Growth and Nutrient Content of Hybrid Bermudagrass Grown for Nursery Purposes at Different Nitrogen, Phosphorus, and Potassium Rates

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Additional index words. *Cynodon dactylon* × *C. transvaalensis*, nursery production, fertilization, stolon growth, nodes

Summary. The objective of this research was to study the effect of different nitrogen (N), phosphorus (P), and potassium (K) rates on growth and nutrient content of hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) grown in pots for nursery purposes (producing stolons to obtain one-node sprigs to be used as propagation material). Starting from control N, P, and K rates (314, 52, and 198 mg·L^{-1} substrate, respectively), each element was reduced to zero, halved, doubled, or tripled while the other two were kept unchanged (13 treatments in all). As expected, N, P, and K proved to be necessary for plant growth and development. In fact, when one element was not supplied, plants showed reduced growth and pale-green color. The dry weight of aerial part (shoots plus stolons) was mainly affected by N and increased along with this element with a nonlinear less than proportional trend. Phosphorus had a larger effect than N or K on the number of primary stolons, which varied along with P rate fitting a nonlinear regression model. Potassium rate influenced the characteristics of primary stolons (length, number of nodes, and ramifications) more than N or P. A significant linear regression was observed for the number of ramifications (secondary stolons), while stolon length and the number of nodes fit a nonlinear regression model. Plant growth response to the imposed rates revealed the possibility to halve N or P in respect to control rates, while for K the control rate proved to be necessary. In fact, when K rate was halved, the number of nodes, which is a main parameter for nursery purposes, significantly decreased. Half N, half P, and control K rates also ensured a satisfactory plant mineral composition, consistent with values previously reported for bermudagrass. Potassium competition with both calcium and magnesium was observed. Nitrogen, P, or K rates higher than the respective controls are not advisable since they did not enhance plant growth or mineral content.

Nitrogen, P, and K are the primary nutrients to be supplied to turfgrass through fertilizer application (Beard, 1973; Turgeon, 2007). Nitrogen, being the nutrient required in greatest amounts by turfgrass, is the basic element of turf fertilization programs. It has a major influence on shoot, root, rhizome, and stolon growth; turf density and color; cold tolerance; and drought resistance (Beard, 1973; Carrow et al., 1987; Trenholm et al., 1998). Symptoms of N deficiency appear first in older leaves, which gradually lose green color (Christians, 1998); plants show a non-healthy appearance, with short and thin leaf blades and stolons (Oertli, 1963). Conversely, overapplication of N promotes excessive shoot growth and results in poor root and stolon development (Pettit and Fagan, 1974). Potassium is second only to N in the amounts required to sustain turfgrass quality and growth. Various studies have focused on the importance of adequate K fertilization to maintain turfgrass quality, enhance root growth and cold hardiness, and improve disease resistance and tolerance to drought, heat, and wear (Beard, 1973; Turner and Hummel, 1992). Potassium deficiencies in turfgrass result in a general reduction in growth, chlorosis of leaf blades, and increased disease incidence, while excessive K fertilization can reduce calcium (Ca) and magnesium (Mg) in plant tissues (Miller, 1999; Snyder and Cisar, 2000). The K rate normally recommended for turfgrass ranges between one-half and two-thirds the N rate (Sartain, 2002; Snyder and Cisar, 2000), although in recent years the trend for turf managers to fertilize with K in amounts equal or even exceeding those of N has been observed (Snyder et al., 2007). Turfgrass generally does not have high P requirements, but P deficiencies may be observed during establishment due to limited root development and relative P immobility in some soils (Rodriguez et al., 2002). Main symptoms of P deficiency are purple discoloration of leaf blades and shorter internodes. No symptoms of P excess are described for turfgrass.

Nutrient requirement or status of plants can be assessed by tissue analysis (Hochmuth et al., 2012; Smith, 1962). Also in turf species, plant analysis may help to diagnose possible nutritional disorders and to monitor the effectiveness of a fertility program (Landschoot, 2003; McCrimmon, 2001).

Several studies report nutrient data for warm season turfgrass including bermudagrass (*Cynodon* sp.), the most widely used species for golf courses, sport fields, and home lawns in many transition zones in the world (Wu et al., 2009). Mineral composition of bermudagrass was studied by Barrios et al. (1979), Barrios and

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha^{-1}	0.8922
28.3495	oz	g	0.0353
7.4892	oz/gal	g·L^{-1}	0.1335
1	ppm	mg·kg^{-1}	1
1	ppm	mg·L^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Jones (1980), Goatley et al. (1994), McCrimmon (2001), Peacock (2001), Peacock et al. (1997), Petrovic et al. (2005), Snyder and Cisar (2000), and Walworth and Kopec (2004) with different results depending on the cultivar and on different nutrient sources and rates. All cited studies refer to field conditions, while no data are available on nutrient needs and mineral composition of bermudagrass in the nursery.

