Influence of Lime Type and Rate on Pine Bark Substrate pH.

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Keywords: calcitic lime, dolomitic lime, *Ilex crenata*, lime efficacy, lime rate, substrate.

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ABSTRACT

Pine bark substrate in the southeastern U.S. is the substrate of choice for ornamental plant producers. The low pH of the unbuffered substrate needs to be adjusted with a lime material in order to promote proper nutrient uptake and ensure general plant health to avoid abiotic disorders. The research and data collection from this study evaluated the long-term effect of four lime materials and five rates on the pH of a pine bark substrate that was planted with rooted holly cuttings over nine-months. We found that pH is raised by lime material and rate over time, with >4.5 $kg \cdot m^{-3}$ needed to maintain an optimal pH for ornamental plant growth. Our data along with past research on the subject will benefit producers in using the proper lime material and rate for optimal plant health and to prevent abiotic disorders during crop production.

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Summary

Pine bark substrate in the southeastern U.S. is the substrate of choice for ornamental plant producers. The low pH of the unbuffered substrate needs to be adjusted with a lime material in order to promote proper nutrient uptake and ensure general plant health to avoid abiotic disorders. The research and data collection from this study evaluated the long-term effect of four lime materials and five rates on the pH of a pine bark substrate that was planted with rooted holly cuttings over nine-months. We found that pH is raised by lime material and rate over time, with >4.5 $kg \cdot m^{-3}$ needed to maintain an optimal pH for ornamental plant growth. Our data along with past research on the subject will benefit producers in using the proper lime material and rate to prevent abiotic disorders during crop production.

Additional index words: calcitic lime, dolomitic lime, *Ilex crenata*, lime efficacy, lime rate

Introduction

In 2014, the U.S. nursery industry generated $4.3 billion in annual sales (USDA-NASS, 2014) and $29 billion in consumer sales in 2012 (Burden, 2012). The nursery industry continued growth and expansion nationally and in Virginia began in the 1980s (Robbins, 2010). Approximately 74% of U.S. ornamental horticultural operations produce woody and herbaceous nursery plants in containers accounting for 63% of the revenue. (USDA-NASS, 2014). In the eastern U.S. containerized nursery crops rely primarily on pine bark-based soilless substrates (Owen et al., 2008) due to its abundant availability (Pokorney,1975).

Soilless substrates provide the producer greater control over the edaphic environment including the hydrological properties, pH and subsequent nutrient uptake. Adjusting the pH in the rhizosphere affects nutrient solubility in the soil and subsequent plant uptake (Marschner, 2012). Lime products used to raise the pH of pine bark substrates to a target a 5.5 - 6.5 (Mauseth, 2003) or 5.0 - 6.5 pH (Altland and Jeong, 2016). It is necessary when producing nursery crops in bark based substrates to include calcitic or dolomitic lime. Huang et. al (2007) discusses past research on the effectiveness of lime material neutralizing the acidity of substrates depending on its neutralizing capacity, fineness of grinding, chemical composition and mineralogy. However, lime is selected based on local availability and allied supplied networks instead of the aforementioned properties. Furthermore, adjusting a low 4.52 pH to a more optimal 5.2-6.5 pH is necessary when fertilizing pine bark substrates as high levels of micronutrients can cause micronutrient toxicity (Wright and Hinsley, 1991).

The main objective of our study was to evaluate the effect of lime type and rate on the pH of a pine bark substrate over nine months in order to aid producers in selecting the correct lime product and rate for growing successful crops.

