Quantifying the pH-Response of a Peat-based Medium to Application of Basic Chemicals

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Abstract. The objective was to systematically quantify the dose response from applications of several alkaline materials recommended for raising pH in acidic media. A 70 peat : 30 perlite (by volume) medium was mixed with a pre-plant nutrient charge, a wetting agent, and between 0 and 1.5 kg·m⁻³ of a dolomitic hydrated lime resulting in six starting-pHs between 3.4 and 6.4. The supernatant from a solution of Ca(OH)₂, 2.5 to 40 mL·L⁻¹ of a flowable dolomitic limestone suspension, 99.5% KHCO₃, between 0.6 to 9.6 g·L⁻¹, 85% KOH between 0.056 and 0.56 g·L⁻¹, 15N–0P–12K water-soluble fertilizer at 50 to 400 mg·L⁻¹ N, and a distilled water control were applied at 60 mL per 126-mL container with minimal leaching as a single drench (except the 15N–0P–12K that was applied about every three days). All chemicals increased medium-pH within one day, and pH remained stable until day 28 except for Ca(OH)₂, which showed a 0.2 unit decrease in pH from day 1 to 28. The Ca(OH)₂ and KOH drenches raised medium-pH by less than 0.5 units, and there was a slight decrease in pH from the 15N–0P–12K for starting-pHs lower than 5.0. Flowable dolomitic lime and KHCO₃ raised pH by up to 2 pH units, averaged across starting pHs and 1–28 days after application. The effect on medium-pH increased as concentration of flowable lime and KHCO₃ increased. Effect of flowable lime was greater (up to 2.9 units) at lower starting-pHs, whereas KHCO₃ was less affected by starting-pH. Medium-EC increased by <0.6 dS·m⁻¹ following single applications of all solutions.

In container plant production, medium-pH affects micronutrient solubility and plant availability (Bierbaum and Argo, 1995; Peterson, 1981). If medium-pH is too low, excessive levels of nutrients (mainly Fe and Mn) may accumulate in plant tissue causing damage to the crop (Koranski and Kessler, 1996; Nelson, 1998).

When medium-pH is found to be below the optimum range, rapid amelioration is necessary to prevent crop damage. Chemicals suggested for raising pH in media include nitrate-based water-soluble fertilizer, Ca(OH)₂, CaCO₃, KOH, KHCO₃, and NaHCO₃ (Bailey, 1996; Cox, 1999; Elliott, 1994). Although these materials have been recommended to greenhouse growers for correcting low medium-pH, recommended rates often include a broad range with little or no information on

dose-response effects (Bailey, 1996). Researchers have quantified the dose response of several materials to peat-based media and field soils (Elliott 1994; Jarrell et al., 1979; McNab and Jerie, 1989). A comparison between alkaline materials applied under standard conditions is lacking, however, for peat-based media.

The objectives of this experiment were to: 1) quantify and compare the pH-response for a 70 peat : 30 perlite medium following application of several basic chemicals under standardized conditions; and 2) determine how pH changed over time following the chemical application. In addition, the effect of initial medium-pH on dose response, the equivalency of pH-response for various chemicals, and their effects on growing-medium electroconductivity (EC) were determined. No plants were included in this experiment to eliminate the variable of plant interaction with medium and chemical application.

Materials and Methods

Root medium. The root medium used was (by volume) 70% Canadian sphagnum peat (Fisons professional black bale peat; SunGro Horticulture, Bellevue, Wash.) with long fibers and little dust (Von Post scale 1–2; Puustjarvi and Robertson, 1975), and 30% coarse perlite.

Six 126-mL containers (5.5-cm width × 6.1-cm length × 7.4-cm depth) were filled with the peat : perlite medium. Medium in the containers was irrigated twice with excess water at 30-min intervals, allowed to drain for 60 min, and then weighed. The containers were then placed in a drying oven at 105 °C for 72 h and weighed again. Container water-holding capacity was estimated to be the difference between the drained weight and the oven dried weight. At container capacity, the medium held 79 mL of water per container.

