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ABSTRACT

Dendrobium nobile Lindl. is one of the most cultivated and distributed orchids around the world; however, information on its nutrition is scarce. Our objective was to study the plant development and nutrient accumulation in plants of *D. nobile* weekly fertilized with 100 mL Sarruge nutrient solution at 75% concentration. One plant per replication was randomly collected every month, along 12 months, totaling four plants. Dry matter (DM) and nutrient accumulation were determined for the different plant parts. Plants had already accumulated nearly 50% of total DM up to the flowering stage (240 days after first fertilization, DAFF). Order and amount of accumulated nutrients, at 360 DAFF, was, in mg per plant: K (701.07) > N (339.44) > Ca (289.03) > Mg (135.44) > P (118.83) > S (23.56); in μg per plant, it was Fe (14,122.35) > Zn (5,277.82) > Mn (3,216.87) > B (1,253.02) > Cu (271.25).

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Introduction

Orchids are highlighted as important ornamental and medicinal plants of great economic, ecological, and botanical interest. Orchid culture has progressed to a relevant activity as it now represents one of the most economically significant businesses in the global nursery industry (Silva 2013).

Production and sale of orchids as pot plants comprise an important segment in the sector; Brazil is an importer of seedlings coming, mainly, from the Netherlands, Thailand, and Japan. Imports totaled US$10.739 million in 2013, and these plants are forwarded directly to commercial production (Junqueira and Peetz 2013).

Research on mineral nutrition of orchids is scarce. However, it is known that these plants have nutritional requirements similar to other species; the difference is that orchids usually take longer to show deficiency symptoms due to the slow growth (Naik et al. 2009). Furthermore, according to the literature, plants, in general, present diverse nutritional demands ranging with growth stages. However, most producers use conventional fertilizers available in the market, which are developed with the aim to attend crops of food production (Takane, Yanagisawa, and Pivetta 2010). This results in high cultivation costs and products of poor quality, what explains the importance of knowing the species nutrition requirements (Furtini, Boldrin, and Mattson 2015).

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The genus *Dendrobium* comprises around 900 species. Among them, *Dendrobium nobile* Lindl. stands out for being one of the most cultivated and distributed orchids in the world. It is appreciated for its color range and great number of flowers per plant (Nayak et al. 2002).

In the literature, there are some studies on *Dendrobium* nutrition, for instance, how rates of nitrogen, phosphorus, and potassium may influence growth and flowering of *Dendrobium* Red Emperor "Prince" (Bichsel, Starman, and Wang 2008), and how an interruption and reapplication of fertilization affects growth and flowering of *D. nobile* (Yen et al. 2008). However, these studies do not consider the rate of nutrient uptake in *D. nobile*.

From curves of nutrient uptake, it is possible to understand with great reliability the nutritional demand in each growth stage, so one can monitor the need of a certain nutrient along plant cycle for each phenological stage. The study of nutrient uptake rates in plants is important to quantify nutritional requirements and indicate most appropriate periods for fertilization (Pedrosa et al. 2000). Therefore, our objective was to study the dynamics of growth and nutrient accumulation in *D. nobile* cultivated under protection.

Material and methods

Plant material and cultivation conditions

The experiment was conducted under protection in a greenhouse coated by black nets with 50% shading on its sides and 70% shading on its top (average PPF of 300 μmol m^{-2} s^{-1} at noon), and maximum and minimum temperatures of 34 and 15 °C, respectively.

Seedlings of *D. nobile* were standardized regarding length of the biggest pseudobulb (13–16 cm), pseudobulb number (2–3), and shoot number (1–2). Plants were then transplanted and maintained along 2 months only with irrigation aiming at adaptation to the environment. Evaluations began 30 days after first fertilization (DAFF).

Black plastic pots (11 cm height ×14 cm diameter) were used for plant cultivation, which were filled with a layer of expanded clay on the bottom corresponding to 25% of pot volume, and with a 2:1 (v/v) mixture of pinus bark, and charcoal over it.

