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Nitrogen Nutrition of Southern Seaoats (*Uniola paniculata*) Grown in the Float System[1]

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Abstract

Seeds of southern seaoats (*Uniola paniculata* L.) were removed from storage in July 2004, surface disinfested with 2.6% sodium hypochlorite (NaOCl) for 15 min, and sown in styrofoam tobacco (*Nicotiana tabacum* L.) float trays (flats) filled with a vermiculite-based hydroponic substrate. Trays were floated in plastic tubs (one tray per tub) containing a complete nutrient solution with nitrogen (N) at 10, 60, 120, 180, or 240 mg·L^{-1} (ppm) from a 2N–3.5P–1K ratio (8N–32P_2O_5–5K_2O) liquid slow-release fertilizer. After 10 weeks the study was terminated and data recorded. Total plant, top, leaf, stem, and root dry weights increased quadratically with increasing nitrogen application rate (NAR) with maximum dry weights calculated to occur with N at 140 to 150 mg·L^{-1}, respectively. Other growth indexes of leaf area, root length, root area, plant height, crown growth index, tiller number, and leaf number also increased quadratically with increasing NAR similar to dry weight data. Leaf area, root length, and root area were maximized with N at 157, 140, and 140 mg·L^{-1}, respectively. Root to top ratio and specific leaf area were both unaffected by NAR. Leaf mineral nutrient concentrations of N and phosphorus responded quadratically with increasing NAR whereas, foliar mineral nutrient concentrations of potassium, calcium, sulfur, sodium (Na), manganese, zinc, and copper responded linearly to increasing NARs. With the exception of Na and iron, foliar nutrient content for all analyzed nutrients increased quadratically with increasing NAR. Calculated leaf N concentration at maximum top dry weight was 31 mg·g^{-1}. Southern seaoats can be grown successfully using the float system with optimum N rates of 140 to 150 mg·L^{-1} provided by a fertilizer having a 2N–3.5P–1K ratio.

Index words: beach restoration, dune species, Poaceae, mineral nutrition, fertility.

Significance to the Nursery Industry

Transplants of southern seaoats (*Uniola paniculata*), a major coastal dune stabilizing species of the southern Atlantic and Gulf Coasts of the United States, are currently in great demand. However, research on culture has been limited, particularly with respect to mineral nutrition. Research herein demonstrated southern seaoats can be produced successfully using the float system, and nitrogen (N) in the nutrient solution at 140 to 150 mg·L^{-1} (ppm) will maximize vegetative growth. Use of the float system for production of transplants could provide opportunities for former and current tobacco (*Nicotiana tabacum*) farmers to produce alternative crops using the float system. Production of the species may also provide an additional means to supplement farm incomes.

Introduction

Southern seaoats is a perennial dune grass that in most of its natural range (southern Virginia to the Yucatan Peninsula) is the dominant, coastal sand-binding plant species (30). The species is generally subtropical and its native range is determined by climate as it is intolerant of extremely hot summers or cold winters (30). In southern Virginia and northern North Carolina, southern seaoats is at the northern limit of its range and the plants usually die back to ground level and resprout from rhizomes in the spring. Seed germination occurs in late spring and little growth takes place until adequate sand surrounds the culms (stems), usually by the end of the second year (41). Seaoats has the ability to stabilize dunes upon establishment by utilizing culms and extensive root systems to trap sand (30, 33). Thus, it has been planted extensively to build and stabilize coastal sand dunes (23, 41).

In recent years, transplants of southern seaoats have been in demand to restore beaches and stabilize sand dunes along the southern Atlantic and Gulf Coasts of the United States that have been damaged by tropical storms and erosion. Demand has in turn created a need for information regarding propagation and culture. Considerable research has been reported on propagation, specifically seed germination (3, 4, 34, 35, 40). However, with few exceptions research on culture has been limited (1, 18, 35), particularly with respect to mineral nutrition of container-grown plants. Cultural information, coupled with previous work on seed germination, would result in protocols for production of transplants that may prove profitable to growers such as former and current tobacco farmers who are seeking alternative crops that can be grown in the float system.

Tobacco and vegetable transplants can be grown successfully using the float system (21, 24, 31, 32, 36). This system involves constructing shallow wooden frames on the floor of a greenhouse. The frames are lined with polyethylene sheeting and filled with nutrient solution. Seeds are sown in peat- or vermiculite-based soilless substrates in styrofoam trays (flats), floating on the nutrient solution. Irrigation is by capillary movement of nutrient solution into the substrate.

[1]Received for publication August 31, 2007; in revised form January 2, 2008. This research was funded in part by the North Carolina Agricultural Research Service (NCARS), Raleigh, NC 27695-7643. Use of trade names in this publication does not imply endorsement by the NCARS of the products named nor criticism of similar ones not mentioned. Technical assistance of William M. Reece is gratefully acknowledged in addition to statistical assistance of William H. Swallow. Donation of substrate from Carolina Soil Co., Kinston, NC, is greatly appreciated. From a thesis submitted by D.S.N. in partial fulfillment of the requirements for the MS degree.