At mixing, 0.6 kg·m⁻³ of a commercial 6N–3P–7K–10Ca–1Mg pre-plant nutrient charge [composed of commercial-fertilizer grade KNO₃, Ca(NO₃)₂, gypsum, triple superphosphate, and MgSO₄ (GreenCare, Chicago)] and a wetting agent (Aquatrol 2000 L; Aquatrols, Pennsauken, N.J.) at 0.2 L·m⁻³ were added. A range of initial medium-pHs were achieved by incorporating 0.0, 0.3, 0.6, 0.9, 1.2, or 1.5 kg·m⁻³ of a dolomitic hydrated lime [97% Ca(OH)₂·MgO, National Lime and Stone, Findlay, Ohio] in which 92% of the lime passed through a 45-μm screen. The initial pHs of the lime treatments were 3.38, 3.90, 4.37, 5.03, 5.79, and 6.40, respectively. After mixing, medium from each lime treatment remained in plastic bags with the tops open to the air for gas exchange for 7 d at 17.7 °C (root-medium temperature) before the 126-mL containers were filled.

Basic chemical treatments. A saturated solution of analytical grade Ca(OH)₂ was prepared by mixing 25 g Ca(OH)₂ per L of distilled water. After the solution was allowed to equilibrate overnight at 19 °C, the supernatant solution was drained off and used in the experiment. Flowable dolomitic limestone (FDL) (LimeStone-F; W.A. Cleary Corp., Dayton, N.J.), which is formulated as a slurry, was thoroughly mixed and added to distilled water at 2.5, 5.0, 10.0, 20.0, and 40 mL·L⁻¹. Other chemical treatments (Table 1) were dissolved in distilled water before application to the medium, and included reagent-grade KHCO₃, reagent-grade KOH, and a commercial water-soluble fertilizer [15N–0P–12K, composed of commercial-fertilizer grade KNO₃, Ca(NO₃)₂, NH₄NO₃ and with 90% of N in the nitrate form (GreenCare, Chicago)].

Solution pH, EC, and milliequivalents of CaCO₃ per liter of each treatment are presented in Table 1. Milliequivalents per liter (meq·L⁻¹) of CaCO₃ in Table 1 were calculated based on the formula from Bailey (1996), p.73. Calculations of meq·L⁻¹ for flowable lime, KHCO₃, and KOH were calculated from atomic weights and solution concentrations, whereas milliequivalents for the supernatant of Ca(OH)₂ was calculated from the pH-difference between distilled water and the supernatant solution. Milliequivalents were not calculated for 15N–0P–12K because the solution pH was lower than the distilled water pH.

On 25 Jan. 1998, containers were arranged randomly on mesh benches in a well-ventilated glass greenhouse. During the experiment, medium and air temperature averaged 18.6 °C and 19.4 °C, respectively. Chemical treatments were applied on 26 Jan. 1998 by

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Table 1. Solution pH, electrical conductivity (EC) and milliequivalents of calcium carbonate equivalency/L for alkaline chemical treatments (means of 10 replicate measurements).

Chemical	Concentration	pH	EC (dS·m ⁻¹)	Milliequivalents of base/L
Distilled water control	N/A	6.14	0.00	
Supernatant of Ca(OH) ₂	25 g·L ⁻¹	12.34	7.93	22
Flowable Lime	2.5 mL·L ⁻¹	9.56	0.08	28
(27.75% CaCO ₃ , 24.15% MgCO ₃)	5 mL·L ⁻¹	9.79	0.11	56
	10 mL·L ⁻¹	9.74	0.17	113
	20 mL·L ⁻¹	9.68	0.28	226
	40 mL·L ⁻¹	9.40	0.49	451
KHCO ₃ (99.5%)	0.6 g·L ⁻¹	8.32	0.68	6
	1.2 g·L ⁻¹	8.33	1.36	12
	2.4 g·L ⁻¹	8.44	2.68	24
	4.8 g·L ⁻¹	8.41	5.12	48
	9.6 g·L ⁻¹	8.45	9.94	96
KOH (85%)	0.056 g·L ⁻¹	11.04	0.14	1
	0.56 g·L ⁻¹	11.98	1.41	10
15N-0P-12K	50 mg·L ⁻¹ N	5.70	0.40	
	100 mg·L ⁻¹ N	5.94	0.80	
	200 mg·L ⁻¹ N	4.67	1.47	
	400 mg·L ⁻¹ N	4.45	2.71	

