulations of elemental sulfur may contain wetting agents which may be toxic to the *Thiobacillus* spp organisms responsible for sulfur oxidation. The prilled and flaked sulfur products, both from the same company, may have contained such a wetting agent which could explain why those treatments weren't as able to suppress substrate pH as effectively as the two ground elemental sulfur treatments

Additionally, as stated above, variation in sulfur particle size in the elemental sulfur treatments may explain differences in ability to suppress a rise in substrate pH in some treatments. Both prilled and flaked elemental treatments had approximately 99 and 74%, respectively, of their sulfur particle sizes at 1.83 mm or larger. These large sizes may not have had enough surface area to be effectively oxidized. Conversely, the 90% S and 88% S ground sulfur treatments had a broader range of particle sizes, with only 60 and 35% of their sulfur particles at sizes, respectively, at 1.83 mm or larger. The smaller sized particles with more overall surface area may have been more effectively oxidized, thus suppressing a rise in substrate pH.

Another factor affecting pH suppression may be high levels of total carbonates in the irrigation water. A noticeable drop in total carbonates occurred on August 27, 2002, where CaCO₃ levels dropped from 190 mg/liter to 175 mg/liter. Media samples collected from several treatments on this date show response to this drop. Mean substrate pH in both aluminum sulfate and flaked elemental sulfur treatments at the highest rate (2.67 kg S/m³) dropped 1.25 pH units. After two weeks the aluminum sulfate had risen back to its previous level while the flaked elemental sulfur treatment remained suppressed until the termination of the study. Similarly, ferrous sulfate treatments at the high rate (2.67 kg S/m³) and

ground elemental sulfur treatments (88% S) at the low rate (0.89 kg S/m³) showed a drop in mean substrate pH of over 0.5 units. After four weeks, substrate pH in the ferrous sulfate treatment rose back to its previous level, while the ground sulfur treatment remained suppressed until the end of the study. Other treatments showed a slight response to this change in total carbonates, but not nearly as dramatic as the four cases mentioned above.

Implementation of container production schedules using sulfur products for substrate pH control will require testing on the growers' part as substrate components, fertilizer, and irrigation water from will vary from site to site. Additionally, checking elemental sulfur particle size for distribution and consistency will be essential for reliable results.

Literature Cited

1. Bailey, D., T. Bilderback, and D. Bir. 1999. Water considerations for container production of plants. Horticulture Information Leaflet 557, North Carolina Cooperative Extension Service, North Carolina State University.
2. Bailey, J.S. and J.N. Everson. 1937. Further observations on a chlorosis of the cultivated blueberry. Proc. Amer. Soc. Hort. Sci. 35:495–496.
3. Bennett S.M. and J.C. Peterson. 1989. The effect of pH on sulfate availability in sphagnum peat. Commun. Soil Sci. Plant Anal. 20:1769–1776.
4. Beverly, R.B. and D.L. Anderson. 1987. Effects of acid source on soil pH. Soil Science 143:301–303.
5. Bishko, A.J., P.R. Fisher, and W.R. Argo. 2003. The pH-response of a peat-based medium to application of acid-reaction chemicals. HortSci. 38:26–31.
6. Elliott, G.C. 1996. pH management of container media. Commun. Soil Sci. Plant Anal. 27:635–649.
7. Hall, I.V., L.E. Alders, and L.R. Townsend. 1964. The effects of soil pH on the mineral composition and growth of lowbush blueberry. Can. J. Plant. Sci. 44:433–438.
8. Janzen, H.H. and J.R. Bettany. 1987. Oxidation of elemental sulfur under field conditions in central Saskatchewan. Can. J. Soil Sci. 67:609–618.
9. Kidder, G., M.J. Holsinger, and T.H. Yeager. 1990. Lowering of calcareous soil pH in field-grow containers. J. Environ. Hort. 8:1–4.
10. Lindemann, W.C., J.J. Aburto, W.M. Haffner, and A.A. Bono. 1991. Effect of sulfur source on sulfur oxidation. Soil Sci. Soc. Am. J. 55:85–90.
11. Peterson, D.V., C.A. Mullins, D.A. Lietzke, and D.E. Deyton. 1987. Effects of soil-applied elemental sulfur, aluminum sulfate, and sawdust on growth of Rabbiteye blueberries. J. Amer. Soc. Hort. Sci. 112:612–616.
12. Rathier, T.M. 1984. Various sulfur sources differ in their effects on media pH levels. Am. Nurseryman 159(5):39–44.
13. Robbins, J.A. and M.R. Evans. 2005. Growing media for container production in a greenhouse or nursery part II (physical and chemical properties). FSA-6098 Greenhouse and Nursery Series, Cooperative Extension Service, University of Arkansas.
14. Rosen, C.J., P.M. Bierman, and R.D. Eliason. 1998. Soil test interpretations and fertilizer management for lawns, turf, gardens, and landscape plants, University of Minnesota Extension Bulletin BU-01731.
15. Swanson, B.T., C. Rosen, R. Munter, C. Lane. 1985. Soil testing and fertilizer applications for nursery management and production. AG-BU-2830 Agricultural Extension Service, University of Minnesota.
16. Thomas, G.W. 1996. Soil pH and soil acidity. Methods of soil analysis. Part 3. Chemical Methods-SSSA Book Series no. 5.
17. Townsend, L.R. 1971. Effect of acidity on Growth and nutrient composition of the highbush blueberry. Can. J. Plant. Sci. 51:385–390.
18. Watson, M.E. and J.R. Brown. 1998. Recommended soil test procedures for the north central region. Missouri Agricultural Experiment Station SB 1001.
19. SPSS Inc. 1997. Statistical Product and Service Solutions User's Guide, SPSS base 7.5 for Windows. SPSS Inc. Chicago, IL.