**Determination and Assessment of Procedures of the Pour-through Nutrient Extraction Procedure for Bedding Flats and Plug Trays**

by

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(ABSTRACT)

A study was conducted to develop, demonstrate and assess the Pour-through nutrient extraction procedure for bedding flats and plug trays. The Pour-through technique involves pouring a prescribed volume of water on a recently irrigated medium, then collecting and analyzing the leachate to predict nutrient availability in the medium. The volume of water necessary to collect a Pour-through from a 1204 bedding flat was determined to be 5 ml per cell based on leachate pH and electrical conductivity (EC) at various volumes of water applied. *Impatiens wallerana* 'Super Elfin Red' and *Tagetes erecta* 'Apollo' were grown in 1204 bedding flats at three fertilizer concentrations to assess the overall potential of the Pour-through procedure. Analysis of leachate EC, pH, and macro- and micro-nutrients indicated that the Pour-through method of nutrient extraction was sensitive and effective in extracting available nutrients. Leachate analysis was positively correlated to fertilizer nitrogen concentration, shoot tissue dry weight, and nutrient concentrations of conventional Saturated Media Extract methods. Preliminary studies indicated that evenly applying

200 ml of water per plug tray cells produced adequate leachate (50 ml) for laboratory analysis of EC, pH, and macro- and micro-nutrients. *Impatiens wallerana* 'Super Elfin Red' and *Tagetes erecta* 'Apollo' were grown in plug trays at three fertilizer concentrations to assess the overall potential of the Pour-through procedure. Analysis of leachate EC, pH, and macro- and micro-nutrients indicated that the Pour-through method of nutrient extraction was sensitive and effective in extracting available nutrients. Pour-through leachate analysis was positively correlated to fertilizer nitrogen concentration and to whole shoot tissue.

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# CHAPTER ONE: LITERATURE REVIEW

There has always been great interest in monitoring available nutrients in both soil and soilless media (Bunt, 1988). Plant growth and development are based not only on nutrients that are present in the soil or medium, but more importantly, those nutrients which are available for absorption (Mengel and Kirkby, 1987). To optimize crop yield, it is important that nutrients are available in both adequate amounts and suitable proportions. Application of commercial fertilizers helps ensure that plants will receive all necessary macro- and micro-nutrients, and that crop quality and yield are maximized (Carlson et al., 1992; Mengel and Kirkby, 1987; Nelson, 1985).

Greenhouse and container nursery industries rely heavily on commercial fertilizer application due to the use of soilless media (Ball, 1992a; Nelson, 1991). Constant fertilization has necessitated the monitoring of macro- and micro-nutrients, pH and soluble salts on a regular basis (Carlson et al., 1992; Markus and Steckel, 1980; Nelson, 1985; Poole and Chase, 1990; Wright, 1984; Wright, 1986). Electrical conductivity (EC) indicates the relative concentration of soluble salts present in the growing medium, and is indicative of medium fertility. Electrical conductivity is positively correlated to fertilizer application concentration, with EC values increasing with increased fertilizer N concentration (Peterson, 1989). Levels of macro- and

micro-nutrients are carefully evaluated to avoid nutrient deficiencies, toxicities, and imbalances.

Typically, available nutrients are analyzed by means of soil or medium sampling. The most common method used is the Saturated Medium Extract (SME)(Warncke, 1986), also referred to as the Saturated Paste Extract (Holcomb et al., 1982) and Saturated Soil Extract (Wright, 1986) methods. The SME method was developed at Michigan State University (Warncke, 1986) and was based on the Intensity-Balance method of soil testing for nutrient availability (Holcomb and White, 1980). This involved air drying a known volume of medium, saturating the medium with a known volume of distilled water, and vacuum separating the liquid from the solid. The liquid was then analyzed for macro- and micro-nutrients, pH and EC.

The SME was an effective and accurate method when used on crops receiving soluble fertilization (Bunt, 1988). However, SME required the physical handling of media which may have resulted in disruption of controlled-release fertilizer prills (Warncke, 1986). Prill disruption may result in erroneously high extract nutrient levels (Holcomb et al., 1982).

Other methods of soil or medium testing are numerous, but less frequently employed. The Intensity-Balance method involved air drying 250 g of soil or medium, adding distilled water in small increments until the sample was saturated, and allowing for an equilibration time of four hours before filtration (Warncke, 1986). In the procedure described by Peterson (1989), several core samples were

mixed and allowed to dry naturally. Distilled water was then added so that the volume of water was twice that of the medium, and an equilibration time of approximately 12 hours was used. Differential equilibration times, that is, the time the supersaturated sample is allowed to remain undisturbed prior to filtration, may have resulted in differential nutrient levels (Wright,1984). Nutrient levels increased with increased equilibration time (Wright, 1984).

The displacement method involved packing soil or medium into a column and adding distilled water to the point of medium surface glistening or saturation. This method produced a solution that was almost identical to the soil solution, but it lacked consistency in regard to the amount of soil that was packed (Holcomb et al., 1982). To overcome medium volume inconsistencies, methods such as soil:water, by weight (Poole and Chase, 1989;); soil:water, by volume (Poole and Chase, 1989); Saturated Paste or SME (Markus and Steckel, 1980; Peterson, 1989; Warncke, 1986; Yeager et al., 1983); 1:2 (Sonneveld and Van den Ende, 1971); 2+1 (Sonneveld and Van den Ende, 1971; Van den Ende, 1969); and 1:5 (Sonneveld and Van den Ende, 1971) were developed.

Soil:water, by weight and by volume differed only in that the former used soil or medium mass, and the latter volume in determining the appropriate ratio of soil and water. The 1:2 and 2+1 methods were similar to each other in that each used one part water and two parts soil by volume. These methods were more accurate than the 1:5 by weight method, especially when sampling soil or medium that

contained large amounts of gypsum; more gypsum and limestone dissolved in the 1:5 than the 1:2, which resulted in artificially high readings of phosphorus, calcium and magnesium (Warncke, 1986). When using soilless media, Poole and Chase (1989) recommended that a method based on volume be used when testing for available nutrients, due to differences in media bulk densities.

In the early 1980's, Holcomb et al. (1982) devised a method of estimating available nutrients that did not involve the removal of soil or medium from the container. Rather, a vacuum was used to remove the liquid soil solution from container grown crops. This technique could also be more reliably used for media to which encapsulated fertilizer had been applied, as no prill disruption occurred. Holcomb et al. (1982) found this technique acceptable, though nutrient levels were significantly different than that of the Saturated Paste method; for example, levels of potassium and nitrate, and EC were higher in Saturated Paste Extract than in vacuum separated extract.

In 1983, Yeager et al. (1983) developed a technique known as the Pour-through method of nutrient extraction. This method was similar to that of Holcomb et al. (1982) in that there was no physical handling of the medium. The Pour-through method involved saturating the medium in a container, and allowing for an extraction time of approximately 4 hours. Enough water was applied to the surface of the medium so that at least 50 ml of leachate collected in a tray. The leachate could be analyzed for medium solution nutrient levels, pH and EC (Wright, 1986;

Wright, 1984).

It is crucial that the soil or medium be saturated when Pour-through samples are collected, or else the analysis will be adversely affected; reducing the moisture content of the media will result in lower levels of extractable nutrients (Wright, 1984). The volume of water applied to the surface of a medium that was at container capacity was not as important as medium saturation, though it was not recommended that so much be applied that the leachate be diluted (Wright, 1986; Wright, 1984). Approximately 50 ml applied water per 15 cm (diameter) pot, or 100 ml per 1 liter container would be appropriate (Wright, 1984). Dilution of the sample may have resulted in artificially lower concentrations of soil solution nutrients.

Poole and Chase (1990; 1989; 1987) and Conover et al. (1992) used the Pour-through method to monitor foliage plant leachate EC and pH, and found the method easy to use, rapid and effective. Yeager et al. (1983) also found the Pour-through method to be accurate and effective when monitoring EC, pH, and available nutrient concentrations in a pine bark medium.

The Pour-through method of nutrient extraction had several advantages compared to SME. Electrical conductivity and pH determination could be made immediately on site, allowing growers to immediately correct existing or potential problems, rather than wait 3-9 days for commercial SME analysis, or 12 hours for on site SME analysis (Wright et al., 1990). Leachate EC and pH values were found to be indicative of media fertility, and to generally increased with increased fertilizer

nitrogen concentration (Poole and Chase, 1989). Since there was no physical handling of the soil or medium, there was no disruption of encapsulated or controlled-release fertilizers (Wright, 1986; Wright, 1984; Wright et al., 1990; Yeager et al., 1983). The Pour-through method was rapid, requiring approximately three minutes for leachate collection, and no specialized equipment was needed (Wright, 1984). Further, leachate EC and pH could be evaluated on site with portable meters. With currently available portable individual ion meters, nutrient levels could also be assessed on site.

However, there were some disadvantages associated with the Pour-through method. There were no recommended Pour-through leachate ranges of ions established for specific greenhouse crops, though recommended ranges were available for SME samples (Wright et al., 1990). Macro- and micro-nutrients values were higher in Pour-through samples than in SME from the same container, so that recommended values established using the SME could not be applied to Pour-through samples (Phillips and Bilderback, 1989; Wright et al., 1990).

Economically, the Pour-through method was advantageous. Since the media was not physically handled, no crop losses were experienced, and the plant materials could be sold intact (Wright et al., 1990). No specialized equipment was necessary to collect a Pour-through, and leachate could be analyzed for EC and pH by means of a portable conductivity and pH meter, respectively. Pour-through leachate samples could also be sent to commercial laboratories for complete analysis which required

one to two days less than an SME sample because no sample preparation was required (Wright, 1986).

Growers of bedding flats and plug trays were recommended to use SME to determine media nutrient availability (Ball, 1992b; Koranski and Laffe, 1985; Kuack, 1991). SME required that the bedding flat or plug tray media be removed, which resulted in crop disruption and destruction. During later stages of crop development, SME was no longer feasible, due to large plant root mass in comparison to media volume. The Pour-through method could benefit growers of bedding flats and plug trays by providing them with a non-destructive, yet sensitive method of assessing available nutrients.

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# CHAPTER TWO: DETERMINATION OF PROCEDURES AND SENSITIVITY OF THE POUR-THROUGH NUTRIENT EXTRACTION PROCEDURE FOR BEDDING FLATS AND PLUG TRAYS

## ABSTRACT

A study was conducted to develop and demonstrate a practical and sensitive method of applying the Pour-through nutrient extraction procedure to bedding flats and plug trays. The Pour-through technique involves pouring a known volume of water on recently irrigated medium, then collecting and analyzing the leachate for EC, pH and nutrient concentrations. The volume of applied water necessary to collect sufficient Pour-through leachate from a 1204 bedding flat or plug tray was determined based on leachate pH and EC at various volumes of applied water; 5 ml per cell per 1204 pack was an appropriate application volume. Bedding flat Pour-through leachate EC decreased linearly with increasing volume of applied water, indicating leachate dilution above 5 ml. pH was not affected by the volume of

applied water. To examine the sensitivity of the Pour-through method on bedding flats, media amended with nine combinations of lime concentrations and soluble fertilizer application concentrations were subjected to Pour-through leachate analysis. There were significant differences in 1204 bedding flat Pour-through leachate pH as affected by lime, and significant differences in 1204 bedding flat Pour-through leachate EC as affected by fertilizer concentration, indicating that the Pour-through method was sensitive in determining soil solution pH and EC. Preliminary studies indicated that evenly applying 200 ml of water per plug tray produced sufficient Pour-through leachate (approximately 50 ml). To assess the sensitivity of the Pour-through method on plug trays, three concentrations of calcium hydroxide were combined with three concentrations of potassium chloride, and incorporated into the medium. Plug tray Pour-through leachate pH and EC, respectively, increased linearly with the corresponding increase in lime concentration. Results indicate that the Pour-through method of nutrient extraction can be used on bedding flats and plug trays to extract available nutrients from the soil solution.

## INTRODUCTION

To optimize plant growth, nutrients must be available in adequate amounts and suitable proportions (Mengel and Kirkby, 1987). The critical nutrient level of bedding flat and plug tray medium must be obtained and maintained, and is generally accomplished by commercial fertilizer application (Carlson et al., 1992; Nelson, 1985). Regular analysis of the growing medium is recommended to indicate relative concentrations of soluble salts and nutrient concentrations to avoid toxicities, deficiencies, and imbalances (Ball, 1992b; Carlson et al., 1992; Wright et al., 1990).

Typically, the Saturated Media Extract (SME) method is used by growers of bedding flats and plug trays to assess the availability of nutrients (Koranski and Laffe, 1985; Kuack, 1991). This process involves the removal of a given amount of medium from the tray or flat cells, saturating the medium with a prescribed amount of distilled water for a specific equilibration time, and finally, separating the liquid from the medium using a vacuum (Bunt, 1988; Sonneveld and Van den Ende, 1971; Van den Ende, 1969; Wright, 1986; Wright, 1984; Wright et al., 1990). The solution is analyzed for individual nutrient concentrations, pH and EC. However, SME requires the removal of container medium, resulting in crop destruction. During later stages of bedding flat crop development, SME may no longer be feasible, due to large plant root mass relative to medium volume.

During the early 1980's Wright (1984) developed a method of extracting

available nutrient levels from soilless media. This technique, known as the Pour-through Nutrient Extraction Procedure, involves pouring a known volume of water on a recently irrigated medium, and collecting the leachate which is then analyzed (Wright, 1984; Wright et al., 1990). The growing medium of the crop is not handled during the Pour-through process, so that plant roots are not disturbed, and thus no crop losses are experienced (Poole and Chase 1989; Wright, 1984; Wright, 1986; Wright et al., 1990; Yeager et al., 1983). Partial Pour-through leachate analysis can be run on site, saving valuable time using portable EC and pH meters (Wright et al., 1990).

Though the Pour-through method has been implemented by some container nursery and greenhouse growers, few bedding flat or plug tray producers have implemented the procedure. The primary reason for this disparity is lack of information and recommended ranges of nutrient concentrations based on Pour-through sampling (Wright et al., 1990). The objective of this experiment was to develop and demonstrate a practical, sensitive and effective method of applying the pour-through method of nutrient extraction to bedding flats and plug trays by: (1) Determining the volume of water that must be applied to each cell of a 1204 bedding flat to collect sufficient Pour-through leachate without dilution of the substrate solution; (2) Assessing the sensitivity of the Pour-through nutrient extraction procedure using the determined application volume; (3) Determining the volume of water that must be applied to a plug tray to collect sufficient Pour-through leachate

without dilution the soil solution; (4) Assessing the sensitivity of the Pour-through nutrient extraction procedure using the determined application volume.

## MATERIALS AND METHODS

### *DETERMINATION OF BEDDING FLAT APPLICATION VOLUME*

Sixteen 1204 bedding flats (12 packs per flat; 4 cells per pack; individual cell volume 115.5 cm $^{3}$) were filled with Sunshine Mix 1 (Fisons Horticultural Inc., Vancouver, BC Canada), and were saturated and further irrigated, using a hose and breaker, with tap water so that leaching occurred, daily for two weeks to establish medium compaction. Medium had a particle distribution (by weight) of 10-40% > 6 mm, 35-70% < 12 mm, 25-55% <20 mm, 10-35% <40 mm, 0-10% < 100 mm. Flats were then saturated, using a hozon and hose with breaker, with 400 mg N·liter$^{-1}$ (20N-4.4P-16.6K, Peters Peat-lite, Grace-Sierra, Milpitas, Calif.) daily for one week. Prior to collecting Pour-through samples, flats were saturated with fertilizer solution, and allowed an equilibration time of 1.5 hours. There were four Pour-through volume application treatments: 5, 10, 20, or 40 ml/cell, which were applied by hand with a beaker. Pour-through samples were then collected on each cell of each

experimental unit. An experimental unit consisted of 6 packs, with each pack consisting of four cells. Leachate from individual cells of each experimental unit was combined to obtain a minimum of 50 ml for nutrient analysis. Leachate was analyzed for EC (Myron L Agri-meter) and pH (Orion Expandable ionAnalyzer). A completely randomized design was used, with eight replicates per treatment.

