The influence of nitrogen source and shade on the growth and quality of *Philodendron oxycardium*

by

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DEDICATION

This work is dedicated to my husband, Marty, for his unyielding patience and technical assistance throughout the entire term. This research is also dedicated to my parents for their encouragement.

ABSTRACT

Solution culture experiments were established to evaluate the efficiency of NO_3^-, NH_4^+, urea, and NH_4^+ + NO_3^- N sources in the production of a marketable foliage crop (Philodendron oxycardium) under 3 shade regimes and varying N levels. At the termination of the experiments plant growth and mineral composition of the leaf tissues were determined.

Crop quality and yield, irrespective of N source, increased as shade intensity decreased, although the differences between the low and intermediate shade levels were slight. Growth was severely restricted under the highest shade intensity. Overall, shade intensity appeared to have a greater influence on Philodendron growth than N source. Nitrate-N produced optimum growth responses in each of the experiments. Ammonium-N resulted in variable plant responses. For some plant growth measurements NH_4^+ produced an optimum response, whereas other measurements were significantly lower. Urea produced lower yields in one experiment in comparison to NH_4^+, urea, and NH_4^+ + NO_3^-; however, it resulted in optimum Philodendron growth in the other studies. The growth responses and leachate pH values under NH_4^+ + NO_3^- nutrition in one study were similar to NO_3^--N, whereas in other experiments NH_4^+ + NO_3^- resulted in similar effects as NH_4^+. Leaf N, P, K, Ca, Mg, Fe, Mn, and Zn concentrations varied with shade levels and N source. However, all elements determined in these

tissues were in the range suggested for normal P. oxycardium development. There were no differences in plant yield measurements between the 5, 10, or 15 meq/liter N levels tested. The lack of plant response to increased N levels was presumably due to insufficient light availability at the 65% shade level utilized during the course of this experiment.

INTRODUCTION

The foliage plant industry in the United States is a multimillion dollar enterprise, having expanded greatly during the late 1960's and early 1970's (10). It continues to grow annually as people become further removed from rural settings into urban areas. Although the monetary value of the industry dictates that additional research is justified to produce more vigorous and higher quality plants, little work on nutritional and environmental growing conditions has been reported.

Smith and Strain (70) reported that Philodendron oxycardium annually accounts for 14% of the total volume of sales of the foliage plant industry. It remains the most popular sale item today (30). Most of the P. oxycardium related research to date includes shade intensity studies (20, 21, 73) and influences of commercial fertilizer sources (21, 22, 62) on crop quality and yield.

At the present time no studies on the influence of nitrogen source on P. oxycardium growth have been reported. This is an important aspect of nutrition since the source of nitrogen may have a profound influence on plant physiology, thus affecting crop quality and yield. Also N source efficiency would have economic implications in terms of crop production as well. Therefore, the objectives of this research project were: to determine the most effective source of

nitrogen on the quality and yield of Philodendron oxycardium, and to observe the interaction of varying levels of shade and nitrogen level with N source.

LITERATURE REVIEW

Foliage Plant Industry

The foliage plant industry in the United States was initiated in the early 1900's. It became situated in Florida by 1914, with the major production area located near Apopka (23). Conover et al. (23) deduce Florida was chosen for the establishment of the venture due to its mild climate, high relative humidity, land and water availability, and good soil type. The entire inventory in 1914 consisted of one plant species, Nephrolepis exaltata (Boston fern), which was distributed to local "five and dime" stores (23).

The Boston fern remained the primary product until the 1930's when plants that responded to similar cultural practices were introduced (23). Philodendron cultivars were among the new species produced.

Since the 1930's the industry has experienced a vast expansion. It now produces several hundred species of tropical foliage plants for wholesale and retail distribution across the United States. Barmby et al. (10) reported that the industry grew from an estimated net worth of 11.7 million dollars in 1966 to an estimated value of 110.6 million dollars in 1976.

The plant genus which comprises the highest percentage distribution and sales for the industry continues to be Philodendron. Conover et al. (23) reported that Philodendrons

constituted 35.6% of the total Florida industry's sales in 1967. However, in recent years there has been a slight decrease in consumer demand of all species of Philodendron. Total sales of Philodendron oxycardium[1] has dropped from 35.6% of the foliage plant inventory in 1967 to 14% in 1975 (70). Commercial growers of tropical foliage plants, however, continue to rank P. oxycardium as the most popular sale item (30).

Since foliage crops are a relatively new agricultural commodity in the United States, little research has been reported in this field relative to other horticultural crops. Philodendron oxycardium has been one of the most extensively studied foliage plants because it makes up a large portion of the total volume of sales for the industry.

Philodendron oxycardium is a vining plant which is found growing on and around the base of trees in tropical and subtropical areas (4). Cultural conditions initially developed by growers attempted to reproduce the environmental conditions under which these plants evolved (23). To simulate these conditions growers generally shade P. oxycardium, raise them in organic soils, and strive for high relative humidity (23).