Materials and Methods

All research herein was conducted at the Virginia Tech Hampton Roads Agricultural Research and Extension Center in Virginia Beach, VA (lat. 36˚53’31” N; long. 76˚10’45” W). On 12 Dec. 2016 *Ilex crenata* `Bennett’s Compacta´ (holly) rooted cuttings were obtained from Lancaster Farms Inc., Suffolk, VA. Holly liners were transplanted into #1 NSY C300 (2.8L) containers (Classic Nursery Supplies Inc. Chambersburg PA.) using 15.9 mm (5/8 in.) or finer, aged pine bark (*Pinus taedus*, PM2, Pacific Organics, Henderson, NC) not amended or amended with calcitic or dolomitic lime. Newly transplanted holly plants were hand watered to saturation and cut to height of 13 cm (5-1/8 in) with Corona Bypass hand pruners. Plants were grown on mesh benches in a heated glass greenhouse environment maintained at ≈20˚C (68˚F) until 27 April 2017. The plants were then moved to an open-air, overhead irrigated production pad until the completion of the study. Weeds growing in the pots were controlled by hand pulling, being careful not to disturb the container substrate. (Stewart et al. 2017) discusses the challenges of container plant weeding and the lack of post emergent herbicides available.

The substrate was amended with a lime treatment and 5.5 $kg \cdot m^{-3}$ (11 lb/yd^3) 18-2.2-10 coated, controlled-release fertilizer (Osmocote, 18-5-12, 8-9 mo, ICL Specialty Fertilizers, Dublin, OH). The lime products chosen for this study were selected by regional availability, mineral composition (calcitic vs dolomitic), and sieve analysis (pulverized vs ground or granular) (Table 1). The four lime amendments were: 1, pulverized dolomitic (Pro Limestone, Pulverized Dolomitic Limestone; Oldcastle Stone Products, Lee, MA), 2, pulverized calcitic (Pro Limestone, Pulverized Calcitic Limestone; Oldcastle Stone Products), 3, ground dolomitic (Agricultural Ground Limestone Dolomitic, Unburnt; Rockydale Quarries, Roanoke, VA), and 4, granular calcitic (Pro Limestone, Granular Calcitic Limestone; Oldcastle Stone Products) lime (Table 1). Each of the four lime products were amended at a rate of 0, 0.5 (1 lb/yd), 2.5 (5 lb/yd.), 4.5 (9 lb/yd) and 6.4 (13 lb/yd) $kg \cdot m^{-3}$, respectively. Each lime product and rate treatment was incorporated into ≤ 0.057 m^3 of pine bark by being hand mixed three times to ensure uniform distribution of amendments before potting nine replicates per treatment. An additional treatment was included in which bark was mixed three times without a lime or fertilizer amendment.

The examination of leachate via pour through (LeBude and Bilderback, 2009) from our samples occurred at ≈30 day intervals beginning 4-day after initiation (DAI) and concluding at 267 DAI (5 Sept. 2017). Each date's pour through was conducted utilizing different containers/replicates than the two previous measurements to prevent confounding issues from repeated measures. The pour through process began with plants being watered with well water to container capacity in which mineral nutrients are dissolved into the pore water and available for plant uptake. Then, an additional 100 ml of deionized (DI) water was applied uniformly across the surface of the container substrate to displace gravitational and capillary water over a 45 to 60 min span. The displaced pour-through water was collected in 20 cm (8 in) diameter plastic pans, and then 40 mL were transferred to 50 mL glass test tubes for transport to the lab for pH analysis. Electrochemical properties of the extracted pore-water were measured in random order using a pH/conductivity bench top meter (Orion 4-Star; Thermo Fisher Scientific Inc., Beverly, MA) with pH (Orion™Sure-Flow™ 9172BNWP, refillable pH electrode; Thermo Fisher Scientific Inc.) and EC probe (DuraProbe™ 4-Electrode and Conductivity Cell, Thermo Fisher Scientific Inc.). Prior to analysis the EC probe underwent a single point calibration at 1405 $\mu S \cdot cm^{-1}$, the pH electrode underwent a two-point calibration, pH 4.0 and 7.0, and both probes were rinsed with DI water before analysis of each sample. The electrochemical properties of the leachate, electrical conductivity (EC) and pH, provide diagnostics for adjusting substrate fertility, information used by scientists and growers alike (LeBude and Bilderback, 2009). Initial pine bark pH was also determined by saturated media extract (SME) method four days after initiation. An analysis of water quality (W004) was performed for both the greenhouse and open-air nursery by Brookside Laboratories, New Bremen, OH.