A new nursery activity has been recently developed for stoloniferous turfgrass since an innovative technique for establishment of warm season species, based on the transplant of single prerooted plantlets in peat plugs, has been introduced (Volterrani et al., 2008) (Fig. 1). The use of plug plants shows several advantages: easy transport, long preplanting life, availability of transplanting machines, ease and versatility of transplant, even on no-tilled soil. The technique is particularly useful for noninvasive putting green conversion, since the use of plants with fully developed root systems and actively growing shoots enhances their colonization potential and minimizes the effects of no-tillage conversion (Volterrani et al., 2012). The nursery activity is carried out under controlled environment (greenhouse), where plants are cultivated in pots filled with peat with the aim to produce stolons (donor plants); stolons are divided in one-node sprigs, and the harvested sprigs are grown in alveolate trays until complete plantlets are formed (Lenzi et al., 2012) (Fig. 1). Obviously, donor plants are expected to produce as many stolons as possible, and stolons should be well-developed and contain many nodes. These goals as well as the cultivation system (greenhouse, pot-grown plants) imply different fertilization management in respect to turf fertilization programs. In general, greenhouse crops are intensive growing systems that involve higher fertilizer inputs than open-field crops (Sonneveld, 1993). Moreover, fertilizer demand is influenced by pot cultivation. In fact, when plants are container-grown, the limited volume of substrate available for roots in comparison with the volume explored by soil-grown plant roots means limited supply of nutrients (Raviv et al., 2002). In addition, in growing media normally used for container cultivation, included organic substrates such as peat, the amount of naturally occurring available nutrients is small (Dresbøll, 2004; Raviv et al., 1986).

The objective of this research was to study the effect of different N, P, and K rates on the growth and the