overhead irrigation at a rate of 60 mL per container (sufficient to bring containers to saturation with minimal leaching). After application, containers were irrigated overhead to container capacity (with minimal leaching) using 40 mL per container when they reached between 40% and 50% container capacity as determined gravimetrically (about every 3d). Distilled water was used to irrigate all treatments except the 15N-0P-12K, which was reapplied at each watering.

Medium-pH and EC were measured using the saturated-medium extract method with distilled water as the extractant (Warncke, 1986). Medium-pH was measured on 10 destructively-sampled containers before the chemical application (day 0) and on four containers 1, 7, 14, 21, and 28 d after the application. Medium-pH was measured directly in the saturated medium using an Orion 620 pH-meter (Orion Technologies, Beverly, Mass.). Medium-EC was tested before the chemical application and 1 and 28 d after the application. Medium-EC was measured in the filtered extract using an Orion 130 electroconductivity-meter (Orion Technologies).

The experiment was a completely randomized factorial in which alkaline chemical treatments were applied at several rates, along with a distilled water control, to the peat : perlite medium at six starting-pHs. Each chemical treatment was applied to 20 containers per starting-pH, and 40 containers per starting-pH for the control. Analysis of covariance (ANCOVA) was run for each chemical to test how EC and pH were affected by starting-pH, days after application (1–28, analyzed as a continuous variable), the chemical concentration, and their interactions. ANCOVA was initially used to test whether the absolute pH effect of each chemical was significantly different from the control. We were also interested in change in pH (Δ pH) compared with that of the distilled water control at different starting pH levels. The Δ pH was calculated by subtracting each individual pH-measurement from the average pH for the distilled water control on the corresponding measurement day, and Δ pH data were reanalyzed using

ANCOVA. SAS software (SAS Institute, Cary, N.C.) was used for all statistical analyses. Type III sums of squares were used to test hypotheses, and Tukey's honestly significant difference (HSD) multiple comparison test was used to compare treatment means. Mean Δ pH was graphed for each combination of starting-pH and chemical concentration.

Results

Varying the lime rate that was blended into the medium resulted in differences in initial pH, which ranged from 3.4 to 6.4 at day zero (Fig. 1). Each of the six lime rates resulted in medium-pHs that were statistically different from all other rates on each day. Medium-pH in the distilled-water control pots increased by an average 0.25 units over the 28-d period, particu-

larly at lower starting-pHs, but throughout the experiment medium-pH from each lime-incorporation rate was statistically different on a given measurement day (Fig. 1). For clarity, the initial lime incorporation rates will be described in this article as different "starting pHs" based on the control pH at time zero.

Medium-EC of the control pots was not affected by initial lime rate. In all lime treatments, medium-EC did not change between days 0 and 1 (0.67–0.69 dS·m⁻¹). Medium-EC declined to 0.31 dS·m⁻¹ by day 28, possibly because of a combination of slight leaching and fertilizer salt stratification. Salt stratification is thought to be caused by evaporation from the root-medium surface (Argo and Biernbaum, 1994, 1995) or by a water front moving into the medium with each irrigation (Yelanich, 1995), and the top 1-cm was removed from soil-test samples in this study.

All alkaline chemical treatments significantly changed medium-pH compared to that of the control treatment ($P < 0.001$). Therefore, the focus of the remainder of the paper will be on the alkaline chemical effects on Δ pH. ANCOVA results are summarized in Table 2. All chemicals had a very rapid effect on media-pH. The Δ pH did not change after day 1 (Table 2) except for Ca(OH)₂, which declined slightly over time. Charts (Figs. 2–6) therefore present Δ pH as least-square means for each chemical treatment over time.

