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# Diagnosis of the fertility of compost-based growing media: Method comparison and monitoring in pot plant cultivation

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ABSTRACT

Using compost instead of peat as an ingredient in substrate mixtures is a way of increasing the sustainability of pot plant nurseries. However, this use should also include monitoring to assess crop fertility, given that compost generally has a high fertilizer content. Of the different monitoring methods, the most effective, objective and preventive one involves monitoring the nutrient status of the substrate. The main objective of this study was to provide evidence-based information on fast methods used in the field to characterize substrate fertility compared to a water extract method in order to apply these methods in cultures with unusual alternative substrates.

We observed a high level of agreement between the concentration of nutrients measured using the IP method and the concentration using the fertility assessment methods most commonly used in horticulture (leachate and water extract methods). By using different compost-based substrates and comparing them to a control substrate, we have shown that the IP method is useful for monitoring substrate fertility in pot plants. Results show that the IP method indicates the nutrient composition of the functional part of the different substrates (root zone) and their development. The induced percolate method is a useful, nondestructive field method for quickly checking the nutrient content of the functional part of substrates.



## 1. Introduction

Using compost instead of peat as an ingredient in substrate mixtures is one of the measures proposed to increase the sustainability of nurseries that produce ornamental pot plants (Dennis et al., 2010). Because of the significant presence of the livestock industry in Western society, there is considerable interest in the potential of using composted manure solids as a substitute for peat (Shober et al., 2010; Al Naddaf et al., 2011). How its use affects crop fertilization and nutrient leaching must be closely studied (Bugbee, 1996; Marfà et al., 2002; Shober et al., 2010).

By regularly measuring substrate fertility, crop fertilization can be objectively assessed and supply can be adjusted (fertilizer type and mode) to optimize growth and minimize fertilizer loss, which can be quite significant (Yeager et al., 2010; Narváez et al., 2011, 2012, 2013). The induced percolate (IP) method (or pour-through method) is a procedure for obtaining a sample from the substrate solution by means of displacement (Yeager et al., 1983; Wright, 1986). It involves pouring about 100 mL of displacing solution (distilled water, irrigation water or NS) on the surface of the substrate and then collecting the resulting percolate from the bottom of the substrate. Through the piston effect, the displacing solution displaces the aqueous solution in closest contact with the roots so it can be collected (induced percolate) (Guérin et al., 1995; Lemaire et al., 1995). The advantages of this method include the ease and speed with which the sample is obtained and the fact that the method is nondestructive (Torres et al., 2010). In certain areas of the United States, nursery growers monitor substrate composition using the IP method and manuals are then used to assess substrate fertility (Yeager et al., 2010). The relationship between medium nutrient levels extracted with the IP and saturated media extract procedures (SME) has been investigated (Yeager et al., 1983; Wright et al., 1990; Cavins et al., 2004).

However, the SME method presents several practical drawbacks. It is time-consuming and difficult to precisely define the

*Abbreviations:* A-13®, perlite of particle size interval: 3–5 mm; B-12®, perlite of particle size interval: 0–5 mm; EC, electrical conductivity; EX, extract; IP, induced percolate; IRTA, Research and Technology, Food and Agriculture; LE, leachate; MCU, Multi Computer Unit; M-CS, mixture compost of solid fraction of cattle manure using static composting with B-12 perlite; M-CD, mixture compost of solid fraction of cattle manure slurry using dynamic composting with B-12 perlite; M-CDP, compost of solid fraction of cattle manure slurry with pine debris using dynamic composting with B-12 perlite; M-CON, peat with A-13 perlite; NS, nutrient solution; *R*, correlation coefficient; vol/vol, volume/volume.

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saturation state of the sample (Bunt, 1986; Ansorena, 1994). That is why water extract methods rather than the SME method are used to a great extent in Europe, and correlations between the English and Dutch methods have been established (substrate to water extract ratio of 1:6 and 1:1.5, respectively) (Ansorena, 1994).

The leachate method is being used to monitor the fertility of greenhouse soilless cultures where inorganic substrates are used. There are only few references on its use in the diagnosis of fertility in outdoor cultures when chemically active organic materials are used. The leachate method has not been correlated with other methods.

The bibliography does not include studies that validate the use of the IP method and establish possible correlations to methods widely used in Europe based on obtaining a water extract and leachates.

The main objective of this study was therefore to provide evidence-based information on fast methods used in the field to characterize substrate fertility compared to a water extract method, especially when using substrates that are alternatives to peat, given that substrate fertility must be carefully controlled in these cases due to its great variability. Several studies have analyzed the feasibility of replacing peat with compost-based substrates based on crop response, but the chemical composition of fertilizing ingredients is not generally monitored during growing using a nondestructive method that is easy to apply under field conditions.

Therefore, the main objectives of this study were:

- To gain greater insight into the relationship between nondestructive methods for monitoring substrate fertility in the field and the widely used water extract method (EX) based on a water/substrate volumetric ratio.
- To use the IP method to describe root-zone fertility during outdoor cultivation using high-fertility substrates.

Our general objectives were achieved with regard to the following topics:

- To study the correlation between the IP method of monitoring root-zone fertility and the water extract method, and to study the correlation between the nondestructive LE and IP methods.
- To describe the evolution of the fertility of mixtures of cattle-manure compost substrates during outdoor culture of container-grown bush species using the IP method.

## 2. Materials and methods

It is important to point out that this study of method comparisons was carried out:

- Under field conditions and using four different substrates, instead of using different doses of fertilizers. Therefore, the study was carried out under actual growing conditions.
- In particular, by conducting an experiment on an ornamental outdoor culture lasting six months and using a widely used species (oleander) that grew in up to four different organic substrates, including compost-based growing media.