Fertilization was performed weekly with an application in each pot of 100 mL Sarruge complete nutrient solution at 75% concentration (Bernardi et al. 2004). Nutrient concentration in Sarruge solution, in mg L^{-1}, is: 225 nitrogen (N); 31 phosphorus (P); 234 potassium (K); 200 calcium (Ca); 48 magensium (Mg); 64 sulfur (S); 0.5 boron (B); 0.5 manganese (Mn); 0.05 zinc (Zn); 0.02 copper (Cu); 0.01 molybdenum (Mo); 5 iron (Fe); and 0.7 chloride (Cl) (Sarruge 1975).

The N was provided in the form of nitrate and ammonium in equal proportions; and Fe-ethylenediaminetetraacetic acid was used as the source of Fe.

Irrigation was done manually by supply of 100 mL distilled water [pH 6.8 and electrical conductivity (EC) = 164.9 μS cm^{-1}] per pot three times a week.

Nutrient uptake rate

With the aim to comprise all plant development stages, treatments consisted of plant collection every 30 days along 12 months. Each sample was composed of four plants, so each plant was considered one replication. Morphometric characteristics of leaves, pseudobulbs, roots, and inflorescences were then determined.

The following characteristics were measured monthly to evaluate plant development: leaf area (dm^2), with the help of an electronic leaf area meter (Li-Cor, Lincoln, NE; model L1-3100®); leaf number; pseudobulb number; pseudobulb diameter (mm), with a digital caliper rule (Digimess®, amplitude of 0.01–300 mm); pseudobulb length (cm), with a ruler; shoot number; and dry matter (DM) of leaves, pseudobulbs, roots, inflorescences, and the entire plant (g). After washed, the

plant material was dried in a forced air circulation heater at 70 °C until reaching constant weight on a digital scale (0.01 g precision) for determination of DM.

After DM was measured, the plant material was ground for determination of macro (N, P, K, Ca, Mg, and S) and micronutrient (B, Cu, Fe, Mn, and Zn) concentration in the different plant parts (leaves, pseudobulbs, roots, and inflorescences) according to Malavolta, Vitti, and Oliveira (1997). From nutrient contents, nutrient accumulation was calculated via multiplication of contents by DM values to obtain the nutrient uptake rate.

Monitoring of pH and EC was performed from the pour throw. Therefore, at collection time, plants were maintained at maximum water retention capacity of the substrate using distilled water at pH 7.0. After 2 hr, 50 mL water was added in each pot so the pour throw could be collected for later measurement of pH and EC (Kämpf 2005).

Statistical analysis

Data of DM from the different plant parts, pseudobulb length, number, and diameter, shoot number, leaf area and number, were submitted to polynomial regression with the aim to verify plant behavior along one-year cycle. From results of DM and nutrient concentration, curves of nutrient accumulation were obtained.

Data of pH and EC were submitted to variance analysis, and means were compared by the Tukey test at 5% probability.

Results and discussion

Plant growth and development

Along the experimental period, there was a gradual increase in pseudobulb number, length, and diameter. Maximum mean values were reached at 360 DAFF, so greatest pseudobulb length was 28.9 cm, largest diameter was 1.45 cm and average number was three (Figure 1). At 300 DAFF, we observed the highest mean number of shoots, that is, 1.95 (Figure 1). Mean leaf area, at cycle end, was 708.68 dm^2, while maximum leaf number was 7.9 (Figure 1).

Along the 360-day evaluation period, there was an increase in total plant DM with a differentiated matter increment from 240 DAFF; besides the linear gain observed for roots and leaves, there was also a rise in pseudobulb matter (Figure 2). From total plant DM, 47.13% came from pseudobulbs, 20.36% from roots, and 32.52% from leaves.

