Mineral Nutrition of *Adenium obesum* ‘Red’

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Abstract. *Adenium obesum* (Forssk.), Roem. & Schult. has been increasingly produced as a flowering potted plant; however, there is no information regarding its tissue mineral composition. This study evaluated plant performance of *A. obesum* ‘Red’ grown in two container sizes and under four rates of a controlled-release fertilizer. Nutrient concentrations in flowers, leaves, stems, and roots were analyzed. Results showed that canopy height and width, stem caliper, top and root dry weights, and average flower count of *A. obesum* ‘Red’ increased linearly with the increased rate of fertilizer regardless of pot size. Tissue analysis indicated that nitrogen (N), phosphorus (P), and potassium (K) concentrations were lower in all organs compared with those reported for other ornamental potted plants such as *Bouvardia* Salisb., *Euphorbia* L., *Rhododendron* L., and *Rosa* L. The lower levels of tissue N and P accompanied with higher dry matter accumulation suggest that *A. obesum* ‘Red’ is efficient in use of N and P. The low tissue K levels were largely attributed to sodium (Na) substitution for K. Leaf K and Na concentrations were almost equal except at the highest fertilizer treatment in 1.25-L pots and the last two higher treatments in 3.0-L pots. The levels of other mineral elements were comparable to those of other reported ornamental potted plants. To produce high-quality plants in 1.25-L pots, *Adenium* ‘Red’ should be fertilized with 1.08 g N per liter of potting mix. For plants grown in 3.0-L pots, N rates of 0.36 g or 0.72 g per liter of potting mix would be recommended with a preference for 0.36 g.

Adenium obesum, commonly referred to as desert rose, is a relatively new flowering plant in the ornamental plant industry (McBride et al., 2014). Desert rose is a member of the dogbane family, Apocynaceae, and is native to Africa, south of the Sahara from Senegal to Sudan and Kenya, and through Saudi Arabia, Oman, and Yemen (Plaizier, 1980). As a result of its wide range of flower color among cultivars, attractive sculptural caudex and roots, and drought tolerance (Rowley, 1987), desert rose has been increasingly produced as flowering potted plants and as landscape plants in tropical and subtropical regions (Dimmitt et al., 2009).

Increasing desert rose production, however, has not been accompanied by science-based information as to how environmental and cultural factors affect the growth and flowering of this species. McBride et al. (2014) reported that best quality and highest flower number for *A. obesum* ‘Red’ and ‘Ice Pink’ could be achieved by production under light intensity of 1255 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. If plants were produced in 1.25-L pots, a nutritional regime

of N at either 0.9 or 1.4 g per pot from a controlled-release fertilizer should be provided. Poorest plant quality ratings occurred at a N level of 0.4 g per pot regardless of production light levels (McBride et al., 2014).

Tissue mineral compositions are the basis of studying plant requirements for nutrient elements (Marschner, 2012). Although there were some reports about fertilizer application to plants within the family Apocynaceae such as *Plumeria rubra* L. (Huante et al., 1995), *Mandevilla* Lindl. (Deneke et al., 1992), and *Dipladenia sanderi* (Hemsl.) Woodson (Plaza et al., 2009) as well as *A. obesum* (Dimmitt, 1998; McBride et al., 2014), none of these reports presented mineral compositions in plant tissues. With increased awareness for sustainable production of nursery crops, a better understanding of nutrient requirements is essential for developing the best nutrient management practices for plant production (Chen et al., 2001; Majsztrik et al., 2011).

To determine mineral compositions of *A. obesum*, this study evaluated plant performance of *A. obesum* ‘Red’ fertilized with a controlled-release fertilizer at four N rates in 1.25-L (15.2-cm diameter) and 3.0-L pots (20.3-cm diameter), respectively; analyzed nutrient concentrations in flowers, leaves, stem, and roots; and documented nutrient requirements of this cultivar. It is anticipated that tissue mineral compositions obtained from this cultivar could provide insight into the nutrition of this species.