The study was designed and conducted as a 4 (products) x 4 (rates) x 11 (pore-water sampling) factorial with a non-amended pine bark as a control. Data presented in tables and figures with associated statistics were analyzed in JMP Pro (12.0.1, SAS Institute, Inc.; Cary, NC).

Results and Discussion

Our findings do not support the conventional wisdom that smaller particle size lime (≈ 87% percent passing through a mesh sieve) will not last throughout a production period of 6 to 16 months. The main effect of lime material on substrate pour-through pH was not significant; however, the significance of sampling time (DAI) x rate x material indicates the interaction of the three factors together may provide opportunities for growers to have increased control over substrate pH. Current best management practice (BMP) is using a ratio of coarse and fine lime to increase longevity and minimize pH decline over production periods > 7 mo. Findings herein do not fully support this hypothesis nor the suggested BMP. The fineness, total neutralizing value (ENV) and calcium carbonate equivalence (CCE) reported in Table 1 are each measures of the lime effectiveness in neutralizing acidity and longevity of liming effect. Per the products specifications, pulverized calcitic and dolomitic lime would have greater liming effectiveness as measured by ENV and fineness, suggesting these materials would result in the greatest pH increase. This corresponds with the research of Drs Leda and Wright on lime particle size and container medium pH (Leda and Wright, 1991). Calcium carbonate equivalence (CCE), the percent of material utilized in 1-year to neutralize acidity, were similar between lime materials ranged from 94.0% (ground dolomitic) to 99.6% (pulverized calcitic) indicating there may be no or little difference in longevity as hypothesized by T.E.. Bilderback in 1990’s (personal communication).

The main effects of sampling time (DAI) and rate were analyzed independently (Table 2) to make generalizations prior to an in-depth analysis of interactions. The finding that lime material size was insignificant differed from our original hypothesis in which particle size or material alone would make a difference in lime effectiveness to raise and maintain the pH. Initial non-fertilized, non-limed (control) pine bark pH was 4.52 ± 0.16 SD and 4.56 ± 0.03 SD determined by SME and pour through (Handreck and Black, 2010), respectively, four days after initiation (DAI). However, the non-limed, fertilized pH was approximately half a pH unit (4.10 ± 0.02 SD) less than when non-fertilized illustrating the acidity of the fertilizer which had already begun to release resulting in pore-water EC of 2876 $\mu S \cdot cm^{-1}$ ± 221 SD compared to 404 $\mu S \cdot cm^{-1}$ ± 124 SD in the control (non-fertilized, non-limed) bark. The pH of the fertilized only, non-limed substrate remained ≈ 1 unit pH lower than the pooled lime treatments beginning at ≈ 50 DAI until experiment termination (Fig. 1). Additionally, at ≈ 50 DAI until study completion there was little difference between holly potted pine bark which was limed and fertilizer versus the non-limed, non-fertilized control (Fig. 1).

Increasing incorporation rate of lime, regardless of lime material used, into pine bark resulted in a > 2 pH unit sigmoidal increase from ≈ 4.0 to 6.4 (Fig. 2). Figure 1 illustrates practitioners of liming need to add ≈ 2.3 $kg \cdot m^{-3}$ lime material to aged pine bark to overcome the media fertilizer acidity and return the substrate pH to the same as the control (shown as 0 on y-axis), ≈ 4.84 pH, when incorporating a 8-9 mo, 18-2.2-10 control released fertilizer and applying water having a low alkalinity (greenhouse = 20.6 $mg \cdot L^{-1}$; open-air nursery = 27.1 $mg \cdot L^{-1}$). In the system studied, based on effect of application rates recorded across lime materials and time, practitioners would need to add 4.5 to 6.5 $kg \cdot m^{-3}$ to maintain an optimal pH range of 5.2 to 6.5 which is currently recommended for general healthy plant growth. However, the authors remain uncertain that lime rates of > 5.0 $kg \cdot m^{-3}$ would have a significant impact on increasing pH beyond observed since effectiveness of lime decreases with increasing rate beyond a critical point (Altland et al. 2008).