### 2.1. Treatments: preparing mixtures of growing media

Three mixtures were prepared of different kinds of compost from the solid fraction of cattle slurry (CSF) and different proportions of perlite B-12® (0–5 mm) (Table 1). Sphagnum peat mixed with perlite A-13® (3–5 mm) (Hidalgo and Harkess, 2002; Shober et al., 2010) was used as the control substrate in a control treatment. The different proportions and kinds of perlite were used to create

**Table 1**
Organic material and perlite mixtures used in the experiment.

| Mixture | Organic material (OM) | OM (%) (vol/vol) | Perlite (PER) | PER (%) (vol/vol) |
|---|---|---|---|---|
| M-CS | CSF-S | 75 | B-12® | 25 |
| M-CD | CSF-D | 45 | B-12® | 55 |
| M-CDP | CSF-DP | 30 | B-12® | 70 |
| M-CON | PEAT | 40 | A-13® | 60 |

CSF-S: compost of solid fraction of cattle manure slurry using static composting; screened (grid size = 10 mm).
CSF-D: compost of solid fraction of cattle manure slurry using dynamic composting; screened (grid size = 10 mm).
CSF-DP: compost of solid fraction of cattle manure slurry using dynamic composting with pine debris as a bulking agent; screened (grid size = 10 mm).
B-12®: perlite, particle size: 0–5 mm, A-13®: perlite, particle size: 3–5 mm.
OM: organic material; PER: perlite.

similar physical properties in all four substrates (Fig. 1) (Cáceres, 2003) (Table 1).

The organic components of the mixtures (CSF) were obtained at a composting pilot plant at the IRTA research center in Cabrils (Barcelona, Catalonia, Spain) (41°25′ N, 2°23′ E, altitude of 85 m). The types were as follows: CSF-S: compost of the solid fraction of cattle manure slurry using static composting; CSF-D: compost of the solid fraction of cattle manure slurry using dynamic composting; CSF-DP: compost of the solid fraction of cattle manure slurry using dynamic composting with pine debris as the bulking agent. The composting period lasted 14 months. The CSF-S compost had a high nitrate content because of its rate of high nitrification during composting (Cáceres et al., 2006) and it also presented a high K and P content (expressed in mg $L^{-1}$ substrate) ($NO_3^-$: 1958, $K^+$: 1396; P: 111). The CSF-D compost presented a high nutrient content ($NO_3^-$: 843, $K^+$: 1587, P: 51) and the CSF-DP compost showed lower values (except for P) because of the dilution effect of the bulking agent ($NO_3^-$: 105, $K^+$: 1099, P: 57) (Cáceres, 2003) (Table 2).

### 2.2. Plant material and growing conditions

The experiment was carried out at an outdoor plot at the IRTA research station in Cabrils. Homogeneous rooted cuttings of oleander (*Nerium oleander* L.) were planted in 5-L pots placed at a distance of 40 cm from the other pots in all directions, thus resulting in a density of 6 plants $m^{-2}$.

A total of 24 plants were used for each treatment. An electrotensiometer was installed in one plant for each treatment; it activated the irrigation system when a matric potential of −2 kPa was reached. This threshold was chosen based on the physical

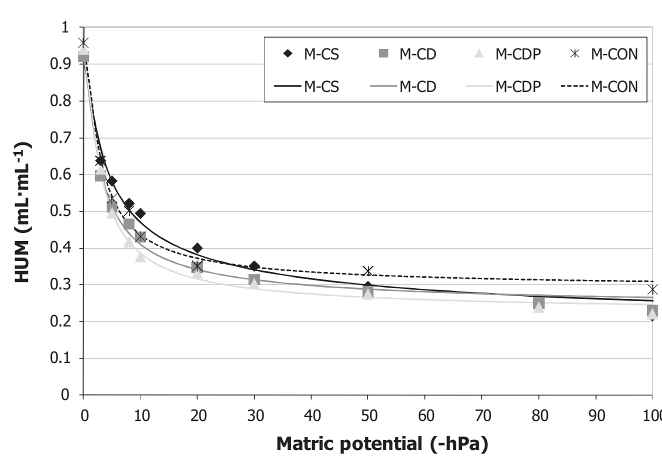


**Fig. 1.** Water retention curves of the four substrates used in the experiment (Cáceres, 2003).

**Table 2**
Nutrient content of mixtures used to grow oleander plants. Three replicates were used for each parameter.

| Mixture | pH | EC (dS m$^{-1}$) | $NO_3^-$ (mg L$^{-1}$) | $NH_4^+$ (mg L$^{-1}$) | $K^+$ (mg L$^{-1}$) | P (mg L$^{-1}$) | $Ca^{2+}$ (mg L$^{-1}$) | $Mg^{2+}$ (mg L$^{-1}$) | $Na^+$ (mg L$^{-1}$) | $SO_4^{2-}$ (mg L$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| M-CS | 5.84 c | 3.58 a | 1157 a | 6.54 a | 815 a | 83 a | 415 a | 150 a | 713 a | 294 a |
| M-CD | 6.82 b | 2.30 b | 499 b | 5.91 a | 626 b | 28 b | 141 b | 59 b | 617 b | 203 b |
| M-CDP | 7.40 a | 1.04 c | 72 c | 2.81 b | 234 c | 16 c | 48 c | 11 c | 289 c | 93 c |
| M-CON | 5.86 c | 0.13 d | 7.7 d | 6.71 a | 13.2 d | 4.0 d | 14.5 d | 1.6 c | 28.6 d | 15.4 d |
| *p* | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

Parameters measured using the water extract method (1:1.5, vol/vol).
Any two means within a column not followed by the same letter are significantly different according to Tukey's test at $p < 0.05$ probability level.

properties of the four substrates (Fig. 1); starting at −2 kPa, water-retention curves begin to be asymptotic and thresholds below this matric potential may indicate an undesirable risk factor in irrigation management (Fig. 1). For irrigation, a dripper with a nominal flow of 2 L h$^{-1}$ was used for each plant. The crop was watered with a nutrient solution by means of continuous fertigation (Table 2) formulated and supplied by an automatic irrigation system with microcontroller (Multi Computer Unit, MCU; FEMCO, Damazan, France). The leaching rate was set at 20–30%.

