

Study on Phosphorus Supply Management of Poinsettia Grown in Peat-Based Substrate

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ABSTRACT

Poinsettia (Euphorbia pulcherrima cv. 'Premium Red') as an ornamental pot plant is widely grown in peat-based substrates with high phosphorus (P) fertilization. The aim of the current study was to evaluate the P demand of poinsettia according to its P depletion ability during the growth stages by using a mechanistic simulation model. For this purpose, rooted poinsettia cuttings were grown in the medium with 80: 20 (V:V %) peat+mineral component (generally called as clay) and treated with different P levels of zero, 10, 35, 100, and 170 mg P [L substrate]⁻¹. The yield and quality performance of the plants were evaluated thoroughly. Also, depletion of P around the root surface and the effect of buffering power on the depletion profile were assessed by means of mechanistic simulation model. The results showed that, in peat-based substrates, P was transported to the root surface mainly by mass-flow. The simulation approach also revealed that the well supplied plants cultivated in the peat-substrates needed a higher concentration gradient (30-50 μM) to drive the necessary flux and that the amount of plant available P (C_s) was limiting at later growth stages. The optimum yield and quality of poinsettia was obtained at the P application rate of 35 mg L⁻¹ substrate, with C_s of 11-12 and 15-16 mg [L substrate]⁻¹ at planting and 53 days after planting. It was concluded that, to ensure a sufficiently high concentration gradient, P had to be supplemented by frequent fertigation at later growth stages, but not at the early growing stage.

Keywords: Concentration gradient, Fertigation, Modeling, Uptake.

INTRODUCTION

Poinsettia (Euphorbia pulcherrima), as a small semi-woody ornamental plant native to tropical America, has been used mainly as a traditional Christmas decoration for many years throughout the world with visibly colored bracts and contrasting foliage color. This crop is widely grown in peat-based substrates and usually is provided with elevated levels of phosphorus from propagation to flowering and bract formation. Mixing of mineral components with soilless media may positively affect the growth and quality of ornamental crops (Ehret *et al.* 1998;

Verhagen, 2004). Indeed, nutrients are traditionally applied as common fertilizers in peat-substrates without recognizing the mobility of nutrients in these substrates, in particular for P, which is considered as clearly immobile nutrient in mineral soils. The mobility of nutrients in soils is well characterized and in fact, the total transport of nutrients in the soil towards root system is assumed as the sum of mass-flow and diffusion. Among these two main driving forces for the movement of nutrients through mineral soil, diffusion has a key role for the movement of P and less than 4% of P taken up by the plants reaches the root surface by mass-

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flow (Claassen and Steingrobe, 1999). Theoretically, evaluation of the concentration gradient necessary to meet the P demand of poinsettia plants grown in peat-substrates revealed that, if P is assumed to be transported to the root surface only by diffusion (which is the main driving forces for P in the mineral soils), the transported P will meet the demand of this crop just at the early growth stages, but, at the later growth stages, an overlapping of depletion zones is expected and plants suffer from P deficiency and available P is a limiting factor at these stages (Khandan-Mirkohi and Schenk, 2009b). As a result, the situation in the soils and peat-based substrates seems to be completely different, since buffering power is reported to be considerably low in peat-based substrates compared to the mineral soils (Khandan-Mirkohi and Schenk, 2008). Accordingly, mass-flow is expected to be the main driving force of P to the root surface in these substrates.

In order to estimate the uptake ability of the plant, mechanical evaluation of nutrient depletion around the root system by using a model called NST 3.0 is also feasible (Claassen and Steingrobe, 1999). In this model, nutrients are assumed to be transported to the root surface by the sum of mass-flow, diffusion, and inflow into the root following Michaelis-Menten kinetics. The water uptake rate as well as root morphological traits such as root radius, root hairs, and the competition between roots are also considered in this model.

The modeling of nutrient uptake enables the adaptation of the fertilization program to the nutrient demand of the crop during the developmental stages. The aim of the current study was to manage and adapt the P fertilization program to the demand of poinsettia during its developmental stages.