Rooted stem cuttings of *A. obesum* ‘Red’ produced in 50-cell trays were transplanted singly to 48 1.25-L and 48 3.0-L azalea pots filled with Fafard 2 mix (65% peat, 20% perlite, and 15% vermiculite by volume; Conrad Fafard Inc., Agawam, MA). At the time of potting on 25 July, 2011, terminal shoot tips on each liner were removed to promote branching. Potted plants were hand-watered as needed and topdressed with a controlled-release fertilizer: Nutricote Total (18N–6P₂O₅–8K₂O with micronutrients, 140 d; Chisso-Asahi Fertilizer Co., Ltd., Tokyo, Japan) at 2, 4, 6, or 8 g (0.36, 0.72, 1.08, or 1.44 g N) per liter of potting mix, which equaled 2.5, 5.0, 7.5, or 10.0 g of the Nutricote per 1.25-L pot and 6.0, 12.0, 18.0, or 24.0 g per 3.0-L pot. In addition to N, P, and K, the controlled-release fertilizer also contained 1.2% water-soluble magnesium (Mg); 0.02% boron (B); 0.05% copper (Cu); 0.2% iron (Fe); 0.06% water-soluble manganese (Mn); and 0.02% molybdenum. The plants were arranged in a randomized complete block design with 12 replications in a greenhouse covered with a clear double polyethylene roof under a mean light intensity of 1255 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with a natural photoperiod. Temperatures in the greenhouse ranged from 20 to 32 °C and relative humidity varied from 50% to 100%.

To monitor substrate soluble salts and pH, root-zone solutions were collected every 3 weeks from three randomly selected pots of each treatment using the pour-through method (Wright, 1986). Solution soluble salts were measured using a Corning Conductivity Meter (Corning Inc., Corning, NY). The pH of the same solution was determined using an Accumet Basic pH Meter (Model No. AB15; Fisher Scientific, Hanover Park, IL).

The majority of plants had their flower opening on 19 Sept. 2011 at which time weekly flower counts were started and continued until the experiment was ended on 15 Dec. 2011. Final data collections consisted of canopy height and widths (the widest canopy width and the width perpendicular to the widest width), the largest leaf length and width, stem caliper at the soil line, final weekly flower number, root and top dry weights, and visual plant quality rating. Stem caliper was measured with a Vernier Caliper (General Tools Manufacturing, New York, NY). Plants were graded visually for overall quality (growth form and vigor, leaf greenness, and flower numbers and color) based on the following scale: 1 = poor; 2 = fair; 3 = saleable; 4 = good; and 5 = excellent (Chen et al., 2003; McBride et al., 2014). The plant top was harvested by cutting the stem at the potting mix line and manually divided into its leaf, flower, and stem components, which were then placed separately into brown paper bags for oven drying in a TD Vac Dryer (Heat Pipe Technology, Gainesville, FL) at 73 °C for 2 weeks. Roots were removed from the pots, and the potting mix was washed off. Cleaned roots were allowed to air-dry for 1 to 2 h and then placed into brown paper bags for

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oven-drying. Root dry weight was recorded. Final top dry weight was determined by combining the weights of leaves, flowers, and stems. Total dry weight was the final top dry weight plus root dry weight.

For analysis of mineral elements in plant tissues, dried flowers, leaves, stems, and roots were taken from three randomly selected plants of each treatment. Dried tissue was ground in a stainless steel Wiley Mill Grinder (Arthur H. Thomas Co., Philadelphia, PA) to pass through a 60-mesh screen. Mineral elements N, P, K, calcium (Ca), Mg, sulfur (S), Fe, Mn, Cu, zinc (Zn), and Na in the flowers, leaves, stems, and roots of *A. obesum* 'Red' were analyzed by Midwest Laboratories, Inc. (Omaha, NE). To determine N use efficiency (NUE) (Fageria et al., 2008), total dry weight (g) was divided by the amount (g) of N applied per liter of potting mix.

