

Controlled-release Fertilizers Improved Croton Growth and Reduced Nitrogen Leaching

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Abstract. Fertilizer management is an essential step in the production process, as it allows the plant to use its productive capacity to the fullest extent possible. Researchers have tested maximum nutrient use with reduced losses to the environment aiming to increase productivity with fewer environmental impacts. This study compared the effects of controlled-release fertilizers (CRFs) with water-soluble fertilizer (WSF) and clear water (control) on the growth and nutrient uptake of croton (*Codiaeum variegatum* L.) and nitrogen leaching. The experiment was conducted with three replications and six treatments: two rates (1.5 g and 3.0 g per liter of substrate) of two CRFs [Osmocote Plus (15% N, 3.93% P, and 9.96% K) and Basacote (15% N, 3.49% P, and 9.96% K)], WSF, and clean water as control. All CRFs were applied before planting and WSF was supplied as nutrient solution through automated moisture sensor activated irrigation system. Plant growth (number of leaves, leaf area, stem height, root volume, and shoot and root dry weights) and total nutrient contents in the leaf tissue were evaluated every 30 days. Electrical conductivity (EC), pH, nitrate, ammonium, and total nitrogen contents were measured in the leached solution. Indeed, results showed that CRFs at a low rate provided similar development and quality of croton plants compared with WSF. Plant growth indicators were similar until 90 days after transplanting (DAT). After that, at 150 DAT, the highest values to number of leaves and leaf area occurred with WSF and with the lowest CRF rate as compared with the other treatments and control. The highest root volume was found with the WSF, which resulted in larger roots compared with the other treatments. These results showed WSF can be replaced by CRFs at low rates on croton growth. Moreover, according to the visual scale, the best treatments were WSF and Basacote at the low rate, where plants were bright, with multicolored leaves with prominent orange shades. However, CRFs maintained pH and EC within the recommended range for the growth of croton and reduced the nitrogen leaching from the pots.

Croton (*Codiaeum variegatum* L.) belongs to the Euphorbiaceae family and is one of the most popular ornamental tropical shrubs worldwide (Mollick et al., 2011). This tropical woody shrub grows up to 4 m tall with simple alternate leaves of various shapes, divided by the midrib, of varied colors like red, purple, and yellow (Whistler, 2000). Croton plants have attained a prominent place among foliage species because of their adaptability to indoor conditions and shaded gardens, including leaf shape and color range. In addition, croton can be cultivated as landscape plants or grown in pots. Grown as a potted plant, croton requires more

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fertilizer per unit of surface area than plants grown in the landscape. In addition, its esthetic quality of foliage due to intensity of foliar coloration depends on proper nutrition (Stamps and Osborne, 2003).

CRFs are commonly used as fertilizer sources in container production systems (Grable et al., 2017). CRFs can improve plant growth and quality, increasing the fertilizer use efficiency and preventing losses of nutrients, especially nitrogen (N) by leaching or denitrification (Fageria and Baligar, 2005). CRFs are designed to release nutrients into the grown medium at a rate more closely matched to nutrient demand during growth stages, with a single application at time of planting, thereby reducing labor costs compared with split applications of the conventional fertilizers (Shaviv, 2001; Trenkel, 2010). CRFs are derived from water-soluble mineral nutrient salts encapsulated by a polymer and/or resin coating of varying thickness to dictate longevity (Grable et al., 2017).

CRFs are usually applied at time of planting in containerized production because of their long-term nutrient release. The type of coating is responsible for the release mechanism of coated fertilizers, which is the transfer of the nutrient from the fertilizer polymer interface to the polymer soil interface by diffusion/swelling, degradation of the polymer coating, and fracture or dissolution (Shaviv, 2001). The rates of nutrient release from various coated fertilizers are positively correlated with the temperature of the substrates (Nelson, 2012; Sonneveld and Voogt, 2009). Therefore, CRF response to environmental conditions depends on the formulation and coating, as polymeric material, from each manufacturer (Carson and Ozores-Hampton, 2013).

By proper use of CRFs, agronomic and environmental benefits can be attained in comparison with conventional fertilizers. CRFs can optimize the nutrient supply, release rate, and leaching, aiming at high yields and decreased leaching losses (Conover and

Table 1. Mean values of number of leaves, leaf area, stem height, root volume, shoot, and root dry weight of croton plants grown in containers affected by different rates and types of fertilizers.

