Empirical Models of Phosphorus Uptake under Different Nitrogen Sources in *Dieffenbachia amoena* ‘Tropic Snow’

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Abstract. The study of models for better nutrient uptake estimation can help to improve integrated fertigation management, allowing enhanced water and fertilization use efficiency. The aim of this work was the development of empirical models that permit the prediction of the phosphorus (P) nutritional needs of *Dieffenbachia amoena* to increase P use efficiency in a recycled system. To achieve this, P uptake was correlated to climate parameters, such as temperature (T), vapor pressure deficit, and global radiation (Rg), and to growth parameters such as leaf area index (LAI). In addition, the influence of the N form supply (NO_3^- -N or NH_4^+ -N) on P uptake was studied. The trial was carried out with *Dieffenbachia amoena* ‘Tropic Snow’ plants growing in a recycled system with expanded clay as substrate. The crop was placed in an INSOLE buried solar greenhouse, with the plants supplied with equal amounts of N, differing in the percentage of the N form applied: Ta ($100 \text{ NO}_3^- : 0 \text{ NH}_4^+$), Tb ($50 \text{ NO}_3^- : 50 \text{ NH}_4^+$) and Tc ($0 \text{ NO}_3^- : 100 \text{ NH}_4^+$). The N form applied to *Dieffenbachia amoena* ‘Tropic Snow’ plants affects P and N uptake, but it does not influence K uptake. Nitrogen and P uptake rates are higher in the plants supplied with NH_4^+ or $\text{NO}_3^- + \text{NH}_4^+$ than in the plants provided with NO_3^- alone. The supply of a combination $50 \text{ NO}_3^- : 50 \text{ NH}_4^+$ improves P use efficiency. The study also indicates the possibility of predicting the P uptake rate and P uptake concentration using the proposed models. Phosphorus uptake can be estimated with a model dependent on the LAI in the NO_3^- -N treatments and on the LAI and Rg in the NH_4^+ -N treatments. The P uptake concentration can be calculated with the P uptake, estimated through the previous model, and the experimental water uptake. This parameter would permit the nutritive solutions design, decreasing nutrient losses in open systems.

Nowadays, pH and electrical conductivity (EC) constitute the base fertigation management in soil and soilless greenhouse crops (Jiménez et al., 2005). Changes in the EC and in the composition of the recycled solution result from differences between water and ion uptake, as well as from variations in the nutrient solution concentration (Pardossi et al., 2004). It is difficult to maintain the nutrient balance, because plant uptake can vary among different plant species (Ehret et al., 2005). Adjusting fertility programs according to peak demand periods, production, and environmental conditions will help to prevent periodic nutrient disorders during the crop cycle, and may reduce fertilization costs (Hamlin and Mills, 2001). In recycling systems, it is especially important to find stationary situations in which the accumulation or depletion of an ion does not happen. The recycled solution, because of variations in the nutritive solution, may cause nutrient

deficiency or salt stress, and thus may can reduce crop yield and quality (Kläring et al., 1997). Specifically, phosphorus (P) deficiency is considered to be one of the major limitations to crop production, particularly in the tropics (Raghothama and Karthikeyan, 2005).

Le Bot et al. (1998) consider a dual approach to control plant nutrition: inductive or deductive regulations. Inductive regulation (a posteriori) is based on a purely technological breakthrough and it is rapidly operational, whereas deductive regulation (a priori) depends on the knowledge, and it requires the application of models. In mineral nutrition, the former can be used when the agrosystem is subjected to normal climatic fluctuations, being applied only after an alteration of the system. In other words, the regulator is used to repair the occurrence of change in the agrosystem (Le Bot et al., 1998).

Models that permit estimation of the nutrient uptake can be a useful tool for integrated fertigation management, permitting more rational use of the nutrients and greater water and fertilizer use efficiency (Jiménez

and Lao, 2005). Some models for the estimation P uptake have been developed. The general models that study the P dynamic in the soil, including plant uptake, are ANIMO, GLEAMS, DAYCENT, and MACRO (Lewis and McGeachan, 2002); models based on the average plant phenology, like DYFERT (Battilani, 2003); models based on the root architecture (Yan et al., 2001); models that make use of Michaelis-Menten kinetics (Kelly and Kelly, 2001); and others depending on the environmental conditions that allow the estimation of macronutrient uptake (Le Bot et al., 1998). Pardossi et al. (2004) presented empirical models to predict macronutrient uptake of melon plants. The independent variables considered by the model were global radiation (Rg) and air temperature in the greenhouse, crop age and water uptake, as well as a guide ion. Brun and Chazelle (1996) described the (NO_3^- -N) uptake kinetic on roses with a multiple regression, using agroclimatic factors. Another model was proposed by Kläring et al. (1997), who described the nutrient-to-water uptake ratio as a function of environmental conditions by means of models for photosynthesis and transpiration. Papadopoulos and Liburdi (1989) used light, relative humidity, fruit load, and crop age to adjust the base values of nutrient supply for tomato plants in their models.