Effects of fertilizer rates on plant growth and tissue element concentrations were determined by analysis of variances according to the general linear model procedures of Statistical Analysis System (SAS Institute, Inc., Cary, NC). Linear models between total dry weight and N rate or NUE and N rate were developed through regression and correlation analyses.

Results

Soluble salts of root-zone solutions measured by a conductivity meter increased

curvilinearly with the increased rates of fertilizer regardless of pot size (data not shown). For example, as the rate increased, mean soluble salt readings increased from 254.6 to 1404.4 $\mu\text{S}\cdot\text{cm}^{-1}$ in 1.25-L pots and 530.9 to 2671.3 $\mu\text{S}\cdot\text{cm}^{-1}$ in 3.0-L pots 20 weeks after transplanting. The higher soluble salts in 3.0-L pots could be attributed to the higher amount of fertilizer per pot. The pH of root-zone solutions across treatments ranged from 6.82 to 7.19 in 1.25-L pots and 6.21 to 7.29 in 3.0-L pots.

Canopy heights and widths and stem caliper diameters of *A. obesum* 'Red' grown in 1.25-L pots increased linearly with the increased rates of fertilizer (Table 1). Top dry weights also linearly increased from 15.5 to 39.8 g, and root dry weights increased from 8.2 to 17.3 g. Average weekly flower count increased from 4.6 to 11.5 as the fertilizer rate increased. Overall quality of plants produced at the lowest fertilizer rate was 3.1, whereas quality of plants produced with the other rates was 4.0 or higher. There were no significant differences in leaf length and width of the largest leaf regardless of fertilizer rates. Canopy widths, top dry weights, and flower counts of plants grown in 3.0-L pots increased in a linear fashion with the increased rates of fertilizer (Table 1). Canopy height and root dry weight were increasingly higher as the fertilizer rates increased from 2 to 6 g per liter of potting mix. At the highest rate, however, canopy height and root dry weight

were either slightly lower or showed no change compared with those at 6 g per liter of potting mix. Overall plant quality ratings of plants grown in 3.0-L pots were 4.2 or higher. Plants fertilized with 4 g of fertilizer per liter of potting mix had a caliper of 3.4 cm, the highest. Again, no differences were observed in leaf length and width of the largest leaf regardless of fertilizer rate for those grown in 3.0-L pots.

Mineral elements of N, P, K, Ca, Mg, S, Na, Fe, Mn, B, Cu, and Zn in flowers of *A. obesum* 'Red' were analyzed (Table 2). Concentrations of N, P, and K had rather narrow ranges, 1.4% to 1.6% for N, 0.19% to 0.23% for P, and 2.09% to 2.54% for K, regardless of the fertilizer rate and pot size. Fertilizer rates did not result in significant differences in any of the analyzed elements in flowers except for Na, which increased from 0.17% to 0.74% for plants grown in 1.25-L pots and 0.1% to 0.71% for those grown in 3.0-L pots.

The concentrations of N, P, K, S, Na, and Fe in leaves of plants grown in 1.25-L pots varied significantly, but the other elements were not significantly different by fertilizer rates (Table 3). For plants grown in 3.0-L pots, leaf concentrations of N increased linearly with fertilizer rate increase; leaf P in plants treated with 2 and 4 g of fertilizer were the same but different from those treated with 6 and 8 g of fertilizer. Leaf Na significantly decreased as the fertilizer rate

Table 1. Effect of four rates of a controlled-release fertilizer Nutricote Total (18N–2.6P–6.6K, 140-d formulation) on plant performance of *A. obesum* 'Red' grown in 1.25-L and 3.0-L pots for ≈ 20 weeks.