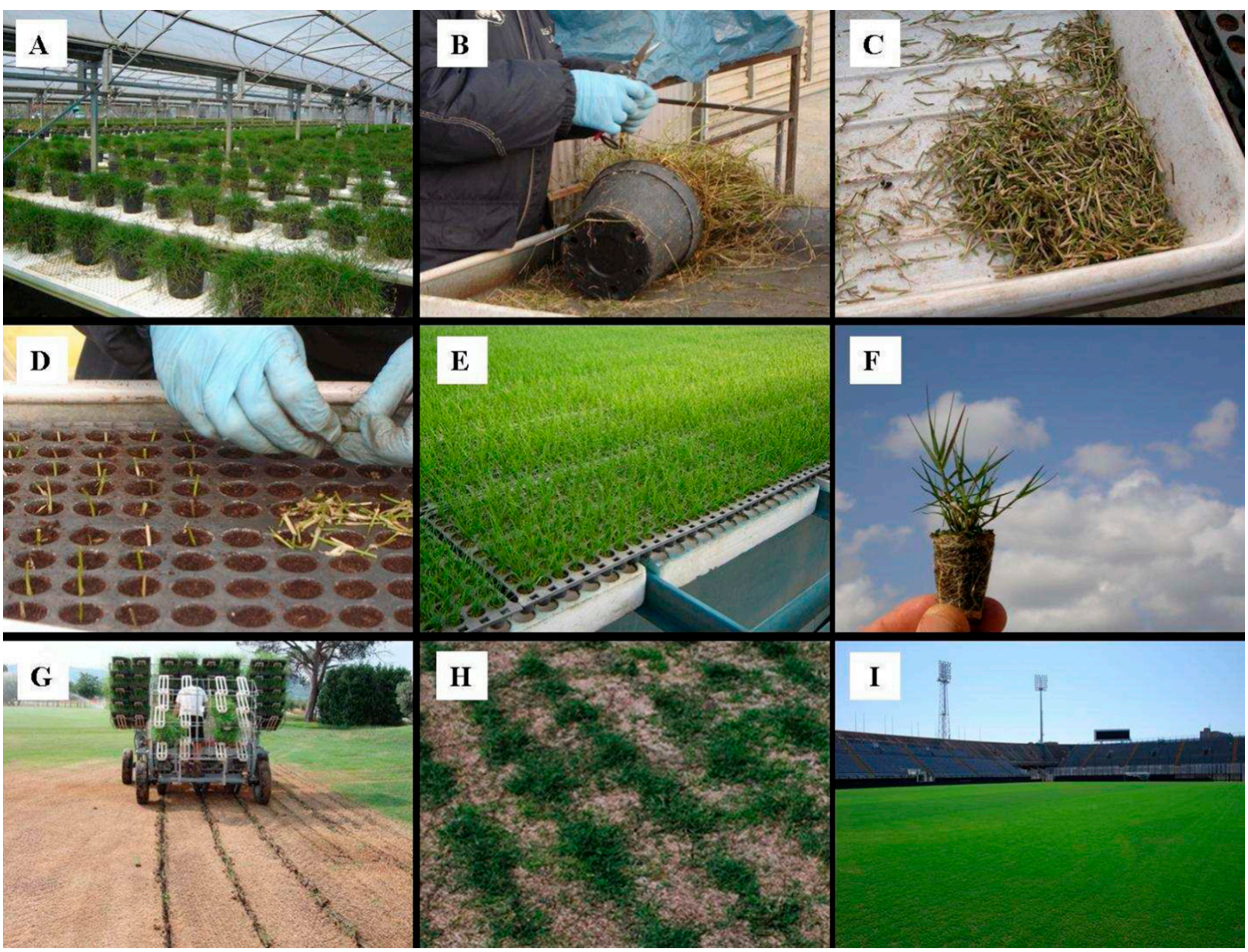

Fig. 1. Nursery production and use of warm season prerooted plug plants in turfgrass industry: (A) donor plants, (B) stolon collection, (C) stolon division, (D) stolon planting, (E) stolon rooting, (F) rooted plantlet, (G) transplant, (H) establishment, and (I) total groundcover on football pitch.

nutrient content of hybrid bermudagrass plants grown in pots as donor plants in the nursery.

Materials and methods

Plant material, growing conditions, and experimental treatments. A study was conducted in the greenhouse at Pacini Horticultural Nursery located in Rigoli (Pisa), central Italy (lat. 45°45′N, long. 10°26′E, 6 m elevation) under 22 ± 3 °C minimum air temperature range, 42 ± 3 °C maximum air temperature range, 56.6% average relative humidity, and natural sunlight. On 7 June 2011, plants derived from one-node sprigs of 'Patriot' bermudagrass, a recently developed high-quality hybrid cultivar (Taliaferro et al., 2006), were transplanted into plastic pots (17-cm deep, 20-cm diameter, 3.8-L volume) placing three plants per pot. Plants were composed by one stolon 10–12 cm long and one shoot 3–5 cm high. A nonamended, nonfertilized sphagnum peat was used as substrate after being adjusted to pH 5.9 with calcium oxide (2.5 $g \cdot L^{-1}$) and fertilized with macronutrients and micronutrients. Nitrogen, P, and K were supplied at different rates. Nitrogen was supplied as ammonium nitrate (34.0% N), P as triple superphosphate (20.1% P), and K as potassium sulfate (42.3% K). As control rates, N, P, and K levels normally imposed by the nursery to bermudagrass donor plants (314, 52, and 198 $mg \cdot L^{-1}$ substrate, respectively) were adopted. Starting from the control rates, each element was reduced to zero, halved, doubled, or tripled while the other two were kept unchanged (13 treatments in all). Fertilization treatments and corresponding N, P, and K rates are listed in Table 1. Magnesium and micronutrients [iron (Fe), copper (Cu), molybdenum (Mo), manganese (Mn), boron (B), and zinc (Zn)] were supplied at only one rate adding to the substrate: 732 $mg \cdot L^{-1}$ magnesium sulfate (9.8% Mg), 14 $mg \cdot L^{-1}$ iron chelate (6.0% Fe), 7.8 $mg \cdot L^{-1}$ copper sulfate (23.0% Cu), 4 $mg \cdot L^{-1}$ sodium molybdate (39.6% Mo), 2.7 $mg \cdot L^{-1}$ manganese sulfate (32.5% Mn), 2.7 $mg \cdot L^{-1}$ borax (11.3% B), and 0.8 $mg \cdot L^{-1}$ zinc sulfate heptahydrate (22.7% Zn).

Pots were arranged in a completely randomized design with four pots per treatments. During the trial, plants were manually irrigated as necessary.

Data collection and statistical analysis. After 1 month of growth in pots, stolons were developed enough to be used for propagation and plants were harvested. The following data were collected from each pot: dry weight (after oven-drying at 80 °C until constant weight) of aerial part (shoots plus stolons); number of primary stolons; and, on three primary stolons per pot, length, number of nodes, and number of stolons developing from the nodes (ramifications or secondary stolons). In addition, aerial dry matter of three pots per treatment was analyzed for N, P, K, Ca, Mg, sulfur (S), Fe, Mn, and Zn content. Nitrogen and S were determined using a Flash Elemental Analyzer 1112 NC (Thermo Fisher Scientific, Waltham, MA) according to the manufacturer's instructions. The other mineral elements (P, K, Ca, Mg, Fe, Mn, and Zn) were extracted by nitric/perchloric acid digestion (Manzelli et al., 2010) and measured by inductively coupled argon plasma emission spectroscopy (IRIS Intrepid II XSP Radial, Thermo Fisher Scientific).

Data were analyzed separately for N, P, or K. Regression analysis was adopted and the coefficients of determination (R^2) were calculated. When treatment effect was significant, means were separated using the Tukey's test.

Results and discussion

Plant growth. As expected, N, P, and K proved to be all necessary for the growth and the development of 'Patriot' hybrid bermudagrass grown in the nursery. In fact, when not supplied with N, P, or K, plants showed a general reduction in growth and pale green color. Nevertheless, the assessed parameters exhibited a different response to increasing rates of nutrients depending on the element.

