Use of Sulfur to Correct Soil pH[1]

Donald H. Bickeihaupt[2]

Bickelhaupt, Donald H. 1987. Use of Sulfur to Correct Soil pH. In: Landis, T.D., technical coordinator. Proceedings, Intermountain Forest Nursery Association; 1987 August 10-14; Oklahoma City, OK. General Technical Report RM-151. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 58-65. Available at: http://www.fcnanet.org/proceedings/1987/bickelhaupt.pdf

Abstract.-- The addition of 1780 lbs/ac of sulfur plus 1780 lbs/ac of sulfur as sulfuric acid resulted in a temporary decrease in soil pH. Seedling quality variables of Norway spruce were related to soil pH at time of sowing.

INTRODUCTION

The New York State Department of Environmental Conservation's Saratoga Tree Nursery, located at Saratoga Springs, New York, currently produces four to five million bareroot conifer seedlings annually (Scholtes 1985). The 100 acre nursery is located on deep loamy sand (80 to 90% sand with 5 to 10% clay). In the past 10 years the nursery has experienced problems in producing high quality seedlings of some species in some sections of the nursery. Problems encountered are poor seed germination, early seedling survival and many of the seedlings grown were stunted and chlorotic (Plumley 1986).

Between 1973 and 1977, the problem areas had received two to 12 inches of composted horse manure, including barn sweeping. This organic material was applied to the sandy soil to improve cation exchange, moisture holding capacity, and the amount of available nutrients. Laboratory analysis of several samples of material applied in 1973 indicated that the pH of the material was 8.16. Elemental analysis indicated that the material was very heterogeneous. Calcium and magnesium concentrations averaged 3.6% and 1.7%, respectively. The concentrations of nitrogen, phosphorus and potassium were 0.8%, 0.2% and 0.7%, respectively. The high pH, and high concentration of calcium and magnesium were the results of lime being sprinkled daily on the floors of the stables to control the odor of urine.

A single, six inch application of composted horse manure in 1974, to one section of the nursery, increased the soil organic matter from 5.0% to 8.0% during the three years following application. The organic matter concentration had returned to approximately pre-treatment level by 1982. Soil pH increased from 5.7 to 7.2 as a result of the single, six inch application of manure. Soil pH was 7.0 twelve years after applying manure.

Soil pH above the recommended range of 5.5 to 6.0 is a concern for nursery managers because of potential problems with damping-off and nutrient imbalance. Damping-off is favored in cool and wet, neutral to basic soils containing large amounts of organic matter (Manion 1981). Nutrients, such as potassium and ammonium, become fixed in soils with a high pH and are, therefore, unavailable to plants. However, phosphorus availability is greatest when soil pH is between 6.0 and 7.0. Solubility of micronutrients increases with acidity and become toxic when soil pH is too low (Tinus 1980). Therefore, soil pH should be maintained within the range where nutrients are available for plant growth but the micronutrients are not at toxic levels.

Some conifer species are intolerant to soil pH above 6.0. Mean total dry

[1]Paper presented at the Intermountain Forest Nursery Association 1987 Annual Meeting. Park Suite Hotel, Oklahoma City, OK. August 10-14, 1987.

[2]Donald H. Bickelhaupt is a Research Assistant, SUNY College of Environmental Science and Forestry Syracuse, New York 13210

weight of red pine (Pinus resinosa Ait.) has been shown to decrease as soil pH increased from 5.4 to 7.8 (Armson and Sadreika 1979). The weight of shoots and roots of greenhouse grown Douglas fir (Pseudotsuga menziesii (Mirb.) Franco), was greatest when soil pH was 5.5 (van den Driessche 1979). Height growth of Norway spruce (Picea abies (L.) Karst.) has been shown to be related to soil pH with the tallest seedlings being produced in soil with a pH of 4.5 (Benzian 1965). Soil pH must be maintained within the recommended range of the species to produce an adequate number of high quality seedlings per unit area.