### 2.3. Sampling

At the beginning of the growing period, substrate samples were taken (three replicates) from the four mixtures used (Section 2.1) and a water extract was taken from each one at a ratio of 1:1.5 (v:v) (EX). Physicochemical and chemical analyses were done on the water extracts following the methodology described in Section 2.4.

On a regular basis during the growing period, samples were taken from the nutrient solution (NS) applied, which was the same for all four treatments/substrates (Table 3).

The leachates produced by each treatment (M-CS, M-CD, M-CDP and M-CON) were gathered daily using a drainage lysimeter designed for collecting the leachates from container plants (Fare et al., 1994; Cáceres, 2003). Therefore, the leachate solution from each sample corresponding to one treatment was made up of a mixture of the leachates from the four containers (Guérin and Charpentier, 1997) and a total of 16 samples per treatment were analyzed during the crop period.

The fertility of the root zone was monitored using the IP method. Each time the NS and leachate samples were taken, IP samples were also taken. The IP method involved pouring 100 mL of NS into the substrate just above the dripper for 2 min and then collecting the percolates generated (Lemaire et al., 1995). This procedure was done in three containers (chosen at random from plants not previously sampled). Therefore, three IP samples of 50–80 mL were taken for each treatment. Some authors have indicated that, for the induced percolate to be collected properly, the moisture content of the substrate must be close to container capacity (Wright, 1986). However, samples were taken at any time in this experiment because the matric potential threshold established ensured a sufficient level of water content for plant growth. Because of this irrigation management, how recently the treatment irrigation had been applied was therefore not taken into account.

The experiment lasted five and a half months and a total of 16 sampling days was scheduled. The liquid samples (NS, LE and IP) were collected weekly in the first three months of the growing period when the speed of crop growth was the highest. At the end of the growing period, samples were taken once every two weeks (for 1 and a half months). A final set of samples was taken at the end of the experiment.

### 2.4. Physicochemical and chemical composition

The EX, LE and IP samples were filtered before analysis was carried out (Charpentier and Guérin, 1996). The pH and EC were determined using a selective ion analyzer (Thermo Scientific Orion model Dual Star selective ion) and Crison conductivity meter (model GLP31), respectively. The samples were frozen until laboratory analysis of the ion content was carried out (Yeager et al., 1983; Wright, 1986; Guérin and Charpentier, 1997). The concentration of anions $NO_3^-$, $SO_4^{2-}$, P and $Cl^-$ was measured with a Metrohm ion chromatography system (model 761 Compact IC Metrohm AG, Herisau, Switzerland). The concentration of cations ($K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$) was measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES, model Vista 730 ES, Varian Australia Pty. Ltd. Scientific Instruments, Victoria, Australia).

### 2.5. Data analysis

#### 2.5.1. Comparison of methods for determining fertility

Because three methods were compared, it was necessary to do the regression analysis in pairs (Scoggins et al., 2002). Therefore, what follows is a description of the methodology used to compare the water extract method and the induced percolate method. Then we provide a description of the methodology used to compare the leachate method to the induced percolate method.

The comparisons of the methods for determining root-zone fertility were done with all the substrates used in the plant experiments, including the control mixture (peat-perlite); one of the requirements for implementing a new method is that it be useful for a wide range of materials (Bunt, 1986). The parameters compared were pH, EC, and the concentration of macronutrients and $Na^+$ and $Cl^-$.

*2.5.1.1. The water extract method and induced percolate method.* The fertility-related parameters measured on the water extracts from the initial mixtures (Table 1) were compared to the parameters measured on the IP samples taken at the beginning of the growing period. The results of the concentration of nutrients in the water extract were calculated bearing in mind the volumetric ratio used to obtain the extract and the moisture of the sample (Charpentier and Guérin, 1996). Each EX or IP concentration value was obtained by taking the mean of the three values corresponding to three water extracts or induced percolates from the substrates of the corresponding sample.

**Table 3**
Nutrient solution (NS) composition.

| | pH | CE (dS m$^{-1}$) | $NO_3^-$ | $H_2PO_4^-$ | $SO_4^{2-}$ | $K^+$ (mequiv. L$^{-1}$) | $Ca^{2+}$ | $Mg^{2+}$ | $NH_4^+$ |
|---|---|---|---|---|---|---|---|---|---|
| NS | 5.80 | 2.3 | 6.80 | 0.60 | 7.57 | 5.40 | 9.86 | 2.04 | 0.00 |

**Table 4**
Parameters of the fitted lines corresponding to linear regressions between water extracts (EX, *x* axis) and induced percolates (IP, *y* axis).

| Parameter | Fitted line | *R* coefficient | Significance |
|---|---|---|---|
| pH | $y = 1.072x - 0.5889$ | 0.7902 | ns |
| CE | $y = 3.2779x - 0.3148$ | 0.9713 | ** |
| $NO_3^-$ | $y = 3.5031x - 2.269$ | 0.9790 | ** |
| $K^+$ | $y = 1.757x + 1.4627$ | 0.9656 | ** |
| $H_2PO_4^-$ | $y = 0.9079x + 0.1645$ | 0.9553 | ** |
| $Ca^{2+}$ | $y = 2.2558x - 2.3274$ | 0.9851 | *** |
| $Mg^{2+}$ | $y = 1.9002x - 0.6357$ | 0.9700 | ** |
| $SO_4^{2-}$ | $y = 2.9264x + 2.2267$ | 0.9746 | ** |
| $Na^+$ | $y = 0.7121x + 2.4182$ | 0.9229 | * |

ns, *, **, ***, ****: not significant or significant at $p \leq 0.10$, 0.05, 0.02 or 0.01, respectively.
Linear regressions are based on 4 pairs of values.