The three-way interaction of the effect of material and amendment rate on pH over time is shown in figure 3. All lime materials applied at less than 4.5 $kg \cdot m^{-3}$ failed to maintain the desired pH (5.2 to 6.5) for ornamental crop production after ≈ 50 DAI. Therefore, rates ≤ 4.5 $kg \cdot m^{-3}$ should only be considered for pH sensitive crops that are produced to be saleable within 2 months. Calcitic lime, regardless if pulverized or granular, resulted in the greatest immediate increase in pH, to approximately 6.5 at ≈ 25 DAI. Dolomitic materials were ≈ 0.5 pH units less than calcific materials at ≈ 25 to 50 DAI. The pulverized lime materials with smaller particle size resulted in the greatest increase to pH over time; however granular calcitc lime at amendment rate of 6.5 $kg \cdot m^{-3}$ also approached a pH of 7.0 from 75 DAI until the completion of the study.

Conclusion

The results of our study indicate the lime material may not matter as much as rate and that particle size may have less impact than originally hypothesized; however, ground dolomitic material had the least effect on increasing the substrate pH and provided no greater longevity than pulverized materials applied at rates > 4.5 $kg \cdot m^{-3}$. Conventional methods of nursery growers to adjust the pH of a pine bark substrate have been to use a combination of pulverized and ground dolomitic liming materials to ensure calcium and magnesium do not become growth limiting during production. The combination was believed to provide quick increase in pH associated with the fine pulverized dolomitic limestone and longevity associated with the larger particle size of the ground dolomitic limestone. Combining products such as granular or ground and pulverized limestone, and then applying at higher rates, is wasteful since lime material had little effect on pH and amendment rates over ≤ 6.4 $kg \cdot m^{-3}$ causes little change in the pH in a common 9 month production period. These findings are in agreement with

Altland et al. (2008) who reported that 3 to 6 $kg\cdot m^{-3}$ had almost no effect on substrate pH and the results from Leda and Wright (1991) match our results that finer particle size adjusted the pH effectively.

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Figure captions

Figure 1. Effect of time, 11 samplings over 267 days, on substrate pH pooled across lime materials and rates and compared to only fertilizer or unlimed and unfertilized pine bark plated with holly. Bars represent standard deviation.

Figure 2. Effect of rate on pH change compared to an unlimed, unfertilized pine bark planted with holly. Data is pooled across lime materials and 11 sampling dates over 267 days. Bars represent standard deviation.

Figure 3. Effect of lime material and rate on substrate pH measured via pour through at 11 sampling dates over 267 days. Bars represent standard error.

Tables

Table 1. Detailed information of four lime products utilized including chemical composition and liming material quality parameters.

		Chemical composition				Liming material quality parameters						
						Calcium carbonate equivalence	Effective neutralizing value	Sieve analysis (mesh)				
Material	Size or grade	Calcium (Ca)	Magnesium (Mg)	Calcium carbonate ($CaCO_3$)	Magnesium carbonate ($CaCO_3$)	(CCE)[z]	(ENV)[y]	100	60	20	10	Fineness[x]
		(---percent					---)	(---percent passing			---)	(unitless)
Calcitic	Pulverized	35.8	2.4	89.5	8.5	99.6	91.6	80	86	100	100	0.92
	Granular	34.0	2.9	85.0	10.0	96.0	63.0	40	50	92	100	0.71
Dolomitic	Pulverized	21.6	10.0	54.0	35.0	95.0	87.0	80	88	100	100	0.92
	Ground	20.0	10.0	50.0	35.0	94.0	59.0	35	50	90	100	0.68

[z]Neutralizing power per weight of material relative to pure calcium carbonate ($CaCO_3$).
[y]The percent of the CCE that will react with soil acidity in the first year of application; CCE x fineness.
[x]Rate of reaction estimate of liming material; {[(percent passing 100 mesh sieve - percent passing 20 mesh sieve) x 0.60] + percent passing 100 mesh sieve} ÷100

Table 2. Analysis of variance table of a 4 (products) x 4 (rates) x 11 (pore-water sampling) factorial.