Main factors	Number of leaves	Leaf area (cm ²)	Stem ht (cm)	Root volume (cm ³)	Shoot dry wt (g)	Root dry wt (g)
Fertilizers (F)						
Control	12.26	584.21	12.31	29.78	5.99	2.71
WSF	16.83	1,014.57	15.35	38.71	8.52	3.10
OSM 1.5 g	15.23	832.40	12.86	32.07	6.83	2.85
OSM 3.0 g	14.97	854.71	12.78	29.31	6.91	2.51
BAS 1.5 g	15.03	774.80	13.15	32.50	6.25	2.91
BAS 3.0 g	14.03	712.41	11.30	24.83	5.57	2.04
Growth period (P)						
30	8.25	401.84	8.75	16.97	3.28	1.55
60	11.83	571.30	10.34	29.98	4.50	1.93
90	15.03	770.44	12.51	30.22	6.15	2.63
120	17.03	876.34	14.61	33.78	7.26	3.15
150	21.50	1,357.66	18.58	45.05	11.30	4.18
Interaction effects						
F × P	*	**	**	*	*	NS
CV (%)	16.82	22.65	15.37	23.46	19.53	24.92
LSD	2.38	164.68	1.73	5.82	1.01	0.53

NS, *, **Nonsignificant or significant at $P \geq 0.05$ or 0.01, respectively.

WSF = water-soluble fertilizer; OSM = Osmocote; BAS = Basacote; LSD = least significant difference.

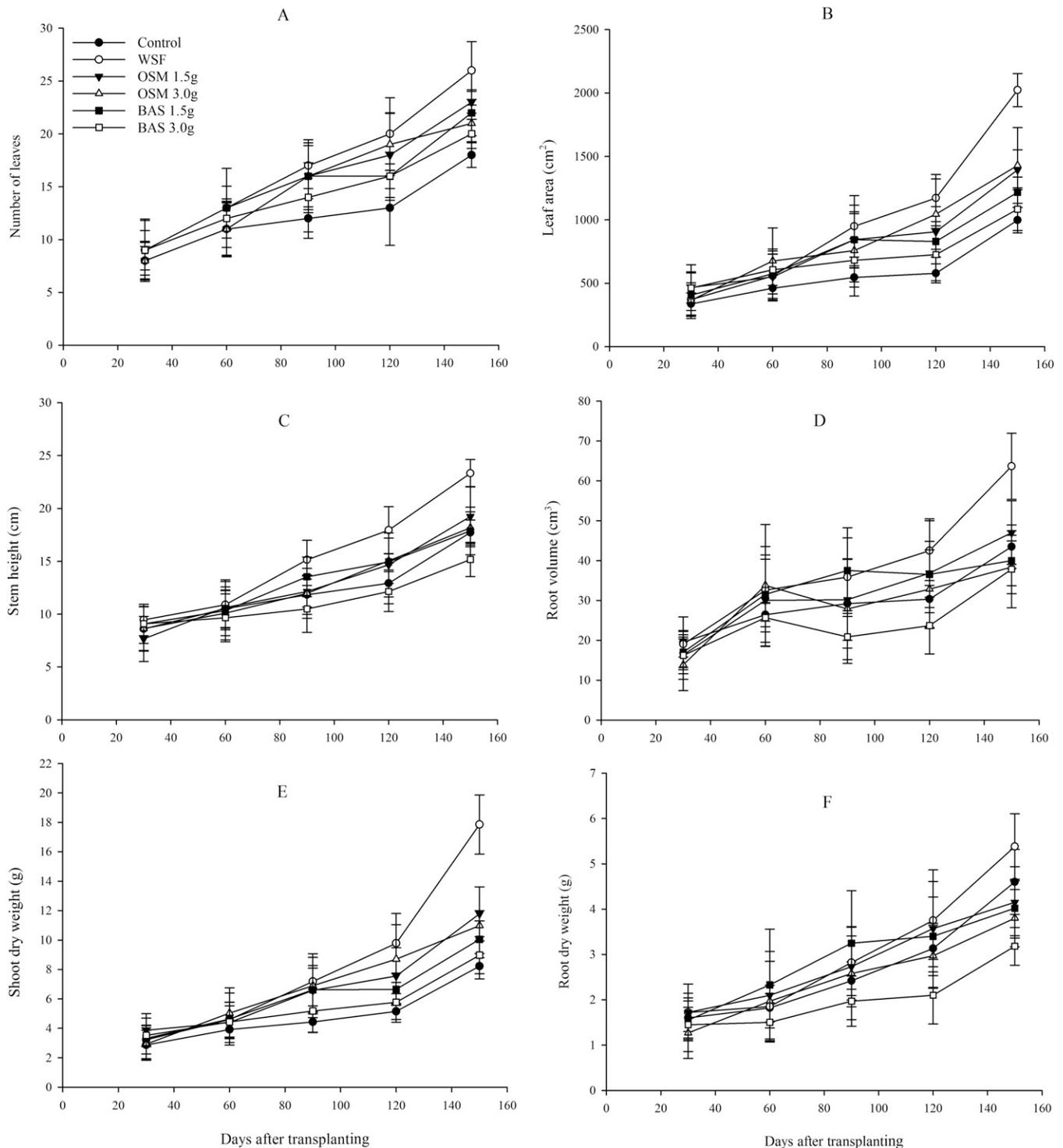


Fig. 1. Effects of types and rates of fertilizer at 30, 60, 90, 120, and 150 DAT on the number of leaves (A), leaf area (B), stem height (C), root volume (D), shoot (E) and root dry weight (F) of croton. Error bars represent 95% confidence intervals based on Tukey's honestly significant difference at the $\alpha = 0.05$ level analyzed by date. WSF = water-soluble fertilizer; OSM = Osmocote; BAS = Basacote.