The values of the different fertility-related parameters of the substrate corresponding to the water extract and induced percolate samples from the four substrates (pH, EC, $NO_3^-$, $H_2PO_4^-$, $SO_4^{2-}$, $K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$) were correlated by means of regression analysis using SAS v.9.1 (SAS Institute, Cary, NC, USA).

*2.5.1.2. The leachate method and induced percolate method.* The values of the parameters of the samples obtained using the LE and IP methods were compared with data pairs of all the substrates used during the 5.5-month oleander growing period, resulting in a total of 60 data pairs.

The values of the different fertility-related parameters of the substrate corresponding to the leachate and induced percolate samples from the four substrates (pH, EC, $NO_3^-$, $H_2PO_4^-$, $SO_4^{2-}$, $K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$) were correlated by means of regression analysis using SAS v.9.1 (SAS Institute, Cary, NC, USA).

#### *2.5.2. Monitoring fertility in compost-based and peat-based growing media*

Given the advantages of the IP method, it was used to describe the evolution of the fertility of the substrates during the 5.5-month growing period. The parameters pH, EC, $NO_3^-$, $H_2PO_4^-$, $SO_4^{2-}$, $Cl^-$, $K^+$, $Na^+$, $Ca^{2+}$ and $Mg^{2+}$ determined on the induced percolates from the four substrates (M-CS, M-CD, M-CDP and M-CON) were charted as a graph, along with the parameters corresponding to the NS.

## 3. Results

### *3.1. Comparison of methods*

#### *3.1.1. Comparison of the composition of water extracts and induced percolates*

The results showed that, except for the pH parameter, the correlation coefficients (*R*) resulting from the regression analysis between the two diagnostic methods were statistically significant (Table 4). The correlation coefficient for pH (0.7902) was not excessively low and was not statistically significant (Table 4). Other authors have indicated that the correlation coefficient for pH between two diagnostic methods is not often statistically significant, as in the case when the IP method is compared to the suction-cup method and the saturated extract method (Cabrera, 1998).

The water extract was obtained by adding water in a proportion of 1/1.5 (vol/vol, substrate/distilled water), whereas the IP samples were obtained by displacement due to the piston effect of the root-zone solution through the slow addition of NS. Because of this, the slopes of the regression lines for most of the ions measured were greater than one (Table 4). Therefore, EX method produces considerable dilution of the root-zone solution (Scoggins et al., 2002). This is not true of the IP method, because the NS is used as the displacing solution instead of distilled water.

#### *3.1.2. Comparison of the composition of leachates and induced percolates*

The regression analysis showed a highly significant correlation ($p \leq 0.01$) between the composition of the leachates and the composition of the induced percolates for the different parameters analyzed (Figs. 2 and 3). The values corresponded to the four substrates used in the experiment during the entire growing period.

In the comparison of the LE and IP methods, unlike what happened when the EX and IP methods were compared, the slopes of the regression lines were closer to 1 (between 0.7 and 1.3) and the line tended to pass close to the origin in most cases (CE, $NO_3^-$, $H_2PO_4^-$, $Mg^{2+}$, $Na^+$ and $Cl^-$), except for $SO_4^{2-}$ and pH (Figs. 2 and 3). This indicates that a specific ion concentration value in the IP solution was similar to its analog in the leachate solution. This is explained by the similarity of the procedure for obtaining each solution in the two methods. Therefore, with the aim of obtaining a water extract to determine the ion composition of the root zone, the "dilution" effect differed greatly from the "leaching" effect (Guérin and Charpentier, 1997).

### *3.2. Monitoring fertility in compost-based and peat-based growing media*

At the beginning of the growing period, the IP from the compost-based substrates showed a very high nutrient concentration compared to the peat-perlite mixture (Figs. 4 and 5). This high nutrient content was attributed to the initial composition of the substrates because the manure-based compost used in the mixtures had high concentrations of fertilizer ions (Table 2); the higher proportion of compost, the higher the ion concentration of the different ions analyzed (in order: M-CS > M-CD > M-CDP).

In practically all the ions analyzed, the nutrient concentration was high during the first 50 days of the growing period, especially in the M-CS mixture (Figs. 4 and 5a and b). After that, the concentration went down, obviously due to plant uptake and leaching. At the end of the growing period, the concentration of nutrients in the induced percolates converged to the levels of the composition of the nutrient solution applied. On the other hand, the control substrate (M-CON) generally showed lower concentrations at the beginning of the growing period; some were even lower than those of the NS, due to the initial concentration of this substrate (Table 2). The ion concentration of the substrate solution of this treatment (M-CON) converged with the NS, but in the opposite direction, i.e., it went from a lower to a higher concentration.