The use of different nitrogen (N) forms (NH_4^+ -N or NO_3^- -N) shows benefits and limitations. For example, one of the advantages of (NH_4^+ -N) is that it is fixed to the soil or substrate particles thanks to the cation exchange capacity of these materials and, therefore, it is not leached, decreasing (NO_3^- -N) pollution (Jiménez et al., 2005). Most plants can use both N forms, but the use efficiency and the preference for each form depend on the species, variety, plant age (Abbès et al., 1995), nutritional conditions (pH and others), environmental conditions, percentage of the two N forms, and concentration of other nutrients (Mengel and Kirkby, 2001). The N form can also have an effect on leaf mineral composition and nutrient uptake (Bar-Tal et al., 2001), modifying fertilizer use efficiency (Jiménez and Lao, 2005). Generally, P uptake and P leaf concentration increase when NH_4^+ -N is replaced by NO_3^- -N (Abbès et al., 1995), as well as in soil culture (Thomson et al. 1993).

The aim of this work is the development of empirical models that permit the prediction of the P nutritional needs of *Dieffenbachia amoena* to increase P use efficiency in a recycled system, although this model can also be applied in principle to other plant species. To achieve this, P uptake has been correlated to climate parameters, such as temperature, vapor pressure deficit (VPD), and Rg, and to growth parameters such as leaf area index (LAI). In addition, the influence of the N form supply (NO_3^- -N or NH_4^+ -N) on P uptake and on the defined as the ratio of P and water uptake, have been studied. The last parameter will be useful to control the nutritive solution concentration.

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Materials and Methods

Plant growth environment and irrigation systems. The trial was carried out in an INSOLE buried solar greenhouse, as described by Lao et al. (2003), 150 m², with zenithal ventilation, with relative humidity and temperature control equipment. Being buried, this type of greenhouse allows one to maintain the best climatic conditions for this crop (Lao et al., 2003).

The variety studied was *D. amoena* 'Tropic Snow'. The plant density was 3.2 plant/m². Single plants were grown in a 17-cm-diameter pot, and the substrate used was expanded clay (3–8 mm). Two trials were conducted. The first trial was conducted from 10 Nov. to 9 June 2001, 200 d after transplanting, and the second trial was carried out from 19 Dec. to 13 Aug. 2002, 240 d after transplanting. During both trials, the crops were in a vegetative phenological state.

A recycled fertigation system was used. The fertilizer was applied through drip irrigation, with one emitter per plant, with a flow rate of 2 L·h⁻¹/emitter. Each irrigation lasted 1 min 15 s, and the timing was one irrigation every 10 min.

Nutritional treatments. There were three treatments tested that differed in the percentage of the N form applied: Ta (100 NO₃⁻ : 0 NH₄⁺), Tb (50 NO₃⁻ : 50 NH₄⁺), and Tc (0 NO₃⁻ : 100 NH₄⁺). The nutrient solutions used are listed in Table 1.

The recycled solution was renewed every 20 d to adjust the nutrient concentration to the initial values. The concentration of NO₃⁻, NH₄⁺, and H₂PO₄⁻ was analyzed by spectrophotometry (Ministry of Agriculture and Fishing, 1994).

Sampling. Climatic parameters were monitored by means of a climate computer (LCC 900 VOLMATIC). External radiation was measured every 15 min with a Q20-B sensor, whereas temperature and humidity were recorded with RTV-5B sounds. To estimate internal radiation, the cover transmission coefficient was estimated fortnightly as a ratio between internal and external radiation, measured with a manual quantum photoradiometer (Delta OHM, model RAD/PAR, Disca, Vicar). A shade screen was used during the summer season.

The VPD was estimated using the equation proposed by Rosenberg et al. (1983): $VPD = e_s - e_a$, $e_s = 0.61078 e^{[(17.269T)/(T + 237.30)]}$ and $e_a = (RH \times e_s)/100$, where e_s is the saturated vapor pressure, e_a is the actual vapor pressure measured in kilopascals (kPa), T is the temperature in degrees Celsius, and RH

is the relative humidity measured as a percentage.