MATERIALS AND METHODS

Preparation of the Growing Medium

The growing medium was prepared by mixing 80% vol. of black peat (BP) that

passed through a 2 mm sieve and 20% vol. of the most frequently used mineral component (consisting of 33% sand, 43% silt, and 24% clay). Phosphorus was applied to the substrate in the form of $\text{Ca}(\text{H}_2\text{PO}_4)_2$ at the rates of 0, 10, 35, 100, and 170 mg P [L substrate]⁻¹. Nitrogen (N) and potassium (K) were applied at the rate of 150 mg (L substrate)⁻¹ in the form of NH_4NO_3 and K_2SO_4 , respectively. Additionally, Flory® 10 (EUFLOR GmbH, Munich, Germany; www.euflor.de), which contains Mg and micronutrients (10% magnesium oxide, 3.5% Fe-HEDTA, 2% Cu-EDTA, 0.8% Mo, 0.5% Mn, 0.5% B, 0.3% Zn, and 0.02% Co) was applied at the rate of 50 mg product [L substrate]⁻¹. The substrate pH was adjusted to 5.7 ± 0.2 by adding calcium carbonate 4-8 g L⁻¹ substrate. Finally, the substrate was equilibrated in an oven at a temperature of 50°C for 24 hours and then at room temperature for 3 days (Khandan-Mirkohi and Schenk, 2008). The wet volume weight of substrates which was determined according to the standard method of VDLUFA (1991) was 800 g (L substrate)⁻¹ at the substrate moisture content of 37% vol. Water holding capacity and pore space volume were 76.4 and 80.7% vol., respectively.

Analytical Procedures

The substrate pH was measured in 0.01 M CaCl_2 suspension using a substrate: solution ratio of 1:2.5. Available P in the substrate (C_s , mg P [L substrate]⁻¹) was measured using CAT extraction (0.01M $\text{CaCl}_2 + 0.002\text{M}$ DTPA) by P-yellow method according to Alt and Peters (1992). Phosphorus concentration in the substrate solution (C_{li} , mg P [L solution]⁻¹) was determined by P-blue method according to Murphy and Riley (1962). Freundlich-function was used to describe the relationship between C_s and C_{li} (Barber, 1995) and buffering power (b) represents the ratio C_s/C_{li} . Plant material was dried at 70°C for 5 days and shoot dry weight was

recorded. Dry matter P content was determined according to Gericke and Kurmis (1952). Mass-flow (MF, $\mu\text{mol cm}^{-2} \text{s}^{-1}$) was determined by multiplying the uptake rate of water into the root cylinder ($\text{cm}^3 \text{cm}^{-2} \text{s}^{-1}$) at C_{li} ($\mu\text{mol cm}^{-3}$), and effective diffusion coefficient (D_e , $\text{cm}^2 \text{s}^{-1}$) was determined using the diffusion coefficient of H_2PO_4^- in water at 25°C (D_L , $\text{cm}^2 \text{s}^{-1}$), the volumetric water content (θ , $\text{cm}^3 \text{cm}^{-3}$), impedance factor (f) and the buffering power (b) as reported by Khandan-Mirkohi and Schenk (2009a). For the extraction of available potassium (K), 160 ml of CAT (0.01M CaCl_2 +0.002M DTPA) solution was added to 50 g of substrate samples (on a basic volume weight of 750 g L^{-1}) and shaken for 1 hour, and K concentration was measured using Flame photometry (ELEX 6361, Eppendorf, Germany). For NO_3^- measurement, 200 ml of 0.1 M KCl as an extraction solution was used and its concentration was measured at 210 nm by spectrophotometer (UVIKON 943, BioTek Instruments, Inc.).

Planting

Poinsettia (*Euphorbia pulcherrima* cv. 'Premium Red') was grown in the prepared substrate. The prepared substrate was packed into plastic pots at a bulk density of 0.4 g cm^{-3} , then, rooted poinsettia cuttings were transplanted into the pots having a volume of 620 cm^3 . Plants were grown in a greenhouse at day/night mean heating temperatures of $25^\circ\text{C}/18^\circ\text{C}$. Daily ventilation temperature was fluctuating from 20 to 28°C and air humidity was in the range of 65-70%. The substrate moisture was maintained at 50% vol. with a zero-leach system during the growth period by weighing and fertigating the pots every two days. The amount of nutrient solution for each single fertigation per pot at every two days varied from 50 to 90 ml on the basis of water loss via evaporation and transpiration. In general, it was observed that plants with low P level received less nutrient solution