The dynamics of nitrates and phosphates during the growing period warrant additional discussion. Starting on day 40 after planting until day 50, the concentration of nitrates began to increase in the M-CS substrate (Fig. 4a). This increase was probably due to the nitrification this material may have experienced at moderately high temperatures (September–October), which favor this microbial activity (Niemiera and Wright, 1987). It has been suggested that sludge-based-compost substrates can experience nitrification (Bugbee and Frink, 1989). The concentration of P suddenly increased during the growing period. In this case, it was attributed to a malfunction in the NS microcontroller equipment (Fig. 4b). As a result, the concentration of P in the solution of all the substrates increased. Once the concentration of P returned to experimentally anticipated levels, the composition of the IP of all the substrates remained below the concentration of P in the NS for approximately 75 days. This indicates the effect of the accumulation of the excess phosphorus supplied in the substrate. By the end of the growing period, the concentration of P in the root zone had evened out in

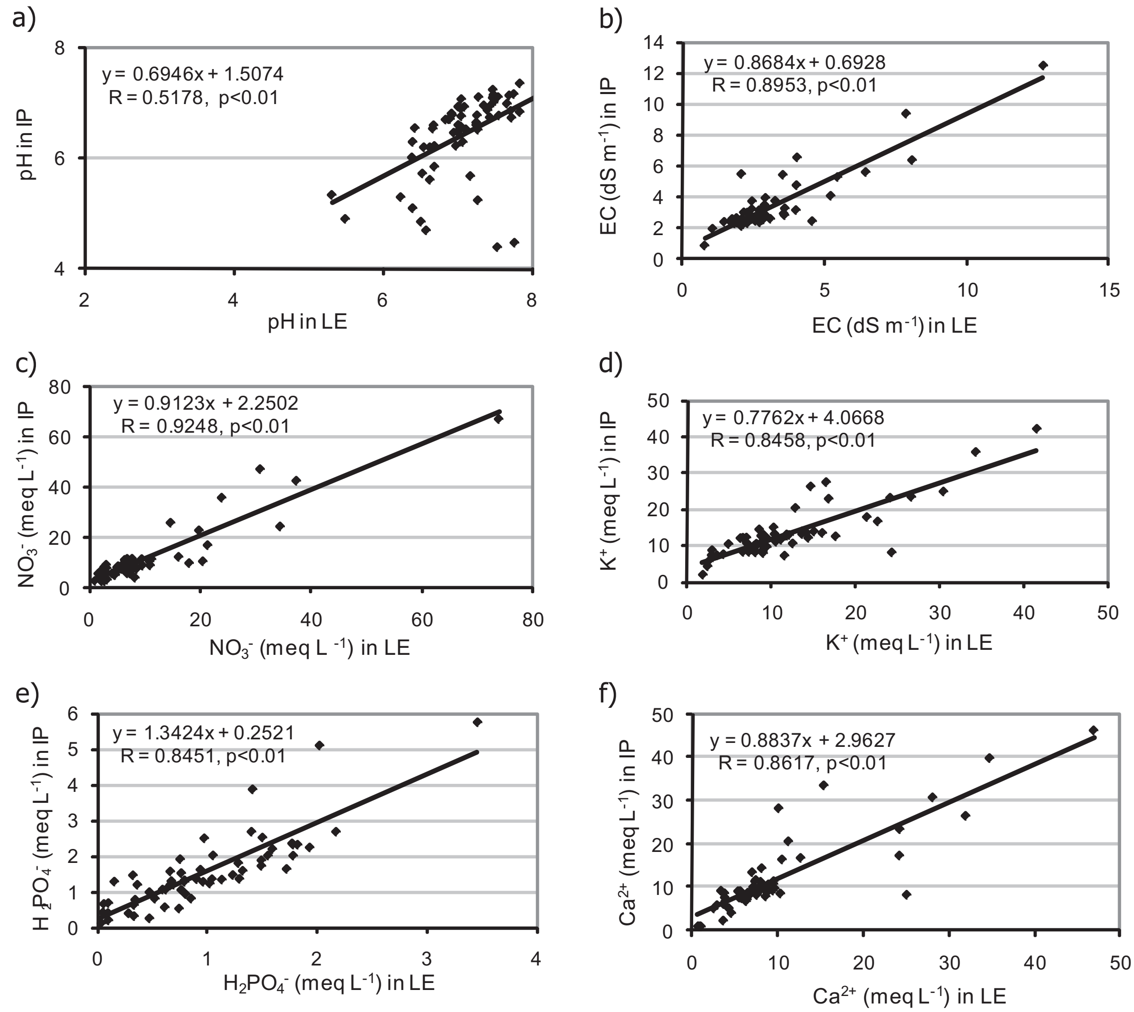


**Fig. 2.** Scatter plot, trendline and parameters of fitted regression lines of LE versus IP; data set from compost-based and peat-based growing media used for growing oleander plants for 5.5 months: pH (a), CE (b), $NO_3^-$ (c), $K^+$ (d), $H_2PO_4^-$ (e), $Ca^{2+}$ (f). Linear regressions are based on 60 pairs of values.

all the substrates and was very similar to the concentration of P in the NS (Lemaire et al., 1995).

The substrate with the highest proportion of compost (M-CS) had a pH that was closer to the pH of the control substrate than to the other two (M-CD and M-CDP) (Fig. 5c), as was the case with the initial pH of the substrates (Table 2). In the beginning, the control substrate had a lower pH, which increased as a result of irrigation with the NS, whose pH was higher; however, it increased slowly due to the considerable pH buffering capacity of peat (Lemaire et al., 1995; Raviv et al., 1985).

The evolution of the EC of the induced percolates (Fig. 5d) showed the higher concentration of nutrients in the M-CS substrate compared to the others and the same nutrient behavior described above. The EC of the M-CS substrate was much higher than 3 $dS\,m^{-1}$ during most of the growing period; it could have been reduced by leaching before or during the growing period (Raviv et al., 1985). However, the oleander plants growing in this substrate were not affected by salinity (data not shown). The oleander plant is moderately tolerant of salinity (Westcot and Ayers, 1990). However, the results of the evolution of EC showed that there was no accumulation of salts during the growing period (Ku and Hershey, 1992).