Poole, 1992). Generally, N is the most important nutrient in coated fertilizers, thus their longevity is based primarily on the rate of release of this nutrient from these materials (Broschat and Moore, 2007). Many types of CRFs with different longevities have been developed to meet the variable nutritional requirements of plants (Hulme and Buchheit, 2007), which depend on the crop and its cycle phases, total nutrient requirement, and spe-

cific periods of demand peaks (Andiru et al., 2013).

Therefore, the physical and chemical properties of substrates, nutrient requirements, and fertilizer sources and rates should be calibrated to different species. Some studies have been realized to evaluate the effects of NPK fertilization on the croton plant (Karam et al., 2009; Mohammad et al., 2004); however, most of them were relatively

short-term investigations with conventional fertilizers. In this study, we compared the nutrient release patterns of two types of CRFs and a WSF and their effects on croton production and losses of N by leaching.

Materials and Methods

Experimental site. The experiment was conducted at the Department of Crop

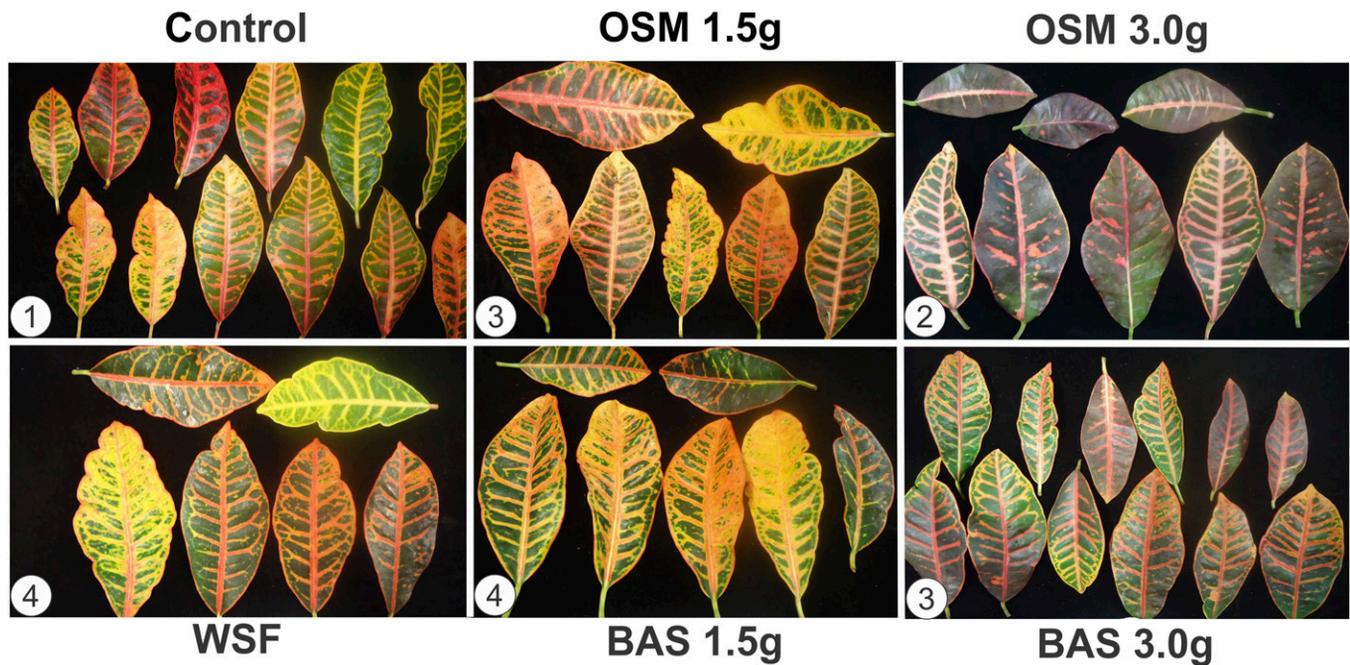


Fig. 2. Effects of types and rates of fertilizer on color leaves at the end of the production phase (150 d after planting). The number of each photo represents graded visually scale notes.

Table 2. Average of nutrient concentration in croton plants during the growth period affected by different rates and types of fertilizers.