Pot size (L)	Fertilizer (g·L ⁻¹)	Canopy ht (cm)	Canopy width (cm)	Caliper (cm)	Leaf length (cm)	Leaf width (cm)	Top DW (g)	Root DW (g)	Mean flower (no.) ^z	Quality (1–5) ^y
1.25	2	19.8	24.9	2.1	8.9	2.1	15.5	8.2	4.6	3.1
	4	23.5	34.5	2.3	9.0	2.3	28.1	12.5	7.5	4.0
	6	25.1	37.7	2.4	8.5	2.0	35.3	13.4	9.8	4.6
	8	25.8	40.5	2.7	9.0	2.1	39.8	17.3	11.5	4.3
	Significance ^x	L**	L**	L**	NS	NS	L**	L**	L**	L*
3.00	2	25.6	35.8	2.6	8.2	1.9	38.7	15.4	10.3	4.2
	4	27.1	45.4	3.4	8.7	2.0	60.6	19.3	19.1	4.7
	6	29.3	47.5	3.2	8.6	2.0	67.4	20.7	23.2	4.6
	8	28.3	52.4	3.2	8.8	2.1	75.2	20.5	24.5	4.3
	Significance	L**	L**	L**	NS	NS	L**	L**	L**	L*

^zAverage weekly flower count.

^yVisual quality rating where 1 = poor; 2 = fair; 3 = saleable; 4 = good; and 5 = excellent (McBride et al., 2014).

^xRegression analysis where NS, L*, and L** indicate nonsignificant and linear significance at 0.05 and 0.01 levels, respectively.

DW = dry weight.

Table 2. Mineral element concentrations in flowers of *A. obesum* 'Red' after plants were grown in 1.25-L and 3.0-L pots fertilized with four rates of Nutricote Total (18N–2.6P–6.6K, 140-d formulation) for ≈ 20 weeks.

Pot size (L)	Fertilizer (g·L ⁻¹)	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Sodium	Iron	Manganese	Boron	Copper	Zinc
		(%)							(mg·kg ⁻¹)				
1.25	2	1.4	0.19	2.20	0.36	0.24	0.15	0.17	31.7	18.3	20.7	9.7	20.0
	4	1.6	0.19	2.09	0.36	0.24	0.15	0.12	32.0	24.3	22.7	10.0	20.0
	6	1.6	0.20	2.21	0.33	0.23	0.16	0.86	28.0	23.7	22.7	9.3	17.7
	8	1.6	0.21	2.35	0.33	0.24	0.16	0.74	32.3	25.3	22.7	8.3	18.0
	Significance ^z	NS	NS	NS	NS	NS	NS	L**	NS	NS	NS	NS	NS
3.00	2	1.5	0.20	2.40	0.35	0.25	0.16	0.10	32.0	27.3	25.3	8.7	16.0
	4	1.5	0.21	2.27	0.32	0.24	0.15	0.76	28.3	23.7	20.7	6.7	18.0
	6	1.5	0.23	2.33	0.31	0.24	0.15	0.60	32.0	23.3	21.3	6.7	21.7
	8	1.5	0.22	2.54	0.31	0.26	0.16	0.71	29.3	21.3	21.3	5.7	16.7
	Significance ^z	NS	NS	NS	NS	NS	NS	L*	NS	NS	NS	NS	NS

^zRegression analysis where NS, L*, and L** indicate nonsignificant and linear significance at 0.05 and 0.01 levels, respectively.

increased. Other elements were not significantly different among fertilizer rates. Compared with the concentrations of analyzed elements in flowers, N on average increased more than 20%, Ca increased more than 3.5-fold, Mg increased 2.5-fold, S increased greater than 40%, and Mn increased over 2.8-fold, but P and K decreased 50% and 75%, respectively, in leaves.

As the fertilizer rate increased, N concentrations in stem tissue increased linearly but Na concentrations decreased for plants grown in 1.25-L pots (Table 4). Concentrations of K, Mg, and B differed among treatments, but no consistent trend could be identified. Concentrations of other elements in stem tissue did

not significantly differ among fertilizer treatments. As to plants grown in 3.0-L pots, N and K concentrations in stems increased linearly; Ca and Mg levels also varied significantly by fertilizer rates. Other elements in stem tissue were not significantly different with increasing fertilizer rates.