At 240 DAFF, plants had developed flower stems, therefore it was the beginning of the flowering stage; at this time, plants already had more than 50% of total DM. Up to 120 DAFF, in general, increase in total DM had greater contribution from pseudobulbs; from 120 to 240 DAFF, increment in total DM was due, mainly, to accumulation of DM in leaves and roots. However, after 240 DAFF, all plant parts added to the accumulation of total DM (Figure 2).

This was expected, once *Dendrobium* plant development is sympodial with apical dominance, so pseudobulbs grow up to a certain size, followed by shoot development that contributes to the emergence of new leaves. Growth of new pseudobulbs is then assisted by the oldest pseudobulb. Therefore, youngest pseudobulbs grow and accumulate more matter than previous ones, resuming the increase in plant height.

Nutrient accumulation

Regarding the total of nutrients accumulated by plants at 360 DAFF, greatest macronutrient accumulation was found in pseudobulbs (Figure 3).

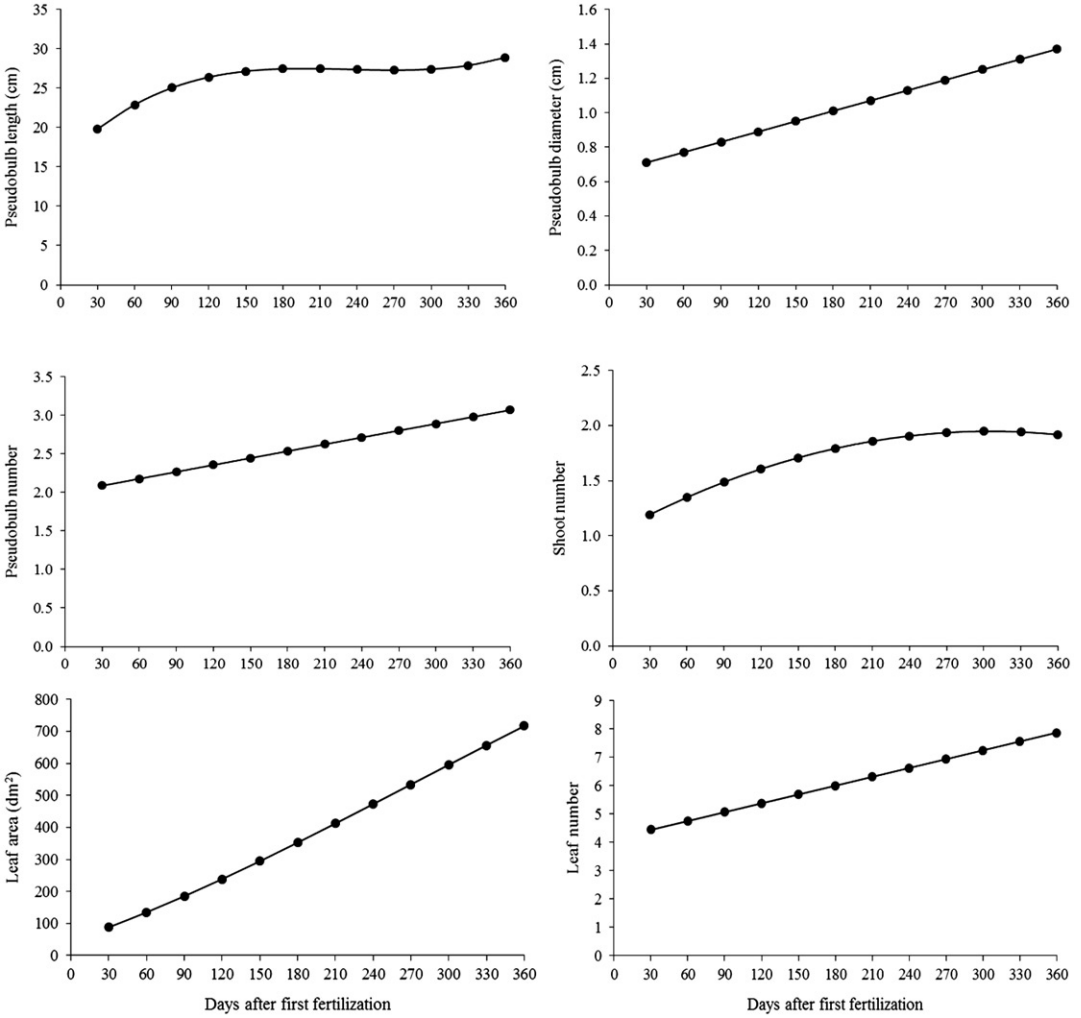

Figure 1. Pseudobulb length, diameter, and number; shoot number; and leaf area and number of *D. nobile* plants cultivated under protection according to DAFF (2 months after seedling transplant).

Macronutrient accumulation in *D. nobile* plants occurred at the daily rate of, in mg plant^{-1}: 0.94 N, 0.33 P, 1.95 K, 0.80 Ca, 0.38 Mg, and 0.07 S (Figure 3). Sulfur was the macronutrient that presented the lowest rate from the first fertilization up to 360 DAFF.

Regarding the total of nutrients accumulated by plants at 360 DAFF (Table 1), the greatest macronutrient accumulation was found in the pseudobulbs.