Use of Sulfur to Reduce Soil pH

The amount of sulfur required to reduce soil pH to a certain value varies with initial pH and the amount of colloidal material in the soil. In general, an application of 500 lbs/ac of granular sulfur is expected to decrease soil pH by 0.5 units in the surface six inches of sandy nursery soils (White et al. 1980). To change soil pH from 7.5 to 6.5, the Western Fertilizer Handbook (1980) recommends the addition of 500, 800 and 1000 lbs/ac of sulfur to a sandy, loam and clay soil, respectively. Stoeckeler and Arneman (1960) suggested that 870 lbs/ac of sulfur would be needed to lower the pH of a silt loam soil from 7.0 to 6.0 and 1525 lbs/ac of sulfur would be required to lower the soil pH from 7.0 to 5.5. To prevent detrimental effects to seedlings, the application of sulfur to a sandy nursery soil should not exceed 750 lbs/ac (Armson and Sadreika 1979).

Sulfuric acid has been shown to be more effective than granular sulfur in reducing soil pH but the results are not permanent (van den Driessche 1969). In contrast, sulfur reacts slowly with the soil to reduce soil pH but the change is considered permanent (Tinus 1980). Utilizing this information, a study was established in the problem areas at the Saratoga Tree Nursery in an attempt to reduce soil pH and improve seedling quality. The application of a combination of sulfuric acid and granular sulfur was considered as a possible method to quickly reduce soil pH and maintain the soil pH between 5.5 and 6.0.

METHODS

Study plots had received a single six inch application of composted horse manure in 1974. The soil pH increased from 5.7 to 7.2 and remained above 6.9 until 1983 as a result of this single application (Table 1). In addition, the application of composted manure increased the level of organic matter to over 8% and the concentration of exchangeable calcium was as high as 2500 ppm. In 1983 the organic matter concentration had decreased to 4.5%, whereas the concentration of exchangeable calcium remained high (1900 ppm). The cation exchange capacity was 10.2 meq per 100 g and the base saturation was 114% in 1983.

A single application of granular sulfur was applied at the rate of 0, 890, 1780, 2670 and 3560 lbs/ac in October 1984. During the same period, concentrated sulfuric acid was applied at the rate of 890 and 1780 lbs/ac of

Table 1. Effects of applying six inches of composted lime-treated horse manure on soil properties at the Saratoga Tree Nursery, New York.

Year	pH	OM	N	P	K	Ca	Mg
		---- % ----		------------- ppm ------------			
1974[1]	5.7	3.6	0.06	83	28	396	31
1975	7.3	9.1	0.21	297	462	1216	338
1976	7.0	8.4	0.21	250	210	1426	355
1977	6.9	9.1	0.22	278	178	2509	549
1983	7.1	4.5	0.15	230	76	1900	231

[1] Horse manure was applied after the 1974 samples were collected.

sulfur. In addition, two combination treatments were established with granular sulfur and sulfuric acid each being applied at the rates of 890 and 1780 lbs/ac of sulfur. Each treatment was replicated three times. Norway spruce seeds were sown eight months after the application of sulfur.

Soil samples of the surface six inches were collected before treatments were applied, at time of sowing Norway spruce seeds, at the end of each growing season, and during the spring of the second growing season. Number of seedlings per foot of seedbed was determined in October, 1985 and October, 1986. Seedlings were lifted from the seedbeds in October, 1986, and measured for total height, root collar diameter and root volume (Burdett 1979). Additional seedlings were lifted in April, 1987, and measured for total height and root collar diameter. Ten seedlings from each nursery treatment plot were used for root growth capacity determination in April, 1987. Root growth capacity was determined by counting the number of white root tips per seedling after growing in the greenhouse for 28 days (Ritchie 1985).

RESULTS

Soil pH in the study area was 6.5 before treatments were applied. This soil pH was lower than the observed 6.8 to 7.0 found in other parts of the problem area because of the application of 840 lbs/ac of sulfur in the spring before the study was established. At time of treatment, the organic matter concentration was 3.0%; cation exchange capacity was 7.2 meq per 100 g; and concentrations of exchangeable calcium and magnesium were 1097 and 138 ppm, respectively. The base saturation was 92%.