compared to the plants with high P levels, since the growth rate and the water consumption was lower at the lower P levels. Pots without plants were used to estimate the water loss through evaporation mainly until the pot surface was completely covered by the plant crown. Transpiration was calculated as the difference between the amount of water lost from the pots with plants (by weighing the sample pots just before and after fertigation) and evaporation from the pots without plants. Each plant received 8-14, 1-1.5, and 6-12 mg nitrogen (N), phosphorus (P), and potassium (K), respectively, at each single fertigation. The fertigation solution was prepared from NH_4NO_3 , KH_2PO_4 , K_2SO_4 , and MgSO_4 and contained N, P, K, and Mg at concentrations of 160, 18, 133, and 10 mg L^{-1} , respectively. Micronutrients were applied in the form of compound fertilizer (Flory[®] 10) at a rate of 250 mg L^{-1} , consisting of 10% MgO, 3.5% Fe-HEDTA, 2% Cu-EDTA, 0.8% Mo, 0.5% Mn, 0.5% B, and 0.3% Zn. Electrical conductivity (EC) of nutrient solution was 1.5 dS m^{-1} and its pH was kept at 5.8 ± 0.2 . Plants were supplemented with $80 \mu\text{mol m}^{-2} \text{s}^{-1}$ (5,680 Lux) light by the source of metal halide (MH) lamps to keep a constant vegetative growth when the radiation was lower than $100 \mu\text{mol m}^{-2} \text{s}^{-1}$ (7,100 Lux). Light intensity varied from 100 to $250 \mu\text{mol m}^{-2} \text{s}^{-1}$ (7,100-17,750 Lux) during the vegetative growth of the plants.

Harvesting

Plants were harvested at two different developmental stages i.e. at 10 and 53 days after planting (DAP), as the first and second harvest, respectively. Plant morphological and physiological parameters were measured at both harvests and used for modeling. However, only the second harvest data were considered for assessment of quality parameters including plant height and diameter (Cm), number of branches per plant and plant dry matter (g plant^{-1}). Plant height was measured from substrate surface



to the end of growing point and plant diameter was considered as the distance between two vertical side lines of plant spread. Roots were separated and washed with tap water clearly, then, root surface water was removed by gently pressing the roots between pieces of tissue papers, and total root fresh weight (RFW; g plant⁻¹) was measured. Root length (L; cm plant⁻¹) was calculated by line intersect method of Tennant (1975). Root growth rate constant (k; cm d⁻¹) was computed assuming linear growth between the first and the second harvest. Root radius, mean half distance between neighboring roots, and root physiological parameters were recorded as reported by Khandan-Mirkohi and Schenk (2009a). Samples of peat-based media for measuring the EC value were taken from the lower two-third of the pots volume, mixed thoroughly and EC reading was taken in the solution phase of a 1:2 slurry after filtering.

Modeling P Uptake and Depletion

The mechanistic simulation model (NST 3.0) described by Claassen and Steingrobe (1999) was used to predict plant P uptake. This model considers delivery of nutrients to the root surface by mass-flow and diffusion and uptake by the root following Michaelis-Menten kinetics. Phosphorus uptake was predicted assuming linear root growth rate, homogenous root distribution in the pot, and competition between roots for different depletion period. Plant morphological and physiological parameters for modeling are given in Table 2.

Statistical Analysis

Completely randomized block design was used for this study. Substrate was basically treated with five different P levels, treatments were replicated four times, and four plants were used for each treatment in each replicate (5×4×4= 80). Data were analyzed using analysis of variance of SAS (1996) and means were compared between the treatments at $\alpha= 0.05$ using Tukey Test.

RESULTS AND DISCUSSION

Optimum Growth and Quality

The EC value was 1.8 and 2.2 dS m⁻¹ at 10 and 53 days after planting, and substrate pH declined at the final harvest and, for low to high P levels, ranged from 5 to 5.1, respectively. Increase in P supply resulted in a significant increase in shoot dry matter yield, and also improved the quality of poinsettia (Table 1). Increase of shoot dry matter and improvement of quality parameters were in the same range for the three higher P levels during the growth, and clearly above the lower P levels (Table 1). The maximum yield, which is considered as 90% of maximum yield in the optimum growth (Ulrich, 1952), and also the maximum quality, were obtained at applied P level of 35 mg [L substrate]⁻¹ with plant available P (C_s) of 11-12 mg [L substrate]⁻¹ at planting (first harvest) and 15-16 mg [L substrate]⁻¹ at the second harvest. Due to P