Source	**Degrees of freedom**	**Sum of Squares**	**F Ratio**	**Prob > F**
Day after initiation (DAI)	10	35.44	61.40	<0.0001
Lime Material (MAT)	3	0.24	1.36	0.2546
Lime rate (RATE)	3	13.07	75.47	<0.0001
DAI x MAT	30	1.27	0.73	0.8465
DAI x RATE	30	53.79	31.06	<0.0001
MAT x RATE	9	0.44	0.84	0.5773
DAI x MAT x RATE	90	10.30	1.98	<0.0001
Error[z]	351	20.26		

[z]Mean square = 2.99

Figures

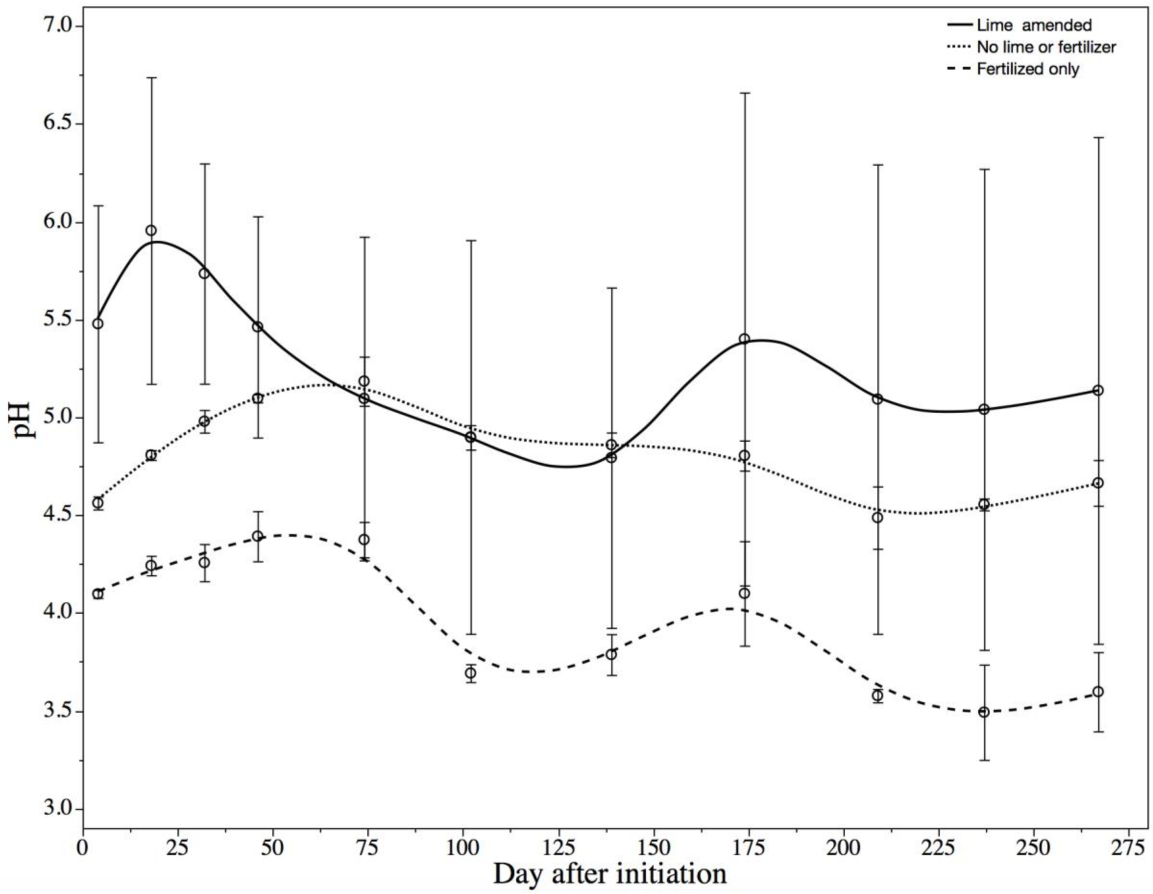

Figure 1. Shows the effect of lime amended substrate with fertilizer, substrate with fertilizer only and substrate with no lime and no fertilizer over time, 11 samplings across 267 days, on substrate pH polled across 4 lime materials and 4 rates. The pine bark substrates were planted with holly, Bars represent standard deviation.