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Potential advantages of the float system over conventional overhead irrigation include lower production costs, more efficient use of water and mineral nutrients, reduced disease pressure (dry plant foliage), and elimination of nutrient leaching to groundwater below the greenhouse (31). Frantz and Welbaum (11) also noted if other crops could be produced successfully using the float system, float systems could potentially produce high-value horticultural crops to supplement farm incomes. Soundy et al. (36) reported that although production of vegetable transplants using the float system has several advantages including improved health of seedlings, production of lettuce (*Lactuca sativa* L.) transplants using the float system resulted in poor root systems.

Some research has been conducted on growing alternative crops using the float system (11, 31, 36, 39). Nash [as reported by Latham (23)], an Agricultural Extension Agent in New Hanover County, NC, has produced transplants of seaoats successfully utilizing the float system. Initially, he attempted to grow southern seaoats using conventional container production but he encountered many problems, particularly with foliar fungal diseases, due to irrigating over the tops of plants (David L. Nash, personal communication). Using the float system reduced dramatically foliar infestations. However, despite successful culture of southern seaoats using the float system, little information has been published on this means of culture to produce transplants of seaoats. Therefore, the following research was conducted to study the influence of N nutrition on vegetative growth of southern seaoats in a float system.

Materials and Methods

On July 12, 2004, seeds of southern seaoats, collected in Fall 2003 from Oak Island, NC, were removed from storage at 4C (39F) and surface disinfested with a solution of 2.6% sodium hypochlorite (NaOCl) for 15 min. Following treatment, seeds were rinsed with tap water and sown in modified Standard Carolina Greenhouse 288-cell styrofoam float trays (Carolina Greenhouse Co., Kinston, NC) with each cell having a volume of 14 cm^3 (0.85 in^3). Trays were modified by cutting them with a serrated knife which reduced a tray from 24 × 12 cells [67 × 34 × 6.5 cm (26 × 13 × 3 in)] to 15 × 12 cells [42 × 34 × 6.5 cm (17 × 13 × 3 in)]. Each modified tray was filled with Carolina's Choice Tobacco Mix (Carolina Soil Co., Kinston, NC), a vermiculite-based hydroponic substrate and floated in gray plastic tubs [50 × 36 × 12 cm (20 × 14 × 5 in)] (Consolidated Plastics Company, Inc., Twinsburg, OH), each tub containing 10 liters (2.6 gal) of tap water. Prior to floating the trays, tubs were rinsed three times with distilled water to which was added Liqui-Nox, a phosphate-free analytical washing agent (Alconox, Inc., White Plains, NY). Cells of trays that were dry after 3 days of floating in the tap water were altered by removing any obstructions preventing water movement or removing air pockets in the growing substrate. Trays were removed from the tubs and three seeds were sown per cell in a 6 × 6 cell square in the center of a modified tray [center was determined from the top (shorter dimension side) of tray counting five cells right and four cells down] and refloated in a gray plastic tub containing 10 liters (2.6 gal) of a complete nutrient solution with varying rates of N. Tubs were maintained under natural photoperiod and irradiance in a greenhouse (Dept. of Hort. Sci., NC State Univ., Raleigh) maintained at days/nights of 27 ± 2C/21 ± 1C (81 ± 4F/70 ± 2F). Temperatures of the nutrient solutions averaged 26C (79F).

Treatments included five rates of N at 10, 60, 120, 180, or 240 $mg \cdot L^{-1}$ from a 2N–3.5P–1K ratio (8N–32P_2O_5–5K_2O) liquid slow-release fertilizer (Growth Products, Ltd., White Plains, NY) which also contained calcium (Ca), magnesium (Mg), and micronutrients. To simplify discussion of the effects of rate of fertilization, only the N rate will be listed but the reader should be cognizant a 2N–3.5P–1K ratio was maintained at all rates of N. Nutrient sources of N, P, and K in the fertilizer were urea, methylene urea, potassium carbonate, diammonium phosphate, and phosphoric acid. The nutrient solution in each tub was replaced weekly, and solutions were prepared with tap water. Tap water averages for NO_3-N, NH_4-N, phosphorus (P), potassium (K), Ca, Mg, and alkalinity were 0.10, 0.96, 0.5, 7.0, 10.0, 4.0, and 20.0 $mg \cdot L^{-1}$, respectively, with a pH of 7.4.

Seedling emergence first occurred on July 16, 2004, and was essentially complete by July 23 when seedlings were thinned to one per cell. On July 28, the outer rows of cells in each float tray were reseeded because of limited emergence. These seeds, also from the same seed lot sown initially on July 12, were surface disinfested with a solution of NaOCl as described previously.