Considering the general balance among nutrients, leaves and pseudobulbs presented equivalent relationships, where total N:P:K ratio was 2.8:1.0:5.9, which is similar to 3.1:1.0:6.6 and 2.8:1.0:6.7 found for leaves and pseudobulbs, respectively. However, roots showed the N:P:K ratio of 2.6:1.0:2.4. Therefore, for development of both leaves and pseudobulbs, the N:P:K ratio close to 3.0:1.0:6.0 may be used, as it is considered appropriate according to total accumulation of N, P, and K (Table 1).

Poole and Sheehan (1982) report that *Cattleya, Phalaenopsis*, and *Cymbidium* orchids have different requirements, so best N:P:K ratios for these genus are: 2.5:1.0:2.0 for *Cattleya* and *Cymbidium*, and 1.25:1.0:1.9 for *Phalaenopsis*. However, for *Cymbidium sinense*, the N:P:K ratio in plant tissues is 6.0:1.0:9.0; K application, particularly, increased soluble sugars, starch, cellulose, and proteins (Pan, Ye, and Hew 1997).

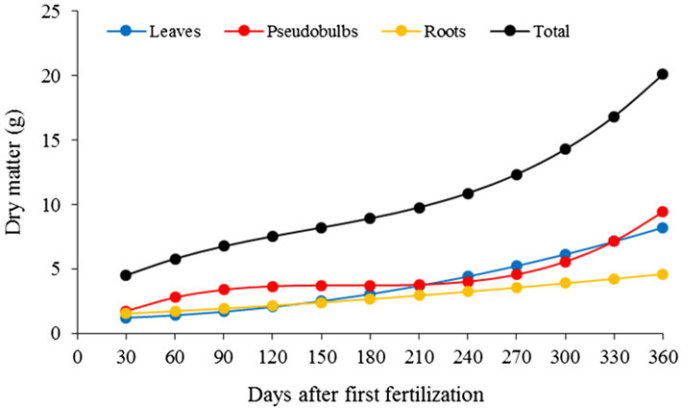

Figure 2. DM of pseudobulbs, leaves, roots, and total DM of *D. nobile* plants cultivated under protection according to DAFF (2 months after seedling transplant).

In general, solutions with similar concentrations of N and K are indicated for *Dendrobium*. Bichsel, Starman, and Wang (2008) report that fertilization with 100 mg L^{-1} N, 25 mg L^{-1} P, and 100 mg L^{-1} K is appropriate for both vegetative and reproductive stages. However, higher K concentrations are used for *Phalaenopsis*, so Wang (2007) indicates fertilization with 300 mg L^{-1} K combined with 200 mg L^{-1} N and P for plant growth and flowering. Regarding P, studies denote that it is the most limiting nutrient for epiphytes, as these plants are adapted to use such nutrient efficiently; in nature, N:P ratios ranging from 16:1 to 14:1 are common, but when plants are cultivated, such ratio is expressively reduced (Zotz 2004).