A significant decrease in soil pH was observed eight months after sulfur application (Table 2). The application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid resulted in further lowering soil pH compared to the other sulfur treatments and was the only treatment to reduce the soil pH to the desired range. After 23 months, the higher combination treatment of sulfur plus sulfuric acid still had a significantly lower soil pH as compared to the control (Table 2).

Table 2. Changes in soil pH of treatment plots as a result of applying sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment Sulfur (lbs/ac)	Acid[1] (lbs/ac)	Months since treatment 0[2]	8	12	20	23
		---- pH ----				
0	0	6.5 a[3]	6.7 a	6.9 a	6.8 a	6.9 a
890	890	6.5 a	6.3 b	6.7 ab	6.6 ab	6.7 ab
890	0	6.5 a	6.3 b	6.4 abc	6.8 a	6.7 ab
0	890	6.5 a	6.3 b	6.4 abc	6.7 a	6.7 ab
1780	0	6.5 a	6.3 b	6.2 bcd	6.6 ab	6.5 ab
2670	0	6.7 a	6.2 b	6.2 bcd	6.5 ab	6.5 ab
3560	0	6.6 a	6.0 b	6.1 cd	6.5 ab	6.4 ab
0	1780	6.5 a	6.0 b	6.2 bcd	6.5 ab	6.6 ab
1780	1780	6.5 a	5.5 c	5.6 d	6.1 b	6.1 b

[1] The acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Month 0 is at time of treatment.
[3] Values followed by the same letter within a column are not significantly different at P = 0.05.

Seedbed density at the end of the first growing season was influenced by the application of sulfur and sulfuric acid (Table 3). The plots that received sulfuric acid had significantly more seedlings per foot of seedbed compared to the control plots.

One beneficial aspect of many nursery soil amendments is the improvement in-seedling quality. After two growing seasons seedlings growing in the plots which had received sulfur or sulfuric acid were significantly taller than the seedlings grown in the control plots (Table 4). Seedlings from the plots that received the heavier application of sulfur plus sulfuric acid were almost twice as tall as seedlings from the control plots. This mean total height represents all seedlings in the plot, including the culls.

Seedling root collar diameter at the end of the second growing season was also related to the application of sulfur (Table 4). The seedlings in plots receiving the higher rate of granular sulfur plus sulfuric acid had significantly larger root collar diameters than those in plots which received only sulfur or sulfuric acid. Seedlings in the control plots had the smallest root collar diameters.

Table 3. Seedlings per foot of seedbed as influenced by the addition of sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment (lbs/ac) Sulfur	Acid[1]	Seedlings per foot of seedbed 1-0	2-0
0	1780	120 a[2]	111 a
2670	0	100 ab	99 ab
1780	1780	99 ab	99 ab
0	890	96 b	95 abc
890	890	95 b	88 abc
890	0	86 bc	86 abc
3560	0	80 bc	80 bc
1780	0	64 cd	69 cd
0	0	53 d	53 d

[1] The acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Values followed by the same letter within a column are not significantly different at P = 0.05.

Root volume of the seedlings in plots receiving the higher rate of granular sulfur plus sulfuric acid was significantly greater than the control plots (Table 4). The heavier application rate of granular sulfur plus sulfuric acid produced more new roots tips than the control and, therefore, had a higher root growth capacity (Table 4) .

Morphological measurements of seedling quality were related to soil pH at time of sowing Norway spruce seeds, but not with soil pH at the end of the first growing season or during the second growing season. Variables strongly correlated with soil pH at time of sowing were seedling height, root collar diameter and root growth capacity. The only variable weakly correlated with soil pH at the time of sowing was root volume.

