Using a Mineral Aggregate to Supply Phosphorus and Potassium for Containerized Crop Production

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Keywords: clay, nutrient, media, ornamental crop growth

Abstract

There is a rising need for increased water and nutrient use efficiency in ornamental container production to maximize profits while minimizing environmental impact. Substrates containing industrial mineral aggregates (clay) can increase water use efficiency and reduce phosphate leaching while retaining maximum crop growth. In addition, these clays may be able to provide a labile source of plant available phosphorus (P) and potassium (K). A study was performed to determine if 9% (by vol.) palygorskite-bentonite industrial clay aggregate amended pine bark substrate could supply adequate P and K to maximize growth of *Cotoneaster dammeri* C.K. Schneid. 'Skogholm'. Plants were top-dressed with single [nitrogen (N) only], incomplete (N and K only), or complete controlled release fertilizer (N, P, and K) and microirrigated cyclically to maintain a 0.25 leaching fraction. Dry mass of Skogholm cotoneaster was greatest when receiving the incomplete fertilizer (N and K) and least when only N was applied (P and K were absent). Foliar P concentration was not limiting in all treatments and greatest in plants receiving N only. In contrast, foliar K was limiting in Skogholm cotoneaster when receiving a fertilizer containing only N. Foliar K increased 46% when grown with a complete (N, P, and K) or incomplete fertilizer (N and K). Water extractable substrate K was unaffected by fertilizer treatment, however substrate extractable P decreased 55% when using single or incomplete fertilizer that contained no P. The clay amendment was able to supply adequate P to maximize growth when using an incomplete fertilizer (N and K).

INTRODUCTION

Clay mineral aggregates have been reported to be a beneficial component of pine bark and peat based soilless substrates (Owen, 2006; Warren and Bilderback, 1992; Carlile and Bedford, 1988). A Georgiana palygorskite-bentonite interstratified mineral has been shown to increase water buffering capacity, retain P, buffer substrate solution pH, and result in increased plant micronutrient content when used to amend pine bark based substrate at 8 to 12% (by vol.) (Owen, 2006). In addition, Owen (2006), utilizing X-ray near edge surface (XANES) spectroscopy determined that calcium phosphate minerals were present in the Georgiana clay aggregate and these minerals release P at the low pH which is maintained in soilless substrates. It is hypothesized that the dissolution rate of P from these minerals into the substrate bulk solution may be adequate to maximize growth of nursery crops. This would reduce the need for P fertilization. In turn, this reduction in P fertilization could reduce dissolved reactive phosphorus leaching from containerized production improving water quality by decreasing incidence of eutrophication. The objective of this study was to determine if a Georgiana palygorskite-bentonite clay amended pine bark substrate could provide adequate plant-available P and potassium to sustain maximum growth of nursery crops in containerized production.

MATERIALS AND METHODS

Two studies were conducted. The experiment design of both studies was a randomized complete block design with four replications with three plants per replication. The experiments were conducted at the Horticulture Field Lab. (lat. 35°47'37", long. -78°41'59"), North Carolina State University, Raleigh, USA. Rooted stem cuttings of *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' were potted into 14 L containers (C-2000, Nursery Supplies Inc., Chambersburg, PA, USA) on 5 May 2005 (study A) and 20 June 2005 (study B) using pine bark amended with 9 and 11% (by vol.), respectively, 0.25 to 0.85 mm (24/48 standard U.S. mesh), LVM palygorksite-bentonite blended-industrial-mineral aggregate (Moll and Goss, 1997) from Ochlocknee, GA, USA (Oil-Dri Corp. of America, Chicago, IL). Four fallow (unplanted) containers of each substrate were placed adjacent to the plants in each replication and received equivalent rainfall and irrigation. Containers in both experiments were top-dressed on 21 June 2005 with 14 g nitrogen (N) using complete (58 g 24-8-16), incomplete (47 g 30-0-14), or single (41 g 41-0-0) six month controlled-release fertilizer (CRF), (Harrell's, Lakeland, FL, USA). The substrates potted on 5 May 2005 (study A) and 20 June 2005 (study b) were amended with 0.9 and 1.2 kg m^{-3} ground dolomitic limestone [$CaMg(CO_3)_2$] and 0.7 and 0.9 kg m^{-3} Micromax, micronutrient package (The Scotts Company Inc, Maryville,. OH, USA), respectively. Two containers of each treatment were placed on 12 separate plots. Effluent volume was measured weekly from irrigation water that was applied via pressure compensated spray stakes [Acu-Spray Stick; Wade Mfg. Co., Fresno, CA (200 ml $min.^{-1}$)]. Irrigation was applied in a cyclic manner, with the irrigation volume divided equally among three applications at 1200, 1500, and 1800 HR EST. Irrigation volume (influent) was applied to each plant to maintain a 0.25 leaching fraction (LF = irrigation water leached ÷ irrigation water applied).