For Ca:Mg ratios, leaves had a higher relationship—2.8:1.0, than pseudobulbs—2.0:1.0, while roots showed the ratio 1.6:1.0. These results indicate that Ca is more required in leaves than Mg. However, for fertilization with Ca and Mg, the ratio 2.0:1.0 (in relation to concentration) is appropriate since the relationship for the entire plant was 2.1:1.0 (Table 1).

In fact, these results also indicate that, for *D. nobile*, Mg is important; such Ca:Mg ratio (2.0:1.0) may be considered low, once in nutrient solutions such as Sarruge or Hoagland, supply of Ca is four times greater than of Mg (Sarruge 1975; Hoagland and Arnon 1950). Poole and Seehan (1977) highlight the importance of Mg on studies of *Cymbidium*, *Phalaenopsis*, and *Cattleya* nutrition; the authors mention that, for daily fertigations, nutrient solutions must comprise 100 mg L^{-1} N, 50–100 mg L^{-1} K, and 25 mg L^{-1} Mg for *Cymbidium* and *Phalaenopsis*, but for *Cattleya*, only 50 mg L^{-1} N, K, and Mg are required.

For macronutrients, greatest sink parts were pseudobulbs, with a mean of 52.1% of the total accumulated, followed by leaves (31.7%) and roots (16.2%). These results suggest that the pseudobulbs acted as nutrient reserves, so such accumulation was expected once there was more DM also in such plant part (Table 1). According to Ng and Hew (2000), pseudobulbs play an essential role on orchid growth and survival, accumulating water, mineral nutrients, and carbohydrates that assist on shoot emission and flowering. In addition, for *Dendrobium* orchids, Wang (1995) reports that the pseudobulb development and growth implies in greater flower number in the following year.

Regarding micronutrient accumulation in the different plant parts, and based on the last plant collection at 360 DAFF, daily uptake rates were, in μg $plant^{-1}$: 3.48 B, 8.94 Mn, and 14.66 Zn (Figure 4). The most accumulated micronutrient was Fe, with the daily rate of 39.23 μg $plant^{-1}$, while Cu was the least accumulated at the daily rate of 0.75 μg $plant^{-1}$.

At final evaluation, there was greater accumulation of macronutrients and Zn in the pseudobulbs, while highest Cu accumulation was found in the roots. For the other micronutrients, leaves were the main sink (Table 1). In general, micronutrients act as enzymatic activators, so Fe and