Seedlings lifted in the fall of 1986 and spring of 1987 were graded to a minimum standard (root collar diameter being 0.09 inches and height being 3.5 inches) (Reese and Sadreika 1979). This grading indicated that over 60% of the seedlings grown in all sulfur plots were plantable, whereas less than 40% of the seedlings grown in the control plots were acceptable (Table 5). The heavier application of granular sulfur plus sulfuric acid resulted in the largest percentage of large and medium size seedlings and the smallest percentage of cull seedlings. The control plots had the largest percentage of culls. The percentage of large, medium and cull seedlings was strongly correlated to soil pH at time of sowing.

Another beneficial aspect of nursery soil treatment is the increase in the number of plantable seedlings per unit area. The largest number of plantable seedlings was produced in the plots that received the heavier application of granular sulfur plus sulfuric acid (Table 6). The lowest number of acceptable seedlings was produced in the control plots. The number of seedlings per foot of seedbed and the cull percentage have been shown to be related to sulfur treatment and soil pH at time of sowing Norway spruce seeds.

Table 4. Morphological characteristic of 2-0 Norway spruce seedlings as influenced by the application of sulfur and sulfuric acid treatments at the Saratoga Tree Nursery, New York.

Treatment Sulfur	Acid[1]	Height (in)	Diameter (in)	Root volume (cm^3)	Number of white root tips
1780	1780	6.14 a[2]	0.100 a	2.28 a	100 a
0	1780	5.41 ab	0.086 bc	1.48 cd	79 ab
3560	0	5.29 bc	0.090 b	2.01 ab	49 bc
890	0	5.22 bc	0.086 bc	1.88 abc	52 bc
2670	0	5.01 bc	0.080 cd	1.17 bcd	65 bc
0	890	4.81 bc	0.079 cd	1.48 abc	59 bc
890	890	4.73 bc	0.082 cd	2.00 ab	63 bc
1780	0	4.46 bc	0.077 d	1.94 abc	53 bc
0	0	3.15 d	0.063 a	1.45 d	44 c

[1] Acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Values followed by the same letter within a column are not significantly different.

Table 5. Percentage of seedlings by size class as influenced by the application of sulfur and sulfuric acid treatments at the Saratoga Tree Nursery, New York. [1]

Treatment Sulfur (lbs/ac)	Acid[2]	Large	Medium	Small	Cull
		- - - - - - - Percent	- - - - - - - - - -		
1780	1780	20.8 a[3]	26.8 a	32.9 d	19.5 c
3560	0	13.8 b	14.8 bc	45.0 abcd	26.4 bc
0	1780	8.5 bc	16.1 b	42.3 abcd	33.1 bc
890	0	6.5 cd	15.8 bc	44.2 abcd	33.5 bc
2670	0	6.4 cd	13.4 bc	49.4 abc	30.8 bc
0	890	6.1 cd	14.4 bc	41.4 bcd	38.1 b
890	890	6.0 cd	8.0 bcd	58.4 a	27.6 bc
1780	0	3.0 cd	7.1 cd	53.0 ab	36.9 bc
0	0	0.6 d	2.4 d	34.6 cd	62.4 a

[1] Large size seedlings: >0.11” diameter and >7.5” height
Medium size seedlings: >0.10” diameter and >6.3” height
Small size seedlings: >0.09" diameter and >3.5" height
Cull seedlings: <0.09" diameter or <3.5" height
[2] Acid treatment is lbs/ac of sulfur as sulfuric acid.
[3] Values followed by the same letter within a column are not significantly different.

DISCUSSION

Results observed from the application of sulfur and sulfuric acid at the Saratoga Tree Nursery revealed that the soil pH at time of sowing and germination of Norway spruce seeds was im.r^_tant in producing quality seedlings. With the expection of root volume, all variables of seedling quality were affected by the soil pH at the time of sowing. The higher application rate of sulfur plus sulfuric acid yielded the lowest soil pH and the highest quality of seedlings.