Leaf area was estimated by a nondestructive method using the formula

$$S = k \times L \times A$$

where S measured in square centimeters is the foliar area, k is a constant, L is the leaf length in centimeters, and A is the leaf width in centimeters. The coefficient k is specific for each species and was estimated experimentally by the regression analysis of 50 leaves of different size, being the leaf area measured with a Delta-T (Disca, Vicar) area meter. Leaf area index (measured in square meter per square meter) was estimated as the leaf area per plantation framework.

Water uptake. The water uptake was estimated as the difference between the initial and the final volumes in a transparent tube previously calibrated and fixed to the nutritive solution tank. The measurements correspond to an interval of 20 d.

Estimation of phosphorus uptake and phosphorus uptake concentration. Net uptake was measured each 20 d as the difference between the initial and the final ion concentrations of the nutrient solution, as proposed by Le Bot et al. (1998), and it was expressed mathematically as

$$A_s = (C_i H_i - C_f H_f)(N/20)^{-1}$$

where A_s is the uptake measured in millimoles per day per plant, C_i and C_f are the initial and final P concentrations during the period measured in millimoles per liter, H_i and H_f are the initial and final nutrient solution volumes during the estimated period respectively, N is the number of days of the period, and 20 is the number of plants that constituted each replication. The P uptake concentration (measured in millimoles per liter) can be defined as P uptake (measured in millimoles per day per plant) per unit of water uptake (measured in liters per day per plant).

Experimental design and statistical analysis. The experimental design was unifactorial (N form), with three treatments, three replications per treatment, and 20 plants per replication, during the two crop cycles. Data analysis was conducted using the software packages Excel 7.0 and Statgraphics plus 4.0 (Ruano informática, S.L., Almería). Analysis of variance and LSD ($P < 0.05$) were undertaken to compare P uptake between treatments. Simple regressions between P uptake concentration and P uptake related to climatic and growth parameters were made to generate models. From all parameters considered, the one with a higher determina-

tion coefficient (R^2) was selected as the principal parameter. Subsequently, a multiple regression, including, one by one, all the variables considered, was conducted. The criterion for accepting a new variable in the model was the increase of R^2 and the lowest correlation coefficient between variables (Canavos, 1988).

Results and Discussion

The Rg, VPD, and temperature for both crop cycles in the greenhouse are presented in Table 2. The different climatic parameter ranges are very narrow and they are included in the optimal ranges defined by different authors for this species: light intensity, from 8–22 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photons; high environmental relative humidity, $\approx 80\%$; and mild temperatures, from 13°C to 30°C (Jiménez and Lao, 2001).

Effect of nitrogen source on phosphorus uptake.

Phosphorus and N uptake display statistical differences ($P < 0.05$) depending on the N form applied (Table 3). Nitrogen uptake is 43% and 39% higher in Tb (50 NO₃⁻ : 50 NH₄⁺) and Tc (0 : 100 NH₄⁺-N) respectively, compared with Ta (NO₃⁻-N); and P uptake is 27% and 18% higher in Tb (50 NO₃⁻ : 50 NH₄⁺) and Tc (0 : 100 NH₄⁺-N) respectively, compared with Ta (NO₃⁻-N). This difference generates a significantly higher concentration in leaves between all treatments as well (Table 3). There are no significant differences between Tb and Tc, but the average P uptake was higher in Tb (Table 3). These results were consistent with those obtained by Lorenzo et al. (2000) and Subbaswamy et al. (2001) in rose and mulberry respectively, who found a higher phosphate uptake when the ammonium (NH₄⁺-N) content increases. However, Elia et al. (1996) detected a decrease in the phosphate leaf content when the NO₃⁻-to-NH₄⁺ ratio decreases in eggplants.

The higher P uptake observed in the NH₄⁺-N treatments may be the result of a stimulation of the H₂PO₄⁻ uptake when the NO₃⁻ uptake is strongly depressed (Mengel and Kirkby, 2001).

Mengel and Kirkby (2001) observed that plants fed with the NH₄⁺-N source contained higher concentrations of inorganic anions (SO₄²⁻, H₂PO₄⁻, Cl⁻), whereas cations (Ca²⁺, Mg²⁺, K⁺) were present in lower concentrations. In contrast, the plants supplied with the NO₃⁻-N form contained a higher cation content (Bar-Tal et al., 2001). However, Raghavendra (1980) reported that the K content of the epidermal tissues of *Commelina benghalensis* L. was higher when no inorganic anion

Table 1. Concentrations, pH, and electrical conductivity of the used nutrient solution.