*DETERMINATION OF BEDDING FLAT POUR-THROUGH ACCURACY*

Thirty-six 1204 bedding flats were filled with Sunshine Mix 1 amended with 0, 2.3, or 4.6 $kg \cdot m^{-3}$ dolomitic lime. In factorial combination with lime treatments, the flats were saturated with 0, 200 or 400 mg $N \cdot liter^{-1}$ (20N-4.4P-16.6K, Peters Peat-lite, Grace-Sierra, Milpitas, Calif.) daily for one week, resulting in 9 treatments. Flats were saturated (and further irrigated so that leaching occurred) with fertilizer solutions and allowed an equilibration time of 1.5 hours. Pour-through samples were collected using an application volume of 5 ml water per cell per experimental unit. Each experimental unit consisted of six 1204 packs. A complete randomized block design was used, with eight replicates per treatment.

*DETERMINATION OF PLUG TRAY APPLICATION VOLUME*

Eight plug trays (406 cells; individual cell volume 1 $cm^3$) were filled with

Sunshine Mix 3 (Fisons Horticultural Inc., Vancouver, BC, Canada), and saturated and further irrigated so that leaching occurred with tap water daily for one week. Medium had a particle distribution analysis (by weight) of 0-15% > 6 mm, 60-90% < 12 mm, 45-65% < 20 mm, 15-40% < 40 mm, and 0-10% < 100 mm. The following week, plug tray medium was saturated and further irrigated so that leaching occurred, and allowed an equilibration time of 15 minutes. Plug tray medium was irrigated with a hand held mist bottle until the tray began to drain. The volume applied and the volume of water collected were recorded, and leachate was analyzed for EC and pH. Preliminary studies indicated that with an equilibration time longer than 15-30 minutes, plants reduced the media moisture content and therefore decreased not only the volume of leachate produced, but also decreased levels of leachate available nutrients. Each plug tray was considered as an individual experimental unit (406 individual cells per plug tray).

*DETERMINATION OF PLUG TRAY POUR-THROUGH ACCURACY*

Twenty-four plug trays were filled with Sunshine Mix 3, which was amended with calcium hydroxide and potassium chloride. The 3 treatments were: 0 g $Ca(OH)_2$ + 0 g KCl; 1.56 g $Ca(OH)_2$ + 0.28 g KCl; 3.36 g $Ca(OH)_2$ + 0.56 g KCl. Plug trays were saturated and further irrigated with a mist nozzle so that leaching occurred with tap water 3 times daily for one week to allow the medium to settle. Plug trays were

saturated and further irrigated using a mist nozzle so that leaching occurred and allowed an equilibration time of 15 minutes. Pour-through samples were collected for each experimental unit using 200 ml applied water per tray. Leachate was analyzed for pH and EC. A randomized block design was used, with eight replicates per treatment.

## RESULTS AND DISCUSSION

### *BEDDING FLATS*

There was a linear relationship between Pour-through leachate EC and the amount of water applied to each cell ($r^2$=0.41, $P$=0.05). As the volume of applied water increased, the EC of the leachate decreased. Five ml applied per cell (per 6 pack per experimental unit) produced sufficient leachate (approximately 50 ml) to conduct a full nutrient analysis. Ten, 20, and 40 ml applied per cell (per 6 pack per experimental unit) also produced an sufficient amounts of leachate for a full nutrient analysis, but the resulting decrease in leachate EC (at 40 ml/cell) indicated that the soil solution was being diluted by the applied water. Though all 4 volumes produced sufficient leachate, 5 ml was determined to be the ideal application volume.

Preliminary studies with colored dye indicated that approximately 8 ml per cell was the maximum volume of water that could be applied without diluting the sample because volumes greater than 8 ml per cell produced red colored leachate, indicating dilution of the soil solution. Electrical conductivity is indicative of media fertility, with EC increasing as a result of increased fertilizer N concentration (Poole and Chase, 1989). Therefore, it is critical that the soil solution not be diluted because dilution would result in lower Pour-through leachate EC readings. Fertilization in response to artificially low EC values could result in nutrient toxicities or imbalances. The relationship between leachate pH and the volume applied was not significant, indicating that dilution of the soil solution had no effect on pH.

There were significant differences between treatment and Pour-through leachate pH, and between treatment and Pour-through leachate EC (lime $r^2$=0.90, $P$=0.0001 and lime $r^2$ 0.57, P=0.0001, respectively)(Table 2.1). For example, Pour-through leachate pH at 0 kg/m$^3$ was 6.0, whereas pH at 4.6 kg/m$^3$ was 6.4, which indicates that the Pour-through procedure can be used to determine differences in medium pH. Individually, lime and fertilization concentration had significant effects on Pour-through leachate pH and EC, but the interaction between lime and fertilization concentration was not significant. Significant differences in lime and fertilizer concentration were detected, showing that the Pour-through method of nutrient extraction can be used effectively on bedding flats to monitor soluble salt levels, pH, and soil solution nutrients.

*PLUG TRAYS*

Preliminary studies indicated that 200 ml evenly misted over each plug tray produced adequate leachate (approximately 50 ml) for nutrient analysis. In the preliminary study, plug trays were misted with a solution of red clothing dye and water until the resulting leachate appeared red in color. The appearance of the red dye in the leachate indicated dilution of the soil solution. The mean volume of water applied to each plug tray for the collection of non-diluted leachate was 200 ml.

In the determination of Pour-through sensitivity for plug trays, differences in leachate pH and EC were detectable and significant (Table 2.2). pH increased linearly with the corresponding increase in $Ca(OH)_2$ ($r^2$=0.99, $P$=0.0001) indicating that the Pour-through method was effective in detecting medium pH altered by liming agents. Controlling the pH of bedding flat and plug tray media is a primary concern of growers, and it is recommended that media be tested every two weeks (Koranski and Laffe, 1985). Pour-through leachate EC between treatments was significant ($r^2$=0.34, $P$=0.01). EC increased with increasing KCl and $CaOH_2$.

In comparison to SME or Saturated Paste Extract methods, the Pour-through technique is much more rapid and efficient in assessing available plant nutrients (Conover et al., 1992; Wright, 1984). A bedding flat Pour-through can be conducted after a 90 minute equilibration period, and a plug tray Pour-through after only a 15 minute equilibration period (equilibration times based on preliminary data indicating that longer periods of time resulted in a decrease in medium moisture content). The

actual Pour-through process requires approximately three minutes, (Wright, 1984) whereas SME requires an equilibration period of at least 2 hours, with 12 hours equilibration being recommended (Peterson, 1989; Warncke, 1986). The SME process is more labor intensive, requiring the removal and preparation of media and thus decreasing the amount of time a grower has to make corrections. This is critical for bedding and plug growers, as most crop schedules are only a few weeks. For example, impatiens seedlings are saleable as plug trays only 4 weeks following germination (Ball, 1992a). Commercial analysis of an SME sample requires approximately 3-9 days or 10-32% of the crop time.

Pour-through leachate samples can be sent to commercial laboratories for full nutrient analysis which has a turn-around time of approximately 1-7 days or 3-25% of the crop time (Wright, 1986). SME and similar methods require additional sample preparation time, thus decreasing the window of time in which a grower has to make necessary nutrient corrections (Wright, 1984). The Pour-through method does not require physical handling of the media itself as does solid sampling methods. This is especially important when controlled-release fertilizer has been amended to medium or when plants are root bound. Disruption of controlled-release fertilizer prills may result in falsely high media nutrient levels (Wright, 1986; Wright, 1984). The non-disruptive nature of the Pour-through method would avoid this problem and also avoid crop loss due to sampling procedures.

In conclusion, the Pour-through nutrient extraction procedure is a viable

option of determining medium nutrient availability, pH and EC for bedding and plug growers. The Pour-through method is rapid and effective in addition to being practical. Electrical conductivity and pH can be monitored on a regular basis without physically damaging the crop or decreasing the volume of media.

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**Table 2.1** 1204 bedding flat EC and pH at various dolomitic lime and fertilization concentrations.

| Lime rate ($k/m^3$) | EC ($dS \cdot m^{-1}$) | pH |
|---|---|---|
| 0 | 2.3 | 6.0 |
| 2.3 | 1.6 | 6.6 |
| 4.6 | 2.0 | 6.4 |
| $R^{2\,z}$ | 0.57 | 0.90 |
| N conc. ($mg \cdot liter^{-1}$) | | |
| 0 | 2.1 | 6.2 |
| 200 | 1.6 | 6.4 |
| 400 | 2.2 | 6.3 |
| $R^2$ | 0.44 | 0.81 |

$^z$ = Linear regression, $P=0.05$. Interaction between lime rate and fertilizer rate not significant at the $P<0.05$.

**Table 2.2** Plug tray Pour-through pH and EC at various Potassium chloride and Calcium hydroxide concentrations.

| Potassium chloride ($kg/m^3$) | Calcium hydroxide ($kg/m^3$) | pH | EC ($dS \cdot m^{-1}$) |
|---|---|---|---|
| 0 | 0 | 6.6 | 1.0 |
| 0.28 | 1.68 | 8.2 | 1.8 |
| 0.56 | 3.36 | 9.0 | 1.4 |
| $R^2$ [z] | | 0.99 | 0.34 |

[z] Linear regression, $P=0.05$.

# CHAPTER THREE: ASSESSMENT OF THE POUR-THROUGH METHOD FOR COMMERCIAL USE ON 1204 BEDDING FLATS

## ABSTRACT

A study was conducted to assess the overall potential of the Pour-through nutrient extraction procedure with impatiens (*Impatiens wallerana* 'Super Elfin Red') and marigolds (*Tagetes erecta* 'Apollo') grown in 1204 bedding flats, fertilized at three concentrations. There were significant relationships between fertilizer application concentration and leachate EC, pH, and macro- and micro-nutrient concentrations. The relationship between fertilizer application concentration and leachate EC was linear for both plant species. *I. wallerana* leachate EC values increased linearly over time and increased linearly with increased fertilizer N concentration, whereas *T. erecta* leachate EC decreased linearly over time and increased with increased fertilizer N concentration. Levels of *I. wallerana* Pour-through leachate $NH_4$-N and K increased linearly over time and with increased

fertilizer N concentration, whereas *T. erecta* Pour-through leachate $NH_4$-N and K concentrations decreased linearly over time, but increased with increased fertilizer N concentration. There were linear relationships between Pour-through leachate and SME electrical conductivity and concentrations of Cu, Mn, Fe, Zn, P, and $NO_3$-N. Electrical conductivity was therefore, a strong indicator of solution macro- and micro-nutrient levels. Although Pour-through leachate nutrient concentrations were higher than SME nutrient concentrations, Pour-through leachate concentrations were positively correlated with SME levels and fertilizer application concentrations. In addition, nutrient levels in plant tissues were also positively correlated to Pour-through leachate nutrient levels. The results indicate that the Pour-through method of nutrient extraction is sensitive and effective in assessing nutrient availability for 1204 bedding flats.

## INTRODUCTION

To optimize early plant growth, nutrients must be available in adequate amounts and suitable proportions (Mengel and Kirkby, 1987). The critical nutrient levels in 1204 bedding flats must be obtained and maintained, and is generally done so by commercial fertilizer application (Ball, 1992b; Carlson et al., 1992; Nelson, 1985). It is recommended that the media be analyzed for available nutrients on a regular basis to avoid detrimentally high salt concentrations, nutrient toxicities,

deficiencies and imbalances (Carlson et al., 1992; Nelson, 1985).

Typically, the Saturated Media Extract (SME) procedure is used by growers of bedding flats to assess nutrient availability during early stages of plant growth (Nelson, 1985). At later stages of plant growth, the limited volume of media relative to large plant root mass make SME less feasible. SME involves the removal of bedding flat media, saturating the media with a known volume of water for approximately 12 hours, and vacuum separating the liquid (Bunt, 1988; Warncke, 1986). The solution is then analyzed for nutrient concentrations, pH and EC.

The Pour-through nutrient extraction procedure is a rapid, economical, and effective method of determining medium nutrient availability (Conover et al., 1992; Peterson, 1989; Poole and Chase, 1990; Poole and Chase, 1989; Poole and Chase, 1987; Wright, 1986). This method involves pouring a known volume of water on a recently irrigated medium, and collecting the leachate (Wright 1986; Wright, 1984; Wright et al., 1990). The leachate is analyzed for EC, pH and nutrient concentrations. The Pour-through method is advantageous in that it does not require the physical disruption of the bedding flat medium, and thus no crop losses are experienced (Wright, 1986). The Pour-through method is rapid, and leachate analysis can be run on site by means of portable EC, pH, and individual nutrient meters (Wright et al., 1990).

Though the Pour-through method has been implemented by some growers in the container nursery and greenhouse industry, few bedding flat or plug tray

producers have made use of the procedure (Wright et al., 1990). The primary reason for this disparity is lack of information and recommended ranges of ions based on Pour-through sampling (Wright et al., 1990). Only recently has the Pour-through method been shown to be sensitive and effective in assessing available bedding flat nutrients (Schweizer and Grueber, 1992). The objective of this experiment was to assess the overall potential of the Pour-through nutrient extraction procedure using to major bedding crops, impatiens and marigolds, by: (1) Monitoring weekly changes in Pour-through leachate EC, pH, $NH_4$-N, $NO_3$-N, P, K, Ca, Mg, Mn, Fe, Zn and Cu; (2) Comparing Pour-through leachate EC, pH, and macro- and micro-nutrient concentrations with SME concentrations; (3) Comparing shoot tissue levels of macro- and micro-nutrients with Pour-through leachate levels of macro- and micro-nutrients.

## MATERIALS AND METHODS

### *IMPATIENS WALLERANA*

On 1 March 1992, twelve 1204 bedding flats (12 packs per flat; 4 cells per pack; individual cell volume 115.5 cm $^3$) were filled with Sunshine Mix 1 (Fisons Horticultural Inc., Vancouver, BC, Canada) and, in each cell, one *Impatiens wallerana* 'Super Elfin Red' plug was planted (average height at planting, 3.8 cm). The cell

packs were separated from one another and placed on a greenhouse bench, with 5 cm between packs. Cell packs were labelled as experimental units, that being 4 individual cell packs for every one experimental unit (total of 16 cells). Three treatments were then randomly assigned to experimental units resulting in 24 experimental units, with 8 replicates per treatment, arranged in a completely randomized design. Greenhouse heating occurred below 21° C, and cooling occurred above 24° C.

Fertilizer application concentrations of 50, 100, or 150 mg N·liter$^{-1}$ (20N-8.4P-15.0K, Peters Peat-lite soluble, Grace-Sierra, Milpitas, Calif.) were applied at each irrigation (one time daily by hand) beginning on 4 March 1992, and ending on 20 March. Pour-through samples were collected weekly (7, 13, 20 March 1992) using 5 ml per cell per pack and an equilibration time of 1.5 hours. The leachate was analyzed for pH (Orion Expandable ionAnalyzer pH meter), EC (Myron L Agri-meter), and macro- and micro-nutrients (K, Ca, Mg, Fe, Mn, Zn, and Cu by means of atomic absorption; P was determined colormetrically; $NO_3$-N and $NH_4$-N by means of ion selective electrodes).