Calcium hydroxide. Ca(OH)₂ increased medium-pH by up to 0.49 pH units above that of the control (Fig. 2, Table 2). The Δ pH response was greatest at the highest starting-pHs, and was only 0.1 units above the control at starting-pH 3.9. The effect on Δ pH declined slightly over time, and ANCOVA estimated that Δ pH was 0.19 units less on day 28 compared with day 1.

Fig. 1. The pH over a 28-d period following an application of distilled water on day zero and subsequently when the medium reached 50% container capacity. Each line represents pH for a peat : perlite medium blended with a single rate of hydrated lime between 0 and 1.5 kg·m⁻³. Symbols represent averages of eight replicate medium samples $\pm$ 95% confidence intervals.

There was no effect of the $\text{Ca}(\text{OH})_2$ application on medium-EC at day 1. However EC was slightly higher than that of the control (by $0.09 \text{ dS}\cdot\text{m}^{-1}$) on day 28 (data not shown).

Flowable dolomitic limestone (FDL). FDL significantly increased medium-pH compared with the control, especially at low starting pH and high concentration (Fig. 3, Table 2). There was no effect of days after application, and averaged across starting-pH and time, the dose response increased from $+0.21$ to $+1.73$ pH units as flowable lime concentration increased from 2.5 to $40 \text{ mL}\cdot\text{L}^{-1}$. FDL had the greatest effect on ΔpH at lower starting-pHs. For example, at the recommended rate of $5 \text{ mL}\cdot\text{L}^{-1}$ of the FDL (Bailey, 1996), the ΔpH was 2.1 and 0.5 with a starting-pH of 3.4 and 6.4 , respectively.

There was a slight effect of the FDL application on medium-EC at day 1 and 28. However, even at the highest rate of FDL, medium-EC was only $<0.2 \text{ dS}\cdot\text{m}^{-1}$ higher than that measured in the control (data not shown).

Potassium bicarbonate. KHCO_3 increased medium-pH by up to 2.3 units above that of the control at the highest concentration (Fig. 4, Table 2), and did not change significantly between days 1 to 28. The dose response averaged across time and starting-pH increased from $+0.22$ to $+1.70$ pH units as KHCO_3 con-

centration increased from 0.6 to $9.6 \text{ g}\cdot\text{L}^{-1}$. The ΔpH was significantly affected by starting pH, and the greatest response occurred at the highest starting-pHs (5.8 and 6.4). KHCO_3 increased medium-EC by up to 0.3 (day 1) and $0.4 \text{ dS}\cdot\text{m}^{-1}$ (day 28) higher than that measured in the control (data not shown).

Potassium hydroxide. KOH caused a small but rapid increase in medium-pH (Fig. 5). The dose response was not affected by increasing the concentration of KOH from 0.056 to $0.56 \text{ g}\cdot\text{L}^{-1}$ ($P = 0.07$), and there was also no effect of time after application ($P = 0.42$). Effect on ΔpH was greatest ($+0.32$ averaged across KOH concentrations) at starting-pH 4.37 , which showed a significantly greater response compared with starting-pHs 3.38 , 5.79 , and 6.40 . There was no effect of KOH on EC at day 1, but EC from the $0.56 \text{ g}\cdot\text{L}^{-1}$ treatment was $0.1 \text{ dS}\cdot\text{m}^{-1}$ higher than the control EC on day 28.

Water-soluble fertilizer. High-nitrate fertilizer ($15\text{N}-0\text{P}-12\text{K}$) caused a slight decrease (-0.09 to -0.12 pH units averaged over time) in medium-pHs with a starting-pH <5 (Fig. 6). This decrease in pH was more pronounced as concentration increased. However, $15\text{N}-0\text{P}-12\text{K}$ did not significantly affect medium-pH for starting-pHs of 5.03 and above. On day 1, $15\text{N}-0\text{P}-12\text{K}$ increased EC by up to

$0.5 \text{ dS}\cdot\text{m}^{-1}$ at the highest concentration ($400 \text{ mg}\cdot\text{L}^{-1} \text{ N}$). $15\text{N}-0-12\text{K}$ was the only chemical treatment that was applied with each irrigation, and after 28 d EC at $400 \text{ mg}\cdot\text{L}^{-1} \text{ N}$ was $1.6 \text{ dS}\cdot\text{m}^{-1}$ higher than the control.