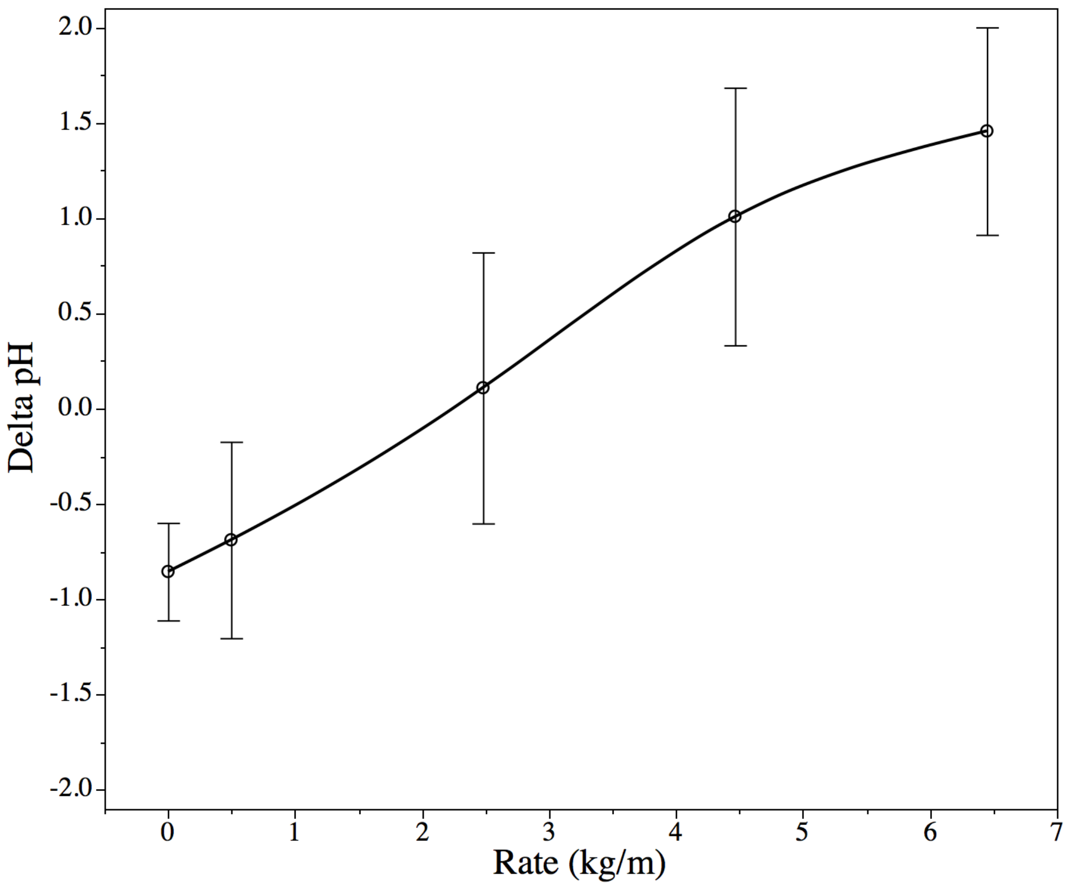

Figure 2. Effect of rate on pH change compared to a non-limed, non-fertilized pine bark planted with holly. Data are pooled across lime materials and 11 sampling dates over 267 days. Bars represent standard deviation.