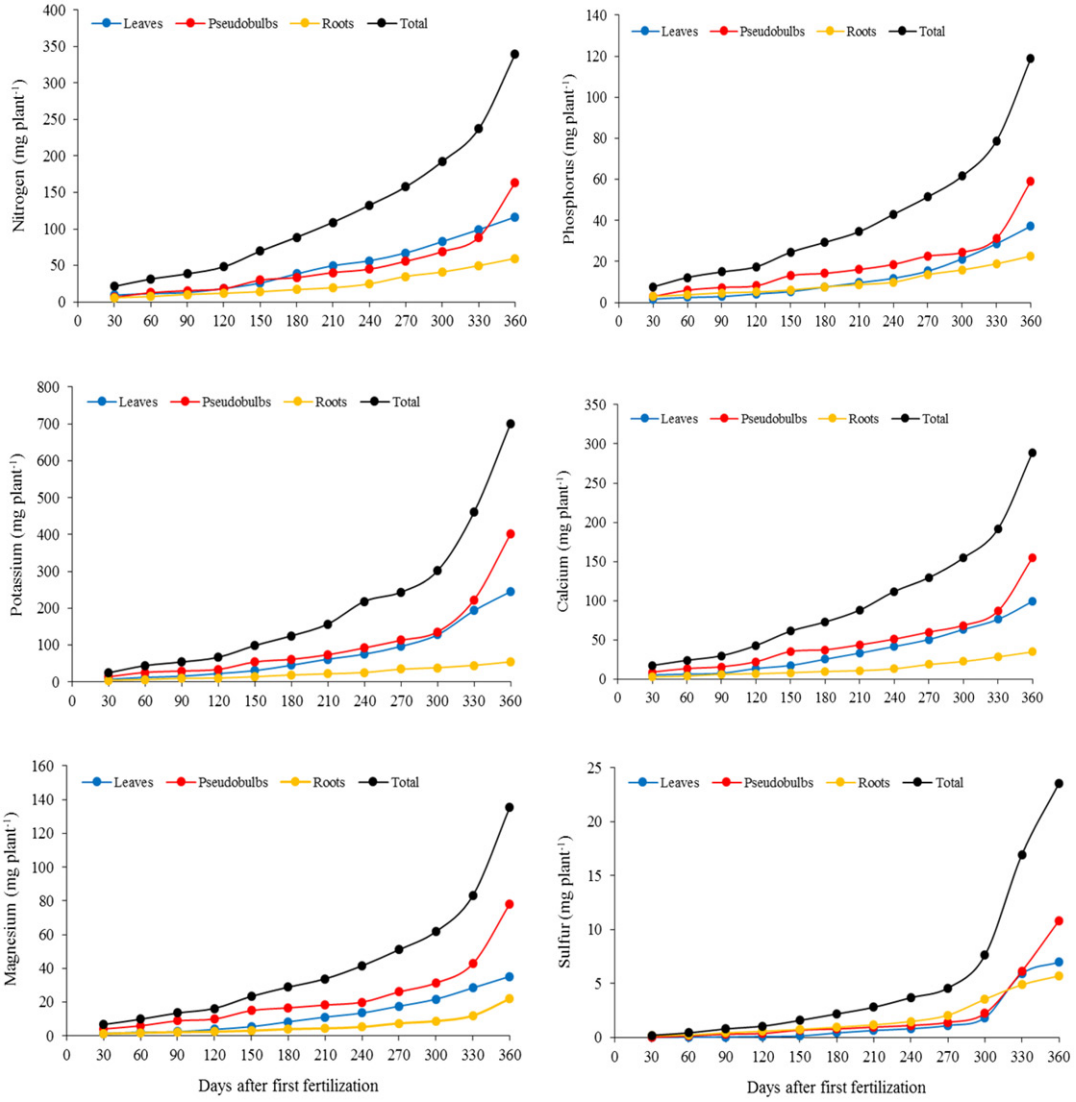

Figure 3. Macronutrient accumulation—nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, in leaves, pseudobulbs, roots, and total accumulation in *D. nobile* plants cultivated under protection according to DAFF (2 months after seedling transplant).

Mn are related to photosynthesis and participate in electron transference and water photolysis (Malavolta 2006). Therefore, higher micronutrient accumulation in leaves was already expected.

Comparing nutrient concentrations in *Cattleya* and *Laelia* orchids with other cultivated plants, Carlucci, Haag, and Bellote (1980) report that, in these orchid species, concentrations of B, Cu, Fe, Mn, and Zn were significantly higher than macronutrient concentration; but we found higher concentrations of macronutrients than micronutrients for *D. nobile*.

Flowering occurred at 240 DAFF. There was an average of two flowers per stem, totaling 11 flowers per plant. DM and accumulated nutrients are shown in Table 2. Following the descending order, most accumulated macronutrients were K, Ca, N, S, Mg, and P and most accumulated micronutrients were Fe, Mn, B, Zn, and Cu.

The high K amount found in flowers (and in the entire plant) suggests that plants have a great demand for such nutrient during the flowering period.

Table 1. Nutrient accumulation in leaves, pseudobulbs, roots, and total accumulated amount in *D. nobile* plants cultivated under protection at 360 DAFF (2 months after seedling transplant).