Treatments	Concn of nutrients on the plants (g·kg ⁻¹) ^z																							
	N		P		K		Ca		Mg		S													
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root												
Control	10.02	c ^y	5.70	b	4.80	a	1.34	b	5.03	a	3.20	b	17.00	a	14.19	abc	6.42	a	8.20	a	2.17	a	1.57	a
WSF	15.63	a	8.88	a	4.08	ab	2.95	a	5.33	a	6.20	a	16.33	a	12.04	bc	5.27	a	5.33	c	2.30	a	1.85	a
OSM 1.5 g	12.66	b	7.27	ab	3.78	ab	1.14	b	5.37	a	4.50	ab	17.68	a	15.52	ab	6.44	a	8.10	ab	2.21	a	1.91	a
OSM 3.0 g	13.39	ab	8.06	ab	4.23	ab	0.92	b	4.90	a	4.30	b	15.66	a	17.30	a	5.66	a	8.46	a	1.99	a	1.82	a
BAS 1.5 g	12.47	bc	7.22	ab	2.91	b	1.78	b	4.80	a	4.10	b	16.21	a	14.96	abc	6.23	a	7.92	ab	2.11	a	1.77	a
BAS 3.0 g	15.93	a	8.27	ab	4.45	ab	1.28	b	5.00	a	3.87	b	16.05	a	11.70	c	6.52	a	6.15	bc	2.30	a	1.77	a
Test F	*		**		*		**		NS		**		NS		*		NS		**		NS		NS	
LSD	2.57		2.69		1.87		1.05		1.02		1.74		3.19		3.67		1.44		2.00		0.77		1.56	

^zValues represent the average of six replications.

^yMeans within a column followed by the same lower case letter were not significantly different according to LSD mean separation test at $P \leq 0.05$.

NS, *, **Nonsignificant or significant at $P \geq 0.05$ or 0.01, respectively.

WSF = water-soluble fertilizer; OSM = Osmocote; BAS = Basacote; LSD = least significant difference.

Science, University of Sao Paulo, located in Piracicaba, SP, Brazil. The greenhouse had 192 m² of ground area, with screen on the walls, diffusive plastic film cover, and thermo-reflective shading screen disposed internally. The greenhouse was controlled by an environmental control system with sensors connected to a datalogger (Campbell CR10), which recorded mean, maximum, and minimum temperatures of 22.9, 32.3, and 18.6 °C, respectively, and 70.7% of mean relative humidity and 10.12 MJ·m⁻²·d⁻¹ of global solar radiation.

Experimental design. Rooted cuttings of croton 'Petra' (Van Noije Ornamentals, Holambra, Brazil) were transplanted into the containers of 4 L filled with Basaplant Ornamentals (Base substrates, Holambra, Brazil), a substrate composed by pine bark, fiber turf, vermiculite, coal, NPK, and micronutrients. The substrate had the following chemical characteristics: 5.8 pH, 0.55% total N, 0.27% total P, 0.62% total K, 0.80% total calcium, 0.14% total magnesium, and 0.14%

total sulfur (Kiehl, 1985). The experiment was established as a randomized block design with three replicates, six treatments, and 14 plants per plot. Treatments included two sources of CRF at rates of 1.5 and 3 g·L⁻¹, a WSF and clean water as a control. The CRFs used were the most common applied in Brazil, Osmocote Plus [OSM, 15N (8.4NH₄-N and 6.6 NH₃-N), 3.93P, and 9.96K] which have longevity of 5 to 6 months, at 21 °C and Basacote [BAS, 15N (8 NH₄-N and 7 NH₃-N), 3.49P, and 9.96K], which have longevity of 5 to 6 months, at 15 °C. The WSF nutrient solution was prepared by adding following nutrients in water: 375 mg·L⁻¹ calcium nitrate (15% N and 19% Ca), 342.5 mg·L⁻¹ potassium nitrate (45% K₂O and 12% N), 126.92 mg·L⁻¹ monoammonium phosphate (12% N and 60% P₂O₅), 105.12 mg·L⁻¹ ammonium nitrate [33% N (50% nitrate and 50% ammonium)], and 61.3 g·L⁻¹ magnesium sulfate (9% Mg and 11.9% S). CRF fertilizers were incorporated into the substrate at a rate of 6

or 12 g per pot before planting, whereas the WSF was applied by nutrient solution.

Irrigation management and leachates analysis. Plants were drip-irrigated with an automated moisture sensor (Irrigation Controller-MRI; Hydrosense, Jundiai, Brazil) activated system when the substrate moisture potential reached 4 kPa. For the treatment with WSF, plants received only nutrient solution. A plate was placed under each pot to collect leachates. Three pots per plot were irrigated every 10 d with 300 mL of clear water to collect 100 mL of leached solution that was filtered through grade 42 filter paper, acidified with sulfuric acid (1%, v/v), and stored at -10 °C before analyzed for pH, EC, nitrate (NO₃-N), and ammonium (NH₄-N).