On 20 March, 1992 shoot tissue from each cell was harvested at the media surface and dried for 7 days at 21° C. Dry weights were recorded and shoot tissue samples were analyzed for macro- and micro-nutrient levels (percent nitrogen determined using a modified micro-Kjeldahl method, according to the methods of Peterson and Chester, 1964). There were 16 plants per experimental unit.

SME samples of approximately 200 ml from each cell of each cell pack of each experimental unit were collected on 20 March and placed in 200 ml beakers. Distilled water was added to each beaker until the point of glistening on the medium surface. Samples were allowed an equilibration time of 12 hours. The liquid was vacuum separated from the solid and analyzed for available nutrient concentrations (same as Pour-through), EC, and pH. A complete randomized design was used with eight replicates per treatment. Data were analyzed using ANOVA and regression analyses.

*TAGETES ERECTA*

On 7 March, 1992 twelve 1204 bedding flats were filled with Sunshine Mix 1 (Fisons Horticultural Inc., Vancouver, BC, Canada) and in each individual cell, a *Tagetes erecta* 'Apollo' seed was sown. Medium was irrigated when necessary, usually two or three times weekly until germination. On 1 April 1992 cell packs were separated from one another (5 cm between packs) and placed on a greenhouse bench in a completely randomized design. The cell packs were labelled as experimental units, that being four cell packs per experimental unit. Three treatments were then randomly assigned to the experimental units, resulting in 24 experimental units, with eight replicates per treatment. Greenhouse heating occurred below 21° C, and cooling occurred above 24° C. Bedding flat media were saturated and further

irrigated using a mist nozzle so that leaching occurred when necessary with tap water until 10 April. Fertilizer application concentrations of 50, 100, or 150 mg N·liter$^{-1}$ (20N-8.4P-15.0K, Peters Peat-lite, Grace-Sierra, Milpitas, Calif.) were applied at each irrigation by hand beginning on 10 April, 1992 and ending on 1 May, 1992.

Pour-through samples were collected weekly for 4 weeks (10, 17, 24 April, and 1 May, 1992) on each cell of each cell pack of each experimental unit. Pour-through leachate was analyzed for pH, EC, and macro- and micro-nutrients ($NH_4$-N, $NO_3$-N, P, K, Ca, Mg, Fe, Zn, Mn, and Cu). On 1 May, 1992 plant heights were recorded, and shoot tissue was harvested at the media surface and oven dried for 7 days at 21° C. Shoot tissue was analyzed for macro- and micro-nutrients (same as Pour-through). Data were analyzed using ANOVA and regression analyses.

## RESULTS AND DISCUSSION

### *IMPATIENS WALLERANA*

The relationship between fertilizer application rate and Pour-through leachate EC was linear ($r^2$=0.86, $P$=0.0001)(Fig. 3.1). Electrical conductivity values increased linearly over time (fertilizer application concentrations of 100 and 150 mg·N liter$^{-1}$), and increased linearly with increased fertilizer N concentration. The relationship

between fertilizer application concentration and leachate $NH_4$-N concentration was linear ($r^2$=0.91, $P$=0.0001) (Fig. 3.2). The relationship between fertilizer application concentration and K was similar to that of EC and $NH_4$-N ($r^2$=0.91, $P$=0.0001) (Fig. 3.3). The relationship between fertilizer application concentration and leachate P concentration was significant ($r^2$=0.95, $P$=0.0001)(Fig. 3.4). Leachate P levels decreased between weeks 1 and 2, then increased between weeks 2 and 3; however, there were differences between fertilizer application concentration.

There was a linear relationship between fertilizer application concentration and SME EC at week 3 ($r^2$=0.87, $P$=0.0001), with EC values increasing with increased fertilizer N concentration (Table 3.1). SME EC values were lower than week 3 Pour-through leachate EC values, indicating that SME values may not be used as recommended ranges when implementing the Pour-through procedure. There were linear relationships between fertilizer application rate and SME levels of K, Zn, P, $NO_3$-N, and $NH_4$-N ($r^2$=0.88, 0.85, 0.95, 0.93, 0.92 respectively; $P<$ 0.01)(Table 3.1). The levels of Cu, Mn, K, Fe, Ca, Zn, P, $NO^3$-N, and $NH_4$-N increased with increased fertilizer N concentration. This indicates that SME is also an effective method of assessing medium nutrient availability.

Shoot tissue analysis revealed that there were no relationships between fertilizer application concentrations and dry weight, Cu, Mn, and K (Table 3.2). There were linear relationships between fertilizer application concentration and tissue concentrations of Fe, Mg, Ca, Zn, and P ($r^2$= 0.44, 0.46, 0.53, 0.37, and 0.40,

$P<0.01$). There was a linear relationship between Pour-through leachate (week 3) and shoot tissue concentrations of Cu, Fe, Mg, K, Mn, P, and Zn (Table 3.2). Pour-through leachate and shoot tissue concentrations of Cu, Fe, Mg, and K increased linearly with increased fertilizer N concentration. This is consistent with the research conducted by Wright et al. (1990) who also found increasing tissue nutrient concentrations with increased fertilizer N, and indicates that the Pour-through nutrient extraction procedure is effective in determining nutrient availability in the soil solution.

Pour-through leachate EC was assessed as a predictor (data not shown) of macro- and micro-nutrients; a linear relationship exists between Pour-through leachate EC and levels of Pour-through leachate K, Fe, Ca, Zn, P, $NO_3$-N and $NH_4$-N levels. This indicates that Pour-through leachate EC can be used to predict medium nutrient availability.

*TAGETES ERECTA*

There was a linear relationship between fertilizer application rate and Pour-through leachate EC ($r^2$=0.68, $P$= 0.0001)(Fig. 3.5). Electrical conductivity values decreased linearly over time, but increased with increased fertilizer N concentration. The relationship between fertilizer application concentration and Pour-through leachate $NH_4$-N was linear ($r^2$=0.68, $P$=0.0001)(Fig. 3.6). The levels of Pour-through leachate $NH_4$-N decreased over time, but increased linearly with increased fertilizer

N concentration. The relationship between fertilizer application concentration and leachate potassium was similar to that of $NH_4$-N ($r^2$=0.64, $P$=0.0001)(Fig. 3.7). The relationship between fertilizer application concentration and leachate P concentration was significant ($r^2$=0.95, $P$=0.0001)(Fig. 3.8). Leachate P levels decreased between weeks 1 and 2; increased between weeks 2 and 3; then decreased between weeks 3 and 4. However, there were differences in leachate P concentration between fertilizer application concentration.

Shoot tissue analysis revealed that there were linear relationships between fertilizer application concentration and dry weight, and concentrations of Cu, K, Mg, Ca, Zn, P, and N ($r^2$=0.97, 0.47, 0.37, 0.35, 0.28, 0.40, 0.29, 0.59 respectively; $P$<0.01)(Table 3.2). There was a linear relationship between Pour-through leachate (week 4) and shoot tissue levels of Cu, Mn, K, Fe, Mg, Ca, Zn, and P. Levels of Cu, Fe, Zn, and P were higher in Pour-through leachate than in tissue samples.

Pour-through leachate EC was a significant predictor of Cu, Mn, K, Fe, Mg, Ca, Zn, P, $NO_3$-N, and $NH_4$-N (data not shown). The relationships were significant and linear. However, EC was not a significant predictor of pH.

The results indicate that the Pour-through nutrient extraction procedure is an effective indicator of medium nutrient availability and EC of impatiens and marigolds grown in 1204 bedding flats.

Electrical conductivity is indicative of media fertility, with EC values increasing with increased fertilizer N concentration (Conover et al., 1992; Poole and Chase,

1989). The positive correlation between leachate EC and fertilizer application concentration for both plant species signified that the Pour-through method is effective in monitoring soluble salt levels (r=0.92 impatiens, r=0.82 marigolds). In a similar experiment using foliage plants, Conover et al. (1992) found increasing EC values with increased fertilizer N concentration. Impatiens Pour-through leachate EC increased steadily over time indicating that not only were the nutritional requirements of the crop being met, but that there was an excess which resulted in the build up of soluble salts in the medium. Marigold Pour-through leachate EC decreased steadily over time indicating that the available nutrients were being utilized by the crop, and that the crop had an increased demand for nutrients over time.

SME EC values (impatiens) were lower than week 3 Pour-through leachate EC values. This indicates that Pour-through leachate EC values may not be compared to SME EC values. SME levels of Cu, Mn, Fe, Ca, Zn, P, $NO_3$-N, and $NH_4$-N were lower than Pour-through leachate levels, which is consistent with the findings of Yeager et al.(1983) and Wright et al. (1990). Less water is applied during the process of collecting a Pour-through sample than is applied during the SME procedure. The less water that is applied, the less the chance of sample dilution occurring, hence the higher Pour-through leachate nutrient levels.

The positive correlation between fertilizer application rate and leachate $NH_4$-N (r=0.95 impatiens, r=0.82 marigolds) and K (r=0.95 impatiens, r=0.80 marigolds) concentrations for both species signified that the Pour-through method is an effective

indicator of the levels of these nutrients present in the soil solution. Impatiens Pour-through leachate $NH_4$-N and K levels increased over time indicating that there was an excess of the nutrient available which resulted in a build up of $NH_4$-N levels in the medium. Marigold Pour-through leachate levels of $NH_4$-N and K decreased steadily over time indicating that the nutrients were being absorbed by the crop more quickly than they were being supplied via fertilization. Concentrations of impatiens Pour-through leachate P decreased greatly at week 2; concentrations of marigolds Pour-through leachate P levels decreased greatly at week 4 (Fig. 3.8). It is possible that there was a greater demand for P due to the onset of flowering, or that there was an error made during laboratory analysis. However, there were differences in P concentrations between fertilizer application concentrations. This indicates that the Pour-through method is an effective indicator of different P concentrations.

In comparison to SME, the Pour-through technique is much more rapid and effective in assessing available plant nutrients (Conover et al., 1992; Wright, 1984). A bedding flat Pour-through requires a 90 minute equilibration period, with the actual Pour-through process requiring approximately three minutes (Schweizer and Grueber, 1992). SME has a recommended equilibration time of 12 hours (Peterson, 1989; Warncke, 1986). Pour-through leachate can be analyzed immediately for available nutrients, EC, and pH. By means of portable conductivity and pH meters, growers can monitor these factors and immediately correct existing or potential problems (Wright, 1986). This is critical for crops having a rapid turnover time, such

as bedding flats.

The Pour-through method does not require the physical handling of the media itself, as do the SME and Saturated Paste Extract methods. This is crucial when controlled-release fertilizers are implemented. Disruption of controlled-release fertilizer prills may result in falsely high nutrient levels (Wright, 1986; Wright, 1984). Lack of fertilization in response to falsely high nutrient levels may result in deficiencies.

Economically, the Pour-through is advantageous over conventional media testing methods (SME, Saturated Paste Extract). Bedding flat media removal is not required, and thus no crop losses are experienced. During the final stages of bedding flat production it is not always feasible to use SME due to the large root mass in relation to the small media volume. Roots may not only contaminate the solid sample, leading to artificial nutrient levels, but may hinder the removal of media. For example, it was possible to collect SME samples from impatiens, but not from marigolds since plants were root bound. Continuous SME sampling on bedding flats will reduce the amount of media significantly, resulting in crop damage and economic loss.

In conclusion, the Pour-through method is reliable and effective in assessing the nutrient availability in media and the nutritional status of *Impatiens wallerana* and *Tagetes erecta*. Pour-through leachate nutrient levels were significantly related to tissue nutrient levels, showing that the Pour-through method is effective and reliable

in indicating not only the nutritional status of the crop, but also the available nutrients. In addition, leachate EC values were positively correlated to SME values, though Pour-through leachate values were often greater. Bedding flat EC and pH evaluation is rapid, and can be run on location by means of a portable conductivity and pH meters. Further, bedding crops can be monitored on a regular basis without damaging the plants.

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**Table 3.1** *Impatiens wallerana* Pour-through and Saturated Medium Extract pH, EC, and nutrient levels ($mg \cdot l^{-1}$) at various fertilization concentrations.

| Week | N conc (mg·liter-1) | pH | EC (dS·m-1) | $NH_4$-N | $NO_3$-N | P | K | Mg | Ca | Zn | Cu | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PT** | | | | | | | | | | | | | |
| 1 | 50 | 6.3 | 0.53 | 10.5 | 84.4 | 40.5 | 20.0 | 50.0 | 88.0 | 0.47 | 0.01 | 0.28 | 0.23 |
| 1 | 100 | 6.5 | 0.48 | 11.6 | 79.2 | 46.6 | 19.0 | 38.0 | 76.0 | 0.61 | 0.01 | 0.23 | 0.16 |
| 1 | 150 | 6.4 | 0.80 | 21.1 | 111.8 | 60.9 | 35.0 | 60.0 | 106.0 | 1.01 | 0.06 | 0.42 | 0.33 |
| | $R^2$ [z] | 0.00 | 0.38 | 0.68 | 0.35 | 0.87 | 0.43 | 0.08 | 0.14 | 0.80 | 0.74 | 0.29 | 0.19 |
| 2 | 50 | 5.8 | 0.36 | 12.4 | 111.4 | 22.9 | 17.0 | 20.0 | 46.0 | 0.69 | 0.01 | 10.09 | 0.22 |
| 2 | 100 | 5.5 | 0.51 | 21.7 | 68.6 | 27.8 | 22.0 | 25.0 | 52.0 | 0.89 | 0.02 | 0.09 | 0.25 |
| 2 | 150 | 6.1 | 0.87 | 37.9 | 99.3 | 32.2 | 40.0 | 36.0 | 65.0 | 1.39 | 0.06 | 0.23 | 0.37 |
| | $R^2$ | 0.06 | 0.88 | 0.94 | 0.02 | 0.77 | 0.77 | 0.87 | 0.85 | 0.74 | 0.71 | 0.54 | 0.37 |
| 3 | 50 | 6.5 | 0.45 | 11.4 | 63.9 | 47.2 | 31.0 | 31.0 | 66.0 | 0.68 | 0.02 | 0.11 | 0.11 |
| 3 | 100 | 6.5 | 0.72 | 25.3 | 127.5 | 53.5 | 50.0 | 40.0 | 78.0 | 0.84 | 0.02 | 0.12 | 0.13 |
| 3 | 150 | 6.5 | 1.35 | 47.2 | 315.1 | 67.7 | 94.0 | 54.0 | 93.0 | 1.46 | 0.08 | 0.22 | 0.43 |
| | $R^2$ | 0.02 | 0.85 | 0.84 | 0.77 | 0.76 | 0.82 | 0.68 | 0.65 | 0.81 | 0.65 | 0.32 | 0.58 |
| **SME** | | | | | | | | | | | | | |
| 3 | 50 | 6.5 | 0.20 | 1.1 | 10.5 | 53.1 | 18.0 | 18.0 | 50.0 | 0.28 | 0.01 | 0.05 | 0.10 |
| 3 | 100 | 6.4 | 0.45 | 9.5 | 20.2 | 39.3 | 38.0 | 25.0 | 59.0 | 0.40 | 0.01 | 0.10 | 0.09 |
| 3 | 150 | 6.4 | 0.68 | 26.7 | 36.4 | 21.5 | 60.0 | 24.0 | 58.0 | 0.63 | 0.04 | 0.14 | 0.16 |
| | $R^2$ | 0.07 | 0.87 | 0.92 | 0.93 | 0.95 | 0.88 | 0.25 | 0.25 | 0.85 | 0.84 | 0.53 | 0.49 |

[z] = Linear regression, $P=0.05$.