The role of N fertilization in enhancing the production of aboveground matter in bermudagrasses is widely known (Overman et al., 1990; Sartain and Dudeck, 1982; Snyder and Cisar, 2000; Stanford et al., 2005; Trenholm et al., 1998). In this study, N rate influenced aerial dry weight, the number of primary stolons, and their ramifications, but not their length or their number of nodes (Table 2). On the contrary, other authors found an increasing effect of N on stolon length of 'Tifdwarf' (Stanford et al., 2005; Trenholm et al., 1997) and 'Floradwarf' (Trenholm et al.,1997) bermudagrass.

Aerial dry weight increased with increasing N rate with a nonlinear less than proportional trend (Table 2). As shown by R^2 values, N exhibited a greater effect on this parameter than P or K (Table 2). In absence of N fertilization (zero N rate) aerial dry weight was significantly lower than with any other N rates, and increased by 144% passing from zero N to half N rate; its highest value was obtained with triple N rate, that was not different from double N and control rate (Table 2). The number of primary stolons was negatively affected by the absence of N fertilization (zero N rate), while no differences were observed among the other N rates despite a significant nonlinear regression (Table 2). The number of secondary stolons increased along with N increase fitting a linear regression model, but only the difference between zero N and triple N was significant (Table 2). Trenholm et al. (1997) found both linear and quadratic components of N in the response model for the number of stolons produced by hybrid bermudagrasses.

As observed by Guertal (2006), although P is one of the nutrients most commonly applied to turfgrass, research on it is somewhat limited. This author found that shoot density and clipping dry weight of 'TifEagle' bermudagrass increased linearly with increasing P rate (32, 64, 96, 128 $kg \cdot ha^{-1}$ P). On the contrary, Rodriguez et al. (2002) obtained an increase in cover

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) rates applied to 'Patriot' hybrid bermudagrass grown in pots.

Fertilization treatments	Rate ($mg \cdot L^{-1}$ substrate)[z] N	P	K
Control	314	52	198
Zero N	0	52	198
Half N	157	52	198
Double N	628	52	198
Triple N	942	52	198
Zero P	314	0	198
Half P	314	26	198
Double P	314	104	198
Triple P	314	156	198
Zero K	314	52	0
Half K	314	52	99
Double K	314	52	396
Triple K	314	52	594

[z]1 $mg \cdot L^{-1}$ = 1 ppm.

Table 2. Aerial dry weight, number of primary stolons, primary stolon length, number of nodes, and number of secondary stolons in 'Patriot' hybrid bermudagrass plants subjected to different nitrogen (N), phosphorus (P), and potassium (K) rates. Values are means (± SE) of four replications.

Nutrient	Rates	Aerial dry wt [mean ±SE (g/plant)][z]	Primary stolons [mean ±SE (no./plant)]	Primary stolon length [mean ±SE (cm)][z]	Nodes [mean ±SE (no./primary stolon)]	Secondary stolons [mean ±SE (no./primary stolon)]
N	Zero N	1.8 ± 0.13 c[y]	4.8 ± 0.75 b	56.9 ± 3.27	8.5 ± 1.23	4.0 ± 0.89 b
	Half N	4.4 ± 0.49 b	9.8 ± 0.48 a	71.5 ± 5.40	9.3 ± 0.72	5.9 ± 0.37 ab
	Control	5.7 ± 0.36 ab	12.8 ± 0.85 a	75.4 ± 3.45	10.5 ± 0.44	6.3 ± 0.71 ab
	Double N	5.5 ± 0.17 ab	11.8 ± 1.49 a	69.9 ± 3.10	9.3 ± 0.47	6.4 ± 0.25 ab
	Triple N	6.5 ± 0.76 a	12.6 ± 1.17 a	73.9 ± 5.72	9.8 ± 1.05	9.2 ± 1.55 a
	Rate effect[y]	**	**	NS	NS	*
	Linear regression[y]	NS	NS	NS	NS	**
	Nonlinear regression[y]	**	*	NS	NS	NS
	R^2	0.820	0.743	0.436	0.171	0.537
P	Zero P	2.2 ± 0.25 c	4.3 ± 0.48 c	55.0 ± 5.54 b	8.8 ± 1.03	4.9 ± 0.60 b
	Half P	7.8 ± 0.65 a	12.5 ± 0.29 a	79.4 ± 6.95 a	10.7 ± 1.01	9.8 ± 1.13 a
	Control	5.7 ± 0.36 ab	12.8 ± 0.85 a	75.4 ± 3.45 a	10.5 ± 0.44	6.3 ± 0.71 ab
	Double P	5.8 ± 0.87 ab	12.3 ± 0.75 ab	79.5 ± 2.74 a	11.6 ± 0.16	9.0 ± 0.71 a
	Triple P	4.9 ± 0.65 b	9.2 ± 1.37 b	73.4 ± 3.28 ab	10.3 ± 0.64	7.8 ± 0.90 ab
	Rate effect	**	**	*	NS	**
	Linear regression	NS	NS	NS	NS	NS
	Nonlinear regression	**	**	*	NS	**
	R^2	0.749	0.833	0.557	0.341	0.608
K	Zero K	1.2 ± 0.13 b	5.3 ± 1.31 b	47.3 ± 4.30 b	7.8 ± 0.44 b	2.9 ± 0.58 b
	Half K	4.4 ± 0.62 a	9.5 ± 0.96 ab	61.0 ± 2.45 ab	8.0 ± 0.41 b	5.6 ± 0.72 a
	Control	5.7 ± 0.36 a	12.8 ± 0.85 a	75.4 ± 3.45 a	10.5 ± 0.44 a	6.3 ± 0.71 a
	Double K	5.1 ± 0.56 a	12.5 ± 0.96 a	69.2 ± 2.69 a	9.3 ± 0.41 ab	5.6 ± 0.44 a
	Triple K	5.8 ± 1.01 a	12.6 ± 2.35 a	64.3 ± 4.10 a	8.4 ± 0.52 b	6.9 ± 0.42 a
	Rate effect	**	**	**	**	**
	Linear regression	NS	**	NS	NS	**
	Nonlinear regression	*	NS	**	**	NS
	R^2	0.720	0.588	0.711	0.623	0.639