The concentrations of nitrate and ammonium were determined using the Flow Injection Analysis System (Ruzicka and Hansen, 1981) at the Center for Nuclear Energy in Agriculture, University of Sao Paulo (Piracicaba, Brazil). Ammonium was

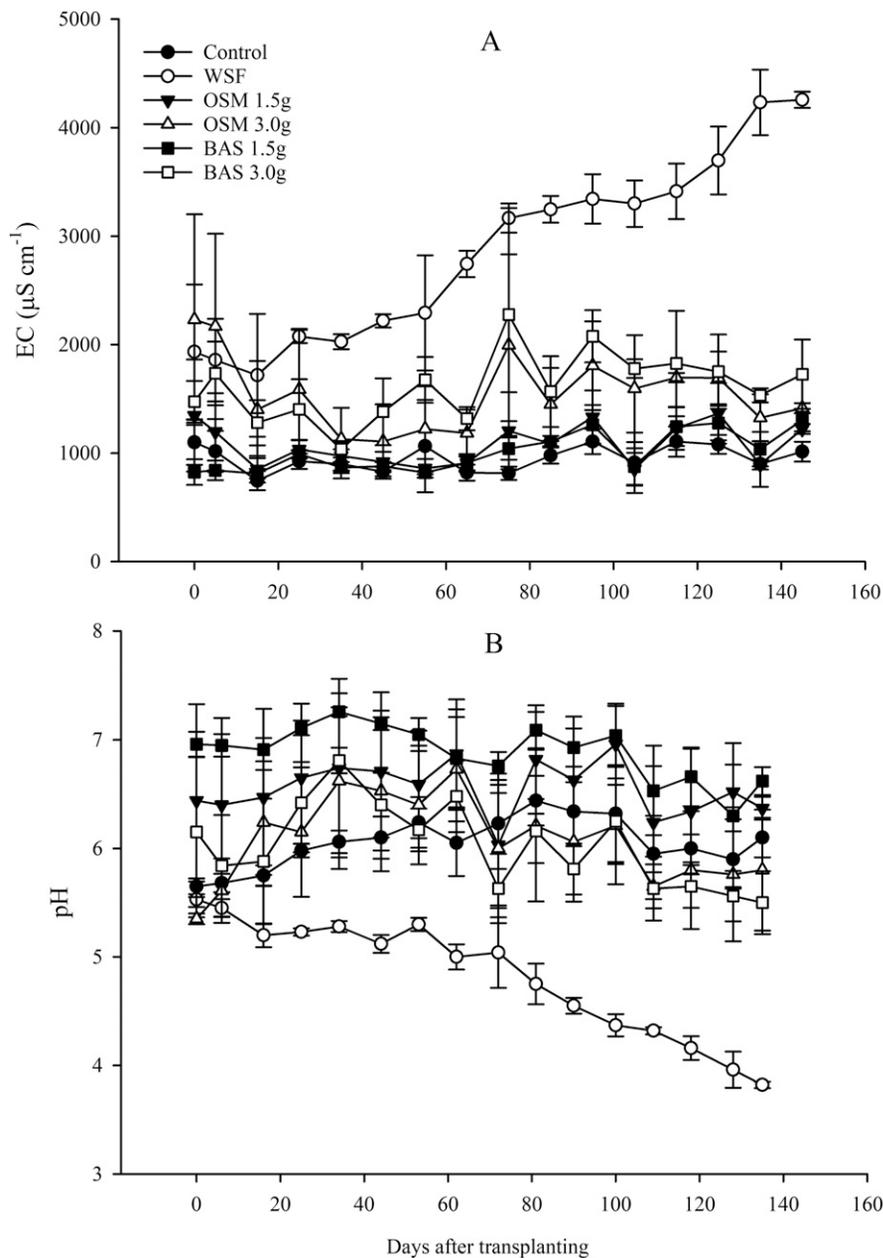


Fig. 3. Effects of types and rates of fertilizer on electrical conductivity (EC) and pH values of drained solution from pots of croton during growth period. WSF = water-soluble fertilizer; OSM = Osmocote; BAS = Basacote.

determined using conductometric method with sodium hydroxide (Solórzano, 1969) and nitrate was determined using a colorimeter with sulfanilamide and N-naphthyl method (Giné-Rosias, 1979). Total nitrogen was calculated by sum of nitrate and ammonium concentrations.

Plant analysis. Two plants per plot were sampled every 30 d to determine the number of leaves, stem height, leaf area (LI-3100 leaf area meter), root volume (Bosa et al., 2003), shoot and root dry weight, and concentrations of N, P, K, Ca, Mg, and S in the shoots and roots according to Malavolta et al. (1997) methodology. The plants were dried in an oven at 65 °C until reaching a constant mass. Samples were weighed to determine the dry mass and subsequently ground in a ball mill (MM200; Retsch GmbH, Haan, Germany).

The dry mass of shoot and roots were homogenized in the laboratory and analyzed for nutrients.

All plants were harvested at 150 DAT when the plants reached a marketable size determined by industry standards. In this growth period, five plants per plot were graded visually based on a scale of 1 to 4: 1 = plants with prominent green color and opaque leaves; 2 = multicolored plants with some dark-purple leaves; 3 = multicolored plants of low brightness; and 4 = multicolored plants with prominent orange color, bright.