Table 1. Quality parameters of poinsettia as affected by P-application rate.^a

P-application rate (mg [L substrate] ⁻¹)	Plant dry matter (g plant ⁻¹)	Plant height (cm)	Plant diameter (cm)	Number of branches (#plant ⁻¹)
0	18.0 b	28.2 b	30 b	6.6 b
10	18.5 b	28.5 b	30 b	6.6 b
35	22.7 a	32.2 a	40 a	7.7 a
100	22.7 a	32.5 a	40 a	7.8 a
170	22.9 a	32.8 a	40 a	7.8 a

^a Different letters indicate significant differences at $P < 0.05$

Table 2. Specific model parameters of poinsettia at optimum growth used for simulation of P uptake at planting (10 DAP) and the first harvest (53 DAP). Some modeling data were taken from Khandan-Mirkohi and Schenk, (2009a).

Days after planting (DAP)	Substrate parameters ^a		Root parameters ^b					
	<i>b</i>	<i>C_{ii}</i>	<i>r₀</i>	<i>r_l</i>	<i>L₀</i>	<i>k</i>	<i>I_{max}</i>	<i>V₀</i>
10	7	0.048	0.04	0.56	620	62	4.2	9.02
53	2.8	0.27	0.04	0.24	3310	133	4.2	9.02

^a *b*= Buffering power, *C_{ii}*= Substrate solution P concentration ($\mu\text{mol cm}^{-3}$); ^b *r₀*= Root radius (cm); *r_l*= Mean half distance between roots (cm); *L₀* = Initial root length (cm plant⁻¹); *k*= Growth rate of roots (cm day⁻¹); *I_{max}*= Maximum uptake rate ($\mu\text{mol cm}^{-2} \text{s}^{-1} \times 10^{-7}$), *V₀* = Water uptake rate of root cylinder ($\text{cm}^3 \text{cm}^{-2} \text{s}^{-1} \times 10^{-7}$).

fertilization, *C_s* increased at lower P levels (Khandan-Mirkohi and Schenk, 2009a). The plant height was retarded under deficient P levels up to 35 mg [L substrate]⁻¹ (Table 1), and the maximum height was attained at 3rd P level (35 mg [L substrate]⁻¹). Retarded plant height was considered as a quality parameter which may improve the aspects and facilitate the handling for marketing of this crop. Recently, mild P fertilization and its limited or buffered application are considered as an effort to control the height of some ornamental plants (Borch *et al.*, 2003). Control of plant height in these crops is most traditionally regulated by application of growth retardants (Armitage, 1993); however, non-chemical alternatives have received a great deal of attention in recent years (Cox, 2001).

Root length density did not change with P supply. However, relating root length to shoot dry matter, it was observed that root: shoot ratio at low P supply was higher than at high P supply at both harvest stages (Figure 1), since shoot dry matter decreased more than root length. Similar results were reported for other crops (Bhadoria *et al.*, 2004; Föhse *et al.*, 1988). High root: shoot ratio was reported to be the reason for P uptake efficiency of wheat, ryegrass (Föhse *et al.*, 1988), and maize (Bhadoria *et al.*, 2004).

Buffering Power (b) and Concentration Gradient

Buffering power of the substrate ranged from 2.8 to 7 at 10 and 53 days after planting,

respectively (Table 2). The observed buffering power (*b*) was much lower than reported for mineral soils (Jungk and Claassen, 1997). Buffering power is an indicator of P adsorption characteristics of soil which was influenced mainly by Fe and Al oxide content of the mineral components, but not by their clay content (Khandan-Mirkohi and Schenk, 2008). Buffering power represents the ratio between available P in the substrate (*C_s*) and phosphorus concentration in the substrate solution (*C_{ii}*). The observed *C_{ii}* for optimum growth of poinsettia (48 μM , Figure 2) was

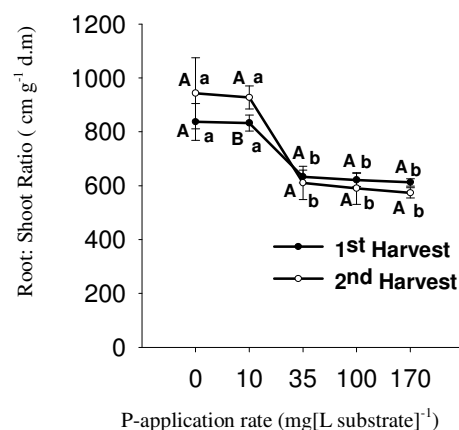


Figure 1. Root-to-Shoot ratio of poinsettia at 1st and 2nd harvest as affected by different P application rate. Different lower case letters indicate significant difference between different P-application rates and different upper case letters indicate significant differences between harvests for a given P-application rates, respectively, at $P < 0.05$.