[z]1 g = 0.0353 oz, 1 cm = 0.3937 inch.
[y]For each nutrient, means in the same column followed by different letters are significantly different (Tukey's test): * = significant for $P \leq 0.05$, ** = significant for $P \leq 0.01$, NS = nonsignificant.

rate and shoot weight during the establishment of four hybrid bermudagrass cultivars passing from 1N:0P:0.66K or 1N:0P:1.41K to 1N:0.17P:0.66K fertilization ratio, but further increasing of P rate to 1N:0.39P:0.66K or 1N:0.57P:0.66K ratios did not produce additional enhancement or even caused a decrease in plant growth. In this study, aerial dry weight, the number and the length of primary stolons, and the number of secondary stolons were influenced by P rates. They varied with increasing P according to a nonlinear regression model and showed an initial increase followed by a decrease (Table 2). The increase that occurred passing from zero P rate to half P was significant for all the P-influenced parameters (Table 2). The highest values were observed with half P rate for both aerial dry weight, with no difference compared with control and double P rate, and the number of secondary stolons, which did not varied further with higher P rates (Table 2). The highest number of primary stolons was obtained with control P rate, but without differences as compare with half P and double P rate, and the longest stolons derived from double P rates, but without differences compared with half P, control, and triple P (Table 2). Phosphorus had a larger effect than N and K on the number of primary stolons, as shown by R^2 values (Table 2).

In a field study conducted by Peacock et al. (1997) growth rates of 'Tifgreen' bermudagrass were unaffected by K fertilization. In contrast, in the absence of any K application, Sartain (2002) and Snyder and Cisar (2000) noticed a reduction in bermudagrass growth; however, above a threshold rate, K did not produce any additional growth. In this study the absence of K caused a decrease in all measured growth parameters, while no differences were noticed among the other K rates except for the number of nodes (Table 2). In studies that are aimed to turf fertilization management this parameter is not evaluated, while it is very important for nursery purposes. The highest number of nodes was obtained with control K rate, which was comparable to only double K (Table 2). The values of R^2 showed that K affected the characteristics of primary stolons (length, number of nodes, and ramifications) more than N and P (Table 2). The variation, due to K rate, of aerial dry weight, primary stolon length, and nodes fits a nonlinear regression model, while the number of both primary and secondary stolons increased with increasing K rate according to a linear regression model (Table 2). Trenholm et al. (1997, 1998) found both no effect and linear and/or quadratic components in the response of bermudagrass to K rate depending on cultivar and daylength. In cultivar FloraDwarf, shoot and stolon growth, stolon number, and stolon length were unaffected by K rates under long-day (>13 h) while a linear effect of K was observed under short-day (<13 h); for the same parameters, cultivar Tifdwarf showed a linear response to increasing K rates under long-day and both linear and quadratic effect under short-day (Trenholm et al., 1997, 1998).

Nutrient content. Tissue nutrient concentration in 'Patriot' hybrid bermudagrass grown in pots was affected by N, P, and K rates. Since no information is available about bermudagrass elemental composition in nursery conditions, representative sufficiency ranges as presented by McCrimmon (2001) and Jones et al. (1991) for this species in field conditions were considered in the present study for macronutrients and micronutrients, respectively (Table 3). The analyzed micronutrients (Fe, Mn, and Zn) resulted within the stated sufficiency ranges at any applied fertilization treatment, while insufficient levels were sometimes detected for macronutrients (Tables 4 and 5).