Nutrient	Leaves	Pseudobulbs	Roots	Total accumulated
		mg plant^{-1}		
N	116.40 (34%)	163.35 (48%)	59.68 (18%)	339.44
P	37.18 (31%)	58.99 (50%)	22.66 (19%)	118.83
K	244.87 (35%)	401.80 (57%)	54.40 (8%)	701.07
Ca	99.19 (34%)	154.96 (54%)	34.88 (12%)	289.03
Mg	35.21 (26%)	78.19 (58%)	22.04 (16%)	135.44
S	6.99 (29%)	10.85 (46%)	5.72 (25%)	23.56
Nutrient	Leaves	Pseudobulbs	Roots	Total accumulated
		μg plant^{-1}		
B	502.92 (40%)	435.07 (35%)	315.03 (25%)	1,253.02
Cu	85.17 (31%)	66.60 (25%)	119.48 (44%)	271.25
Fe	6,208.65 (44%)	4,248.14 (30%)	3,665.56 (26%)	14,122.35
Mn	1,652.18 (52%)	1,360.82 (42%)	203.87 (6%)	3,216.87
Zn	1,689.94 (32%)	2,505.87 (48%)	1,082.01 (20%)	5,277.82

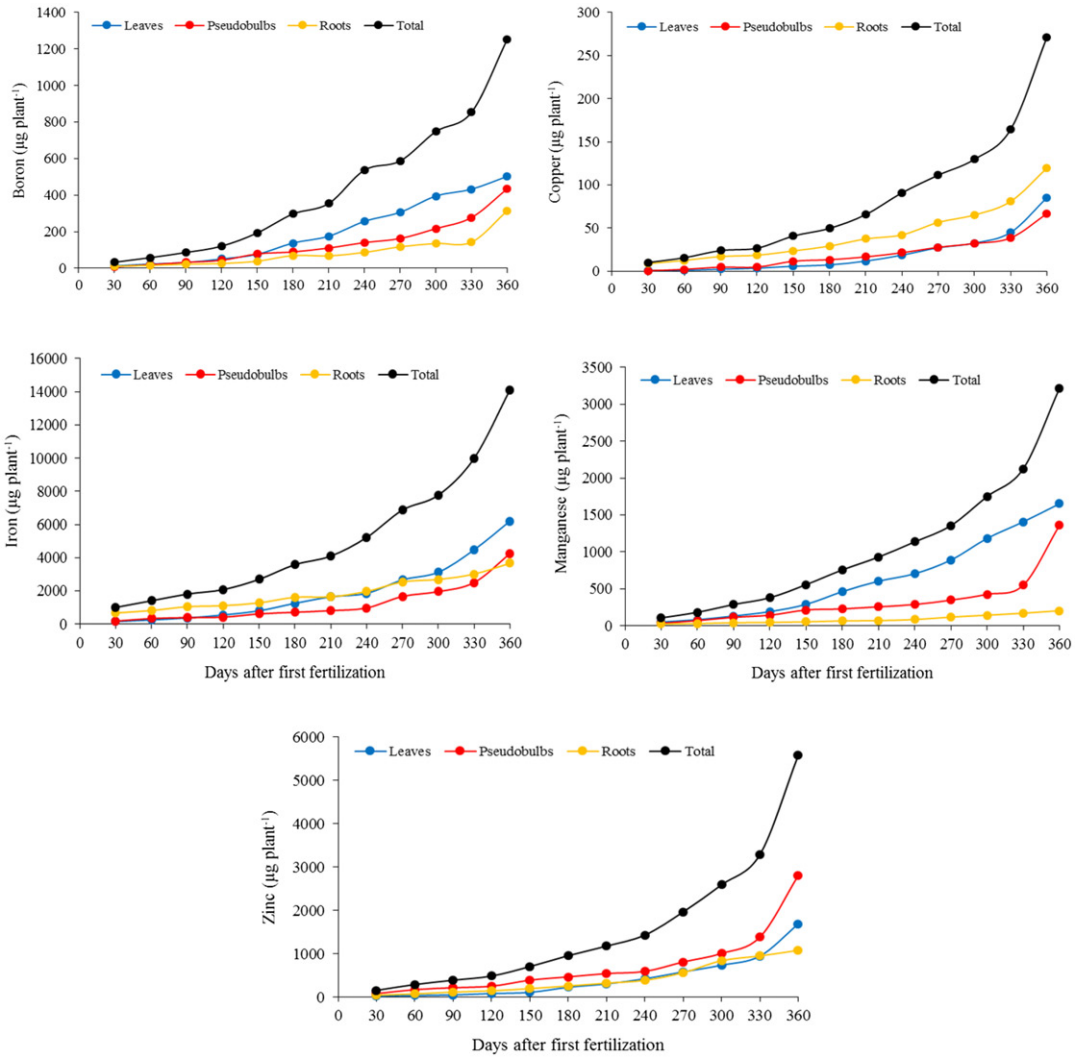

Figure 4. Micronutrient accumulation—boron, copper, iron, manganese, and zinc, in leaves, pseudobulbs, roots, and total accumulation in *D. nobile* plants cultivated under protection according to DAFF (2 months after seedling transplant).

Table 2. Macronutrients, micronutrients, and DM of flowers of *D. nobile* cultivated under protection at 240 DAFF (2 months after seedling transplant).

N	P	K	Ca	Mg	S
			mg plant^{-1}		
6.60	2.70	25.49	6.76	2.76	2.89
DM	B	Cu	Fe	Mn	Zn
g			μg plant^{-1}		
0.85	52.82	8.76	431.00	58.88	20.74

Table 3. Means of pH and EC of the pour throw collected from the substrate of *D. nobile* pots according to DAFF (2 months after seedling transplant).

DAFF	pH	EC (μS cm^{-1})
30	5.13^{a,b,c}	190.6^{b,c,d}
60	5.59^{a}	178.3^{d,e}
90	5.49^{a}	205.1^{a,b,c}
120	4.76^{a,b,c,d}	180.0^{d,e}
150	5.19^{a,b}	134.0^{g}
180	4.48^{b,c,d,e}	162.3^{e,f}
210	4.22^{c,d,e}	156.5^{f}
240	3.90^{d,e}	156.3^{f}
270	3.97^{d,e}	186.8^{c,d}
300	3.73^{e}	193.1^{b,c,d}
330	4.02^{d,e}	210.0^{a,b}
360	3.99^{d,e}	225.3^{a}