Statistical analyses. Data were subjected to analysis of variance (ANOVA) using the Proc GLM procedure of the SAS software (Version 9.3; SAS Institute, Cary, NC). The mean comparison was by the least significant

difference method at the significance level of 5%. Leachate solution measurements (pH, EC, and nitrate, ammonium, and nitrogen concentrations) were analyzed over time using ANOVA.

Results and Discussion

Growth and quality of plants. There were interactions between fertilizers and growth periods to number of leaves ($P < 0.0001$), leaf area ($P < 0.0001$), stem height ($P = 0.0078$), root volume ($P = 0.048$), and shoot dry weight ($P = 0.0034$). However, root dry weight was affected only by growth period, reaching 4.18 g at the end of the growth period (Table 1).

During croton growth period, plants showed statistical difference between treatments from 90 DAT onward. Before that, the values of characteristics evaluated increased just over time (Fig. 1). At 150 DAT, the highest values to number of leaves and leaf area occurred with WSF and the low CRF rate as compared with the other treatments and control. Leaf size was 18.7% and 73.0% higher with WSF than with OSM and control, respectively. Stem height and shoot dry weight were higher for plants treated with WSF, OSM at low and high rates, and the low BAS rate compared with the high BAS rate and control. The highest root volume was found with WSF, which resulted in larger roots compared with the other treatments. The results showed WSF can be replaced by CRFs at low rates on croton growth because the last one reduced labor use, increasing growers' profit.

According to the visual scale, the best treatments were WSF (grade 4) and BAS at the low rate (grade 4), where plants were bright, with multicolored leaves with prominent orange shades (Fig. 2). Plants treated with 1.5 g of OSM (grade 3) were multicolored, but with low brightness. The plants treated with the higher level of BAS (grade 3) or OSM (grade 2) were multicolored with some dark-purple leaves, but with low brightness. Raese et al. (2007) found similar results, which showed that higher rates of N resulted in a darker green color of leaves. Control plants (no fertilizers) showed opaque leaves with a prominent green color (grade 1) and did not have a uniform shape.

Nutrient concentrations. WSF and high rate of BAS provided a higher N concentration in the shoot than low rates of OSM, BAS, and control, but were similar to high rate of OSM (Table 2), and in the root, the highest rate of N was found in WSF, differing only in the control treatment. Phosphorus concentrations in the shoots were higher with control as compared with these with BAS at low rate. Potassium, Ca, and Mg concentrations in the shoot and S in the shoot and root were unaffected by fertilizer sources and rates during the growth period, which average values were 5.1, 1.5, 6.1, and 2.2 $\text{mg}\cdot\text{kg}^{-1}$, respectively (Table 2). The values obtained for P, Ca, Mg, and S in the shoots were in accordance with an ideal range of nutrients in