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[1]Formerly designated as P. cordatum.

Foliage Plant Research

Most tropical foliage plants are generally grown under 80 to 90% shade (20). For years, the recommendation was to grow P. oxycardium at 2000 footcandles (ca. 320 $\mu Em^{-2}s^{-1}$)[1] (17), which is equivalent to 80% shade. Taylor et al. (72) reported an increased number of nodes per vine and larger stem diameters on P. oxycardium under 30 and 60% shade as compared to 90% shade. Conover and Poole (21) obtained higher grade P. oxycardium plants with increased fertilizer levels under 40 and 60% shade than under 80% shade. In another study, on other foliage plants, they noted increased yields at 60% as compared to 80% shade and they also observed reduced yields during the winter months (20).

Fonteno and McWilliams (32) report that before acclimatization to indoor culture Philodendron scandens showed a light compensation point of 33 $\mu Em^{-2}s^{-1}$. In tests with varying light intensities, they also found that net CO_2 uptake increased with each rise in light intensity up to 57 $\mu Em^{-2}s^{-1}$. In 1956 Bohning and Burnside (16) reported the maximum light saturation of several shade species of plants, including P. oxycardium, to be 1000 footcandles (ca. 160 $\mu Em^{-2}s^{-1}$). Carpenter and Nautiyal (17) found that as air velocities increased from 0 mph to 4.4 mph shade intensity of P. oxycardium could be reduced or eliminated.

[1] 320 microeinsteins per meter per second.

Fertilizer trials on P. oxycardium indicated that the leaf surface area and stem length increased as nitrogen level increased from 6.4 meq/liter to 12.9 meq/liter and 25.7 meq/liter but diminished as shade intensity decreased from 90 to 30% shade (73). Hogan and Shanks (39), using P. oxycardium, obtained good plants over a 10-month period with 2000 foot-candles (ca. 320 $\mu Em^{-2}s^{-1}$) and nutrient solutions containing 10.5 meq/liter NH_4NO_3, 3 meq/liter P, and 5 meq/liter of K.

Recently there have been numerous studies on the effects of commercial fertilizers on foliage plants. Increased levels of Osmocote[1] 14-14-14 did not increase yields of aglaonema, peperomia, and maranta (20). Osmocote 18-4-7.5 and liquid fertilizer 18-4-7.5 produced the highest grade P. oxycardium plants at 40 and 60% shade compared to MagAmp[2] 7-17-6.5 which provided the poorest grade at all shade and fertilizer levels (21). Conover and Poole (22) reported no differences between liquid fertilizer 20-20-20 and Osmocote 14-14-14 on the yields of P. oxycardium, Boston fern, and Aphelandea squarrosa (Zebra plant). Fertilizer level did not affect growth of Philodendron but the 1500 or 2000 kg/ha/year rate was best for Boston fern and Zebra plant.

Poole and Conover (62) acquired better growth in P.

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[1]Sierra Chemical Corp., Newark, C.A.

[2]W. R. Grace and Co., Baltimore, Md.

oxycardium treated with Osmocote 14-6-12 or liquid fertilizer 14-6-12 than with a mixture of $(NH_4)_2HPO_4$, ureaform[1] and potassium frit[2], or the same mixture plus KNO_3. The authors noted an increase in vine length and plant grade when the fertilizer level was increased from 1.1 g N/pot to 2.2, 3.3, or 4.4 g N/pot. Leaf tissue N, P, K, and Mg concentrations were higher in plants treated with Osmocote 14-6-12 or liquid 14-6-12 compared to the other fertilizer sources.

Studies on Aechmea fasciata, a Bromeliad, found that applications of N as NH_4NO_3 at 100 to 150 mg/pot/4 weeks and K as KCl at 100 to 120 mg/pot produced higher grade plants (61). Neel and Donselman (50) obtained good growth and quality on Anthurium tikalense, Brassaia actinophylla (Schefflera), Chrysalidocarpus lutescens (Areca palm), Ixora coccinea, and Podocarpus macrophylla when Osmocote 18-6-12, Osmocote plus Tri-Nite[3] 16-1-0, and Sure gro[4] 14-14-12 were the fertilizer sources, while Organic Turfmaster[5] 16-4-8, Pro-Gro[6] 31-6-5, Pro-Gro plus Tri-Nite, and Sta-Green[7] 19-5-10

[1]Methylene urea (38% total N), slow release fertilizer.

[2]K^+ incorporated into silicate or glass, heated, mixed and granulated (slow release).

[3]Florida East Coast Fertilizer Co., Homestead, Fl.

[4]Nurserymans Sure-Gro Corp., West Palm Beach, Fl.

[5]Kerr-McGee Chemical Corp., Jacksonville, Fl.

[6]O. M. Scott, Marysville, OH.