The experiment was a randomized complete block design with six replications and five treatments (N rates). A tub was considered a single experimental unit. Tubs were oriented on a greenhouse bench parallel to the cooling pads to direct uniform airflow across all treatments. Electrical conductivity (EC) and pH of the nutrient solutions were recorded using a HI 9811 Hanna Meter (Hanna Instruments, Inc., Woonsocket, RI) every 3 days and before (sample time 1) and immediately after (sample time 2) weekly replacement of the nutrient solutions. EC at sample time 1 averaged 0.401, 0.811, 1.305, 1.803, and 2.300 $dS \cdot m^{-1}$ for NARs of 10, 60, 120, 160, and 240 $mg \cdot L^{-1}$, respectively. Likewise, pH at sample time 1 for NARs of 10, 60, 120, 160, and 240 $mg \cdot L^{-1}$ averaged 6.9, 6.7, 6.8, 6.9, and 6.9, respectively. EC averages for sample time 2 (after refilling) were 0.409, 0.859, 1.484, 2.076, and 2.692 $dS \cdot m^{-1}$, for N at 10, 60, 120, 160, and 240 $mg \cdot L^{-1}$, respectively, whereas averages for pH were 5.6, 5.6, 6.0, 6.3, and 6.5 for NARs of 10, 60, 120, 160, and 240 $mg \cdot L^{-1}$, respectively.

Algal growth and insect and potential disease problems were concerns of the investigators and were minimized during the study. One particular concern was the potential for algal growth in the nutrient solutions. Control was achieved by several means. First, the Standard Carolina 288-cell styrofoam float trays were modified (reduced in size) to occupy the maximum space (area) in a plastic tub to minimize light penetration to the nutrient solutions. The nutrient solutions were also replaced weekly to provide additional algal control and prior to the tubs being refilled, the tubs were thoroughly rinsed to remove any visible signs of algal growth. Cutrine Plus (Applied Biochemists, Germantown, WI), a chelated copper algaecide, was also added to each nutrient solution at 0.048 $mL \cdot L^{-1}$ (0.0076 fl $oz \cdot gal^{-1}$) [from a stock solution of 25 mL Cutrine Plus/250 mL tap water (0.85 fl oz Cutrine Plus/8.45 fl oz tap water)] starting August 5, 2004, and was increased to 0.065 $mL \cdot L^{-1}$ (0.0083 fl $oz \cdot gal^{-1}$) of nutrient solution on August 15. Fungus gnats (*Orfelia* Costa spp.) were observed on the seedlings and growing medium which required treatment on two occasions. On August 6, the trays were removed from the plastic tubs and sprayed with Merit 2F [Imidacloprid, 1-[(6-Chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimin] (Bayer Environ. Sci., Res. Triangle Park,

NC) at a rate of 0.33 mg·L^{-1}. To further control fungus gnats, float trays were treated on September 10 with Talstar Flowable Bifenthrin (FMC Corp., Philadelphia, PA), at a rate of 0.65 mg·L^{-1}. In early September root samples were tested for the presence of *Pythium* Pringsh. spp. root rot and results were negative.

On September 9, 2004, the study was terminated and data recorded. Seedlings in the outer rows of each modified float tray were discarded to remove edge effects leaving a 4 × 4 square of 16 cells containing 16 plants. Three plants were chosen randomly from the 4 × 4 square and crown growth index (widest diameter + diameter perpendicular to widest diameter ÷ 2), plant height, number of tillers, leaf number, leaf length, leaf area, root length, and root area were recorded. Leaf length and leaf area, and root length and root area were recorded using a Monochrome Agvision System 286 Image Analyzer (Decagon Devices, Inc., Pullman, WA). Leaf, stem, and root dry weights were also recorded following drying at 60C (140F) to a constant weight (48 hr). Top dry weight (leaf + stem dry weight), root:top ratio [RTR (root dry weight ÷ top dry weight], total plant dry weight (leaf + stem + root dry weight), specific leaf area [SLA (leaf area ÷ leaf dry weight)], and root diameter [(root length ÷ root area) ÷ 3.14] were calculated.

Leaves of plants were ground separately using a Foss Tecator Cyclotec™ 1093 sample mill (Analytical Instruments, LLC, Golden Valley, MN) to pass a ≤ 0.5 mm (0.02 in) sieve. Mineral nutrient analysis [N, P, K, Ca, Mg, sulfur (S), sodium (Na), manganese (Mn), zinc (Zn), copper (Cu), iron (Fe), and boron (B)] of leaves of five replications was conducted by the North Carolina Department of Agriculture and Consumer Services, Raleigh. Nitrogen concentrations were determined by oxygen combustion with an elemental analyzer (NA 1500, CE Elantech Instruments, Milan, Italy). All other mineral nutrient concentrations were determined by EPA method 200.7 with an ICP spectrophotometer (Optima 3300 DV ICP Emission Spectrometer; Perkin Elmer Corp., Wellesley, MA), following open-vessel nitric acid (HNO_3) digestion in a microwave digestion system (CEM Corp., Matthews, NC). Mineral nutrient contents of the leaves were based on percentage concentration of a nutrient divided by 100 and multiplied by the leaf dry weight.