These results differed from those observed at the Orono Nursery, located near Toronto, Ontario (Mullin 1964). At the Orono nursery sulfur was applied at 0, 750, 1500 and 2250 pounds per acre, and at the end of three years, soil pH was reduced from 7.4 to 6.5, 6.0, 5.3 and 5.0, respectively. The reduction in soil pH of the control plots at the Orono Nursery may have been the result of the application of ammonium sulfate fertilizer the first year and ammonium nitrate the remaining two years of the study. With the exception of the 2250 lbs/ac treatment, seedlings produced in sulfur treated plots were taller, thicker (larger root collar diameter), and heavier with a lower top-root ratio than seedlings grown in the control plots. The 2250'lbs/ac treatment resulted in increased mortality of seedlings at the end of the first growing season.

The different results obtained in reducing soil pH with the high application rates of sulfur in the Ontario study and the Saratoga study may be related to the differences in cation exchange capacity and buffering capacity of the soils. Another contributing factor is that the organic matter applied at the Saratoga Tree Nursery contained large amounts of calcium and magnesium and served as a buffering agent. In fact, the application of six inches of composted lime-treated horse manure was equivalent to applying 3.5 tons per acre of lime.

Table 6. Number of plantable seedlings per foot of seedbed as influenced by the application sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment: Sulfur (lbs/ac)	Treatment: Acid[1] (lbs/ac)	Number of seedlings
1780	1780	79 a[2]
0	1780	74 ab
2670	0	68 abc
890	890	64 abc
3560	0	59 bcd
0	890	56 bcd
890	0	54 cd
1780	0	42 d
0	0	21 e

[1] Acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Values followed by the same letter within a column are not significantly different.

At the Saratoga Tree Nursery the reduction of soil pH by most treatments however, was only for a short duration. The effect of the addition of 3560 lbs/ac of granular sulfur on soil pH is undetectable 20 months after application. In contrast, the application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid showed a reduction of soil pH for at least 23 months. Primarily analyses indicate a treatment of 1780 lbs/ac sulfur plus 1780 lbs/ac sulfur as sulfuric acid is an acceptable method of lowering soil pH to obtain high quality seedlings.

Most of the study plots at the Saratoga Nursery that received sulfur sulfuric acid had seedbed densities above the recommended 60 to 70 seedlings per foot of seedbed (Richards et al. 1973) at the end of the second growing season. The addition of sulfur plus sulfuric acid combined with the operational sowing rate crated conditions for high seedbed density. Consequently, individual seedling weight may decrease as seedbed density increases because of decreased seedling branching (Richards et al. 1973). By using the higher sulfur plus sulfuric acid treatment in conjuction with a lower sowing rates, desirable seedbed densities of high quality seedlings may be produced at a reasonable cost. A cost-benefit analysis needs to be conducted to examine economic benefits.

Results of the Saratoga study were also similar to other studies where the number and size of seedlings increased as a result of applying sulfuric acid (Hartley 1917). In fact, the application of sulfuric acid provided two benefits: (1) increased the soil acidity and (2) acted as a soil sterilizer. Before organic fumigants were developed, sulfuric acid was often used as a soil sterilizer (Stoeckeler and Slabaugh 1965). High populations of _Fusarium_ reported 4y Plumley (1986) at the Saratoga Nursery may have been controlled by the application of sulfuric acid.

Although heavy applications of sulfur and sulfuric acid improved seedling quality at the Saratoga Tree Nursery, I must stress that these heavy application rates may not be acceptable at all nurseries and all species. Testing with small plots are needed to determine beneficial rates and any potential adverse effects.

CONCLUSIONS

1. The effect of applying six inches of composted lime-treated horse manure resulted in an increase in soil pH; a condition that has persisted for at least 12 years.

2. The heavy application of sulfur resulted in a significant decrease in soil pH eight months after application. The greatest decrease in soil pH was achieved with the application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid.

3. No significant differences were detected in soil pH twenty months after the application of sulfur or sulfuric acid. The combination of sulfuric acid plus sulfur decreased soil pH for at least 23 months.