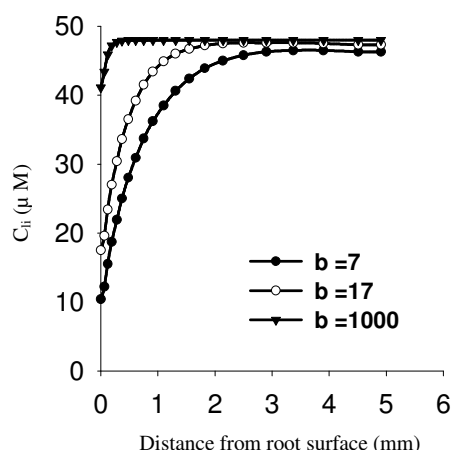


Figure 2. The change of depletion profile for P at root surface of poinsettia at optimum growth as affected by different buffering power (simulation for two days uptake 10 days after planting, DAP).

almost 5 times higher than the highest value ($10 \mu\text{M}$) commonly reported for mineral soils (Barber, 1995; Jungk and Claassen, 1997). Surprisingly, the C_{li} of $10 \mu\text{M}$ was not sufficient for optimum growth of poinsettia in peat-based substrate (Khandan-Mirkohi and Schenk, 2009a), since the concentration gradient was not sufficient to meet the demand at this level of C_{li} . Thus, the well supplied plants cultivated in peat-substrates needed a

high concentration gradient of about $30\text{-}50 \mu\text{M}$ to drive the necessary flux (Figures 2 and 3). The simulation approach revealed that such a high concentration gradient in the peat-substrate was necessary because of very low b ($=7$) compared to that in the mineral soils ($b=1,000$, Barber, 1995) (Figure 2). The highest observed b at optimum P in peat-substrates mixed with different mineral components ($b=17$) (Table 3) slightly changed the depletion profile and decreased the concentration gradient ($30 \mu\text{M}$), but still a huge difference was found between peat-based substrate and mineral soils. However, using b of $1,000$, which is generally well-known for mineral soils, the depletion profile changed dramatically and the concentration gradient ($5\text{-}8 \mu\text{M}$) became close to that normally expected for mineral soils (Barber, 1995).

Simulating the uptake and depletion of P by means of mechanistic model using substrate and root parameters given in Table 2 revealed that the concentration gradient decreased only slightly after 6 days of depletion at early growth stage (Figure 3). However, during the later stages (vegetative growth period) the concentration gradient was reduced by half and even more within 6 days, since mean half distance between roots (r_1) was decreased (Khandan-Mirkohi and Schenk, 2009a). Thus, the amount of C_s was limiting at later stages (high vegetative