Data were subjected to regression analysis in SAS version 8.01 (SAS Inst., Inc., Cary, NC). When significant ($P \leq 0.05$), simple linear and polynomial curves were fitted to data. The maximum of the polynomial curve was calculated as a first order derivative of the independent variable where the dependent variable equaled zero.

Results and Discussion

Growth. Total plant, top, leaf, stem, and root dry weights of southern seaoats responded quadratically to increasing NAR with predicted maximum total plant, top, leaf, stem, and root dry weights at 145, 145, 141, 151, and 143 mg·L^{-1}, respectively (Fig. 1). At maximum dry weight, total plant, top, leaf, stem, and root dry weights increased 196, 237, 208, 316, and 121%, compared to N at 10 mg·L^{-1}. Hester and Mendelssohn (18) reported total dry weight of sea oats grown in containers with dune sand increased 230% when fertilized with macronutrients [10N–10P_2O_5–10K_2O, 732 kg·ha^{-1} (653 lb·A^{-1})] compared to no fertilizer. In contrast, Bachman and Whitwell (1) reported top dry weight of seaoats was less when grown in a peat:perlite substrate with N at 1.8 kg·m^{-3}

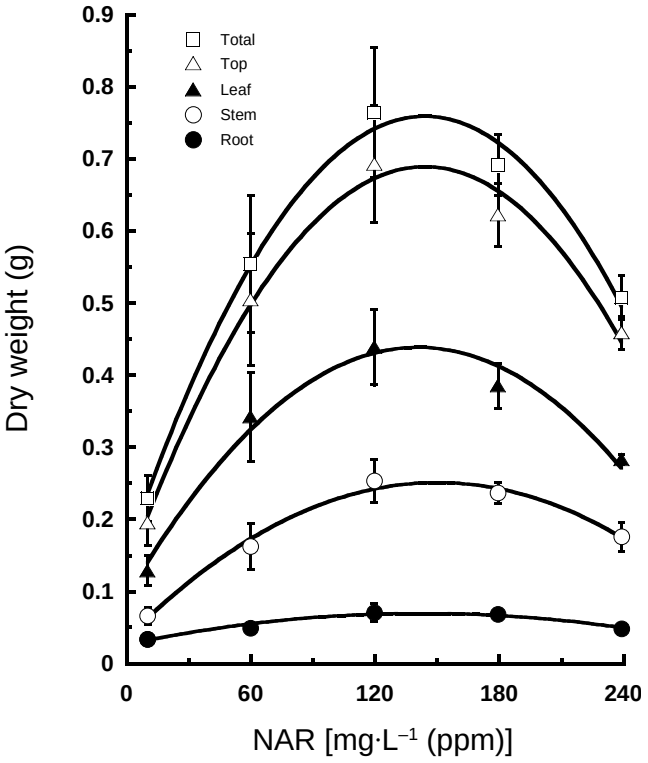

Fig. 1. Influence of nitrogen application rate (NAR) on total plant, top, leaf, stem, and root dry weights of southern seaoats grown in the float system. Data points are means of six observations and vertical bars = ± 1 SE. Regression equations are: total plant dry weight, $y = 0.15 + 0.008x - 0.00003x^2$, $R^2 = 0.99$; top dry weight, $y = 0.13 + 0.008 - 0.00003x^2$, $R^2 = 0.99$; leaf dry weight, $y = 0.09 + 0.005x - 0.00002x^2$, $R^2 = 0.99$; stem dry weight, $y = 0.04 + 0.003x - 0.0000095x^2$, $R^2 = 0.99$; root dry weight, $y = 0.03 + 0.0006x - 0.000002x^2$, $R^2 = 0.98$.

(3 lb·yd^{-3}) in comparison to N at 0.9 kg·m^{-3} (1.5 lb·yd^{-3}). The differences between the aforementioned reports (1, 18) and results herein may have resulted from the substrates used and the frequency of irrigation as the float system provides constant irrigation and nutrients versus an organic substrate which is irrigated less frequently and has lower moisture and nutrient retention.

Research with the container-grown herbaceous perennials, blackfoot daisy (*Melampodium leucanthum* Torr. and Gray) (20), 'Margarete' fall flowering anemone (*Anemone* × *hybrida* Paxton 'Margarete') (10), autumn sage (*Salvia greggii* Gray) (19), and 'Scarlet Sage' salvia (*Salvia splendens* F. Sellow ex Roem. & Schult. 'Scarlet Sage') (22) found maximum growth was achieved with N at 166, 150, 150, and 210 mg·L^{-1}, respectively, similar to results herein for southern seaoats. In contrast, N was required at 400 or 399 mg·L^{-1} applied weekly to maximize growth of container-grown 'Stella de Oro' daylily (*Hemerocallis* L. × 'Stella de Oro') or 'Parigo Pink' Inca lily (*Alstroemeria* L. 'Parigo Pink'), respectively (29, 37). Optimum NARs are dependent upon not only the N rate but also frequency of application. The optimum NAR usually decreases with increasing frequency of application.