Substrate-solution extracts were obtained during the study to monitor substrate solution pH and P concentration. Substrate solution was collected by displacing 50 ml of solution with 600 ml of deionized water after the second daily irrigation application at 1500 HR using the pour thru method Eastern Standard Time (EST). Substrate solution pH measurements were obtained using an Acument pH/eV benchtop meter (Fischer Scientific, Springfield, N.J.) and frozen immediately. Substrate solution P concentration was determined by inductively coupled plasma-optical emission spectroscopy [(ICP-OES) (model HR-1000 DUO, ThermoElemental, Madison, Wisconsin) according to U.S. EPA Method 6010B (USEPA, 1997).

On 28 September 2005, tops from two randomly chosen containers from each replication (total of eight plants per treatment) were removed. Roots were placed over a screen and washed with a high-pressure water stream to remove substrate. Recently expanded mature leaves were removed prior to drying to determine mineral nutrient concentration. Leaf samples, tops, and roots were dried at 65°C for 5 days and weighed. Root : top ratio (RTR) was calculated as root dry weight ÷ top dry weight. Leaf samples were ground using a Foss Tecator Cyclotec™ 1093 sample mill (Analytical Instruments, LLC, Golden Valley, MN) to pass ≤0.5 mm sieve. Leaf samples were analyzed for N, P, K, Ca, Mg, and S concentration by the North Carolina Department of Agriculture, Agronomic Division, Raleigh.

At experiment initiation, five 347.5 cm^3 cores (7.6 cm height × 7.6 cm diameter) and five 100 cm^3 cores, (2.5 cm height × 7.6 cm diameter) were placed in four fallow (unplanted) containers of each substrate. These containers were placed adjacent to the plants in the research study and received equivalent irrigation and rainfall as the corresponding treatment. After 9 weeks, the 347.5 cm^3 cores were extracted and total porosity (TP), container capacity (CC), available water capacity (AW), and air filled porosity (AS) were determined using the NCSU Porometer™ as described by Fonteno and Bilderback (1993). Unavailable water (UW), water held in the substrate at ≥1.5 MPa, was determined with the 100 cm^3 cores via a procedure developed by Milks et al. (1989). Bulk density (D_b) was determined using oven dried (110°C) substrate in the 347.5 cm^3 cores.

All data were subjected to analysis of variance (PROC GLM, SAS Institute Inc., Cary, NC) with a $P\leq0.10$ to reduce the risk of a Type II error (Marini, 1999). Treatment comparisons between fertilizers were made by Fisher's Protected LSD, $P=0.05$.

RESULTS AND DISCUSSION

Studies A and B had similar substrate physical properties (Table 1). The greatest difference was in AW, which decreased 5% in the second trial (B). The pine bark used in study B was less aged than the pine bark used in study A which has been shown to affect AW capacity (Bilderback et al., 2005).