**Table 3.2** *Impatiens wallerana* and *Tagetes erecta* shoot tissue dry weight and nutrient concentrations at various fertilization concentrations.

| N conc (mg·liter$^{-1}$) | Dry Wt (g) | N % | P % | K % | Fe ppm | Mg % | Ca % | Zn ppm | Cu ppm | Mn ppm |
|---|---|---|---|---|---|---|---|---|---|---|
| *I. wallerana* | | | | | | | | | | |
| 50 | 2.6 | 5.6 | 1.15 | 0.92 | 510.0 | 0.97 | 2.28 | 63.0 | 9.0 | 1050.0 |
| 100 | 2.5 | 6.0 | 1.10 | 0.90 | 550.0 | 0.79 | 1.85 | 45.0 | 7.0 | 900.0 |
| 150 | 2.5 | 6.3 | 1.00 | 0.96 | 710.0 | 0.67 | 1.58 | 54.0 | 8.0 | 990.0 |
| $R^2$ [z] | 0.06 | 0.19 | 0.40 | 0.02 | 0.44 | 0.46 | 0.53 | 0.37 | 0.25 | 0.14 |
| *Tagetes erecta* | | | | | | | | | | |
| 50 | 10.6 | 2.0 | 0.57 | 1.52 | 270.0 | 0.58 | 1.18 | 54.0 | 2.0 | 543.0 |
| 100 | 19.3 | 3.0 | 0.59 | 1.47 | 270.0 | 0.43 | 0.92 | 69.0 | 3.0 | 460.0 |
| 150 | 25.3 | 2.9 | 0.78 | 2.79 | 350.0 | 0.35 | 0.84 | 70.0 | 4.0 | 450.0 |
| $R^2$ | 0.97 | 0.59 | 0.29 | 0.37 | 0.20 | 0.35 | 0.28 | 0.40 | 0.47 | 0.14 |

[z] Linear regression, $P=0.05$.

**Table 3.3** *Tagetes erecta* Pour-through pH, EC, and nutrient levels ($mg \cdot l^{-1}$) at various fertilization concentrations.

| Week | N conc. ($mg \cdot liter^{-1}$) | pH | EC ($dS \cdot m^{-1}$) | $NH_4N$ | $NO_3$-N | P | K | Mg | Ca | Zn | Cu | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50 | 6.4 | 0.17 | 1.7 | 14.4 | 6.7 | 20.0 | 27.0 | 61.0 | 0.72 | 0.02 | 0.07 | 0.20 |
| 1 | 100 | 6.3 | 0.22 | 1.9 | 18.8 | 13.1 | 25.0 | 32.0 | 67.0 | 1.04 | 0.04 | 0.09 | 0.29 |
| 1 | 150 | 6.2 | 0.35 | 6.2 | 45.9 | 17.4 | 48.0 | 38.0 | 73.0 | 1.41 | 0.07 | 0.14 | 0.44 |
| | $R^2$ [z] | 0.32 | 0.47 | 0.45 | 0.48 | 0.60 | 0.47 | 0.33 | 0.30 | 0.51 | 0.58 | 0.42 | 0.36 |
| 2 | 50 | 5.1 | 0.10 | 1.0 | 3.8 | 4.5 | 15.0 | 14.0 | 46.0 | 0.58 | 0.03 | 0.01 | 0.09 |
| 2 | 100 | 5.5 | 0.17 | 3.0 | 11.1 | 10.6 | 24.0 | 18.0 | 53.0 | 1.12 | 0.11 | 0.04 | 0.26 |
| 2 | 150 | 4.4 | 0.25 | 4.5 | 13.3 | 7.9 | 45.0 | 24.0 | 63.0 | 1.33 | 0.17 | 0.11 | 0.74 |
| | $R^2$ | 0.12 | 0.72 | 0.72 | 0.36 | 0.92 | 0.60 | 0.78 | 0.85 | 0.88 | 0.94 | 0.89 | 0.88 |
| 3 | 50 | 6.2 | 0.10 | 1.0 | 3.8 | 14.8 | 17.0 | 15.0 | 57.0 | 0.62 | 0.03 | 0.02 | 0.22 |
| 3 | 100 | 6.0 | 0.15 | 1.5 | 8.3 | 32.4 | 29.0 | 17.0 | 57.0 | 1.06 | 0.10 | 0.07 | 0.63 |
| 3 | 150 | 5.9 | 0.28 | 4.2 | 16.2 | 44.0 | 54.0 | 22.0 | 66.0 | 1.04 | 0.14 | 0.15 | 1.53 |
| | $R^2$ | 0.64 | 0.64 | 0.73 | 0.58 | 0.90 | 0.61 | 0.34 | 0.06 | 0.62 | 0.88 | 0.80 | 0.77 |
| 4 | 50 | 6.3 | 0.10 | 1.0 | 6.7 | 1.4 | 15.0 | 11.0 | 25.0 | 0.45 | 0.01 | 0.01 | 0.22 |
| 4 | 100 | 6.1 | 0.17 | 1.3 | 4.0 | 2.7 | 25.0 | 14.0 | 31.0 | 0.71 | 0.05 | 0.04 | 0.40 |
| 4 | 150 | 6.1 | 0.21 | 2.9 | 7.0 | 3.9 | 39.0 | 20.0 | 44.0 | 1.01 | 0.11 | 0.10 | 0.89 |
| | $R^2$ | 0.20 | 0.66 | 0.62 | 0.00 | 0.94 | 0.78 | 0.70 | 0.73 | 0.94 | 0.95 | 0.57 | 0.91 |

[z] Linear regression, $P=0.05$.