## 4. Discussion

### 4.1. Comparison of methods

#### 4.1.1. Comparison of the composition of water extracts and induced percolates

For the set of substrates studied, the IP method was comparable to the EX method at the beginning of the growing period, even though the water extracts were obtained in different ways in these two methods: extraction using distilled water from a substrate sample (EX method) and displacement through the piston effect (IP method) (Guérin and Charpentier, 1997). The effect of nutrient dilution has been described in extracts taken from saturated media when compared to the IP method (Cabrera, 1998; Yeager et al., 1983; Cavins et al., 2004). In an experiment with *Thuja plicata* grown in a mixture of peat and perlite, it was shown that the EC and nitrates were lower in the water extracts than in the induced percolates (Lemaire et al., 1995). In that experiment, the behavior pattern of P was different, given that the concentrations of P in the induced percolates and water extracts were similar to the concentrations of P in the nutrient solution (Lemaire et al., 1995); these results also agreed with those obtained in our study, given

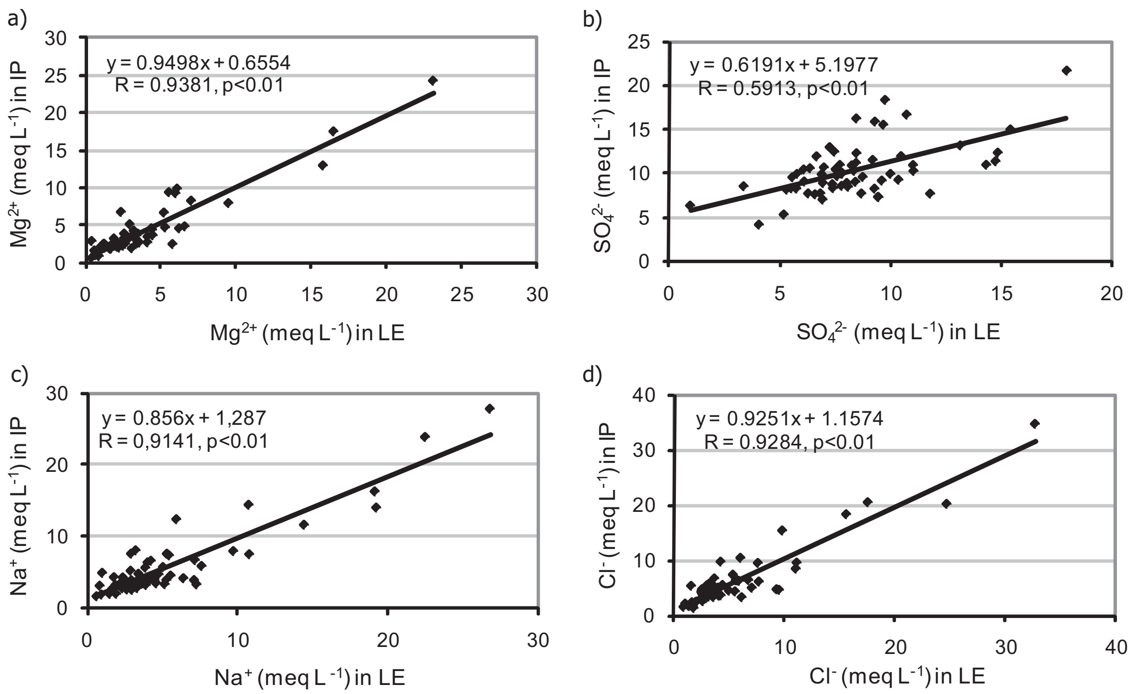


**Fig. 3.** Scatter plot, trendline and parameters of fitted regression lines of LE versus IP; data set from compost-based and peat-based growing media used for growing oleander plants for 5.5 months: $Mg^{2+}$ (a), $SO_4^{2-}$ (b), $Na^+$ (c), $Cl^-$ (d). Linear regressions are based on 60 pairs of values.