Discussion

Obtaining an acceptable pH for plant growth is critical for growing quality crops. The alkaline materials tested in this experiment should not be considered as an alternative to pre-plant control of medium-pH, which is based on incorporation of limestone (Nelson, 1998). There are times during the production period, however, when medium-pH falls below an acceptable level and must be readjusted with basic chemicals such as those tested here.

Using a high-nitrate fertilizer had little effect on medium-pH in this experiment, which was expected because plants were not grown in the medium. It is known that applying high-nitrate fertilizers to a crop will raise medium-pH over time because of OH^- or HCO_3^- ion secretion by plant roots to balance nitrate uptake (Marschner, 1995). However, there are situations in which the plant has a limited ability to take up NO_3^- such as newly planted seedlings or stressed plants with little growth. Under these conditions, it would be advisable to use alternative methods for raising medium-pH besides high-nitrate fertilizers.

The effect of the other materials tested [KOH, supernatant $\text{Ca}(\text{OH})_2$, KHCO_3 , FDL] depended on the concentration applied. One reason that $\text{Ca}(\text{OH})_2$ and KOH had minimal effect on ΔpH was that the concentration applied (and base strength in terms of milliequivalents per liter of CaCO_3 , Table 1) was too low. With $\text{Ca}(\text{OH})_2$, the supernatant solution is the maximum concentration obtainable. In other experiments (unpublished data), we have sometimes measured greater pH-response from applications of $\text{Ca}(\text{OH})_2$. Elliott (1994) also found variability in saturated solutions of calcium hydroxide, because the quantity of suspended particles varied. Lack of a consistent pH-response is an undesirable characteristic of $\text{Ca}(\text{OH})_2$ for use in correcting low medium-pH. With KOH, higher concentrations are obtainable than $\text{Ca}(\text{OH})_2$ and increasing concentration above $0.56 \text{ g}\cdot\text{L}^{-1}$ would probably have affected ΔpH more than the results reported here. KOH is a strong base, however, and higher concentrations of KOH than those tested may be caustic to both plants (McNab and Jerie, 1989) and people.

Flowable dolomitic lime and KHCO_3 were the most effective materials tested for increasing medium-pH. They were also used at the highest concentration and base strength of the treatments (Table 1) and therefore it would be expected that they would have the greatest effect on ΔpH . FDL increased medium-pH to a maximum pH of ≈ 7.5 , whereas medium-pH reached over 8.5 in some cases following application of KHCO_3 . This maximum response of FDL may be related to limited limestone solubility at medium-pHs above 7.5 (Lindsay, 1979). Flowable dolomitic lime required constant agitation in the stock solution

Table 2. Analysis of covariance summary for the effects of five chemicals on ΔpH (mean treatment pH minus mean control pH) for a peat/perlite growing-medium with six starting pHs between 3.4 and 6.4 .

Factor ^a	$\text{Ca}(\text{OH})_2$ solution	Flowable lime	KHCO_3	KOH	$15\text{N}-0\text{P}-12\text{K}$
Starting pH	**	***	***	*	***
Concentration	NA ^y	***	***	NS	*
Starting pH * conc	NA	***	**	NS	NS
Days after application	*	NS	NS	NS	NS

^aAbbreviations: "conc" = concentration, "Starting pH" = starting pH at day zero before application.

^yThere was no concentration factor in the ANCOVA for the supernatant of $\text{Ca}(\text{OH})_2$, because there was only one level of the treatment.

NS, *, **, *** Nonsignificant at 95% level; significant at the 95%, 99%, and 99.9% levels, respectively.