The similar response of all plant parts to NAR (Fig. 1) was unexpected as roots and tops frequently respond differently to increasing NAR. Griffin et al. (15) and Cabrera and Devereaux (5) reported for containerized 'Green Giant'

Table 1. Effect of nitrogen application rate (NAR) on leaf area, specific leaf area (SLA), root length, and root area of southern seaoats grown in the float system.[z]

NAR ($mg \cdot L^{-1}$)	Leaf area (cm^2)	SLA[y] ($cm^2 \cdot g^{-1}$)	Root	
			Length (cm)	Area (cm^2)
10	40 ± 7[y]	313 ± 25	77 ± 15	10 ± 2
60	91 ± 13	313 ± 30	164 ± 25	20 ± 2
120	137 ± 31	316 ± 55	179 ± 46	24 ± 7
180	123 ± 20	321 ± 48	192 ± 17	25 ± 3
240	108 ± 7	385 ± 21	125 ± 27	16 ± 5
Significance[x]				
Linear	*	NS	NS	NS
Quadratic	**	NS	**	**

[z]Data are means of six observations ± 1 SE.

[y]SLA = leaf area (cm^2) ÷ leaf dry weight (g).

[x]NS,*, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively. Regression equations are: leaf area, $y = 26.6 + 1.40x - 0.0045x^2$, $R^2 = 0.99$; root length, $y = 62.9 + 1.90x - 0.0068x^2$, $R^2 = 0.98$; root area, $y = 7.9 + 0.249x - 0.0009x^2$, $R^2 = 0.99$.

arborvitae (*Thuja* × 'Green Giant') and 'Tonto' crape myrtle (*Lagerstroemia indica* L. × *fauriei* Koehne 'Tonto') that root dry weight decreased quadratically or linearly, respectively, with increasing NARs, whereas top dry weight increased quadratically. In addition, observance of root dry weight peaking at a similar NAR as top dry weight is unusual, since root growth is often maximized at a lower NAR (15, 28). Response of root growth to NAR appears to be very species specific. However, similar to data herein, Dubois et al. (10) working with 'Margarete' fall flowering anemone and Conden et al. (8) working with Japanese ternstroemia (*Ternstroemia gymnanthera* Thunb.) reported root dry weight increased quadratically with increasing NAR with calculated maximum root dry weight occurring with N at 119 and 86 $mg \cdot L^{-1}$, respectively, which was similar to NAR that maximized top dry weights for each species. Based on our results, sea oats appear to require high initial rates of N to maximize growth when grown in the float system.

Similar to plant dry weights, leaf area, root length, and root area responded quadratically to NAR (Table 1). Maximum leaf area, root length, and root area were predicted with N at 157, 140, and 140 $mg \cdot L^{-1}$ (ppm), respectively. At the maximum value, leaf area, root length, and root area increased 241, 153, and 146% compared to 10 $mg \cdot L^{-1}$. Root diameter (mean = 2.67 mm ± 0.12 SE) was unaffected by NAR (data not presented) indicating NARs did not alter root morphology. Plant height, crown growth index, tiller number, and leaf number responded quadratically to NAR with calculated maximum height (mean = 167.7 cm), crown growth index (mean = 3.9 mm), number of tillers (mean = 1.2), and number of leaves (mean = 7.2) occurring at 162, 148, 140, and 139 $mg \cdot L^{-1}$ (ppm), respectively (data not presented).

RTR was unaffected by NAR (data not presented) indicating carbon allocation between the top and roots was unaffected by NAR. In contrast, most plants typically allocate a larger fraction of carbohydrates to top growth with increasing NAR (12). RTR of lettuce grown in the float system was less when grown at a NAR of 100 $mg \cdot L^{-1}$ compared to 60 $mg \cdot L^{-1}$ (36).