Root N, K, and S concentrations of plants grown in 1.25-L pots linearly increased with fertilizer rate increase (Table 5). The concentrations of B in roots were variable quadratically. The other elements were not significantly different among treatment. For plants grown in 3.0-L pots, N, K, S, and B concentrations in roots significantly differed linearly by the fertilizer rates. Calcium

concentrations varied both quadratically and cubically. The other elements in roots were not apparently different by treatment. Iron concentrations in roots of plants grown in both pot sizes regardless of fertilizer rate were at least 3-fold higher than those in flower, leaf, and stem tissues.

With the increased rates of N, total dry weights linearly increased from 23.7 to 57.1 g for plants grown in 1.25-L pots and 54.1 to 95.7 g for those grown in 3.0-L pots, and correlation coefficients were 0.96 and 0.90, respectively (Fig. 1). However, NUE linearly decreased from 65.8 to 39.7 or 50.1 to 22.2 for plants growing in 1.25-L or 3.0-L pots and their correlation coefficients were 0.98 and

Table 3. Mineral element concentrations in leaves of *A. obesum* 'Red' after plants were grown in 1.25-L and 3.0-L pots fertilized with four rates of Nutricote Total (18N-2.6P-6.6K, 140-d formulation) for ≈ 20 weeks.

Pot size (L)	Fertilizer (g·L ⁻¹)	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Sodium	Iron	Manganese	Boron	Copper	Zinc
		----- (%) -----							----- (mg·kg ⁻¹) -----				
1.25	2	1.7	0.09	0.69	1.40	0.85	0.21	0.78	29.0	70.0	43.3	5.0	11.0
	4	2.1	0.09	0.40	1.50	0.80	0.24	0.47	39.0	91.3	40.3	6.0	11.0
	6	2.1	0.10	0.47	1.50	0.91	0.23	0.46	33.3	104.0	45.0	5.3	10.0
	8	2.3	0.11	0.46	1.70	0.91	0.26	0.35	45.3	121.0	45.3	6.0	9.7
	Significance ^z	L**	L**	L* Q*	NS	NS	L**	L**	L** C**	NS	NS	NS	NS
3.00	2	2.1	0.10	0.61	1.70	0.91	0.24	0.55	42.3	102.0	40.7	5.0	9.3
	4	2.2	0.10	0.50	1.50	0.87	0.23	0.41	38.7	102.7	37.7	4.7	8.7
	6	2.3	0.12	0.60	1.60	0.86	0.26	0.35	42.7	130.7	44.3	4.3	9.0
	8	2.4	0.12	0.70	1.50	0.84	0.25	0.36	51.0	113.0	43.3	5.0	9.0
	Significance ^z	L**	L**	NS	NS	NS	NS	L** Q**	NS	NS	NS	NS	NS

^zRegression analysis where NS, L*, L**, Q*, Q**, and C** indicate nonsignificant, linear significance at 0.05 and 0.01 levels, quadratic significance at 0.05 and 0.01 levels, and cubic significance at the 0.01 level, respectively.

Table 4. Mineral element concentrations in stems of *A. obesum* 'Red' after plants were grown in 1.25-L and 3.0-L pots fertilized with four rates of Nutricote Total (18N-2.6P-6.6K, 140-d formulation) for ≈ 20 weeks.