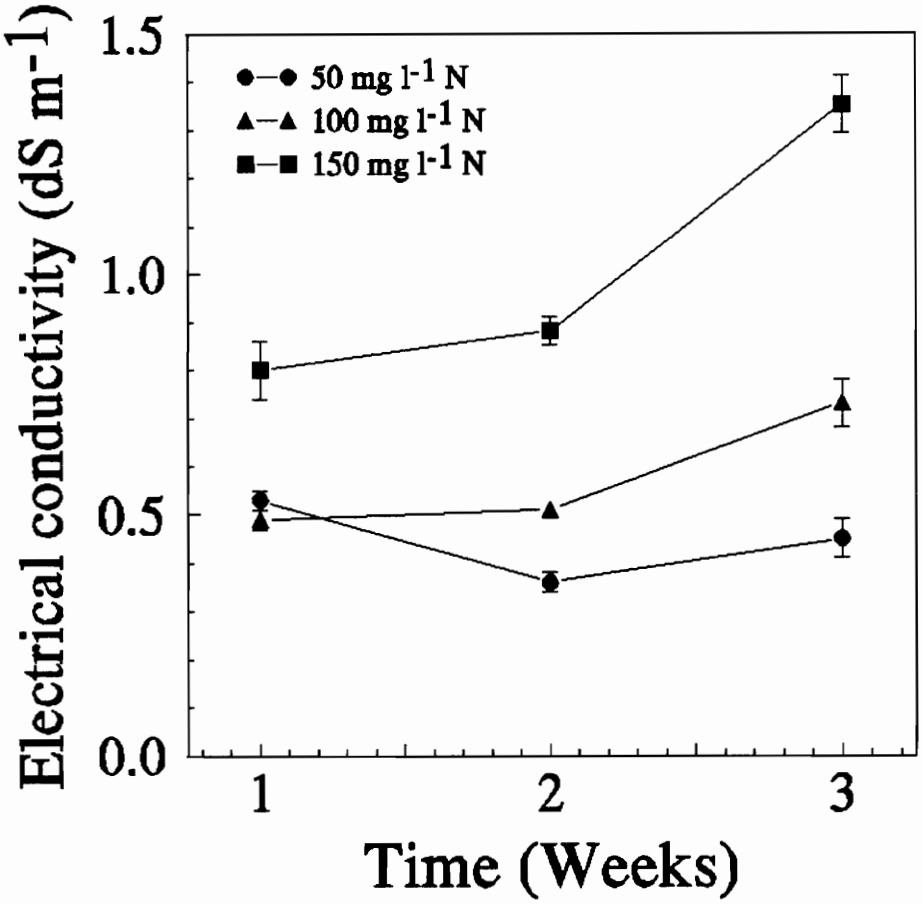


**Figure 3.1** Electrical conductivity of *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

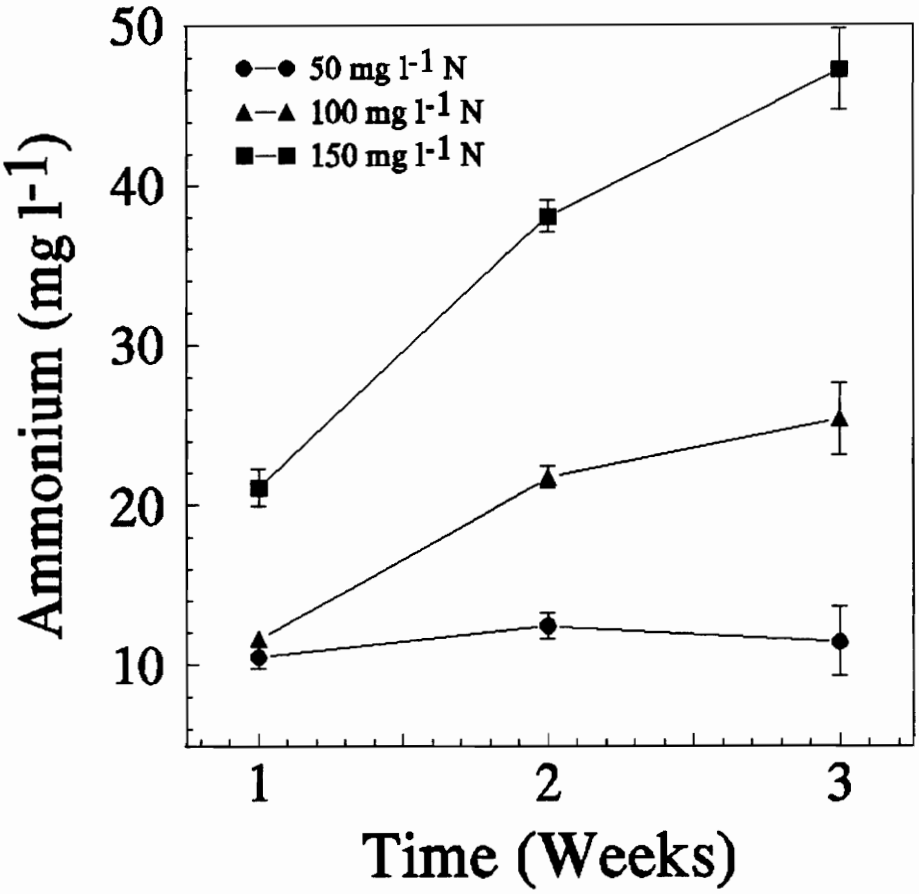


**Figure 3.2** Ammonium levels of *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

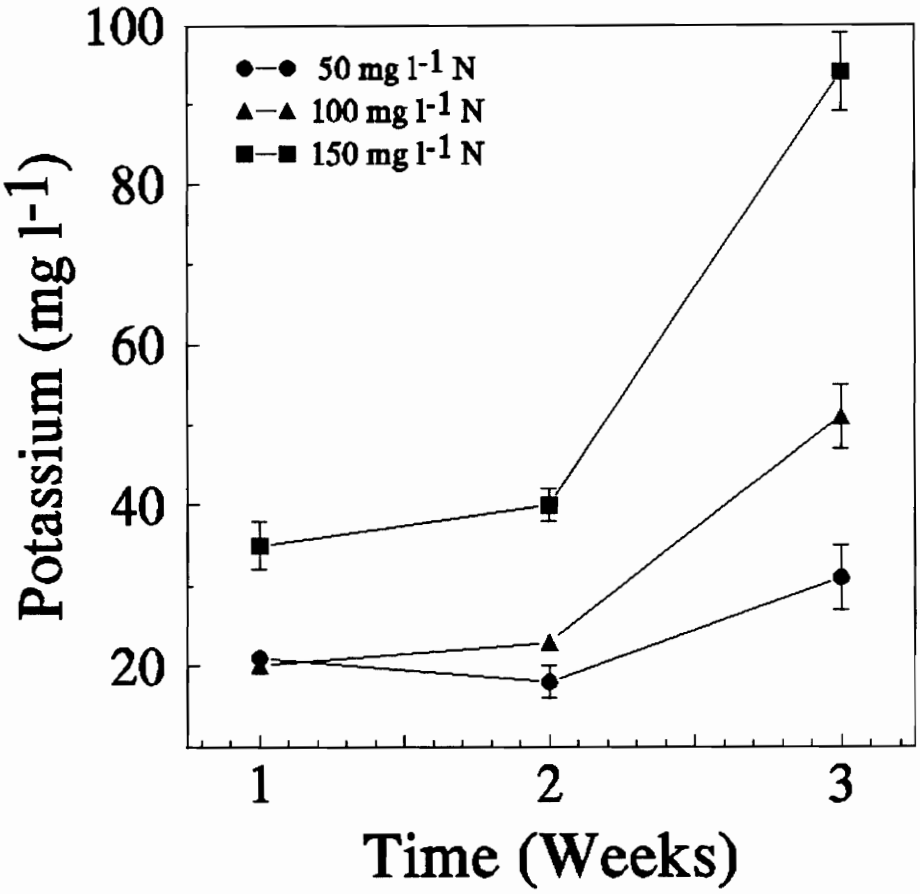


**Figure 3.3** Potassium levels in *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

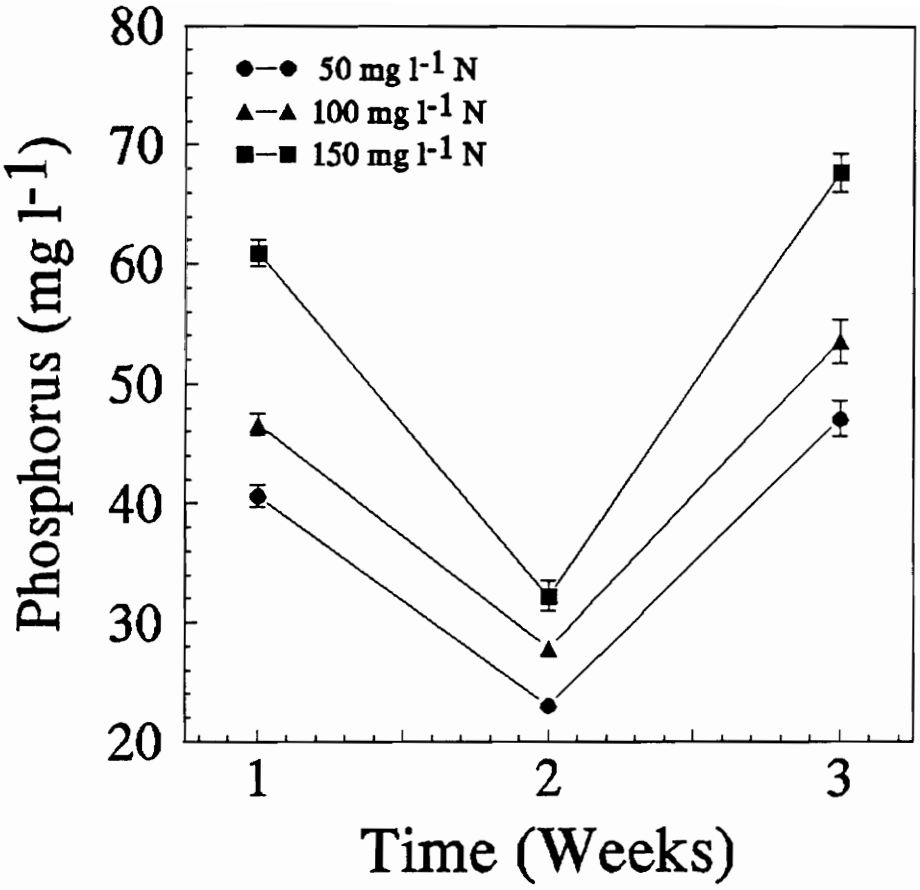


**Figure 3.4** Phosphorus levels in *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

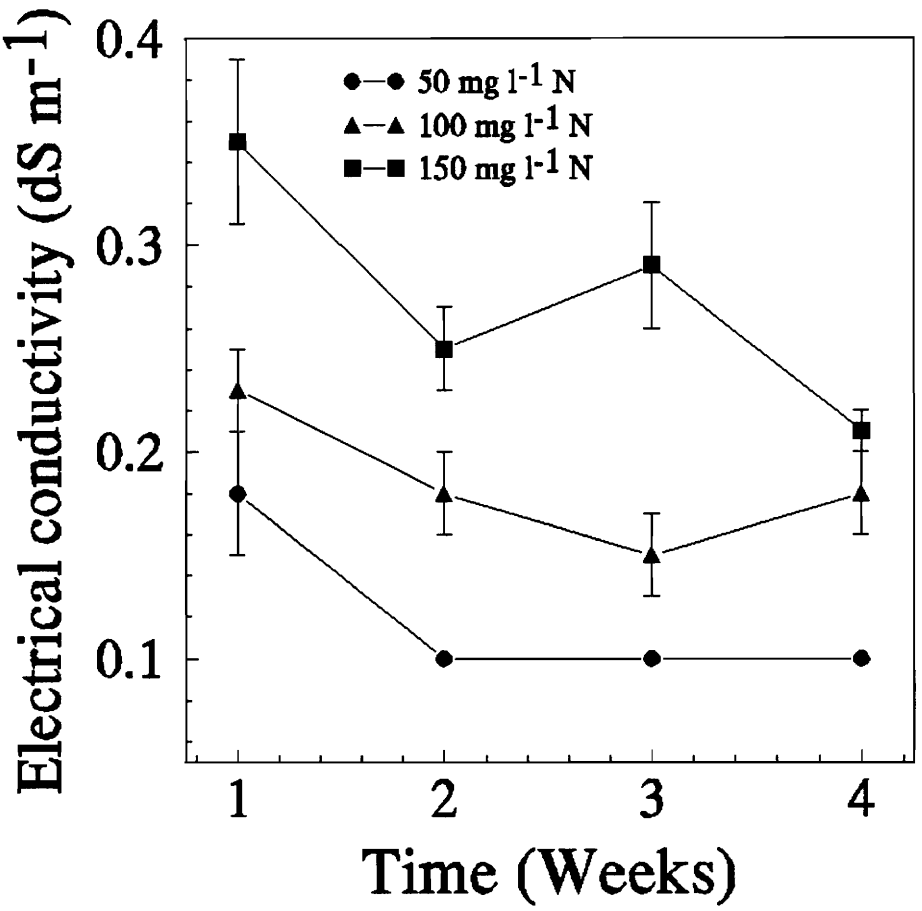


**Figure 3.5** Electrical conductivity of *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

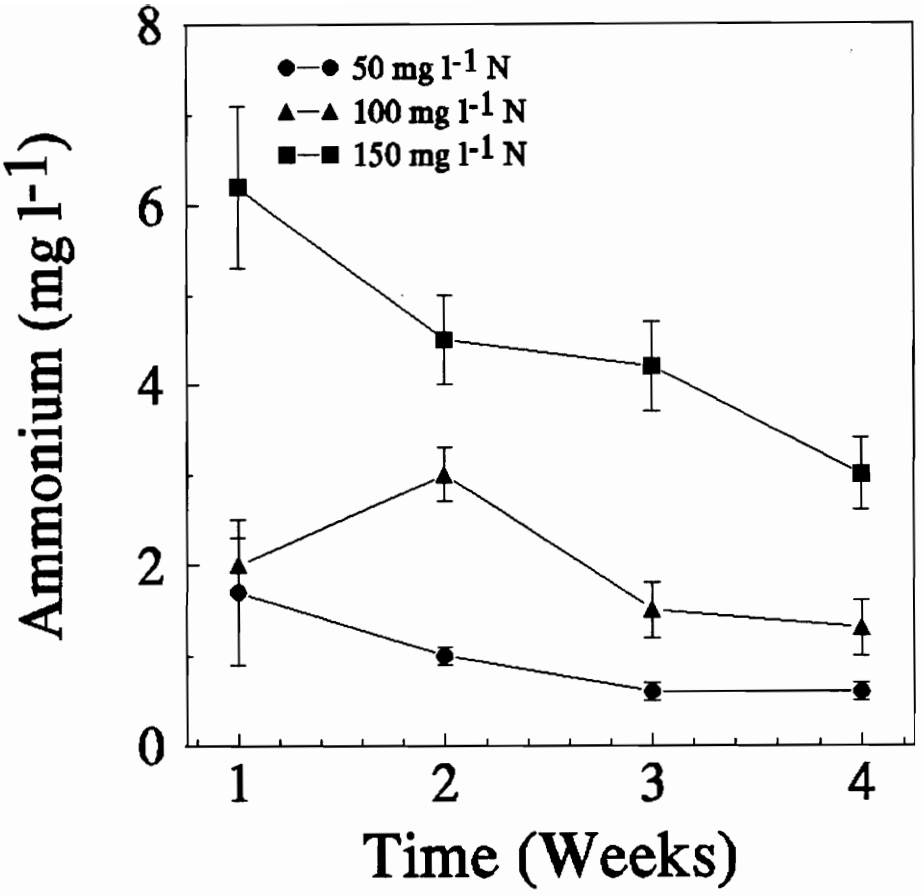


**Figure 3.6** Ammonium levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

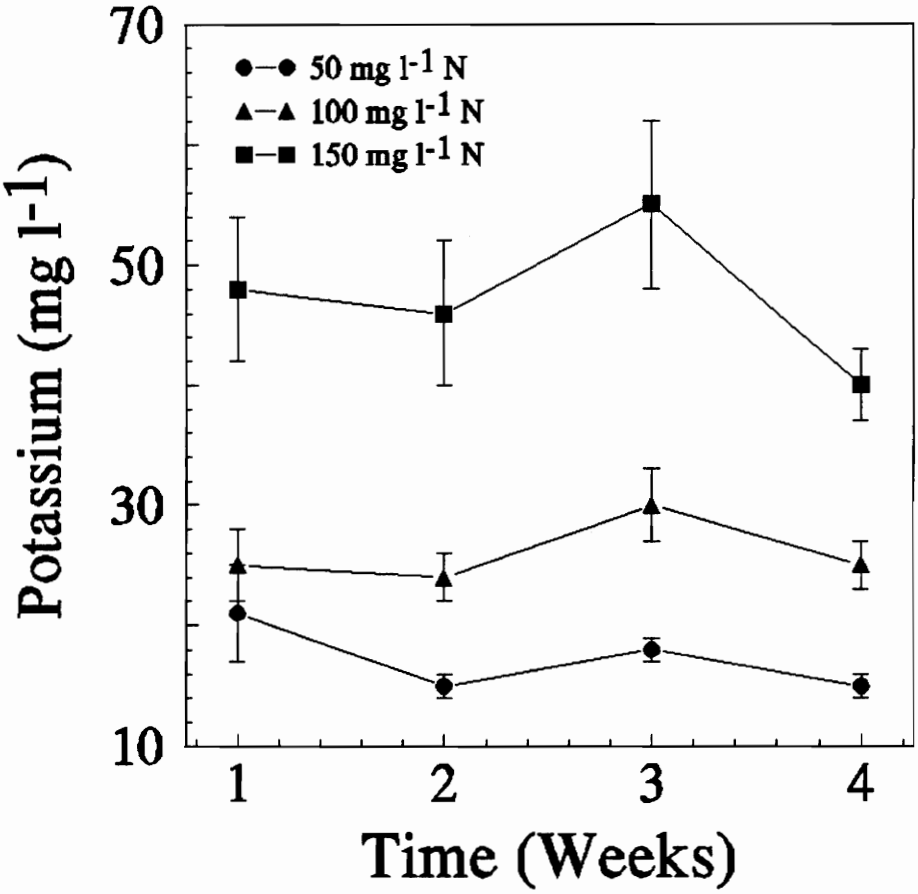


**Figure 3.7** Potassium levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

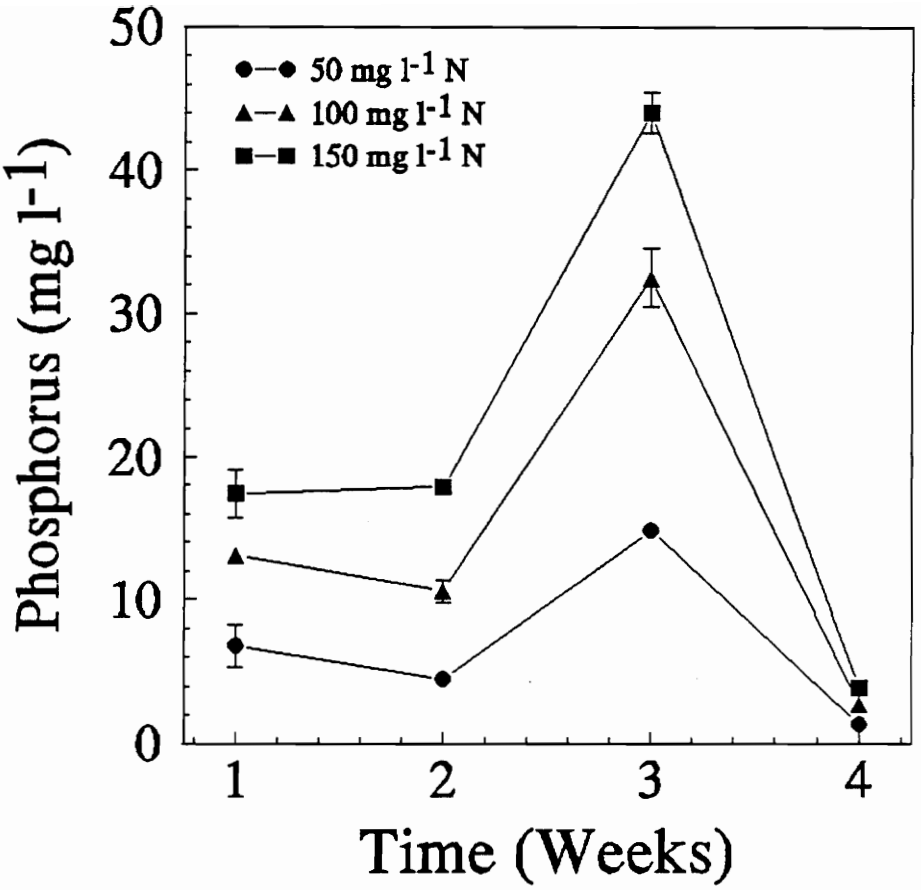


**Figure 3.8** Phosphorus levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a 1204 bedding flat. Vertical bars represent standard error.

# CHAPTER FOUR: ASSESSMENT OF THE POUR-THROUGH METHOD FOR COMMERCIAL USE ON PLUG TRAYS

## ABSTRACT

A study was conducted to assess the overall potential of the Pour-through nutrient extraction procedure with *Impatiens wallerana* 'Super Elfin Red' and *Tagetes erecta* 'Inca Orange' grown in plug trays and fertilized at three concentrations. There were differences noted between fertilizer application concentration and leachate EC, pH, $NH_4$-N, $NO_3$-N, P, and K, for both species. The relationship between fertilizer application concentration and leachate EC was linear, with leachate EC values increasing with increased fertilizer N concentration. pH decreased linearly with increasing fertilizer N concentration. Levels of P, K, $NH_4$-N, and $NO_3$-N increased linearly with increased fertilizer N concentration. Whole shoot tissue analysis indicated similar results. The relationships between whole shoot dry weights of *Impatiens wallerana* and *Tagetes erecta* and fertilizer application rate were

significant, with values increasing with increased fertilizer N concentration. The relationships between whole shoot tissue levels of N and K and fertilizer application concentrations were also significant with values increasing with increased fertilizer N concentration for both species. Results indicate that the Pour-through nutrient extraction procedure is sensitive and effective in assessing available nutrients in plug trays.

## INTRODUCTION

To optimize early plant growth, nutrients must be available in adequate amounts and suitable proportions (Mengel and Kirkby, 1987). The critical nutrient level of plug tray medium must be obtained and maintained, and is generally done so by commercial fertilizer application (Carlson et al., 1992; Koranski and Laffe, 1985). It is recommended that plug tray medium be analyzed for available nutrients every two weeks to avoid detrimentally high salt concentrations, nutrient toxicities, deficiencies, and imbalances (Koranski and Laffe, 1985).

Plug tray growers are recommended to implement the Saturated Media Extract (SME) method to assess available nutrients (Koranski and Laffe, 1985). This process involves the physical removal of a given amount of media, saturating the media with a known volume of water for 12 hours, and vacuum separating the liquid (Bunt,

1988). The solution is analyzed to determine nutrient concentrations. During later stages of plug tray development, SME is no longer feasible due to large plant root mass relative to media volume. Large root masses make it difficult to remove media and may contaminate solid samples such as SME, resulting in false nutrient levels. Continuous sampling decreases the media volume substantially, and physically damages the crop.

The Pour-through method of nutrient analysis involves pouring a known volume of water on a previously saturated medium, and collecting the leachate (Wright, 1986; Wright, 1984; Wright et al., 1990). The Pour-through method is rapid and effective, and requires no specialized equipment (Schweizer and Grueber, 1992; Wright, 1986; Wright, 1984; Wright et al., 1990). A 1204 bedding flat Pour-through can be conducted in approximately 3 minutes (90 minute extraction period), and EC and pH analyzed immediately on site by means of portable meters (Wright, 1986). Electrical conductivity is indicative of media fertility, with EC values increasing with increased fertilizer N concentration. Conover et al. (1992) and Wright et al. (1990) found a positive correlation between fertilizer application concentration and Pour-through leachate EC for foliage plants and poinsettia respectively, indicating the Pour-through method was an effective indicator of available nutrients.

Though the Pour-through method has been implemented by some greenhouse and container nursery growers, very few growers of plug trays have adopted this method. The primary reason for the disparity is lack of information and

recommended ranges of ions based on Pour-through sampling (Wright et al., 1990). Plug tray crop schedule are most often only a few weeks, requiring that nutrient toxicities, deficiencies or imbalances be corrected immediately. The Pour-through method requires 1-7 days for commercial lab leachate analysis (on site analysis can be done immediately following a 15 minute equilibration time), whereas SME requires 3-9 (on site analysis can be done immediately following a 12 hour equilibration time). The objective of this experiment was to assess the overall potential of the Pour-through method using *Impatiens wallerana* and *Tagetes erecta* plug trays by: (1) Monitoring weekly Pour-through leachate EC, pH, $NH_4$-N, $NO_3$-N, P, and K concentrations; (2) Comparing Pour-through leachate concentrations of $NH_4$-N, $NO_3$-N, P, and K with whole shoot tissue concentrations of these ions.

