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Optimum Fertilization for Production of Containerized Seabeach Amaranth (*Amananthus pumilus*)©

Daniel S. Norden, Stuart L. Warren, Frank A. Blazich, and David L. Nash
Department of Horticultural Science, North Carolina State University, Raleigh, North Carolina 27695–7609
Email: frank_blazich@ncsu.edu

Seeds of seabeach amaranth (*Amaranthus pumilus* Raf.) in dry storage at 4 °C since Nov. 2003, were removed from storage in Feb. 2005 and graded. Half the graded seeds were stratified (moist-prechilled) for 90 days at 4 °C. The remaining seeds were returned to dry storage at 4 °C. After 89 days these seeds were removed from storage and placed in a solution of K-GA_3 at 1000 mg·L^{-1} for 24 h. After treatment, both groups of seeds were sown in containers of two differing volumes, 139 or 635 cm^3, with a substrate of peat and pine bark (1 : 1, v/v) amended with one of two rates of pulverized dolomitic limestone (2.24 or 4.48 kg·m^{-3}). The containers were maintained in a greenhouse and after seedling emergence, seedlings were fertilized with a 20N–4.4P–8.2K (20N–10P_2O_5–20K_2O) acidic, water soluble fertilizer or a 15N–2.2P–12.3K (15N–5P_2O_5–15K_2O) basic, water soluble fertilizer. Each fertilizer was applied thrice weekly at N application rates (NARs) of 75, 150, 225, or 300 mg·L^{-1}. In June 2005, 8 weeks after sowing of seeds the study was terminated and data recorded. Regardless of fertilizer, acidic or basic, top dry weight and leaf area of seabeach amaranth increased linearly with increasing NAR, and maximum top dry weight and leaf area occurred with N at 300 mg·L^{-1}. In contrast, root dry weight was unaffected by NAR. Seabeach amaranth can be produced successfully in containerized production with maximum top growth occurring with N at 300 mg·L^{-1} provided by an acidic or basic fertilizer having a 4.5N–1P–1.9K or 6.8N–1P–5.6K ratio, respectively.

INTRODUCTION

Seabeach amaranth is a summer annual native to the beaches and barrier islands of the Atlantic Coast and once ranged from Massachusetts to South Carolina (Weakley et al., 1996). However, by 1990 it no longer occurred in two-thirds of its original range with the remaining populations occurring in New York, North Carolina, and South Carolina (Weakley et al., 1996). Disappearance of the species from a large portion of its historic range and vulnerability of the plant to various threats, both natural and human, resulted in seabeach amaranth being listed as "threatened" by the U.S. Fish and Wildlife Service (1993), prompting development of a recovery plan by Weakley et al. (1996).

Loss of seabeach amaranth from many areas where it was once endemic has raised concerns as it plays an important role in the initial stages of the development of sand dunes by trapping and binding sand on the beach (U.S. Fish and Wildlife Service New York Office, 2004; Weakley et al., 1996). The plant is also regarded by ecologists as an indicator species which allows one to access the vitality and vigor of a beach ecosystem. Thus, various state and federal agencies are interested in restoring seabeach amaranth to areas where it once grew. Beach restoration and

sand renourishment projects have also created a demand for seedling transplants of the species that are unavailable. Therefore, to reestablish the plant in locations where it was once endemic and meet the demand for transplants will require protocols for propagation and culture. A logical approach would involve production of seedlings that can be planted in suitable beach environments. If production protocols are developed for the species they may provide opportunities for growers to produce and sell plants to interested agencies for recovery efforts.

Although procedures for seed germination have been published (Baskin and Baskin, 1998; Blazich et al., 2005; Norden et al., 2007), little quantitative data have been published regarding culture. Skaradek and Murray (2005) reported successful greenhouse culture of seedlings of seabeach amaranth in 5-cm^2 containers with "a mixture of half peat and half sand thoroughly moistened to saturation." The seedlings were later transplanted to the field and grown in a loamy soil, where plants grew in the field to maturity producing seeds. Unfortunately, the report of Skaradek and Murray (2005) is sketchy and does not include such information as volume of the containers in which seedlings were grown, fertilization of seedlings, and substrate pH. Thus, the following research was conducted to develop protocols for containerized production of seedling transplants of seabeach amaranth. To develop such protocols various factors were investigated including the influence of K-GA_3 treatment of seeds on subsequent seedling growth, container volume, substrate pH, and nitrogen (N) source and rate.