Pot size (L)	Fertilizer (g·L ⁻¹)	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Sodium	Iron	Manganese	Boron	Copper	Zinc
		----- (%) -----							----- (mg·kg ⁻¹) -----				
1.25	2	1.3	0.10	1.20	1.10	0.80	0.17	0.62	44.7	18.7	31.0	8.7	39.3
	4	1.6	0.10	0.68	1.10	0.59	0.17	0.62	44.7	25.0	27.7	8.3	32.7
	6	1.8	0.11	0.93	0.93	0.52	0.19	0.39	32.3	27.0	27.7	8.3	27.3
	8	2.0	0.13	1.00	0.89	0.53	0.23	0.37	29.7	28.0	28.3	8.3	27.3
	Significance ^z	L**	NS	Q* C*	NS	L* Q*	NS	L**	NS	NS	L** Q**	NS	NS
3.00	2	1.6	0.11	1.00	1.00	0.77	0.23	0.46	29.0	27.7	26.3	8.0	29.7
	4	1.7	0.11	1.10	0.81	0.57	0.22	0.38	38.3	27.7	26.0	8.0	32.0
	6	1.9	0.15	1.30	0.71	0.56	0.25	0.34	25.3	21.7	25.0	8.0	24.0
	8	2.2	0.15	1.60	0.75	0.56	0.27	0.35	33.0	25.7	27.7	8.3	22.7
	Significance ^z	L**	NS	L** Q*	L** Q*	L** Q*	NS	NS	NS	NS	NS	NS	NS

^zRegression analysis where NS, L*, L**, Q*, Q**, and C* indicate nonsignificant, linear significance at 0.05 and 0.01 levels, quadratic significance at 0.05 and 0.01 levels, and cubic significance at the 0.05 level, respectively.

Table 5. Mineral element concentrations in roots of *A. obesum* 'Red' after plants were grown in 1.25-L and 3.0-L pots fertilized with four rates of Nutricote Total (18N-2.6P-6.6K, 140-d formulation) for ≈ 20 weeks.

Pot size (L)	Fertilizer (g·L ⁻¹)	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Sodium	Iron	Manganese	Boron	Copper	Zinc
		----- (%) -----							----- (mg·kg ⁻¹) -----				
1.25	2	1.3	0.12	1.40	0.45	0.66	0.16	1.20	310.3	24.7	18.0	10.3	24.0
	4	1.7	0.14	1.80	0.39	0.66	0.19	0.93	264.3	21.7	16.0	8.7	19.7
	6	2.1	0.16	2.10	0.39	0.68	0.22	1.00	222.7	20.3	16.7	9.0	22.7
	8	2.2	0.16	2.20	0.48	0.84	0.25	0.90	413.7	28.3	18.0	11.0	25.0
	Significance ^z	L**	NS	L**	NS	NS	L**	NS	NS	NS	Q**	NS	NS
3.00	2	1.7	0.14	1.90	0.47	0.75	0.19	1.00	395.7	33.7	16.0	11.0	24.0
	4	1.9	0.19	2.70	0.29	0.89	0.25	0.79	139.7	14.3	14.0	7.0	23.7
	6	2.3	0.23	2.50	0.42	0.86	0.25	0.74	260.7	20.7	18.7	9.7	21.0
	8	2.8	0.26	3.30	0.43	1.12	0.30	0.90	148.0	27.0	20.7	9.3	21.3
	Significance ^z	L**	NS	L**	Q* C*	NS	L**	NS	NS	NS	L**	NS	NS

^zRegression analysis where NS, L**, Q*, Q**, and C* indicate nonsignificant, linear significance at the 0.01 level, quadratic significance at 0.05 and 0.01 levels, and cubic significance at the 0.05 level, respectively.

Fig. 1. Total dry weight (g) or nitrogen use efficiency (NUE) of *A. obesum* 'Red' as a function of nitrogen (N) rate provided by a controlled-release fertilizer, Nutricote Total (18N–6P₂O₅–8K₂O) when plants were grown in 1.25-L (A) or 3.0-L pot (B) for ≈20 weeks.

0.96, respectively. The line of total dry weight increase crossed the line of NUE at the N rate of 1.08 g for plants grown in 1.25-L pots. For plants grown in 3.0-L pots, the two lines were closest at the N rate of 0.36 g.