Likewise, SLA was unaffected by NAR suggesting leaf thickness was unaffected by NAR (Table 1). SLA is a mor-

Table 2. Effect of nitrogen application rate (NAR) on foliar mineral nutrient concentrations of southern seaoats grown in the float system.[z]

NAR ($mg \cdot L^{-1}$)	N	P	K	Ca	Mg	S	Na	Mn	Zn	Cu	Fe	B
	($mg \cdot g^{-1}$)							($\mu g \cdot g^{-1}$)				
10	20.8 ± 0.7	3.7 ± 0.2	17.3 ± 0.8	2.2 ± 0.10	1.5 ± 0.08	1.5 ± 0.10	1.8 ± 0.10	95.0 ± 3.4	35.2 ± 2.0	8.3 ± 0.4	54.4 ± 4.4	7.4 ± 0.4
60	27.3 ± 0.4	5.4 ± 0.1	20.8 ± 0.6	1.6 ± 0.09	1.4 ± 0.05	2.0 ± 0.03	1.6 ± 0.06	104.2 ± 3.9	48.8 ± 5.5	9.7 ± 0.1	65.0 ± 3.6	8.7 ± 1.7
120	30.2 ± 0.9	6.0 ± 0.1	20.7 ± 1.5	1.4 ± 0.07	1.4 ± 0.05	2.1 ± 0.07	1.0 ± 0.07	124.8 ± 8.8	62.7 ± 2.6	11.5 ± 1.0	81.6 ± 18.3	8.9 ± 1.3
180	31.3 ± 0.8	6.3 ± 0.2	21.9 ± 0.3	1.3 ± 0.04	1.3 ± 0.03	2.2 ± 0.03	0.6 ± 0.01	125.6 ± 3.6	76.6 ± 4.2	12.5 ± 1.0	242.6 ± 166.2	7.8 ± 0.5
240	30.6 ± 0.8	5.8 ± 0.1	21.7 ± 0.7	1.3 ± 0.03	1.4 ± 0.05	2.6 ± 0.40	0.6 ± 0.02	141.5 ± 9.1	78.9 ± 2.7	11.5 ± 0.5	63.6 ± 2.0	10.7 ± 0.8
Significance[y]												
Linear	***	***	**	***	NS	***	***	***	***	**	NS	NS
Quadratic	***	***	NS	**	NS	NS	*	NS	NS	*	NS	NS

[z]Data are means of six observations ± 1 SE.

[y]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. Regression equations are: N, $y = 20.0 + 0.131x - 0.0004x^2$, $R^2 = 0.99$; P, $y = 3.5 + 0.035x - 0.0001x^2$, $R^2 = 0.99$; K, $y = 18.4 + 0.017x$, $R^2 = 0.83$; Ca, $y = 2.0 - 0.004x$, $R^2 = 0.89$; S, $y = 1.6 + 0.004x$, $R^2 = 0.95$; Na, $y = 1.9 - 0.006x$, $R^2 = 0.96$; Mn, $y = 92.1 + 0.255x - 0.0002x^2$, $R^2 = 0.98$; Zn, $y = 36.3 + 0.198x$, $R^2 = 0.98$; Cu, $y = 8.8 + 0.016x$, $R^2 = 0.86$.

Table 3. Reported foliar mineral nutrient concentrations of field- and container-grown southern seaoats and foliar mineral nutrient concentrations at optimal N rate for top growth of southern seaoats grown in the float system.

Mineral nutrient	Reported foliar concn. ($mg \cdot g^{-1}$)		Predicted foliar concentration ($mg \cdot g^{-1}$) at maximum top growth (N at 145 $mg \cdot L^{-1}$)	Predicted maximum foliar concn. ($mg \cdot g^{-1}$)
	Field-grown[z]	Container-grown[y]		
N	17.7 to 21.4	14.5 to 18.5	31.2	31.7
P	0.7 to 1.3	1.0 to 1.6	6.3	6.4
K	15.5 to 16.0	12.5 to 15.1	20.9	22.5
Ca	1.2 to 1.3	2.8 to 5.0	1.5	2.0
Mg	1.4 to 1.9	1.1 to 1.6	NA[x]	NA
S	NA	NA	2.2	2.6
Na	2.2 to 4.1	NA	1.0	1.8
Mn	0.02 to 0.05	0.04 to 0.05	0.12	0.16
Zn	0.01 to 0.02	0.01 to 0.02	0.07	0.08
Cu	0.02 to 0.03	0.003 to 0.004	0.01	0.01
Fe	NA	NA	NA	NA
B	NA	NA	NA	NA

[z]Means for southern seaoats reported by Hester and Mendelssohn (18).

[y]Means for southern seaoats reported by Bachman and Whitwell (1).

[x]NA = Not available.

phological index of leaf expansion with a high ratio often corresponding to a thinner leaf (13). However, contrary to our results, SLA of lettuce transplants grown in the float system increased linearly with increasing rates of K (36).