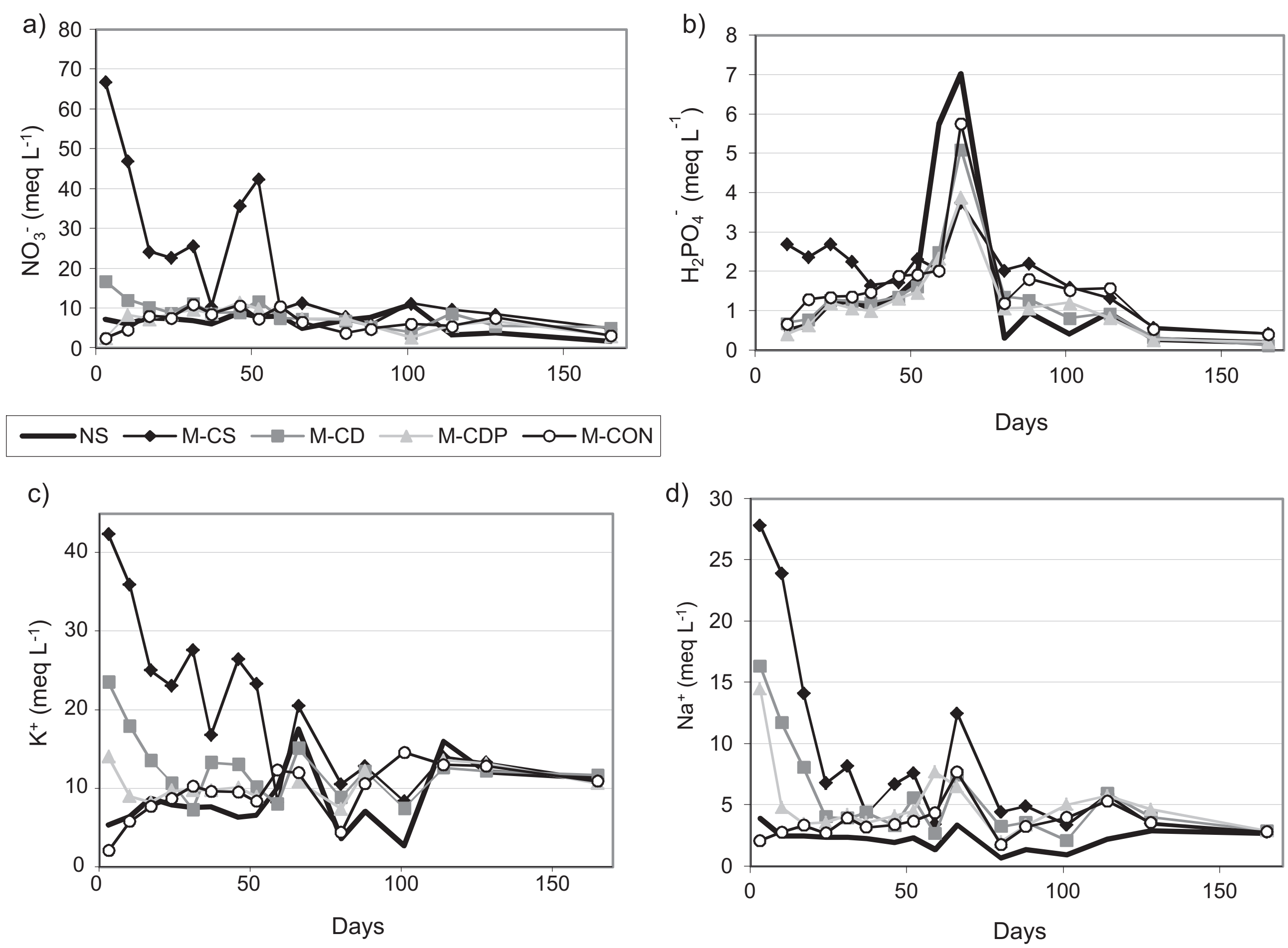


**Fig. 4.** Evolution of the nutrient solution (NS) and induced percolates in substrates (M-CS, M-CD, M-CDP and M-CON) in terms of the composition of: (a) $NO_3^-$, (b) $H_2PO_4^-$, (c) $K^+$, (d) $Na^+$.