When N was not provided (zero N rate), N, K, and Mg concentrations in plant tissue were below the stated sufficiency ranges; magnesium concentration was below the sufficiency range also when N rate was tripled, while Ca concentrations did not reach the stated sufficiency range irrespective of the N rate applied (Table 4). All the nutrients whose tissue concentration was influenced by N fertilization (N, K, Mg, Mn, and Zn) varied with increasing N according to a nonlinear regression model: nitrogen, K, and Mg increased significantly passing from zero N to control rate and did not show any further increase; Mn and Zn concentrations were significantly higher when control rate was applied in comparison with both lower and higher N rates (Tables 4 and 5). As obvious, tissue N content was especially affected by N rate (R^2 = 0.922), but also Mn concentration was influenced by N more than by P or K (Tables 4 and 5). Nitrogen rate did not affect P, Ca, S, and Fe (Tables 4 and 5).

Phosphorus rate influenced the tissue content of all the analyzed nutrients except for Ca and Fe (Tables 4 and 5). The variation of N fit a linear regression model, while the other P-influenced nutrients changed according to a nonlinear regression model (Tables 4 and 5). Plants that were not supplied with P (zero P rate) showed a significant reduction in N concentration compared with plants fertilized with double P and triple P rates (Table 4). Phosphorus content in control plants was significantly higher than in plants not supplied with P or fertilized with half P rate, but significantly lower compared with double P rate (Table 4). When P was not provided, K concentration was significantly lower than that observed with any other P rate (Table 4). Differences were noticed between zero P rate and control, double, and triple P rates, and between half P and double P in Mg

Table 3. Representative sufficiency ranges for macronutrient and micronutrient content in bermudagrass tissue.

Nutrient	Range		Reference
Nitrogen	2.0–5.0	% dry matter	McCrimmon (2001)
Phosphorus	0.2–0.5		
Potassium	2.0–5.0		
Calcium	0.5–1.5		
Magnesium	0.2–0.5		
Sulfur	0.2–0.5		
Iron	5–350	ppm[z] dry matter	Jones et al. (1991)
Manganese	25–300		
Zinc	25–300		

[z]1 ppm = 1 $mg \cdot kg^{-1}$.

Table 4. Macronutrient [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)] content in aerial part of 'Patriot' hybrid bermudagrass plants subjected to different N, P, and K rates. Values are means (± SE) of three replications.

Nutrient	Rates	N	P	K	Ca	Mg	S
		[mean ±SE (% dry matter)]					
N	Zero N	1.63 ± 0.17 b[z]	0.37 ± 0.02	1.94 ± 0.08 b	0.35 ± 0.04	0.15 ± 0.01 b	0.36 ± 0.08
	Half N	3.59 ± 0.30 a	0.47 ± 0.03	2.86 ± 0.13 a	0.40 ± 0.02	0.23 ± 0.01 a	0.56 ± 0.04
	Control	3.71 ± 0.25 a	0.41 ± 0.06	2.84 ± 0.11 a	0.41 ± 0.03	0.24 ± 0.02 a	0.49 ± 0.01
	Double N	4.18 ± 0.08 a	0.47 ± 0.04	2.74 ± 0.06 a	0.34 ± 0.03	0.21 ± 0.02 ab	0.46 ± 0.06
	Triple N	4.17 ± 0.01 a	0.45 ± 0.02	2.48 ± 0.06 a	0.34 ± 0.01	0.19 ± 0.00 ab	0.48 ± 0.02
	Rate effect[z]	**	NS	**	NS	**	NS
	Linear regression[z]	NS	NS	NS	NS	NS	NS
	Nonlinear regression[z]	**	NS	**	NS	**	NS
	R^2	0.922	0.360	0.874	0.387	0.747	0.464
P	Zero P	3.18 ± 0.11 b	0.14 ± 0.01 c	1.91 ± 0.14 b	0.30 ± 0.05	0.15 ± 0.03 c	0.34 ± 0.02 b
	Half P	3.65 ± 0.17 ab	0.26 ± 0.03 c	2.55 ± 0.11 a	0.40 ± 0.03	0.18 ± 0.01 bc	0.41 ± 0.03 ab
	Control	3.71 ± 0.25 ab	0.41 ± 0.06 b	2.84 ± 0.11 a	0.41 ± 0.03	0.24 ± 0.02 ab	0.49 ± 0.01 a
	Double P	4.08 ± 0.12 a	0.58 ± 0.01 a	2.94 ± 0.12 a	0.41 ± 0.00	0.26 ± 0.00 a	0.53 ± 0.05 a
	Triple P	3.99 ± 0.18 a	0.55 ± 0.02 ab	3.03 ± 0.04 a	0.36 ± 0.01	0.24 ± 0.01 ab	0.44 ± 0.03 ab
	Rate effect	*	**	**	NS	**	**
	Linear regression	**	NS	NS	NS	NS	NS
	Nonlinear regression	NS	**	**	NS	**	*
	R^2	0.630	0.932	0.870	0.514	0.764	0.724
K	Zero K	3.90 ± 0.14	0.55 ± 0.03 a	1.78 ± 0.21 b	0.54 ± 0.02 a	0.31 ± 0.01 a	0.58 ± 0.06
	Half K	3.91 ± 0.11	0.51 ± 0.01 ab	2.60 ± 0.06 a	0.40 ± 0.01 ab	0.26 ± 0.02 ab	0.46 ± 0.02
	Control	3.71 ± 0.25	0.41 ± 0.06 ab	2.84 ± 0.11 a	0.41 ± 0.03 ab	0.24 ± 0.02 bc	0.49 ± 0.01
	Double K	3.93 ± 0.01	0.37 ± 0.01 b	3.06 ± 0.09 a	0.31 ± 0.01 b	0.21 ± 0.00 bc	0.46 ± 0.02
	Triple K	3.87 ± 0.02	0.44 ± 0.04 ab	2.96 ± 0.07 a	0.35 ± 0.06 b	0.20 ± 0.02 c	0.49 ± 0.02
	Rate effect	NS	*	**	**	**	NS
	Linear regression	NS	*	NS	**	**	NS
	Nonlinear regression	NS	NS	**	NS	NS	NS
	R^2	0.153	0.676	0.877	0.752	0.803	0.481