## MATERIALS AND METHODS

On 19 and 9 October, respectively, *Impatiens wallerana* 'Super Elfin Red' and *Tagetes erecta* 'Inca Orange' were mechanically sown into 24 plug trays (406 individual cells; cell volume 1 $cm^3$, respective of species, at a commercial plug facility (Aarons Creek Farm, Buffalo Junction, Va). Seedlings were irrigated with tap water during Stage I of development (germination to unfolding of cotyledons). Plug trays were shipped and received at Virginia Polytechnic Institute and State University on

30 October, 1992. On 30 October, 1992, seedlings were at the beginning of Stage II (first set of true leaves), the time when fertilization normally begins (Koranski and Laffe, 1985).

Each species was placed on a separate greenhouse bench lined with clear plastic and a capillary mat. Plug trays were randomly assigned one of three fertilizer application concentrations; 0, 100, or 200 mg·N liter$^{-1}$ (20N-4.4P-16.6K, Peters Peat-lite complete soluble, Grace-Sierra, Milpitas, Calif.). Each tray was irrigated twice daily with tap water using a mist nozzle, and the capillary mat flooded. Greenhouse heating occurred below 21° C, and cooling occurred above 24° C. Plug trays were arranged in a completely randomized design, with eight replicates per treatment. On 5, 12, and 19 November marigold and impatiens plug trays were removed from the greenhouse bench (to avoid fertilizer contamination of the capillary mat) to receive the designated fertilizer application concentration (hozon and breaker). Following a 15 minute equilibration period, Pour-through samples were collected by placing each tray in an inverted germination dome, such that the bottom of the plug tray did not touch the bottom. Each plug tray was irrigated with 200 ml of tap water (plastic mist bottle) and allowed to drain. Leachate (approximately 50 ml) from each experimental unit (individual plug tray) was collected. On 26 November additional Pour-through samples were collected from impatiens plug trays. Leachate was filtered and analyzed for EC (Myron L Agri-Meter), pH (Orion Expandable ionAnalyzer pH meter), P (colormetric), K (atomic absorption), $NO_3$-N, and $NH_4$-N

(ion selective electrodes).

On 19 and 26 November, 1992, shoot tissue was harvested from each marigold and impatiens plug tray, respectively. Seedlings were cut at the media surface (approximately 350 seedlings per plug tray). Tissue was oven dried for 7 days at 21° C, weighed, and ground for analysis of N (modified micro-Kjeldahl method according to the methods of Peterson and Chester, 1964), P (colormetric), and K (atomic absorption). Data were analyzed using ANOVA and regression analyses.

## RESULTS AND DISCUSSION

### *IMPATIENS WALLERANA*

The relationship between fertilizer application concentration and leachate EC was positive and linear ($r^2$=0.98, $P$=0.0001)(Fig.4.1). The relationship between fertilizer application concentration and Pour-through leachate K was linear, with levels of K increasing with increased fertilizer N concentration ($r^2$=0.98,

$P$=0.0001)(Fig.4.2) Pour-through leachate concentrations of K decreased between weeks 1 and 2, then increased linearly over weeks 2, 3, and 4, with the exception of the unfertilized treatment. Fertilizer application concentration 0 leachate K levels decreased steadily over time.

Levels of leachate $NH_4$-N and $NO_3$-N increased with increased fertilizer N concentration [$r^2$($NH_4$-N)=0.98, $P$=0.0001; $r^2$ ($NO_3$-N)=0.99, $P$=0.0001](Fig.4.3, 4.4) Leachate levels of $NH_4$-N increased linearly over time, with the exception of the unfertilized treatment, which remained fairly constant (Fig.4.3). Levels of $NO_3$-N initially decreased, followed by a steady increase, with the exception of fertilizer application rate 0, which continued to decrease.

Levels of Pour-through leachate P increased with increased fertilizer N concentration ($r^2$ =0.99, $P$=0.0001)(Fig.4.5). Levels of P decreased between weeks 1 and 2, then increased linearly over weeks 2, 3, and 4.

The relationship between fertilizer application concentration and Pour-through leachate pH was linear, with pH values decreasing with increased fertilizer N concentration ($r^2$ =0.81, $P$=0.0001)(Fig.4.6). Shoot tissue analysis indicated similar results (Table 4.1) with levels of N, P, and K increased linearly with increased fertilizer N concentration ($r^2$= 0.92, 0.65, 0.92, and $P$=0.0001, 0.0001, 0.0001, respectively).

Visual observations of the plug trays seedlings further confirmed Pour-through and tissue analysis results. Unfertilized seedlings were highly chlorotic and stunted,

reaching a height of only 0.5 cm after 6 weeks growth. Fertilizer application concentration 100 and 200 plug tray seedlings were dark green and reached an average height of 5.5 cm.

*TAGETES ERECTA*

The relationship between fertilizer application concentration and leachate EC was linear, with EC values increasing with increased fertilizer N concentration ($r^2$=0.99, $P$=0.0001)(Fig.4.7). Levels of Pour-through leachate K, $NH_4$-N, $NO_3$-N, and P increased linearly with increased fertilizer N concentration ($r^2$=0.94, 0.96, 0.99, 0.98, $P$=0.0001 respectively)(Fig. 4.8, 4.9, 4.10, 4.11). The correlation between Pour-through leachate potassium, $NH_4$-N, $NO_3$-N, and P and fertilizer application concentration is consistent with the research of Wright et al. (1990) who also found increasing concentrations of leachate potassium, $NH_4$-N, $NO_3$-N, and P. This indicates that the Pour-through method is sensitive and effective in assessing soil solution nutrients. Pour-through leachate P levels increased steadily over time, with the exception of fertilizer application concentration 100 mg·N liter$^{-1}$, which decreased (Fig. 4.8). Potassium and $NH_4$-N concentrations decreased over time (Fig. 4.8, 4.9). Nitrate concentrations initially decreased, then increased between weeks 2 and 3 (Fig.

4.10). This could be attributed to either an increased demand for $NO_3$-N during week 2, or an error in laboratory analysis.

The relationship between fertilizer application concentration and Pour-through Pour-through leachate pH was significant and linear, with leachate pH values decreasing with increased fertilizer N concentration ($r^2$ =0.78, $P$=0.0001)(Fig. 4.12). Fertilizer application concentration of 0 leachate pH increased steadily over time, whereas fertilizer application concentration of 100 and 200 leachate pH decreased over time. The pH of plug tray media is critical and must be monitored on a regular basis so that necessary corrections can be made (Koranski and Laffe, 1985). The Pour-through nutrient extraction procedure is a sensitive and effective technique in detecting differences in media pH.

Shoot dry weights increased linearly with the corresponding increase in fertilizer N concentration ($r^2$=0.93, $P$=0.0001)(Table 4.1). Levels of N, P, and K were linear, and increased with increased fertilizer N concentration ($r^2$=0.86, 0.82, 0.60, $P$=0.0001 respectively)(Table 4.1).

Visual observations of plug trays further validated Pour-through and shoot tissue analysis results. Unfertilized seedlings were stunted (1.5 cm) and chlorotic, whereas fertilizer application concentration of 100 and 200 plug tray seedlings were a healthy green color and reached a height of 5.5 cm.

The above results indicate that the Pour-through nutrient extraction procedure is a sensitive and effective indicator of medium nutrient availability, pH, and EC for

impatiens and marigolds grown in plug trays.

Leachate from the unfertilized treatment (impatiens) had an EC value of 0.1 $dS \cdot m^{-1}$, whereas fertilizer application concentrations 100 and 200 $mg \cdot N\ l^{-1}$ had EC values of approximately 0.5 and 0.9 $dS \cdot m^{-1}$, respectively. It is recommended that Stage II and III plug tray medium have an SME EC reading of 1.0-1.5 (Kuack, 1991). Pour-through leachate EC values were lower than the recommended SME values; however, seedlings receiving fertilizer applications were not visually or nutritionally deficient (tissue levels not deficient based on standard values according to Nelson, 1985).

Electrical conductivity is indicative of media fertility, with EC values increasing with increased fertilizer N concentration (Conover et al., 1992; Poole and Chase, 1989). For both species, Pour-through leachate EC increased with increased fertilizer N concentration. This is consistent with the research of Conover et al. (1992) and Wright et al. (1990), in which leachate EC values increased with increased fertilizer N concentration. Impatiens Pour-through leachate increased steadily over time, indicating that not only were the nutritional requirements of the crop being met, but also that there was an excess of available nutrients which resulted in a build up of soluble salt levels in the medium. Marigold Pour-through leachate EC decreased steadily over time indicating that the nutrients available in the soil solution were being utilized by the crop. The unfertilized treatments of both plant species had a constant EC reading of 0.1 $dS \cdot m^{-1}$. The positive correlation between leachate EC

and fertilizer application rate indicates that the Pour-through technique is an effective procedure for monitoring available nutrients of impatiens and marigolds grown in plug trays (r=0.98, impatiens; r=0.99, marigolds). Fertilizer application concentration could be distinguished based on Pour-through leachate EC values and nutrient values.

Impatiens Pour-through leachate concentrations of $NH_4$-N and K increased steadily over time in the fertilized treatments. Unfertilized treatments were basically static. Marigolds Pour-through leachate concentrations of $NH_4$-N and K decreased steadily over time in the fertilized treatments. Unfertilized treatments remained constant. Decreases in Pour-through leachate nutrients concentrations in fertilized treatments indicates that the crop is absorbing the nutrients at a faster rate than they are applied via fertilization. Increases in Pour-through leachate nutrient concentrations indicate that there is an excess of nutrients available to the crop which may result in plant damage.

Impatiens Pour-through leachate $NO_3$-N and P concentrations increased over time, whereas marigolds Pour-through leachate $NO_3$-N concentrations decreased over time and P levels increased over time. This may be due to differential crop nutrient requirements, temperature or light.

pH is a critical factor in growing plug tray seedlings, and should be monitored every two weeks (Koranski and Laffe, 1985). The Pour-through nutrient extraction procedure indicates that it is effective in detecting medium pH differences. There

were statistically significant differences between fertilizer application concentration and leachate pH.

There was a positive correlation between Pour-through leachate nutrient levels and shoot tissue nutrient levels, further confirming the validity of the Pour-through method in detecting available nutrients ($r=0.80$ for P; $r=0.95$ for K, impatiens; $r=0.90$ for P; $r=0.77$ for K, marigolds). These findings are consistent with the research of Wright et al. (1990) who also found a positive correlation between Pour-through leachate nutrient levels and shoot tissue nutrient levels.

In comparison to the SME or Saturate Paste Extract methods, the Pour-through technique is more rapid and effective in assessing available nutrients (Wright, 1984). A plug tray Pour-through can be conducted following an equilibration time of only 15 minutes (Schweizer and Grueber, 1992), whereas an SME requires a recommended equilibration time of 12 hours (Peterson, 1989; Warncke, 1986). The actual Pour-through process requires approximately three minutes and is less labor intensive than the SME or Saturated Paste Extract which require the removal of plug tray media (Wright, 1986).

Timing is critical when dealing with plug trays due to the rapid rate of crop turnover. For example, *Impatiens wallerana* germinate in approximately 18 days, and require an additional four weeks to become saleable (Ball, 1992a, b). Commercial SME analysis requires 3-9 days or 10-32% of the crop time, whereas the Pour-through method only requires 1-7 days or 3-25% of the total crop time.

Economically, the Pour-through is advantageous in that the plug tray media is not physically handled, and thus no crop losses are experienced. Plug trays can be assessed for available nutrients and seedling still be sold intact, an option not available when implementing the SME. During the final stages of plug tray production, it is not always feasible to use SME due to the large root mass relative to the small volume of media. Roots may not only contaminate the solid sample leading to artificially high nutrient levels but may hinder the removal of media. Physical damage may also result causing unnecessary economic losses. For example, impatiens grown in plug trays cost approximately $.08 and marigolds approximately $.09 (commercial price lists, 1992). This brings the cost of an impatiens plug tray (saleable count 350) to $24.00 and a marigold plug tray (saleable count 300) to $28.00.

In conclusion, the Pour-through method is reliable and effective in assessing the nutritional status of impatiens and marigolds grown in plug trays. Pour-through leachate nutrient levels were significantly related to tissue nutrient levels, indicating that the Pour-through method is effective and reliable in indicating available

nutrients. In addition, leachate EC values were positively correlated to SME values, though Pour-through leachate values were often greater. Plug tray EC evaluation is rapid and can be run on site by means of a portable conductivity meter. Plug tray media can be monitored on a regular basis without damaging the seedlings.

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**Table 4.1** *Impatiens wallerana* and *Tagetes erecta* shoot tissue dry weight and percent nutrient levels at various fertilization concentrations.

| N conc. ($mg \cdot liter^{-1}$) | Dry Weight (g) | N | P | K |
|---|---|---|---|---|
| *Impatiens wallerana* | | | | |
| 0 | 0.81 | 1.26 | 0.66 | 2.50 |
| 100 | 2.29 | 2.60 | 0.76 | 4.84 |
| 200 | 3.12 | 3.36 | 0.85 | 5.81 |
| $R^{2z}$ | 0.93 | 0.92 | 0.65 | 0.92 |
| *Tagetes erecta* | | | | |
| 0 | 3.25 | 1.15 | 0.50 | 5.76 |
| 100 | 4.69 | 2.45 | 0.59 | 6.41 |
| 200 | 5.36 | 3.06 | 0.60 | 6.71 |
| $R^2$ | 0.93 | 0.86 | 0.82 | 0.60 |

$^z$ = Linear regression, $P=0.05$.