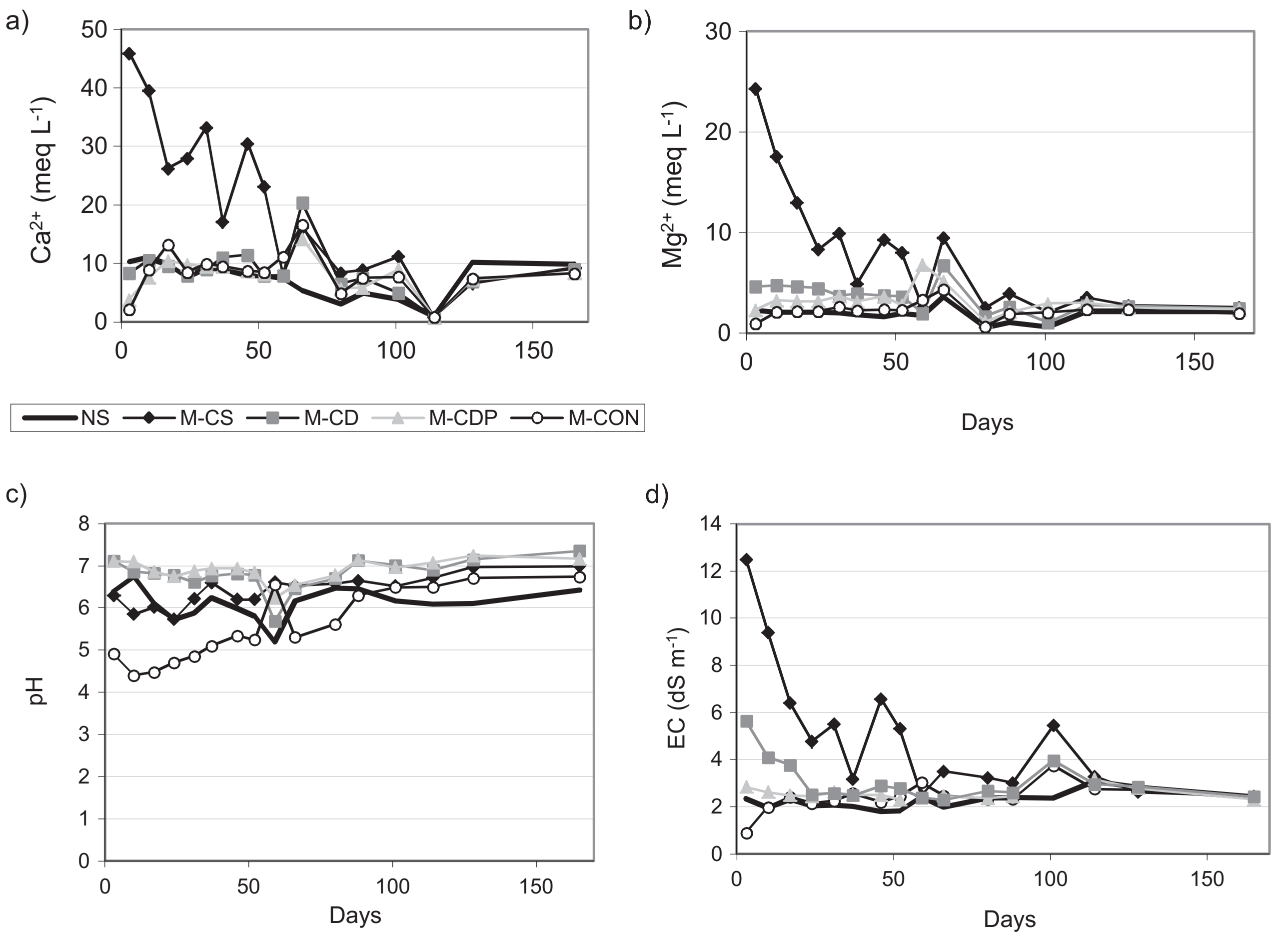


**Fig. 5.** Evolution of the nutrient solution (NS) and induced percolates in substrate (M-CS, M-CD, M-CDP and M-CON) in terms of the composition of $Ca^{2+}$(a) and $Mg^{2+}$ (b), and parameters pH (c) and EC (d).

that the slope of the correlation line obtained was close to 1 and the independent variable was close to zero (Table 4, $H_2PO_4^-$).

*4.1.2. Comparison of the composition of leachates and induced percolates*

The IP method is a highly effective way of gaining insight into the nutrient status at the root zone of the substrate, as is confirmed by the correlation between the values from the EX method and LE method compared to the IP method. In a study of a crop of *Prunus laurocerasus* with a substrate consisting of a mixture of peat and perlite, other authors described the correlation between the LE and IP methods but without indicating the statistical significance of the correlation (Charpentier and Guérin, 1996; Guérin and Charpentier, 1997).

Unlike what happened in our comparison of the EX and IP methods, in the comparison of the LE and IP methods, the diluent was the same (NS) and the dilution proportion was probably not excessively different. The leachates were gathered carefully on daily basis under controlled conditions, which probably played a part in favoring the correlation arising from this comparison.

Through the IP method, a water sample with a low dilution is obtained from the substrate solution, as mentioned by other authors (Scoggins et al., 2001).

*4.2. Monitoring fertility in compost-based and peat-based growing media*

The physicochemical parameters (pH and EC) and fertility parameters of the substrate were different for the different mixtures and evolved differently during the growing period (Figs. 4 and 5). Therefore, the values of the parameters measured in the induced percolates were different from the values of the different parameters of the NS applied (Guérin et al., 1995; Lemaire et al., 1995). Other authors have described how ion concentration values converged toward the corresponding values of the NS when it was applied during the entire growing period (Guérin and Charpentier, 1997).

The information obtained from monitoring $Na^+$ is relevant, even though it is not an essential nutrient for plants. It should be monitored because of its toxicity at high concentrations (Scoggins et al., 2002). The concentration of $Na^+$ in the induced percolates was always higher than the concentration in the NS. The $Na^+$ ion is present in high concentrations in cattle manure compost, such as the solid fraction of pig manure slurry compost (Michiels et al., 1980). However, $Na^+$ is easily leached out during the first irrigation periods if a leaching fraction is applied. This has been described for coir fiber, a widely accepted alternative substrate that can contain an initially high concentration of $Na^+$ if it is not leached out before the fiber is used (Meerow, 1994).

The results show that the IP method reflects the different ion composition, the pH and EC of the growing media solution in the most active area of the root zone in the different substrates studied. The IP method is therefore a useful, nondestructive field method for quickly checking the nutrient content in the root zone (Wang, 1998). Some authors use the IP method to detect relatively small variations in the composition of the root zone. When a mixture of turkey manure compost and tree bark was used as the substrate to grow two different kinds of bushes, a higher concentration of P was observed in the compost-based substrates than in the control substrate when the IP method was used (Kraus and Warren, 2000). This shows that organic materials can play a major role by maintaining stable P concentrations in the substrates used to grow potted plants (Williams and Nelson, 1992; Kraus and Warren, 2000). In the same experiment (Kraus and Warren, 2000), differences were detected in the induced percolates from the substrates when the substrates received different doses of N.

We have shown that monitoring the nutrient status of compost-based substrates is necessary, given that the composition may be high in ions or may change quickly during the growing period (Bugbee and Frink, 1989; Williams and Nelson, 1992). Because the nutrient content of compost-based substrates is high at the beginning of the growing period, it is advisable for the NS applied in this period to have a low ion concentration (Williams and Nelson, 1992).

## 5. Conclusions

Comparison of methods to determine root-zone fertility

- For most of the parameters, there was a significant correlation between the water extract method and the induced percolate method at the beginning of the growing season. Moreover, the nutrient concentrations in the water extracts were always lower than those in the induced percolates.
- For all the parameters monitored, there was a significant correlation between the leachate and induced percolate methods during the entire *Nerium oleander* growing period and the ion concentration values were similar.

Monitoring in compost-based growing media during pot cultivation

- The concentrations of nutrients in the induced percolates reflected the inherent differences in the fertility of the different substrates used. During the growing period, there was a gradual convergence in terms of ion content, pH and electrical conductivity between the induced percolates and the nutrient solution applied.
- Because it is simple, fast and does not require a solid substrate sample, the induced percolate method is useful for monitoring the nutrient composition of the root zone of substrates during the growing period in manure-based compost substrates with high concentrations of nutrient ions. The method provides reliable, useful and quick information for monitoring the ion composition of the substrate solution during the growing period.

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