Discussion

This is the first report of nutrient concentrations in flowers, leaves, stems, and roots of an *Adenium* cultivar. Nitrogen ranged from 1.3% to 2.8%, P from 0.09% to 0.26%, and K from 0.4% to 3.3% across the tested tissues (Tables 2 to 5). Considering the fact that leaf tissue is commonly used for diagnosis of plant nutrient status (Marschner, 2012), leaf N (1.7% to 2.4%), P (0.09% to 0.12%), and K (0.46% to 0.70%) in *Adenium* (Table 3) are lower than those of other ornamental plants such as *Bouvardia* Salisb., *Euphorbia* L., *Rhododendron* L., and *Rosa* L. where N, P, and K are much greater than 2%, 0.2%, and 2%, respectively (Santos et al., 2011; Sonneveld and Voogt, 2009; Tamimi et al., 1999). This characteristic is probably related to the edaphic niches of its origination. As mentioned, *A. obesum* originated from desert environments where soil nutrient levels were likely lower. Adaptation to the low nutrient environment could result in plant tissue having low nutrient contents (Chen and Gabelman, 1995). However, when cultivated with a sufficient nutrient supply, *A. obesum* growth (dry weight) linearly increased (Fig. 1),

suggesting that *A. obesum* could actually be a nutrient use-efficient plant species. For example, NUE ranged from 65.8% to 39.7% in 1.25-L pots and 50.1% to 22.2% in 3.0-L pots (Fig. 1) when grown with increasing rates of the controlled-release fertilizer.

Another characteristic of *Adenium* nutrition is Na substitution for K. Flower tissue maintained K within a narrow range of 2.09% to 2.54%, where Na concentration varied from 0.1% to 0.86% (Table 2). However, K in leaf tissue ranged between 0.40% and 0.70% and Na varied from 0.35% to 0.78% (Table 3). In fact, leaf K and leaf Na contents were almost equal except at the highest fertilizer treatment in 1.25-L pots and the two higher treatments in 3.0-L pots. The ratios of K to Na in stem and root tissues ranged from 1.5 to 2.7 and 1.16 to 3.7, respectively. As mentioned previously, plants were fertilized with 2, 4, 6, or 8 g of Nutricote Total (18N–6P₂O₅–8K₂O) per liter of potting mix; the corresponding K rates were 0.13, 0.25, 0.37, or 0.5 g. Under such an increased rate of K, the high levels of Na in plant tissues strongly suggest that Na can partially substitute K in *Adenium*. Wakeel et al. (2011) reported partial replacement of K by Na in a group of plant species including barley (*Hordeum vulgare* L.), beet (*Beta vulgaris* L.), and tomato (*Solanum lycopersicum* L.). It is unknown if Na is essential to *A. obesum*. The ability to transport and accumulate Na in high concentrations

in flowers, leaves, stems, and roots suggests that Na is a beneficial element to *A. obesum*.

To produce plants in 1.25-L pots, 1.08 g N per liter of potting mix is the optimal rate (Fig. 1). This rate equals to 1.35 g N per 1.25-L pot, which is within the range of 0.9 to 1.4 g suggested by McBride et al. (2014). *Adenium* 'obesum' 'Red' produced at this rate had a total dry weight of 48.7 g, an overall quality of 4.6, and NUE of 45.1%. For producing *Adenium* 'Red' in 3.0-L pots, a preferred N rate would be 0.36 g (1.08 g N per 3.0-L pot) because this rate resulted in plants with an overall quality of 4.2 and NUE as high as 50.1%, which satisfies the current trend in ornamental production of both marketability and sustainability (Chen et al., 2005; Majsztrik et al., 2011). From an ornamental point of view, a compromise of NUE, 0.72 g N per liter of potting mix (2.16 g N per 3.0-L pot) could be an acceptable rate. The drawback at this rate was an NUE at 37%, but plants produced at this rate had a dry weight of 79.9 g, quality reading of 4.7, and average flower number of 19.1.

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