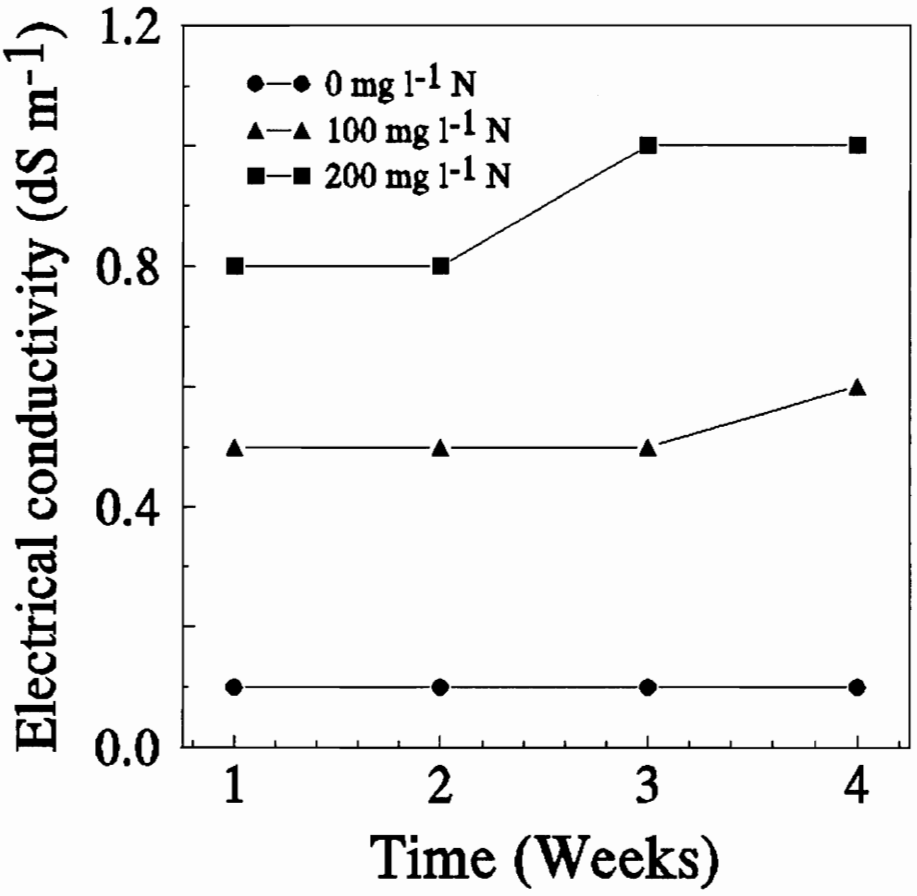


**Figure 4.1** Electrical conductivity of *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

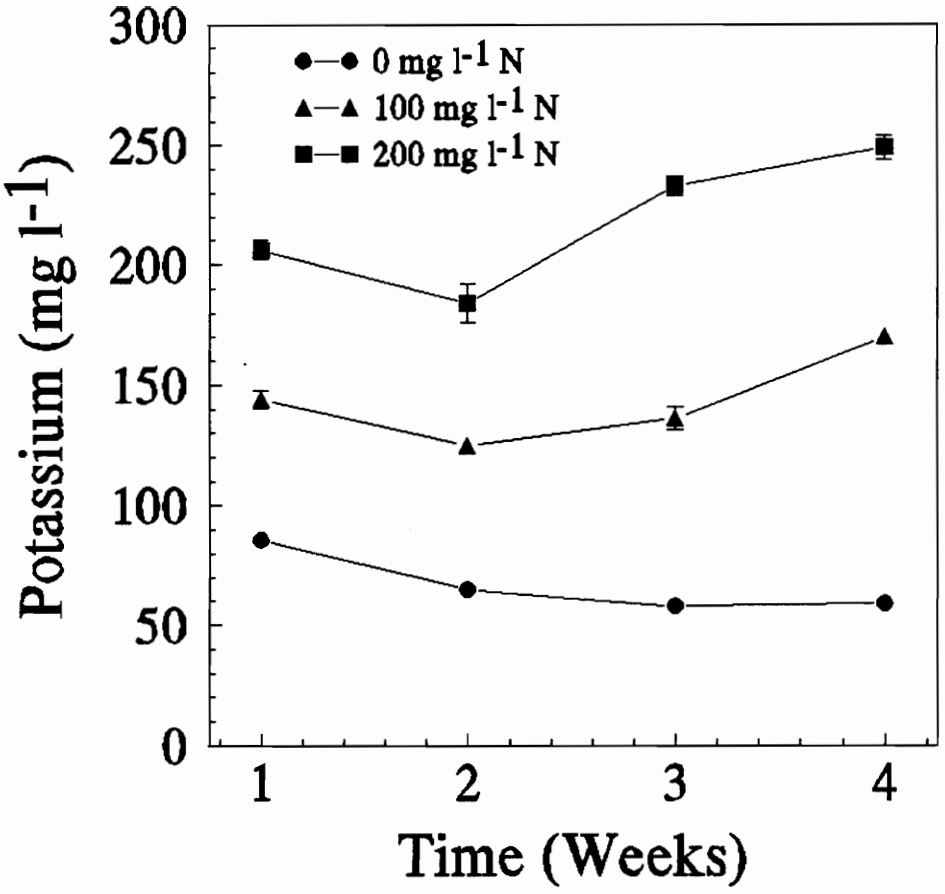


**Figure 4.2** Potassium levels in *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

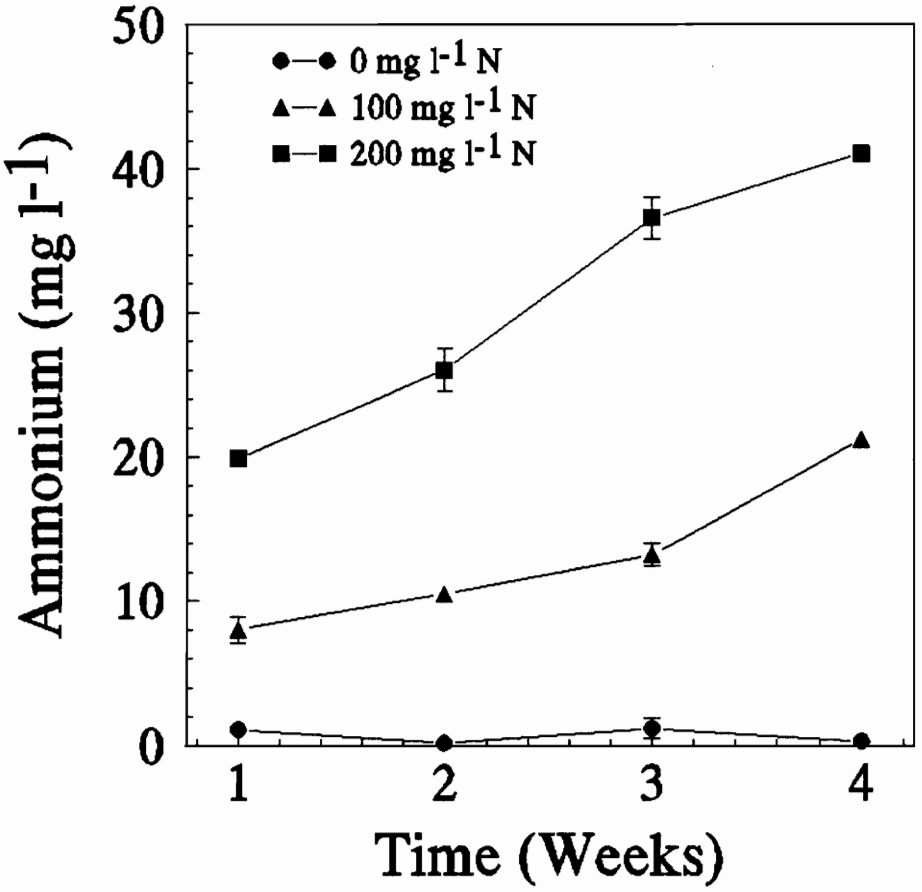


**Figure 4.3** Ammonium levels in *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

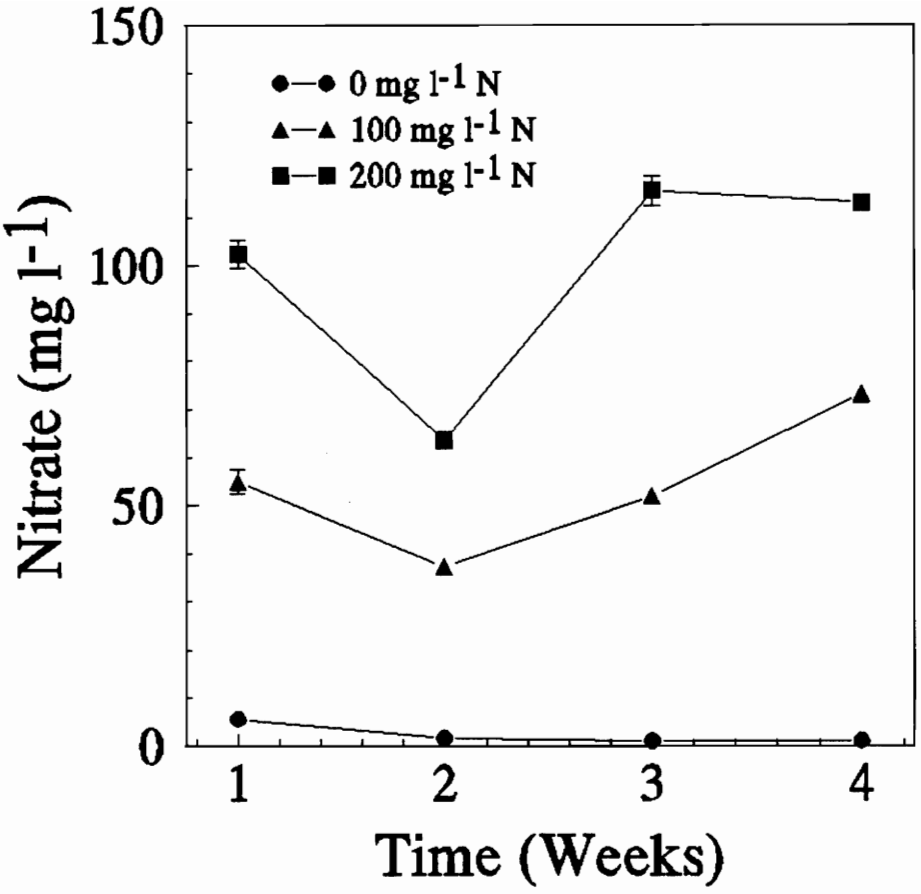


**Figure 4.4** Nitrate levels in *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

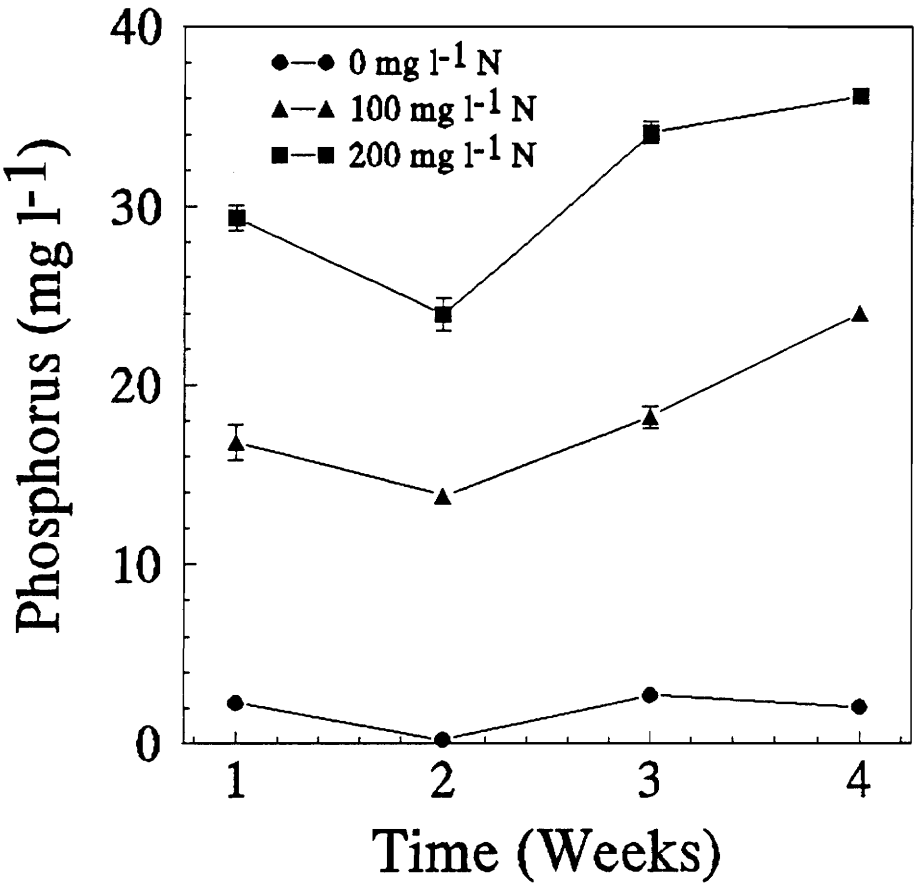


**Figure 4.5** Phosphorus levels in *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

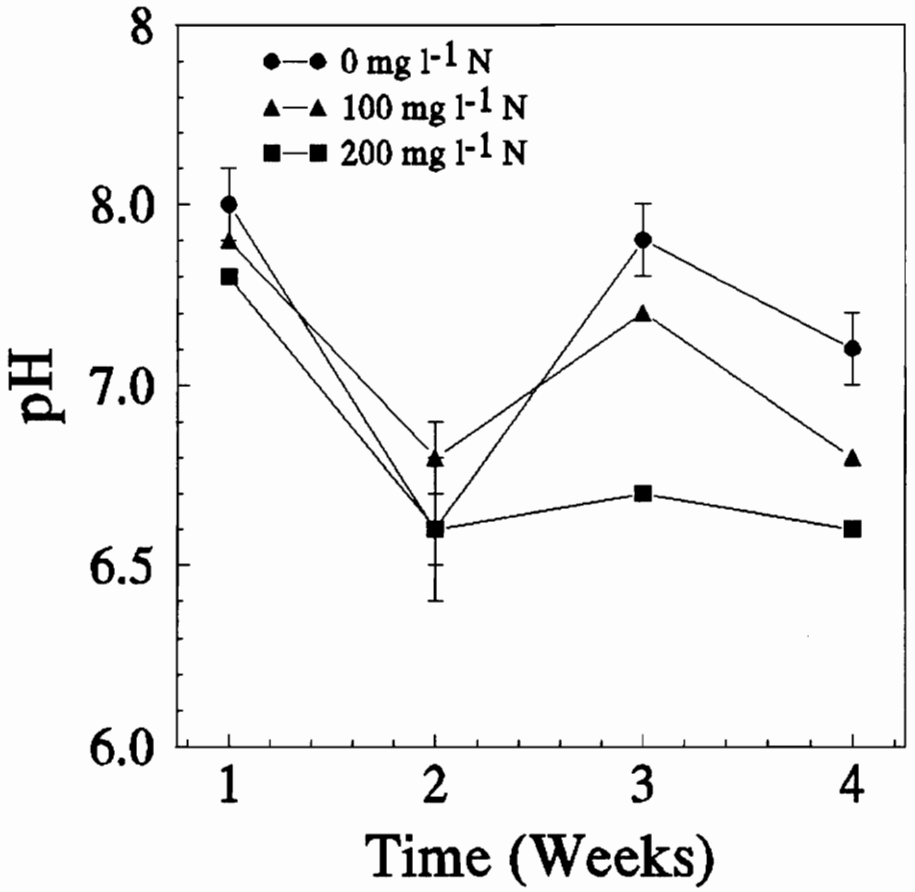


**Figure 4.6** pH of *Impatiens wallerana* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

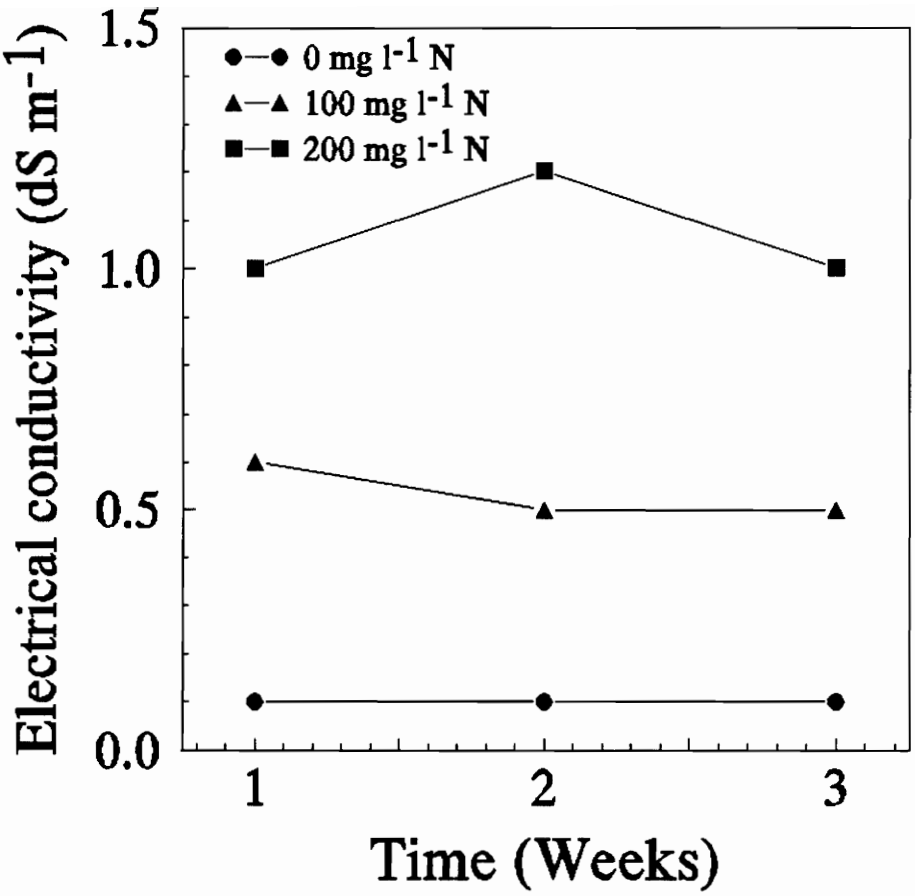


**Figure 4.7** Electrical conductivity of *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

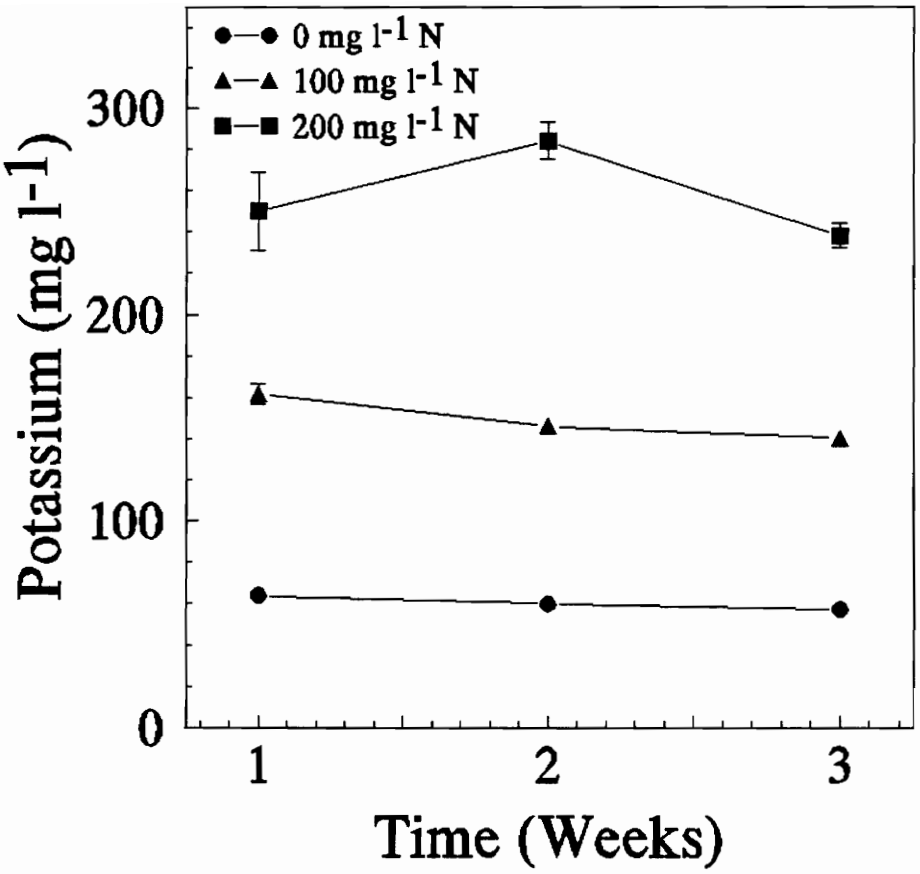


**Figure 4.8** Potassium levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

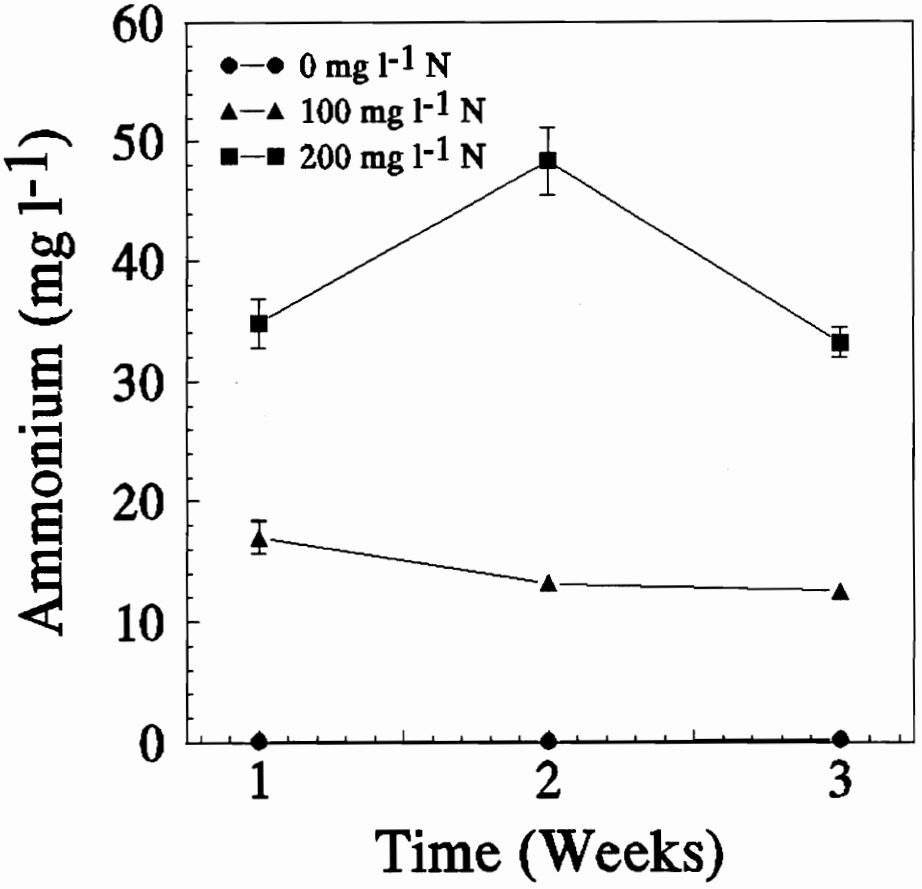


**Figure 4.9** Ammonium levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

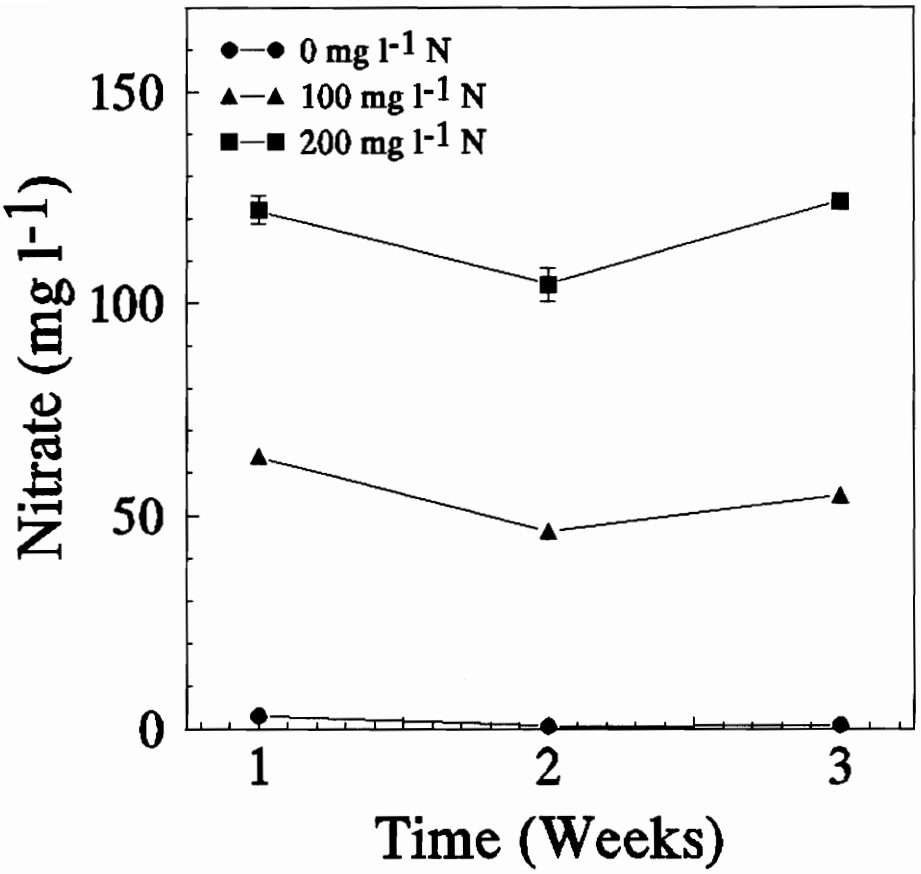


**Figure 4.10** Nitrate levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

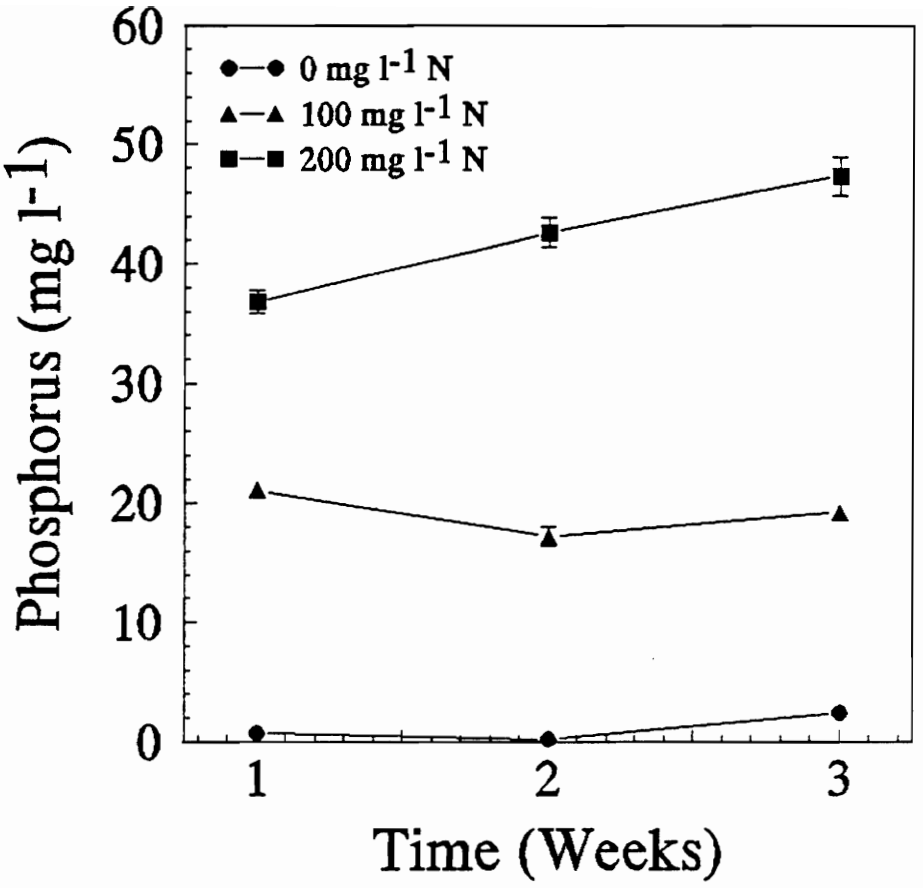