Mineral nutrient concentrations and contents. Leaf mineral nutrient concentrations of N and P responded quadratically with increasing NAR, whereas foliar mineral nutrient concentrations of K, Ca, S, Na, Mn, Zn, and Cu responded linearly to increasing NARs (Table 2). Nitrogen concentrations in tops of 'Parigo Pink' Inca lily and 'Scarlet Sage' salvia responded similarly to increasing NAR (22, 37). Nitrate is absorbed continually by plants as long as it is present in the substrate solution with excess nitrate being stored when supply exceeds demand for growth (9). Maximum top dry weight occurred at a calculated NAR of 145 $mg \cdot L^{-1}$, with a corresponding foliar N concentration of 31 $mg \cdot g^{-1}$ (Table 3). Thus, foliar N concentration ≥ 31 $mg \cdot g^{-1}$ appears adequate for maximum growth. This foliar N concentration is higher than leaf N concentration at 21.4 and 18.5 $mg \cdot g^{-1}$ reported for seaoats by Hester and Mendelssohn (18) and Bachman and Whitwell (1), respectively (Table 3). However, this value is lower than N at 45 and 47 $mg \cdot g^{-1}$ required for maximum growth of the perennials, 'Parigo Pink' Inca lily and 'Margarete' fall flowering anemone, respectively (10, 37).

At maximum top dry weight, foliar P and K concentrations were 6.3 and 20.9 $mg \cdot g^{-1}$, respectively (Table 3). Concentrations of P and K increased with increasing NAR. Thus, increasing foliar P and K concentrations might be expected with increasing NAR. Foliar K concentrations of lettuce transplants grown in the float system (36), also increased with increasing rate of K application. In recent studies, foliar P and K concentrations increased quadratically or linearly with increasing NARs for both an herbaceous and a woody perennial plant (8, 16). The lowest foliar P concentration reported herein [(3.7 $mg \cdot g^{-1}$ (Table 2)] was greater than the foliar P concentrations (1.3 and 1.6 $mg \cdot g^{-1}$) reported by Hester and Mendelssohn (18) and Bachman and Whitwell (1) indicating even the lowest P rate (17.5 $mg \cdot L^{-1}$) was not limiting growth in this study. In addition, P at 2.5 and 5 $mg \cdot L^{-1}$ (lowest rate applied) was adequate for maximum growth of *Rhododendron* 'Victor' and 'Helleri' holly (*Ilex crenata* Thunb. 'Helleri'), respectively (17, 42).

Leaf Ca concentrations decreased with increasing NAR (Table 2). Reductions of major cations (Ca and Mg) in leaf tissue concentration with increasing NARs have been reported in studies in which the NH_4^+ form is a significant fraction of the N supply (5). Reduced levels of Ca can be attributed to antagonistic effects between cations in the substrate solution competing for uptake by the roots or dilution due to increased growth with increasing NARs. Foliar Ca content increased quadratically with increasing NAR with a predicted maximum at 141 $mg \cdot L^{-1}$ (Table 4), indicating decreasing foliar Ca concentration with increasing NAR was due to dilution. Foliar nutrient content for the other mineral nutrients increased quadratically with increasing NARs except for Fe (data not presented) and Na, which were unaffected by NARs (Table 4). Increasing leaf Mg concentrations with increasing NARs might be expected as it is a vital component of chlorophyll and a cofactor for many regulatory enzymes (27) all of which should increase from chlorotic, N stressed to healthy, N sufficient plants due to increasing NARs. However, in the present investigation top Mg concentration was unaffected by NAR (Table 2).

Since S is a constituent of many proteins and enzymes associated with growth, foliar S concentration might be expected to increase with increasing NAR (25, 26) which is what occurred herein (Table 2). However, Cabera and Devereaux (5) reported foliar S concentrations decreased with increasing NAR, which impacted the N:S ratio. They attributed a decrease in growth to the increasing N:S ratio. The N:S ratio was unaffected by NARs in the present investigation (data not presented).

Leaf Na concentration decreased linearly with NAR (Table 2). This decrease in Na concentration could be due to the ability of a halophyte to tightly regulate Na uptake at salinity levels below or equivalent to seawater (14). Southern seaoats belongs to the subfamily Chloridoideae (7). Most members of this subfamily are regarded as salt tolerant (halophytes) and have the ability to absorb salt from soil and then exude the salts through microhairs on the leaf surface that function as salt glands after translocation through the grass (6).

Table 4. Effect of nitrogen application rate (NAR) on foliar mineral nutrient contents of southern seaoats grown in the float system.[z]

NAR (mg·L^{-1})	N	P	K	Ca	Mg	S	Na	Mn	Zn	Cu	Fe	B
						(mg)						
10	66 ± 5	12 ± 1	55 ± 4	7.0 ± 0.7	4.8 ± 0.4	4.6 ± 0.5	5.8 ± 0.6	0.3 ± 0.02	0.1 ± 0.01	0.03 ± 0.002	0.17 ± 0.02	0.02 ± 0.001
60	178 ± 22	36 ± 4	134 ± 15	10.4 ± 0.9	8.8 ± 1.1	13.1 ± 1.6	10.5 ± 1.3	0.7 ± 0.07	0.3 ± 0.05	0.06 ± 0.009	0.42 ± 0.05	0.05 ± 0.010
120	286 ± 54	58 ± 11	191 ± 30	13.5 ± 2.5	13.0 ± 2.4	19.8 ± 3.7	10.3 ± 2.7	1.2 ± 0.20	0.6 ± 0.10	0.10 ± 0.020	0.70 ± 0.07	0.08 ± 0.010
180	222 ± 40	46 ± 10	158 ± 33	9.0 ± 1.7	9.6 ± 2.1	16.1 ± 3.3	4.4 ± 0.9	0.9 ± 0.20	0.5 ± 0.10	0.09 ± 0.020	1.26 ± 0.67	0.06 ± 0.010
240	181 ± 33	34 ± 6	127 ± 21	7.4 ± 1.2	8.3 ± 1.2	15.1 ± 2.6	3.6 ± 0.6	0.8 ± 0.09	0.5 ± 0.06	0.07 ± 0.008	0.37 ± 0.05	0.06 ± 0.020
Significance[y]												
Linear	NS	NS	NS	NS	NS	*	NS	*	*	NS	NS	NS
Quadratic	**	**	**	**	**	**	NS	**	**	**	NS	*