[z]For each nutrient, means in the same column followed by different letters are significantly different (Tukey's test): * = significant for $P \leq 0.05$, ** = significant for $P \leq 0.01$, NS = nonsignificant.

concentration (Table 4). Control plants and plants supplied with double P rate showed a significantly higher S concentration than plants that were not provided with P (Table 4). Control P rate resulted also in higher Mn concentration than half P rate and higher Zn concentration compared with any other P rate (Table 5). Ca concentrations did not reach the stated sufficiency range irrespective of the P rate applied, and other values below the sufficiency range were observed for P, K, and Mg when P was not provided, and for Mg when P was halved in respect to the control rate (Table 4). As obvious, tissue P content was especially affected by P rate ($R^2 = 0.932$), but also S concentration was influenced by P more than by N or K (Table 4).

Nitrogen, S, and Fe concentrations in plant tissue were unaffected by K rates, while significant effects were observed for all the other analyzed elements (Tables 4 and 5). Phosphorus, Ca, and Mg decreased with increasing K rates according to a linear regression model (Table 4). For P, a significant difference was detected between zero and double K rates; zero K rate differed from double and triple K in Ca concentration; magnesium concentration in plants not supplied with K was higher than in plants provided with control, double, and triple K rates, and half K differed from triple K rate (Table 4). Potassium competition with both Ca and Mg was previously observed in bermudagrass by Miller (1999). The zero K rate was the only treatment in the whole experiment to ensure a Ca concentration within the stated sufficiency range. Nevertheless, no symptoms of Ca deficiency were observed in this study. That could suggest that the representative sufficiency ranges for Ca as presented by McCrimmon (2001) are possibly too high. In fact, McCrimmon, who reported the mineral composition of 12 bermudagrass cultivars under different N:K treatments, found lower Ca values in most cases. Moreover, according to Turgeon (2007), Ca is absorbed by turfgrass at levels equal to or even below those of P, that is, usually, not over 0.5%.

Potassium, Mn, and Zn varied with increasing K according to a nonlinear regression model (Tables 4 and 5). Potassium concentration was below the sufficiency range in plants not supplied with K (zero K rate) and significantly increased passing to control rate, but did not show further increase (Table 4). Manganese and Zn concentrations were higher when control rate was applied in comparison with both lower and higher K rates (Table 5). On the basis of R^2 values, K was the nutrient showing the main

Table 5. Micronutrient [iron (Fe), manganese (Mn), zinc (Zn), and sodium (Na)] content in aerial part of 'Patriot' hybrid bermudagrass plants subjected to different nitrogen (N), phosphorus (P), and potassium (K) rates. Values are means (± SE) of three replications.