Season long average substrate solution pH was 5.95±0.04 SE and 5.60±0.11 SE for study A and B, respectively (data not presented). Substrate solution pH responded similarly to the CRFs in both studies except for study B where the pH increased 0.4 unit when using a single nutrient CRF (N only) compared to a complete CRF. However substrate pH remained in adequate range (below 6.5) throughout the duration of both studies (Yeager et al., 2007).

Maximum top growth of Skogholm cotoneaster was achieved with NK in both studies. However, in study B top growth produced with NPK was similar (Table 2). Growth was unaffected in the absence of only P in both studies. Top growth was reduced 20% when fertilized with N only, regardless of trial. In study B, root dry weight increased 45 and 32%, respectively when fertilized with NK and NPK compared to N alone, whereas root dry weight was unaffected by CRF in study A. Root to shoot ratio was unaffected by fertilizer treatment in either study.

Foliar N concentration increased an average of 16 and 8% in studies A and B, respectively, when Skogholm cotoneaster was fertilized with N only compared to NK or the complete fertilizer regardless of study (Table 3). Similarly, foliar P increased an average of 13 and 16%, in study A and B, respectively, when Skogholm cotoneaster was fertilized with N only compared to NK or the complete fertilizer regardless of study. A similar trend was also seen with other macronutrients, Ca, Mg, and S, in study A. Calcium and Mg were 27 and 29%, respectively greater when not receiving P or K fertilization, whereas S was 10% greater. An inverse trend was seen with K foliar concentration which decreased ≥32% in the absence of K fertilization (Table 3). The decreased K foliar concentration resulted in decreased Skogholm cotoneaster growth indicating K was possibly the limiting factor. This agrees with Yeager et al. (2007) who suggest woody plant foliar K concentrations between 1.5 and 2.0% (dry wt.). In both studies foliar K foliar concentration of Skogholm cotoneaster was 1.1% (dry wt.).

Substrate solution P concentration decreased in the absence of P fertilization in both studies (Table 4). Phosphorus substrate solution concentration decreased ≥90% (4 mg L^{-1}) at the initiation of either study (June) and remained ≈1 to 2 mg L^{-1} near the end of the studies in late September. On average substrate solution concentration was reduced 1-fold (100%) resulting in a 2.5 mg L^{-1} reduction in effluent P concentration. Without P fertilization the substrate containing the industrial mineral was able to maintain an initial and final substrate solution concentration of 4 and 1.8 mg L^{-1} (Table 4). Warren et al. (1995) reported resin-coated CRF P maintained a low, constant rate of P loss at approximately 1 mg day^{-1} which was sufficient to maximize growth of Rhododendron 'Sunglow' (Carla hybrid) grown in a 3.8 L container using a pine bark-based substrate. Lea-Cox and Ristvey (2003) suggested containerized P application be reduced 80%, thus making the optimal substrate solution P concentration ≤2 mg L^{-1}. Therefore, it is likely that the clay mineral aggregate was able to provide adequate P to maximize plant growth

CONCLUSION

Georgiana Palygorskite-bentonite can supply adequate P, but not K, to sustain maximum crop growth of Skogholm cotoneaster in a pine bark based soilless substrate.

Foliar P concentration did not decrease in the absence of P, however foliar K concentration decreased when N only was used.

ACKNOWLEDGEMENTS

Research was funded in part by USDA-ARS Floriculture and Nursery Initiatives grants (SCA #58-6618-2-2027) and Horticulture Research Institute, and Oil-Dri Corporation of America. We would like to gratefully acknowledge William Reece for technical assistance.

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Tables

Table 1. Physical properties of pine bark substrates amended with 9% and 11% (by vol.) 0.25 to 0.85 mm Georgiana palygorskite-bentonite clay aggregate used in study A and B, respectively, to grow Skogkolm cotoneaster until 28 Sept 2005.