MATERIALS AND METHODS

The study was a $2 \times 2 \times 2 \times 4 \times 2$ factorial with six replications in a split-plot design. The main plots were two container volumes, two rates of limestone substrate amendment, and two fertilizers with differing sources of N with four rates of each fertilizer. The sub-plot was two treatments for removing seed embryo dormancy, stratification at 4 °C for 90 days or treatment with K-GA_3 at 1000 $mg \cdot L^{-1}$ for 24 h prior to sowing.

Containers included 635-cm^3 Regal 45G plastic pots (Kord Products, Inc., Brampton, Ontario, Canada) or a 2×2 cell square (individual cell volume = 139 cm^3) from modified Traymaster Rosepot flats, (Mackenzie Nursery Supply, Inc., Perry, Ohio). The substrate was peat and pine bark (1 : 1, v/v) amended with one of two rates of pulverized dolomitic limestone (2.24 or 4.48 $kg \cdot m^{-3}$). The containers were filled with the appropriate substrate and tapped twice on a bench to settle substrate. The filled containers were then moistened with tap water.

Seeds of an Oak Island, North Carolina, population of seabeach amaranth collected in Sept. 2003 and placed in dry storage at 4 °C in Nov. 2003 were removed from storage 2 Feb. 2005 and graded. The seeds were graded under a dissecting scope to remove abnormal or damaged seeds and any debris not removed by previous cleaning. From the graded seeds, two lots consisting of 650 seeds per lot were removed from the graded seeds. One lot of seeds was mixed with 200 ml of moist sand [dry sand and tap water (10 : 1, v/v)] and the seed/sand mixture was placed in a nonvented 3.8-L polyethylene food storage bag. The polyethylene bag was sealed with a twist tie and the bag was placed in the dark at 4 °C where it remained for 90 days to allow for seed stratification. The other lot of 650 seeds was returned to dry storage at 4 °C for 89 d. On 1 May 2005 this lot of seeds was removed from dry storage at 4 °C and the seeds were placed in a 125-ml Erlenmyer flask containing

50 ml of a solution of K-GA_3 at 1000 mg·L^{-1}. The solution had been prepared by dissolving K-GA_3 in distilled water (pH of distilled water = 6.3). The flask was wrapped with aluminum foil to exclude light and placed on a rotary shaker (100 revolutions per min) for 24 h at 21 °C. Following treatment of both seed lots, seeds were sown (experiment was initiated) on 2 May 2005 in containers of two differing volumes.

Prior to seeding, the 635-cm^3 containers were partitioned with a wooden stake placed horizontally in the center of the pot with one partition being for K-GA_3 treated seeds and the other for stratified seeds. Three seeds of seabeach amaranth were then sown (covered to the minimum diameter of the seeds) in both container volumes, in each respective partition of the 635-cm^3 container and two of four designated cells in the 2 × 2-cell squares. The two designated cells in a 2 × 2 square were diagonally opposite and in one cell stratified seeds were sown and in the other cell seeds treated with K-GA_3 were sown.

Following sowing, containers were moved to the Department of Horticultural Science greenhouses and maintained under natural photoperiod and irradiance with days/nights of 28±2/19±2 °C. Two pressure compensated Chapin E0W60 emitters (Chapin Watermatics, Inc., Watertown, New York.) were placed on each side of the partition in the large 635·cm^3 containers. In the 2 × 2-cell square containers, an emitter was placed in each of the cells in which seeds were sown. Two fertilizers were selected based on the sources of N: Peter's 20N–4.4P–8.2K (20N–10P_2O_5–20K_2O) Professional Water Soluble Peat-lite Special (Scotts-Sierra Hort. Products Co., Marysville, Ohio) with N derived from ammonium nitrate and potassium nitrate (an acidic fertilizer) and Peter's 15N–2.2P–12.3K (15N–5P_2O_5–15K_2O) Excel Cal-Mag water soluble fertilizer (Scotts-Sierra Hort. Products Co.) with N derived from ammonium nitrate, calcium nitrate, potassium nitrate, urea phosphate, and magnesium nitrate (a basic fertilizer).

Micronutrients were present in both fertilizers and no source of S was added other than as an anion. Each fertilizer was applied at N application rates (NARs) of 75, 150, 225, or 300 mg·L^{-1}. To simplify discussion of the effects of rate of fertilization, only N rate will be listed but the reader should be cognizant a 4.5N–1P–1.9K or 6.8N–1P–5.6K ratio for the acid or basic fertilizer, respectively, was maintained at all rates of N. Containers were fertigated three-times weekly starting 16 May 2005. Prior to fertigation, containers were misted daily with tap water to prevent seed washout.