Nutrient	Rates	Fe	Mn	Zn
		[mean ±SE (ppm dry matter)][z]		
N	Zero N	79.3 ± 14.23	189.5 ± 15.52 b[y]	111.0 ± 12.96 c
	Half N	58.4 ± 5.70	187.7 ± 6.46 b	144.7 ± 8.07 bc
	Control	61.0 ± 3.49	270.0 ± 8.67 a	238.2 ± 8.23 a
	Double N	66.5 ± 8.54	157.9 ± 17.49 bc	161.8 ± 16.08 b
	Triple N	58.6 ± 7.72	117.2 ± 4.05 c	155.0 ± 3.87 bc
	Rate effect[y]	NS	**	**
	Linear regression[y]	NS	NS	NS
	Nonlinear regression[y]	NS	**	**
	R^2	0.287	0.902	0.884
P	Zero P	62.0 ± 6.57	178.3 ± 37.42 ab	138.2 ± 27.22 b
	Half P	57.5 ± 4.68	152.4 ± 15.39 b	101.6 ± 11.37 b
	Control	61.0 ± 3.49	270.0 ± 8.67 a	238.2 ± 8.23 a
	Double P	62.3 ± 2.11	178.5 ± 5.96 ab	152.6 ± 5.62 b
	Triple P	69.5 ± 1.90	179.5 ± 19.67 ab	151.1 ± 11.05 b
	Rate effect	NS	*	**
	Linear regression	NS	NS	NS
	Nonlinear regression	NS	**	**
	R^2	0.309	0.657	0.822
K	Zero K	65.2 ± 1.75	231.4 ± 16.67 ab	109.8 ± 4.51 b
	Half K	68.8 ± 3.34	206.8 ± 7.46 b	136.0 ± 11.60 b
	Control	61.0 ± 3.49	270.0 ± 8.67 a	238.2 ± 8.23 a
	Double K	57.0 ± 5.20	189.7 ± 2.03 bc	145.6 ± 3.99 b
	Triple K	76.1 ± 29.64	143.0 ± 16.34 c	106.5 ± 11.36 b
	Rate effect	NS	**	**
	Linear regression	NS	NS	NS
	Nonlinear regression	NS	**	**
	R^2	0.104	0.868	0.940

[z]1 ppm = 1 $mg\cdot kg^{-1}$.
[y]For each nutrient, means in the same column followed by different letters are significantly different (Tukey's test): * = significant for $P \leq 0.05$, ** = significant for $P \leq 0.01$, NS = nonsignificant.

effect not only on K concentration in plant tissues, but also on their Ca, Mg, and Zn contents (Tables 4 and 5).

Most of the studies about the mineral composition of bermudagrass concern N, P, and K levels. Nitrogen content detected in this study was consistent with that found by several authors in bermudagrass turf clippings obtained under field conditions (Barrios et al., 1979; Goatley et al., 1994; Peacock, 2001; Petrovic et al., 2005; Snyder and Cisar, 2000; Walworth and Kopec, 2004).

The foliage of adequately fertilized turfgrass usually contains about 10% as much P as N (Snyder et al., 2007), and P absolute concentration of dried turfgrass clippings is usually less than 0.5% (Mc Crimmon, 2001; Petrovic et al., 2005; Turgeon, 2007; Walworth and Kopec, 2004). In this study, P content in aerial part of 'Patriot' hybrid bermudagrass ranged from 7% to 14% of N content with the exceptions of plants not provided with P (4% as much P as N) or with N (23% as much P as N). Phosphorus content above 0.5% was detected in plants fertilized with double and triple P rates, zero K, and half K.

Although in turfgrass tissue K levels may reach up to 5% of dry weight where liberal quantities have been supplied through fertilization, normal percentages are about half that much (Turgeon, 2007), corresponding about to half N percentage (Snyder et al., 2007). In many studies on bermudagrass, K levels in clippings were close to 2% or slightly lower (Barrios et al., 1979; Goatley et al., 1994; McCrimmon, 2001; Peacock, 2001; Petrovic et al., 2005; Snyder and Cisar, 2000; Walworth and Kopec, 2004). Potassium content found in 'Patriot' hybrid bermudagrass ranged on average from 1.78% to 3.06%, but values lower than 2% were detected only in plants not supplied with N, P, or K. These plants excluded, 'Patriot' contained from 59% to 80% as much K as N. This result may indicate that stolons, which represented the prevalent material in the samples analyzed in this study, contain higher K amounts than leaves, prevailing in clippings.

Conclusion

On the basis of the growth response of 'Patriot' hybrid bermudagrass grown in pots to different N, P, and K rates, and considering the system under study here (aimed to the production of one-node sprigs from stolons to be used for propagation), the possibility to halve N or P in respect to control rates (314 $mg\cdot L^{-1}$ N and 52 $mg\cdot L^{-1}$ P substrate, respectively) was detected, while K control rate (198 $mg\cdot L^{-1}$ substrate) proved to be necessary. In fact, while no difference was observed in the growth achieved by the plants supplied with half N and half P rates in comparison with the respective controls, in the case of K halving the control rate caused a significant reduction in the achievable multiplication rate since stolons were formed by a lower number of nodes. Half N, half P, and control K rates also ensured a satisfactory plant mineral composition.

Neither negative effects on growth parameters nor significant variations in plant nutrient contents resulted from doubling or tripling N, P, or K control rates. But, since no advantage was obtained either, high nutrient applications are not advisable. In contrast, high fertilizer inputs are usually applied in greenhouse systems, contributing significantly to ground and surface water pollution due to nutrient discharges (Voogt, 2005). Therefore, limiting fertilization levels is advantageous for environmental reasons, especially for N, being N the nutrient supplied in the largest amount and highly subject to leaching (Howarth, 2008; Liu et al., 2005; Rejesus and Hornbaker, 1999).

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