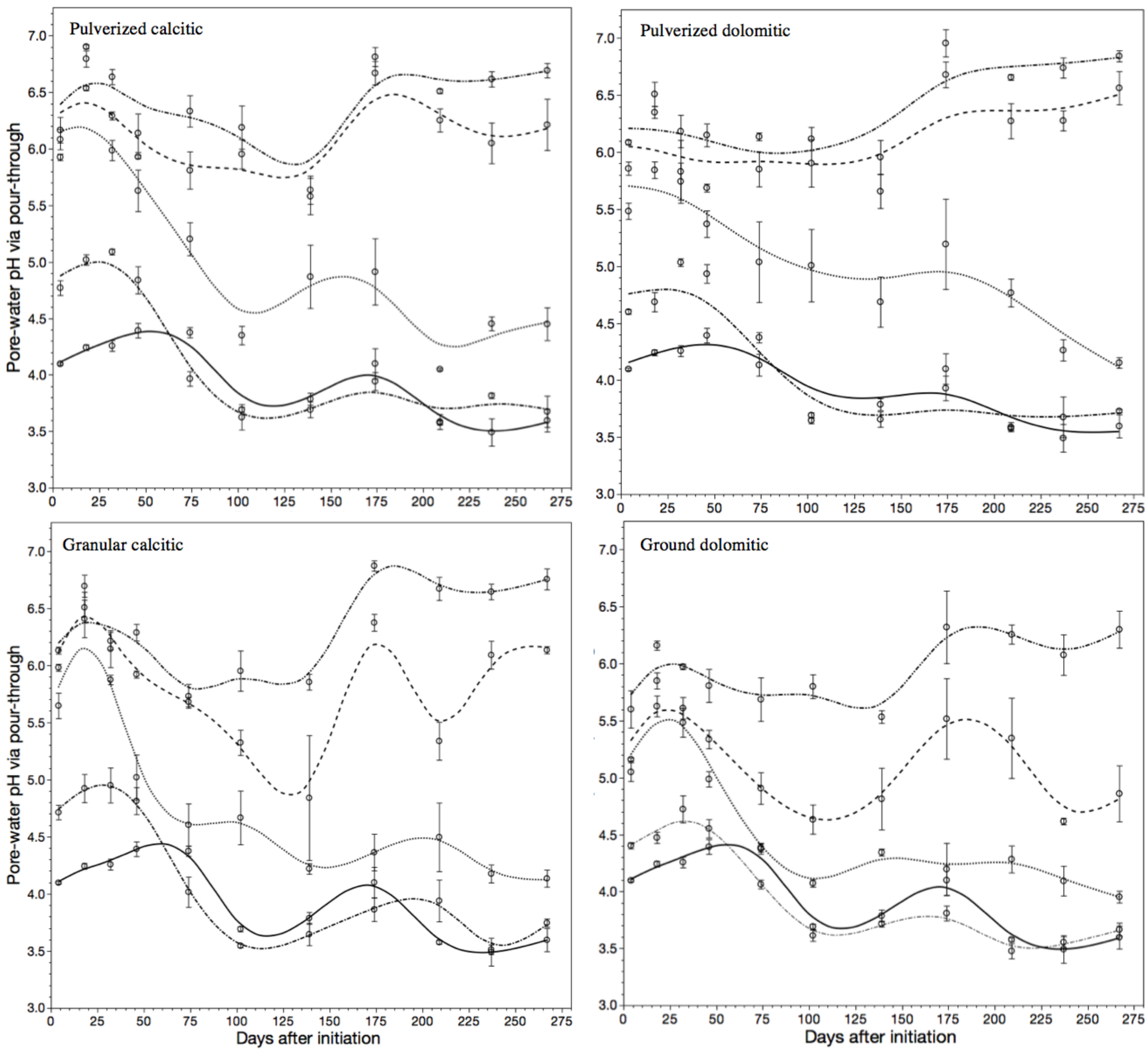

Figure 3. The effect of lime material and rate shown from lower to higher pH along Y axis. #1(0); #2: 0.50, (1lb/yrd³); #3: 2.48, (5lb/yrd³); #4: 4.64,(9lb/yrd³); and #5: 6.48(13lb./yrd³) kg/m) on fertilized pine bark substrate pH used to grow holly. pH was measured via pour through at 11

sampling dates over 267 days. Bars represent standard error. The top two figures consist of the finer lime particle sizes. The pulverized dolomitic and the pulverized calcitic treatments at rates < 4.65 kg/m held the pH higher and longer then the larger particle sizes of the granular calcitic and granular dolomitic limes. The granular lime products had a larger decline in pH and a larger difference between 4.65 and 6.48 kg/m compared to the finer pulverized lime products. All four graphs associated with figure 3 show that no matter the lime type or particle size, the rates <2.48 kg/m declined in pH after DAI 50.