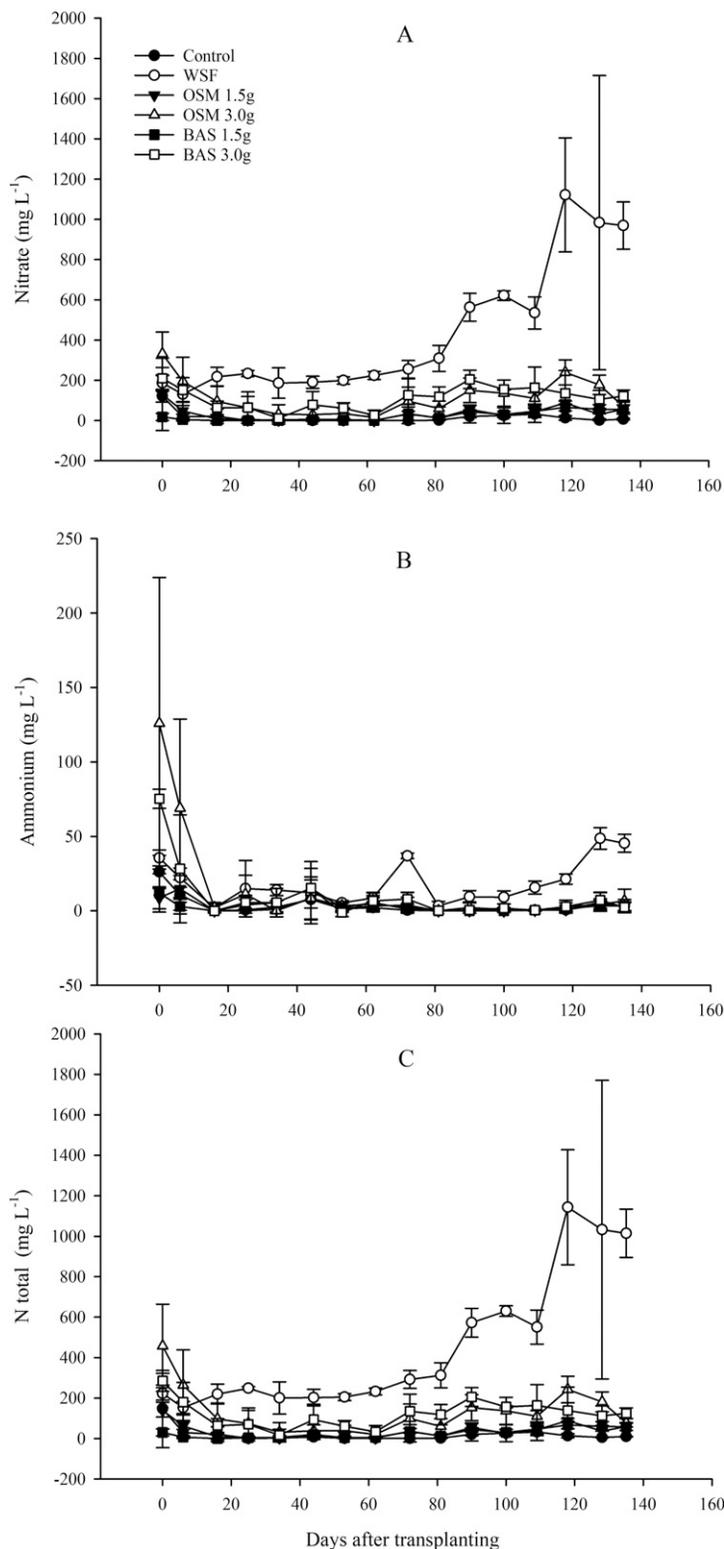


Fig. 4. Effects of types and rates of fertilizer on amounts of nitrate (A), ammonium (B), and total nitrogen (C) leached from pots of croton during growth period. WSF = water-soluble fertilizer; OSM = Osmocote; BAS = Basacote.

mature leaves of croton suggested by Mills and Jones (1996). However, N and K concentrations from our study were lower than the values reported by Mills and Jones (1996), although no nutrient deficiencies were observed in the leaves. Concentrations of P and K were increased with WSF in the roots, whereas Mg concentration in the roots

decreased with WSF as compared with the other treatments and control (Table 2). Studies show an antagonism among K and Mg. High concentrations of K or Mg inhibit the absorption from one another, whereas this antagonism is more intense with K relative to Mg (Epstein and Bloom, 2006). Treatments did not affect the calcium concentrations in

the shoots (Table 2). However, the Ca concentration in the roots was decreased with high rate of BAS. The Ca concentration in the shoots and roots was higher than the other nutrients, because of the high requirement of this element by plants of the family Euphorbiaceae, as described in other studies (Augusto et al., 2003; Laviola and Dias, 2008).

EC and pH. Leached solutions collected from the pots every 10 d were significantly affected by fertilizer types and rates for pH and EC during the growth period (Fig. 3). EC increased with WSF because the frequent applications of nutrient solutions increased salt levels in the substrate as compared with the other treatments, which values ranged from 1.7 to 4.3 dS·m⁻¹. EC values were measured above 3 dS·m⁻¹ from 75 DAT until the end of growth period. However, the salinity did not affect plant production because croton is moderately tolerant (Maas and Hoffman, 1977), maintaining good development under high EC ranges. For CRFs, EC values were between 0.8 and 2.3 dS·m⁻¹.

The pH levels were lower with WSF as compared with the other treatments and control (Fig. 3). The lowest pH range in WSF (4.5 to 3.8) occurred between 95 and 145 DAT, and CRFs registered pH values between 5.3 and 7.5. The decreased pH with WSF was due to the N soluble fertilizer applications as ammonium nitrate because the roots when absorbing ammonium simultaneously exude H⁺ as a way of maintaining the electrochemical equilibrium of the rhizosphere and the constancy of the intracellular pH (Cavins et al., 2004). In addition, NH₄⁺ not absorbed by the roots can suffer a nitrification process that acidifies the rhizosphere (Borgognone et al., 2013).

Ammonium (NH₄⁺), nitrate (NO₃⁻) and nitrogen (N) leaching. After the first 20 DAT, the nitrate (NO₃-N) concentrations in the leachate were significantly higher with WSF, reaching 1121.82 mg·L⁻¹ as compared with the other treatments, in which concentrations were lower than 400 mg·L⁻¹ throughout the growth period (Fig. 4A). Ammonium (NH₄⁺-N) concentration in the leachates was higher during the first 10 d with OSM at high rate than other treatments and control. At the beginning of the experiment, OSM and BAS released 125.97 and 75.22 mg·L⁻¹ of NH₄-N, respectively, whereas NH₄⁺ concentration from WSF was 35.47 mg·L⁻¹. After this period, the NH₄⁺-N concentrations decreased to less than 60 mg·L⁻¹ until the end of the growth period for all treatments (Fig. 4B). The concentrations of NH₄-N released were lower than NO₃-N, agreeing with those reported by Fernández-Escobar et al. (2004) and Newman et al. (2006), who reported NH₄-N values near zero. Considering the N total leaching, the concentrations of N in the leachate were significantly higher with WSF than other treatments, after 20 DAT (Fig. 4C).