Fig. 2. Effect on medium-pH from an application of the supernatant from $25 \text{ g}\cdot\text{L}^{-1}$ of calcium hydroxide to a medium with six starting-pHs ranging from 3.4 to 6.4 . The chart presents ΔpH , quantified as the mean pH from treated media minus the mean pH of media that received the deionized water control. Bars represent the least-square means over time from 20 replicate samples (four destructively-sampled replicates on each of days 1, 7, 14, 21, and 28) $\pm$ one SE. Letters above each bar represent Tukey's mean comparison at the 95% level.

Fig. 3. Effect on medium-pH from an application of flowable dolomitic limestone between 2.5 and 40 mL·L⁻¹ to a medium with six starting-pHs. The chart presents ΔpH, quantified as the mean pH from treated media minus the mean pH of media that received the deionized water control. Symbols represent least-square means over time (1 to 28 d after application) from 20 replicate samples (four destructively-sampled replicates on each of days 1, 7, 14, 21, and 28) ± one SE. Letters above each bar represent Tukey's mean comparison within a starting-pH at the 95% level.

Fig. 4. Effect on medium-pH from an application of potassium bicarbonate between 0.6 and 9.6 g·L⁻¹ to a medium with six starting-pHs. The chart presents ΔpH, quantified as the mean pH from treated media minus the mean pH of media that received the deionized water control. Symbols represent least-square means over time (1 to 28 d after application) from 20 replicate samples (four destructively-sampled replicates on each of days 1, 7, 14, 21, and 28) ± one SE. Letters above each bar represent Tukey's mean comparison within a starting-pH at the 95% level.

to maintain a consistent suspension, in addition to significant cleaning of the injector after application. Because of these problems, FDL may not be compatible with certain irrigation methods (flood subirrigation, low volume drip irrigation). In other experiments with FDL (unpublished data), no phytotoxicity to roots or foliage was measured on bedding plants even at 40 mL·L⁻¹, but at all application rates it was necessary to spray plant foliage with water to remove the lime residue. In comparison, KHCO₃ is soluble and can be used with all irrigation methods. Jarrell et al. (1979) did not report damage from 0.2 M solutions of potassium and sodium bicarbonate applied to three foliage species growing in a peat : sand medium. However, in one trial (unpublished data), root damage to geraniums was observed at 4.8 and 9.6 g·L⁻¹ KHCO₃ and foliar damage was observed on soft-tissued bedding plants (for example, celosia at 2.4 g·L⁻¹ KHCO₃). Other problems may include high K levels in the root medium which may interfere with the uptake of other nutrients.

This experiment is a preliminary comparison between alkaline chemicals proposed to raise pH of soilless medium. The benefit of this research is to evaluate a range of chemi-

Fig. 5. Effect on medium-pH from an application of 85% potassium hydroxide at either 0.056 to 0.56 g·L⁻¹ to a medium with six starting-pHs. The chart presents ΔpH, quantified as the mean pH from treated media minus the mean pH of media that received the deionized water control. Symbols represent least-square means over time (1 to 28 d after application) from 20 replicate samples (four destructively-sampled replicates on each of days 1, 7, 14, 21, and 28) ± one SE. Letters above each bar represent Tukey's mean comparison at the 95% level.

Fig. 6. Effect on medium-pH from an application of 15N-0P-12K between 50 and 400 mg·L⁻¹ to a medium with six starting-pHs. The chart presents ΔpH, quantified as the mean pH from treated media minus the mean pH of media that received the deionized water control. Symbols represent least-square means over time (1 to 28 d after application) from 20 replicate samples (four destructively-sampled replicates on each of days 1, 7, 14, 21, and 28) ± one SE. Letters below each bar represent Tukey's mean comparison within a starting-pH at the 95% level.

cals in highly standardized conditions. In addition, application volume (≈0.5 solution : 1 container volume in this experiment) and or reapplication of the chemical may also be important. Because water-soluble fertilizers, chemicals, medium and plants interact to affect pH, more research is necessary to quantify

the effects of these variables to improve recommendations for raising pH in commercial and research greenhouse environments.

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