Treatment	pH	EC (dS·m ⁻¹)	NO ₃ ⁻ (mmol·L ⁻¹)	NH ₄ ⁺ (mmol·L ⁻¹)	H ₂ PO ₄ ⁻ (mmol·L ⁻¹)	SO ₄ ²⁻ (mmol·L ⁻¹)	K ⁺ (mmol·L ⁻¹)	Ca ²⁺ (mmol·L ⁻¹)	Mg ²⁺ (mmol·L ⁻¹)
Ta (100 NO ₃ ⁻ : 0 NH ₄ ⁺)	6.5	1.0	6.0	0.0	1.2	1.0	4.0	0.9	2.4
Tb (50 NO ₃ ⁻ : 50 NH ₄ ⁺)	6.5	1.4	3.0	3.0	1.2	4.0	4.0	0.9	2.4
Tc (0 NO ₃ ⁻ : 100 NH ₄ ⁺)	6.5	1.8	0.0	6.0	1.2	7.5	4.0	0.9	2.4

EC, electrical conductivity.

was applied than the content when chloride or nitrate (NO_3^- -N) were present in the fertigation solution. In this case, the N form had no effect on K uptake (Table 3).

The higher P uptake observed in the ammonium treatments can also be the result of pH differences in the recycled solution (Mengel and Kirkby, 2001; Yu et al., 2003), because of the great importance of the proton-anion cotransport through the apoplasm (Marschner, 1995). The use of NH_4^+ -N in recycled solutions generates an important pH decrease because of the nitrification process (Jiménez and Lao, 2001) of the mentioned proton release via the NH_4^+ -proton antiport (countertransport). In this trial (data presented in Jiménez and Lao, 2001), the initial pH was 6.5 for all treatments, and the final pH range was 4 to 5 for the NH_4^+ -N treatments, whereas pH increased between 0.5 and 1 point in the NO_3^- -N treatment.

The N-to-P uptake ratio was 3.4, 4.4, and 5.0 for the treatments Ta, Tb, and Tc respectively. These values are similar to those reached by Economakis and Krulj (2002) for a strawberry crop.

These results showed a higher N-to-P uptake ratio in the NH_4^+ -N treatments, which means that the N uptake was higher than the P uptake, but P and N uptakes were higher in NH_4^+ -N treatments (Table 3). For this reason, the N-to-P uptake ratio must be considered in the nutritive solution formulation and it depends on the N supply source.

A low fertilizer use efficiency can influence in a negative way both yield and crop quality (Carrasco, 2002). Nutrient use efficiency can be defined as the dry weight of the organic matter produced (in grams) divided by the nutrient uptake (in grams) (Phiri et al., 2003). Treatments Ta, Tb, and Tc present a P use efficiency of 35, 38, and 43 $\text{g}\cdot\text{g}^{-1}$. In this way, the use of NH_4^+ -N or a combination

NH_4^+ - NO_3^- in the nutrient solution improves P use efficiency.

Empirical models of phosphorus uptake and phosphorus uptake concentration

Phosphorus uptake. A simple regression between P uptake and climate and between P uptake and growth parameters was done to establish models that permit one to estimate P uptake (Fig. 1). Attending to the previous results, Tb and Tc were studied together considering the NH_4^+ -N applied. Temperature, LAI, and water uptake were the best correlated parameters with P uptake. However, these results did not express a good relation between nutrient uptake and Rg ($R^2 = 0.12$ and 0.15 for the NO_3^- -N and NH_4^+ -N treatments respectively) nor between nutrient uptake and VPD (Fig. 1; $R^2 = 0$ for all treatments). However, van Goor et al. (1988) found that a high light intensity is linked to a higher dry weight and to a higher nutrients requirement as well. In addition, a low light intensity leads to a diminution of the nutrient uptake (Kafkafi et al., 1984). Schüssler (1995) found that a high water VPD increases the transpiration from the plant and, therefore, nutrient uptake is also increased. There is no relation between these parameters, perhaps because P is less affected by the transpiration stream, because this element is taken up in an active way (Marschner, 1995).