Cumulative losses of NO₃-N, NH₄⁺-N, and total N from N applied by fertilizers are shown in Fig. 5. Nitrate loss from WSF was

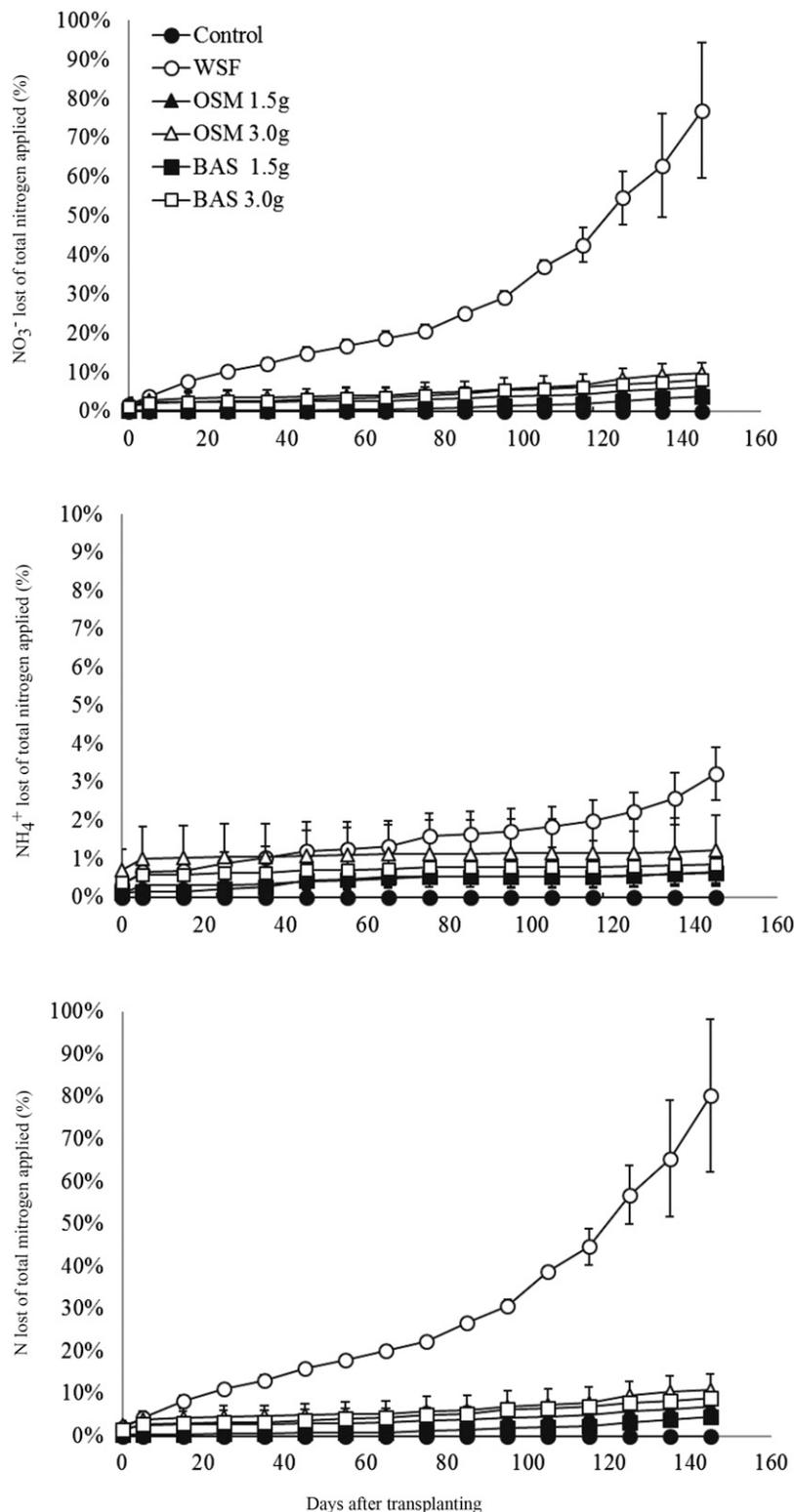


Fig. 5. Effects of types and rates of fertilizers on percentage ratio of nitrate (A), ammonium (B), and total nitrogen (C) leached accumulated from pots of croton and nitrogen applied per treatment during growth period. WSF = water-soluble fertilizer; OSM = Osmocote; BAS = Basacote.

76.95% of the total N applied, whereas the treatments with CRF leached no more than 10%. Throughout the experiment, as expected, the N release of control treatment was near zero. Ammonium (NH₄-N) loss was lower than 5% of the total N applied in the pots for all treatments. Total accumulated N in the leachate per pot was higher with WSF

than CRFs because CRFs release N slowly into the growth media, decreasing N losses.

Conclusions

CRFs maintained the pH and EC between ranges considered adequate to the croton growth and were able to reduce significantly

the N leaching from the pots. Considering all the results, the low rate of BAS (BAS 1.5) is the best treatment to obtain crotons with esthetic quality and low N leaching.

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