On 29 June 2005, 8 weeks after sowing of seeds, the study was terminated and various data recorded. Plants were separated into roots, stems, and leaves and leaf area were measured for replications 1 to 4 using a LI-COR LI-3100 Leaf Area Meter (LI-COR Biosciences, Lincoln, Nebraska). Leaf, stem, and root dry weights were also recorded following drying at 60 °C for 48 h. Top dry weight (leaf + stem dry weight) and root:top ratio [RTR (root dry weight ÷ top dry weight)] were calculated from these data.

All data were subjected to analysis of variance procedures (ANOVA) and regression analysis, where appropriate (SAS Inst. Inc., Cary, North Carolina). All three-way and four-way interactions were nonsignificant. When significant ($P \leq 0.05$), simple linear and polynomial curves were fitted to the N rate data. The maximum of the polynomial curve was calculated as the zero point in a first-order derivative of the independent variable.

RESULTS AND DISCUSSION

Stem and leaf dry weights responded in a similar fashion to all treatments; therefore only top dry weight data are presented. Top dry weight of seabeach amaranth was affected by all treatments, however, there were no significant interactions so only the main effects are presented. Top dry weight of seabeach amaranth increased linearly with increasing NAR, and maximum top dry weight occurred with N at 300 mg·L^{-1} (Table 1). At 300 mg·L^{-1}, top dry weight increased 106% compared to top dry weight with N at 75 mg·L^{-1}. While N at 300 mg·L^{-1} is high, annual plant production N recommendations can be as high as 255 mg·L^{-1} when applied with every irrigation (Nelson, 2003). Similar to top dry weight, leaf area increased linearly with increasing NAR resulting in maximum leaf area at 300 mg·L^{-1} which was 131% greater than leaf area at 75 mg·L^{-1}. In contrast, root dry weight was unaffected by NAR.

RTR decreased linearly with increasing NAR for both fertilizers (Table 1). This was not surprising as increasing NARs typically reduce RTR (Friend et al., 1994). As plants transition from N deficient to adequate N, most plants typically allocate a larger fraction of carbohydrates to top growth (Friend et al., 1994). When grown with the acidic fertilizer, RTR decreased 59% from 75 to 300 mg·L^{-1}, whereas RTR of seabeach amaranth grown with the basic fertilizer decreased 29% from 75 to 300 mg·L^{-1}. Seabeach amaranth can be produced successfully in containerized production with maximum top growth occurring with N at 300 mg·L^{-1} provided by an acidic or basic fertilizer having a 4.5N–1P–1.9K or 6.8N–1P–5.6K ratio, respectively.

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Table 1. Effect of nitrogen application rate (NAR) on top and root dry weight, root:top ratio (RTR), and leaf area of containerized seabeach amaranth.[z]

NAR($mg \cdot L^{-1}$)	Top dry weight (g)	Root dry weight (g)	RTR[y]		Leaf area (cm^2)
			20N–4.4P–8.2K fert.	15N–2.2P–12.3K fert.	
75	0.93 ± 0.60	0.16 ± 0.09	0.22 ± 0.09	0.14 ± 0.05	92.2 ± 50.5
150	1.32 ± 0.66	0.19 ± 0.11	0.15 ± 0.08	0.15 ± 0.05	130.3 ± 58.9
225	1.57 ± 1.12	0.17 ± 0.13	0.12 ± 0.12	0.09 ± 0.05	162.5 ± 111.9
300	1.92 ± 1.13	0.19 ± 0.11	0.09 ± 0.04	0.10 ± 0.03	213.2 ± 107.5
Significance[x]					
Linear	***	NS	***	***	***
Quadratic	***	NS	NS	NS	***

[z]Data for top dry weight, root dry weight, and leaf area are means of 96 observations ± 1 SE. Data for RTR are means of 48 observations ±1 SE.

[y]RTR = root dry weight ÷ top dry weight.

[x]Regression equations are: top dry weight, $y = 0.63 + 0.004x$, $R^2 = 0.99$; RTR (20N-4.4P-8.2K fert.), $y = 0.25 - 0.0006x$, $R^2 = 0.97$; RTR (15N–2.2P–12.3K fert.), $y = 0.17 - 0.0002x$, $R^2 = 0.79$; leaf area, $y = 50.7 + 0.527x$, $R^2 = 0.99$.

NS, *** Nonsignificant or significant at $P \pm 0.001$, respectively.