**Figure 4.11** Phosphorus levels in *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

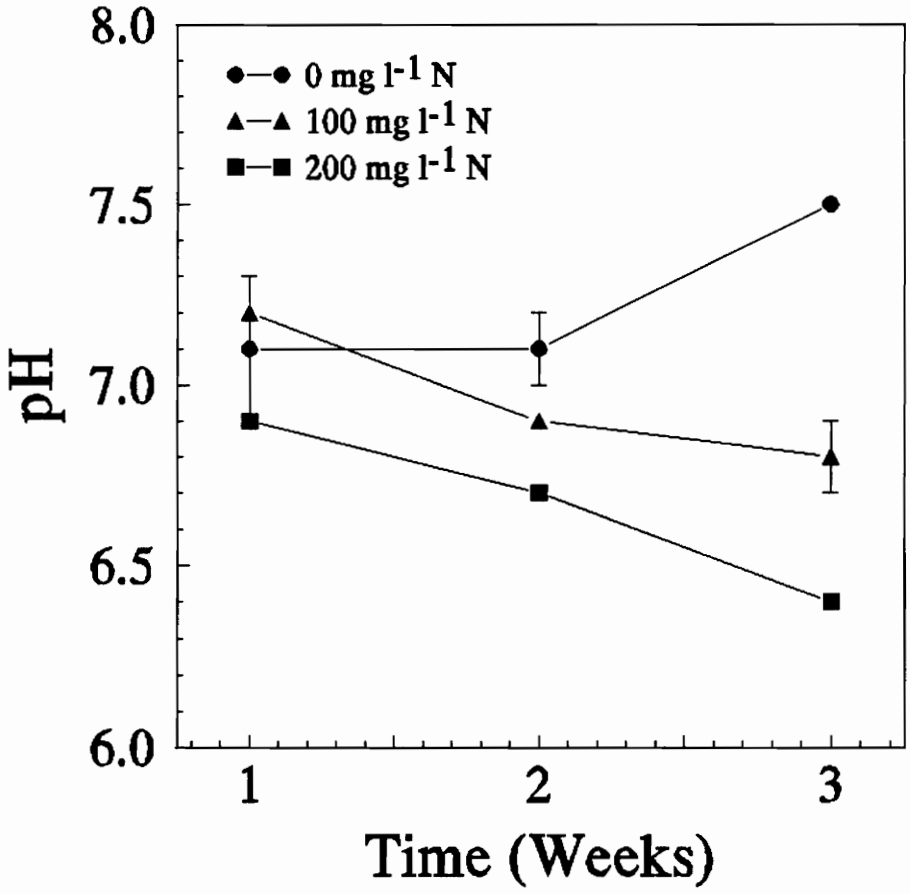


**Figure 4.12** pH of *Tagetes erecta* Pour-through leachate as affected by fertilization concentration in a plug tray. Vertical bars represent standard error.

## Vita

Amelia Lee Schweizer was born in East Lansing, Michigan on 19 March, 1969 to Dr. Conrad J. Schweizer and Mrs. Leona A. Schweizer. Amey spent her childhood with her parents, grandparents, and younger siblings, playing, working and learning at Schweizer Nursery, a three-acre retail establishment in New York City. Amey, who developed a love for plants, animals and people, followed in the footsteps of two previous Schweizer generations, and pursued horticulture as a career.

Amey received her primary and secondary education at St. Joseph Hill Academy, Staten Island, New York. Following her graduation in May of 1987, Amey bid her cronies farewell and headed for the ivy covered walls of Cornell University, in Ithaca, New York. In May of 1991, Amey graduated, with distinction, and a Bachelor of Science in Horticulture. In August of 1991, Amey entered Virginia Polytechnic Institute and State University, Blacksburg, Virginia, and began work on her Master's degree in Horticulture which she received in May of 1993.