The coefficient of regression between P uptake and temperature was $R^2 = 0.51$ and 0.57 for the NO_3^- -N (Ta) and NH_4^+ -N (Tc) treatments respectively. The thermal inertia in container crops is lower than in soil crops, and the environment temperature is similar to the root temperature (García et al., 2002). Economakis and Krulj (2002) observed that there is an increment of the P uptake when the root temperature increases. Plant roots are

able to absorb P from diluted dissolutions by an active uptake process, with an adenosine triphosphate consumption associated with the respiration process (Marschner, 1995). The respiration speed increases ≈ 2.2 times per each 10°C , and it has been found that nutrient uptake is increased when temperature becomes bigger in the same proportion (Joiner et al., 1983). In addition, Raghothama and Karthikeyan (2005) consider that major biochemical processes such as photosynthesis and respiration are activated by inorganic phosphate or its organic derivatives.

The coefficient of regression between P uptake and LAI was 0.70 and 0.67 for NO_3^- -N (Ta) and NH_4^+ -N (Tc) treatments respectively. Leaf area index quantifies directly the plant canopy structure, so it is highly related to a variety of canopy processes, such as photosynthesis and respiration, and it is also associated with dry weight production (Penning de Vries, 1974), temperature, and nutrient supply (Lawlor, 1991). Economakis and Krulj (2002) reported a correlation between nutrient uptake and growth rate.

To improve the model, a multivariable regression between P uptake and the tested parameters (Table 4), taking LAI as the fixed variable, because it had the higher determination coefficient, was undertaken. There were no multiple regressions that could improve the model of P uptake in the NO_3^- -N treatment. However, a multiple regression with LAI and radiation explains better the P uptake in the NH_4^+ -N treatment.

Phosphorus uptake concentration. A regression between P uptake and water uptake was done to estimate the P uptake concentration (P-to-water uptake ratio) for the two trials (Fig. 1). The linear regression equations presented and R^2 value of 0.58 and 0.64 , and slopes of 2.04 and $2.61\text{ mmol}\cdot\text{L}^{-1}$ for the treatments with NO_3^- -N (Ta) and NH_4^+ -N (Tc) respectively. These values are similar to the ones cited by Magán (1999) in tomato crops and are a little bit smaller than those obtained by Sheen and Hsu (1996) in melon crops. This uptake concentration indicates that P and water uptake depend on the N form applied, and that P and water are taken up in different amounts. These results agree with those obtained by Rouphael et al. (2004), who observed that the recycled solution showed 40% depletion after 73 d. The nutrient solution concentration in the growth medium is modified when nutrient solutions with a constant salt concentration are added to a hydroponic system, with these variations incited by changes in the nutrient-to-water uptake ratio. Nevertheless, it is difficult to

Table 2. Average temperature, global radiation, and vapor pressure deficit in the greenhouse for both trials during the days after transplanting.

DAT	First trial			Second trial		
	Rg ($\text{MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$)	VPD (kPa)	T ($^\circ\text{C}$)	Rg ($\text{MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$)	VPD (kPa)	T ($^\circ\text{C}$)
40				2.57	-0.25	20.1
60				2.49	-0.30	18.3
80	2.21	-0.74	22.6	2.41	-0.30	18.5
100	6.22	-1.01	26.6	3.07	-0.44	18.7
120	5.96	-0.88	26.1	3.78	-0.55	20.8
140	2.94	-0.93	27.2	4.13	-0.29	22.6
160	3.73	-0.35	31.2	5.52	-0.51	24.9
180	3.46	-0.07	29.1	6.30	-0.27	24.4
200	3.36	-0.13	30.3	1.92	-0.30	24.1
220				2.24	-0.57	25.1
240				2.49	-0.54	27.2

DAT, days after transplanting; Rg, global radiation; VPD, vapor pressure deficit; T, temperature.

Table 3. Leaf area index, nitrogen (NO_3^- -N + NH_4^+ -N), potassium, and phosphorus uptake and shoot phosphorus concentration as affected by the ratio of NO_3^- -N and NH_4^+ -N in the supplied nutrient solution.