MSD	0.96	20.87
CV (%)	8.60	4.66

Minimum significant difference.
Numbers followed by same superscript letters in the column do not differ from each other by the Tukey test at 5% probability.

Macronutrient accumulation in *D. nobile* flowers was slightly superior to that reported by Carlucci, Haag, and Bellote (1980) for three species of *Laelia* and two of *Cattleya*. The same occurred for micronutrients, with the exception of Mn and Zn.

pH and EC

Initially, the substrate was alkalized due, mainly, to bases in the nutrient solution, such as Ca and Mg adsorbed on the substrate, rising the pH (Table 3). From plant growth and development, pH is usually reduced due to H^+ release because of root ionic absorption (Taiz and Zaiger 2009). These results were similar to those described by Yen et al. (2008), who states that pH decrease occurs especially by root activity.

Besides substrate acidification, there were no negative consequences in plant development, so the pH range of 4.8–6.2 is indicated for orchid development (Takane, Yanagisawa, and Pivetta 2010); according to the authors, 500 μS cm^{-1} EC is the tolerated by orchids, which is twice the maximum value found in this work.

Conclusions

At 360 DAFF, which occurred 2 months after seedling transplant, macronutrient uptake by *D. nobile* plants, following the descending order, was: K > N > Ca > Mg > P > S; for micronutrients, it was: Fe > Zn > Mn > B > Cu. During the flowering period, *D. nobile* has a high demand for potassium. The period of greatest nutrient requirement was after flowering, that is, from 241 to 360 DAFF. Reduction in pH and increase in EC did not influence plant development.

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