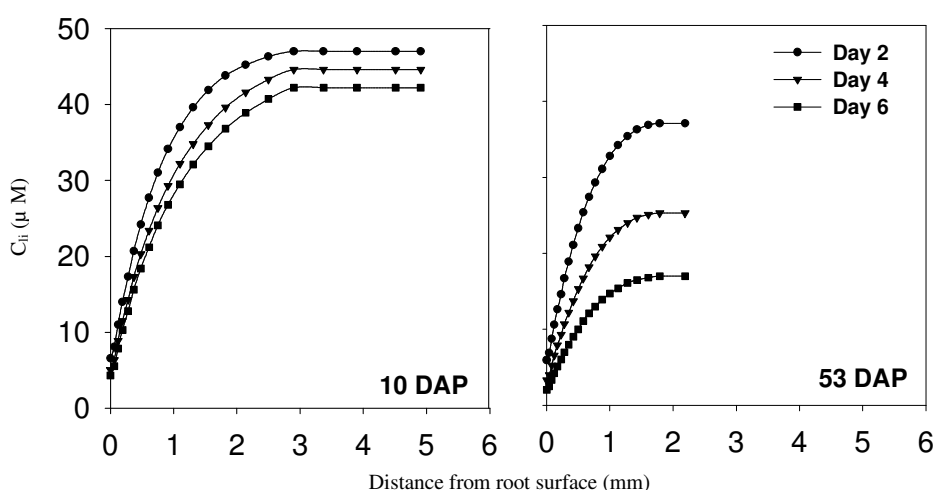


Figure 3. Depletion profile of P at optimum P application rate ($35 \text{ mg } [\text{L substrate}]^{-1}$) for poinsettia 10 days after planting (DAP), and at 53 DAP (simulated for different depletion time).

Table 3. The effective diffusion coefficient (D_e , $\text{cm}^2 \text{s}^{-1}$) of P, K, and NO_3 in peat-substrate compared to mineral soil.^a

Nutrient	D_L ^b	Buffering power (b) ^b		D_e ^b	
		Mineral soil	Peat-substrate	Mineral soil	Peat-substrate
P	08.9	100-2000	1-17	10^{-8} - 10^{-11}	10^{-7} - 10^{-8}
K	19.8	2-8	2-6	10^{-7} - 10^{-9}	10^{-7}
NO_3	19.2	0.2	0.5	10^{-6} - 10^{-7}	10^{-6}

^a Equation for computation of effective diffusion coefficient was $D_e = D_L \theta f \times (1/b)$.

^b D_L ($\times 10^{-6}$, $\text{cm}^2 \text{s}^{-1}$), is diffusion coefficient of nutrients in water at 25°C (Barber, 1995); For volumetric water content (θ) the values of 0.5 and 0.2 $\text{cm}^3 \text{cm}^{-3}$, and for f the values of 0.09 and 0.2 in peat-substrate and mineral soil was used for computations, respectively. For mineral soil f and θ was taken from Barraclough and Tinker (1981) and b for peat-based substrates was taken from Khandan-Mirkohi and Schenk (2008) and for mineral soils from Barber (1995) and Claassen and Steingrobe (1999).

growth period). Consequently, it can be concluded that poinsettia plants could be irrigated every two days and fertigated every six days at early growth stages, but P had to be supplemented by frequent fertigation every two days at later growth stages (just before shift to the reproductive stage) to ensure a sufficiently high concentration gradient. At the reproductive stages of the growth, the P demand of poinsettia declined (Khandan-Mirkohi and Schenk, 2009b).

Root hairs distribution was computed for all P rates. Half distance between root hairs is given as an example for optimum P level of poinsettia: 9.9, 18, 46, 144, and 490 ($\times 10^{-3}$ cm) and of marigold: 6.7, 10.2, 17, 33.7, 81.6, 194, and 361 ($\times 10^{-3}$ cm) in the compartments with 0-0.0167, 0.0167-0.0334, 0.0334-0.05, 0.05-0.067, 0.067-0.0835, 0.0835-0.1, and 0.1-0.117 cm distance from root surface, respectively.

Diffusion Coefficient (D_e)

The calculation of D_e for P, K, and NO_3 in peat-substrate and mineral soil showed that, obviously, D_e increased in the same order in both mineral soil and peat-substrate for $\text{P} < \text{K} < \text{NO}_3$ (Table 3). For K and NO_3 , almost the same D_e was observed for both media. Evidently, D_e for P in peat-substrate was higher than that in mineral soil. This was

because the b for P was considerably lower in peat-substrate compared to mineral soil, whereas the b for K and NO_3 was almost the same for both media. For the high D_e value, both low b and high impedance factor (f) are the main factors (Nye, 1979; Barber, 1995). However, it was reported that the f value was almost similar (0.2-0.3) in peat-substrates and mineral soil at normal conditions (Khandan-Mirkohi and Schenk, 2008). Thus, the high D_e for P in peat-substrates is attributed mostly to the low buffering power (b).