Treatments	LAI, first trial ($\text{m}^2\cdot\text{m}^{-2}$)	LAI, second trial, ($\text{m}^2\cdot\text{m}^{-2}$)	N uptake ($\text{mmol}\cdot\text{d}^{-1}\cdot\text{plant}^{-1}$)	P uptake ($\text{mmol}\cdot\text{d}^{-1}\cdot\text{plant}^{-1}$)	K uptake ($\text{mmol}\cdot\text{d}^{-1}\cdot\text{plant}^{-1}$)	Shoot P concn. ($\text{mg}\cdot\text{g}^{-1}$)
Ta ($100\text{ NO}_3^- : 0\text{ H}_4^+$)	$1.62 \pm 0.30\text{ b}$	$1.47 \pm 0.20\text{ b}$	$0.82 \pm 0.16\text{ b}$	$0.24 \pm 0.09\text{ b}$	$0.55 \pm 0.20\text{ a}$	$3.6 \pm 0.1\text{ c}$
Tb ($50\text{ NO}_3^- : 50\text{ H}_4^+$)	$2.02 \pm 0.20\text{ a}$	$2.34 \pm 0.23\text{ a}$	$1.45 \pm 0.20\text{ a}$	$0.33 \pm 0.14\text{ a}$	$0.71 \pm 0.20\text{ a}$	$3.9 \pm 0.1\text{ b}$
Tc ($0\text{ NO}_3^- : 100\text{ H}_4^+$)	$1.95 \pm 0.21\text{ ab}$	$1.51 \pm 0.25\text{ ab}$	$1.35 \pm 0.15\text{ a}$	$0.27 \pm 0.09\text{ a}$	$0.51 \pm 0.19\text{ a}$	$4.4 \pm 0.2\text{ a}$

Mean separation in rows by LSD ($P < 0.05$).

LAI, leaf area index.

Fig. 1. Simple regression between the phosphorus (P) uptake (mmol·d⁻¹/plant) and water uptake (WU; in liters per day per plant), temperature (T; in degrees Celsius), leaf area index (LAI; in square meters per square meter), global radiation (Rg, in megajoules per square meter per day), and vapor pressure deficit (VPD; in kilo-Pascals). Significance of the correlation, $P < 0.05$.

Table 4. Multiple regressions between phosphorus uptake and climatic and growth parameter.

Treatment	P uptake model	R ²	Covariance between independent variables
Treatment A	f(LnLAI.T)	0.84	-0.81
	f(LnLAI.Wup)	0.81	-0.86
	f(LnLAI.VPD)	0.58	-0.21
	f(LnLAI.Rg)	0.58	0.08
	f(LnLAI.T)	0.69	-0.81
Treatments B and C	f(LnLAI.Wup)	0.67	-0.86
	f(LnLAI.VPD)	0.68	-0.16
	f(LnLAI.Rg)	0.74	-0.01
	f(LnLAI.T)	0.74	-0.01

Coefficients are significant at 0.5% level.

maintain nutrient equilibrium, because plant uptake can be dissimilar for different crops (Ehret et al., 2005). In order to maintain an invariable P concentration in the nutritive solution, the amount of P applied should be equal to the P uptake concentration, but this

relation is not constant because it varies depending on the environmental conditions (Kläring et al., 1997) and the plant age. In this assay, the R² value of the simple regression between uptake concentration and temperature, Rg, VPD and LAI was less than 0.1, so a

regression could not explain the cited concentration variations. However, Kläring et al. (1997) showed that P uptake concentration was strongly affected by temperature, with an R² value of 0.67, but was less influenced by Rg.

Comparison between models to estimate phosphorus uptake concentration

This work proposes two models to estimate the P uptake concentration: 1) a fixed concentration value obtained by the slope of the linear correlation between P uptake and water uptake, and 2) a relation between the estimated P uptake through the model and the experimental water uptake. The 1% error and the SE deviation for the nitrate (NO₃⁻-N) treatment were 0.17, 0.28 and 0.12, 0.16 and, for the ammonium (NH₄⁺-N) treatments, were 0.29, 0.28 and 0.12, 0.2 for the fixed value and the model respectively. The use of a unique P uptake concentration offers low precision and, on other hand, the second model is more closely related to the experimental values.

Conclusion

The N form applied to *D. amoena* plants affects P and N uptake, but it does not influence K uptake. Nitrogen and P uptake rates are higher in the plants supplied with NH₄⁺ or NO₃⁻ + NH₄⁺ than in plants provided with NO₃⁻ alone. The supply of a combination 50 NO₃⁻ : 50 NH₄⁺ improves P use efficiency. The study also indicates the possibility of predicting the P uptake rate and P uptake concentration using the proposed models. Phosphorus uptake can be estimated with a model dependent on the LAI in the NO₃⁻-N treatments, and on the LAI and Rg in the NH₄⁺-N treatments. The P uptake concentration can be calculated with the P uptake, estimated through the previous model, and the experimental water uptake. This parameter would permit a nutritive solutions design, diminishing the nutrient losses in open systems.

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