[z]Data are means of six observations ± 1 SE.

[y]NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively. Regression equations are: N, $y = 37.2 + 3.11x - 0.11x^2$, $R^2 = 0.96$; P, $y = 5.2 + 0.67x - 0.0023x^2$, $R^2 = 0.097$; K, $y = 38.4 + 2.00x - 0.0069x^2$, $R^2 = 0.98$; Ca, $y = 6.3 + 0.094x - 0.0004x^2$, $R^2 = 0.89$; Mg, $y = 3.8 + 0.11x - 0.0004x^2$, $R^2 = 0.93$; S, $y = 3.1 + 0.20x - 0.0007x^2$, $R^2 = 0.96$; Mn, $y = 0.18 + 0.011x - 0.00004x^2$, $R^2 = 0.95$; Zn, $y = 0.03 + 0.007x - 0.00002x^2$, $R^2 = 0.98$; Cu, $y = 0.01 + 0.001x - 0.000004x^2$, $R^2 = 0.97$; B, $y = 0.02 + 0.0007x - 0.000002x^2$, $R^2 = 0.89$.

Concentrations of Mn, Zn, and Cu increased linearly with increasing NAR (Table 2). Foliar mineral nutrient concentrations of Fe (mean = 101.4 ± 33.9 μg·g^{-1}) and B (mean = 8.7 ± 0.5 μg·g^{-1}) were unaffected by NAR. From this we conclude foliar N concentration ≥ 31 mg·g^{-1} was adequate for growth, whereas for all other nutrients (P, K, Ca, Mg, S, B, Cu, Fe, Mn, Na, and Zn) reported means (Table 3) should be considered indicative of good plant vigor, although optimal levels were not determined directly.

Both foliar N concentration and plant dry weight responded quadratically to NARs (Table 2, Fig. 1). Thus, effects of NARs on dry weight can be explained by direct effects of leaf N concentration. In addition, top dry weight was highly correlated to top N concentration ($P = 0.004$, $r = 0.61$). In particular, the decrease in dry weight at higher than optimal NARs appeared to be related to the EC in the nutrient solution.

In summary, southern seaoats can be produced successfully using the float system with optimum N rates of 140 to 150 mg·L–1 provided by a 2N–3.5P–1K ratio liquid slow-release fertilizer. Although the dune environment is relatively nutrient sterile, Broome et al. (2) noted dune grasses, such as seaoats, respond positively to fertilization, even though their extensive fibrous root system allows them to exploit the low nutrient conditions in their native habitat. Limiting fertilizer inputs to the lowest nutrient concentrations consistent with adequate growth is an important consideration for growers. This strategy should be implemented, because it is a cost-saving technique that can significantly reduce the levels of nutrient runoff from nurseries (38).

Results herein provide needed information regarding N nutrition of southern seaoats when grown in the float system, however, survivability and vigor of plants after transplanting warrants investigation. Liptay et al. (24) reported 'TH-318' tomato [*Solanum lycopersicum* L. var. *lycopersicum* (syns. *Lycopersicon lycopersicum* Karst., *Lycopersicon esculentum* Miller) 'TH-318'] transplants produced using the float system at a high N rate (350 mg·L^{-1}) exhibited lower survivability in comparison to transplants produced at lower rates (100 to 200 mg·L^{-1}). Similarily, Welbaum et al. (39) observed 'Krispy King' sweet corn (*Zea mays* L. var. *rugosa* Bonaf. 'Krispy King') transplants grown in the float system flowered earlier and produced fruit earlier than conventional culture, however, fruit and flower quality were lower than direct-seeded methods. Nash [as reported by Latham (23)], has achieved much success with dune establishment of seaoats produced using the float system. Whether differences exist in establishment among seaoats produced using the float system versus other means of culture have yet to be determined. Nevertheless, culture of the species using the float system may allow tobacco farmers to utilize float beds at times of the year when the beds are not in use. Also, seaoats might serve as a possible alternative crop to tobacco or an additional crop to supplement farm incomes.

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