Study[z]	Physical properties (% vol.)				Bulk density (g cm^{-3})
	Total porosity[y]	Air space[x]	Container capacity[w]	Available water[v]	
A	83[u]	24	59	35	0.28
B	82	23	58	30	0.26

[z]Study A and B were potted on 5 May and 20 June 2005, respectively.
[y]Percent volume at 0.4 kPa.
[x]Air space = total porosity – container capacity.
[w]Predicted as percent volume at drainage.
[v]Available water = container capacity – percent volume of water at 1500 kPa.
[u]Each mean is based on 4 observations.

Table 2. Skogkolm cotoneaster dry weight when receiving 14 g N per 14 L container using a complete (NPK), incomplete (NK), or single nutrient (N) controlled release fertilizer.

Treatment	Dry weight (g)		Root:shoot ratio[z]
	Shoot	Root	
Study A[y]			
N	184.2 c[x]	19.9	0.11
NK	230.6 a	24.1	0.11
NPK	205.7 b	23.0	0.11
P value	0.01	0.48	0.93
Study B			
N	116.8 b	10.9 b	0.09
NK	144.7 a	16.0 a	0.11
NPK	144.1 a	12.1 b	0.09
P value	0.02	0.01	0.17

[z]Root dry weight ÷ top dry weight.
[y]Study A and B were potted on 5 May and 20 June 2005, respectively.
[x]Means within a row not followed by the same letter are significantly different as determined by Fishers LSD, P=0.05. Each mean is based on 6 observations.

Table 3. Foliar concentration of recently mature Skogkolm cotoneaster leaves when receiving 14 g N per 14 L container on 21 June 2005 using a complete (NPK), incomplete (NK), or single nutrient (N) controlled release fertilizer.

Treatment	Foliar concentration ($mg\ g^{-1}$)					
	N	P	K	Ca	Mg	S
Study A[z]						
N	31.8 a[y]	2.2 a	10.8 b	12.2 a	5.3 a	1.6 a
NK	27.4 b	1.9 b	16.2 a	9.6 b	4.1 b	1.4 b
NPK	27.5 b	2.0 b	15.8 a	9.6 b	4.1 b	1.5 ab
P value	0.001	0.001	0.001	0.001	0.001	0.002
Study B						
N	31.8	2.5 a	10.8 b	10.4	5.1	1.8
NK	29.6	2.1 b	16.3 a	9.3	4.3	1.6
NPK	29.3	2.2 b	19.4 a	8.2	4.3	1.6
P value	0.27	0.03	0.01	0.13	0.09	0.06

[z]Study A and B were potted on 5 May and 20 June 2005, respectively.
[y]Means within a row not followed by the same letter are significantly different as determined by Fishers LSD, P=0.05. Each mean is based on 6 observations.

Table 4. Substrate phosphorus concentration of a clay amended pine bark soilless substrate receiving 14 g N per 14 L container on 21 June 2005 using a complete (NPK), incomplete (NK), or single nutrient (N) controlled release fertilizer to grow Skogkolm cotoneaster.

Treatment	P substrate solution concentration ($mg\ L^{-1}$)[z]			
	Jul 12	Jul 29	Sep 8	Sep 23
Study A[y]				
N	4.6±1.5 b[x]	5.8±0.3	2.0±0.2 b	1.4±0.0 b
NK	4.4±0.6 b	4.5±0.5	1.8±0.4 b	1.1±0.1 b
NPK	8.5±0.3 a	5.3±0.6	4.8±0.4 a	3.4±0.8 a
Study B				
N	3.1±0.3 b	2.9±0.4	2.4±0.3 b	2.2±0.4
NK	4.2±1.1 b	3.4±0.3	2.1±0.2 b	1.9±0.1
NPK	9.3±1.8 a	4.1±0.5	5.9±0.4 a	4.0±1.3

[z]Substrate solution was collected via the pour-thru method by displacing 50 ml of solution with 600 ml of deionized water after the second daily irrigation application at 1500 HR EST.
[y]Study A and B were potted on 5 May and 20 June 2005, respectively.
[x]Means within a row (date) not followed by the same letter are significantly different as determined by Fishers LSD, P=0.05. Each mean ± standard error is based on 6 observations.