4. The application of sulfur resulted in larger seedlings. The largest seedlings were produced in plots receiving the higher application rate of granular sulfur plus sulfuric acid.

5. Measures of seedling quality strongly correlated with soil pH at time of sowing Norway spruce seeds were height, root collar diameter and root growth capacity.

6. The application of sulfur reduced the percentage of cull seedlings and increased the number of seedlings per foot of seedbed.

LITERATURE CITED

Armson, K.A. and Sadreika, V. 1979. Forest Tree Nursery Soil Management and Related Practices. Ontario Ministry of Natural Resources. Toronto, Ont.

Benzian, B. 1965. Experiments on nutrition in forest nurseries. Forestry Comm. Bull. No. 37. Her Majesty's Stationery Office. London.

Burdett, A.N. 1979. A nondestructive method for measuring the volume of intact plant parts. Can. J. For. Res. 9:120-122

Hartley, C. 1917. The control of damping-off of coniferous seedlings. Bull. 453. US Dept. of Agriculture. Washington, DC.

Manion, P.D. 1981. Tree Disease Concepts. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Mullin, R.E. 1964. Acidification of a forest tree nursery soil. Soil Sci Soc. Amer. Proc. 28:441-444.

Plumley, K.A. 1986. Fusarium as a cause of seedling mortality at the Saratoga Tree Nursery, Saratoga Springs, New York. M. S. Thesis. State Univ. New York, Coll. Environ. Sci. and Forestry. Syracuse, NY.

Reese, K.H. and Sadreika, V. 1979. Description of bare root shipping stock and cull stock. Ontario Min of Nat. Res. Toronto, Ont.

Richards, N.A., Leaf, A.L., and Bickelhaupt, D.H. 1973. Growth and nutrient uptake of coniferous seedlings: comparison among 10 species at various seedbed densities. Plant and Soil 38:125-143.

Ritchie, G.A. 1985. Root growth potential: principles, procedures, nd predictive ability. p:93-105 in .L. Duryea (ed.) Evaluating Seedling Quality: Principles, Procedures, and Predictive Abilities of Major Tests. Forest Research Lab. Oregon State Univ. Corvallis, OR.

Scholtes, J.R. 1985. 1985 Northeastern area state owned nursery production. USDA Forest Service Northeastern Area.

Stoeckeler, J.H. and Arneman, H.F. 1960, Fertilizers in forestry. Adv. Agron. 12:127-195.

Stoeckeler, J.H. and Slabaugh, P.E. 1965. Conifer nursery practice in the pariries-plains. Agri. Handb. 279. USDA Forest Service. Washington DC.

Thompson, B.E. 1985. Seedling morphological evaluation--what you can tell by looking. p:59-71 in M.L. Duryea (ed.) Evaluating Seedling Quality: Principles, Procedures, and Predictive Abilities of M4jor Tests. Forest Research Lab. Oregon State Univ. Corvallis, OR.

Tinus, R.W. 1980. Nature and management of soil pH and salinity. p 72-86 in Proc. North American Forest Tree Nursery Soils Workshop. State Univ. New York, Coll. Environ. Sci. and Forestry. Syracuse, NY.

van den Driessche, R. 1969. Forest nursery handbook. Res. Notes No. 48. Brit. Columbia. For. Serv. Victoria, B. C.

van den Driessche, R. 1979. Soil management in Douglas-fir nurseries. p 278-292 in P.E. Heilman, H.W. Anderson, and D.M. Baumgartner (ed) Forest soils of the Douglas-fir region. Washington State Univ. Pullman, WA

Western Fertilizer Handbook. 1980. The Interstate Printers & Publishers, Inc. Danville, IL.

White E.H., Comerford, N.B. and Bickelhaupt, D.H. 1980. Interpretation of nursery soil and seedling analysis to benefit nursery soil management. p 269-288 in Proc. North American Forest Tree Nursery Workshop. State Univ. New York, Coll. Environ. Sci. and Forestry. Syracuse, NY.