Phosphorus Mobility in the Substrate

Among two main driving forces for the movement of P through mineral soil or peat-based substrate (mass-flow and diffusion), mass-flow showed a key role for the movement of this ion through peat-based substrate (Figure 4). The contribution of mass-flow to P transport to the root surface of poinsettia in peat-substrate was 20-60% at optimum P level (35 mg L^{-1} substrate). This high contribution of mass-flow was mainly due to the higher substrate solution P concentration (C_{ii}) which was observed (48 μM). The results confirmed that P in peat-substrate was more mobile than that in mineral soils. In mineral soils, less than 4% of P taken up by the plants reaches the root

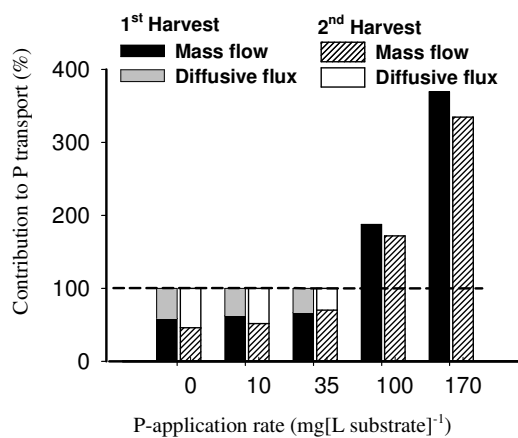


Figure 4. Contribution of mass-flow and diffusion to P transport to root surface of poinsettia at first and second harvest.

surface by mass-flow and, therefore, diffusion has a key role for movement of this ion through mineral soil (Claassen and Steingrobe, 1999).

CONCLUSION

Phosphorus is highly mobile in peat-based substrates and mass-flow showed a key role in the movement of this ion through these substrates. The movement of P in peat substrates is comparable to nitrate movement in the soil; it means that leaching of P must be deeply considered for pot plant production. Also, it was clear that the plant available P (C_s) was sufficient at early growth stages but not at later stages of the growth. At the later growth stages, all substrate volume is occupied by roots volume and the amount of available P is limiting the plant growth. Thus, plants can not satisfy their P demand from unused P-reserves in peat-based substrates unless P supply was frequent. According to the results, the base fertilization was quite adequate at early growth stages, but for the later stages, especially at fast vegetative growth stages (in this case 53 DAP), the

plants might suffer from P deficiency. Consequently, top dressing of P is necessary at later growth stages (just before shift to the reproductive stage) to ensure a sufficiently high concentration gradient. Our observation revealed that nutritional demands of poinsettia declined dramatically when the plants reached the reproductive phase.

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مدیریت تامین فسفر گیاه زینتی سرخ برگه کشت شده در بستر کشت بر پایه پیت

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چکیده

سرخ برگه (بنت القنسلول) گیاه زینتی گلدانی است که به طور گسترده در بستر کشت پیت و با مصرف فسفر زیاد کشت می شود. مطالعه حاضر به منظور ارزیابی نیاز به فسفر سرخ برگه بر اساس توان جذب آن در مراحل رشد مختلف با بهره گیری از یک مدل مکانیکی، تحلیلی انجام گرفت. قلمه های ریشه دار شده سرخ برگه (*Euphorbia pulcherrima* cv. 'Premium Red') در بستر کشت با ۸۰ درصد حجمی پیت و ۲۰ درصد حجمی رس (بخش معدنی) کشت شد و با سطوح مختلف فسفر (۰، ۱۰، ۳۵، ۱۰۰ و ۱۷۰ میلی گرم فسفر در لیتر بستر کشت) تیمار گردید. عملکرد و صفات کیفی گیاه در طی رشد مورد ارزیابی قرار گرفت. خروجی مدل نشان داد که فسفر در بستر کشت بر پایه پیت به طور عمده توسط جریان توده ای به سطح ریشه گیاه منتقل می شود. همچنین نشان داده شد که گیاهان در سطح مطلوب فسفر به یک شیب غلظت بالا (۵۰-۳۰ میکرو مولار) نیاز دارند تا جریان



ضروری به داخل گیاه تامین شود. میزان فسفر قابل دسترس گیاه در مراحل رشد نهایی محدود کننده بود. عملکرد و کیفیت مطلوب گیاه در میزان فسفر قابل دسترس ۱۲-۱۱ میلی گرم در لیتر و ۱۶-۱۵ میلی گرم در لیتر به ترتیب در زمان کاشت و ۵۳ روز بعد از کاشت حاصل شد. بنابراین، به منظور اطمینان از شیب غلظت کافی، این گیاه باید به طور مکرر در مراحل رشد پایانی و نه در مراحل رشد اولیه با فسفر تغذیه شود.