[7]Sta-Green Plant Food Co., Sylacauga, AL.

produced inconsistent and poor results.

Generally, soil mistures used for foliage plants are rich in peat moss and wood by-products which have been shown to be low in the minor elements (24). Therefore, increased yields would be expected with the addition of micronutrients to these soil mixtures. However, studies using Perk[1], Vigoro supplement X[2], and FTE-503[3] as micronutrient sources did not increase growth or yield of zebra plant, schefflera, and Philodendron (29). They observed chlorosis and schefflera and zebra plant when FTE-503 and Perk were applied.

Recently, some research has been done to determine the critical concentration of mineral nutrients in tropical foliage plants. Poole et al. (63) reported satisfactory N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn concentrations in the tissue for 27 species of tropical foliage plants. Joiner and Waters (44) established critical concentrations of N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn in leaf tissues of Dieffenbachia exotica, Monstera deliciosa, Philodendron oxycardium, Sansevieria zeylanica, Scindapsus aureus and Syngonium podophyllum during three seasons.

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[1]Kerr-McGee Chemical Corp., Jacksonville, Fl.

[2]Swift Agricultural Chemical Corp., Winter Haven, Fl.

[3]Frit Industries, Ozark, Al.

Nitrogen

Excluding carbon, hydrogen and oxygen, of the essential elements necessary for plant growth nitrogen is required in the most abundant quantities. Nitrogen is a constituent of all amino acids, proteins, purines, pyrimidines, and several coenzymes (31, 68). It has been well-established that a shortage of nitrogen in the rooting media characteristically results in stunted growth, chlorosis of the older leaves and eventual death of the plant if the lack of nitrogen continues. The yellowing or chlorosis is caused by the degradation of chlorophyll in the chloroplasts (31). Increased nitrogen fertilization will stimulate amino acid and protein synthesis as long as photosynthesis proceeds at a rate sufficient to supply the necessary organic carbons, which will ultimately result in enhanced growth (31).

The most abundant source of nitrogen in soil is the oxidized form, nitrate (NO_3^-), although plants can utilize other sources of nitrogen (6, 26, 40, 47, 69, 74). There have been numerous studies on the effects of oxidized versus the reduced ammonium (NH_4^+) nitrogen form on various vegetable (3, 49, 59), fruit (33), agronomic (14, 15), and floricultural (28, 34, 43) crops.

Nitrogen uptake and charge balance

It has been well documented that nitrogen source has a significant effect on soil acidity and alkalinity (55, 56, 58).

Numerous investigators have reported that a predominance of NO_3^- nitrogen in cropped and unbuffered root media causes a shift of pH toward alkalinity while NH_4^+ results in an increase in acidity (7, 9, 19, 29, 46, 54). In solution culture urea is generally taken up as a whole neutral molecule, which maintains the pH intermediate between NO_3^- and NH_4^+ (46). Various shifts in pH have been noted when different ratios of NO_3^- plus NH_4^+ are utilized as the nitrogen source depending on the concentration of one ion over the other, preference by the plant for one of the ions, and the influence of NH_4^+ on NO_3^- uptake and reduction (33, 43).

The ability of a particular crop to use the various nitrogen sources, particularly NH_4^+, is dependent on the rate of N assimilation and availability of organic carbon for protein synthesis (5). Many species of plants develop NH_4^+ toxicity when grown in unbuffered media containing large amounts of NH_4^+-N (9, 19, 49). Maynard and Barker (49) have characterized NH_4^+ toxicity symptoms on susceptible species as reduced growth, wilting, marginal necrosis and interveinal chlorosis of terminal leaves and eventual death of the plant. Not all plants, however, are susceptible to NH_4^+ toxicity. There are reports of increased yields when NH_4^+ is applied compared to NO_3^-, particularly under low light conditions (5, 34, 35).

Cytosol pH must be maintained near neutrality for plant metabolism to function normally (27, 46, 66). Nitrogen

source, as previously mentioned, may shift the external pH away from the desired range (46). Raven and Smith (66) have discussed in considerable detail the shifts in cytosol pH which occur during NO_3-N and NH_4-N assimilation and the "biochemical pH stat" which maintains the internal pH near neutrality.

When NO_3^- is taken up, some of the ions may be reduced to NH_3 and assimilated into organic-N compounds in the root. The resulting compounds are translocated via the xylem to the leaves and shoot (53). Much of the inorganic NO_3^- is translocated to the shoot and leaves where it may be stored for later use or reduced and utilized immediately (53). In either case, an excess of OH^- ions accumulate thereby increasing cytosol pH (27, 66). However, electroneutrality is maintained in plant tissues (27, 46, 66). To accomplish the neutralization of excess OH^- generated under NO_3^- nutrition, NO_3^- uptake and assimilation must be accompanied by cation uptake (Ca^{+2}, Mg^{+2}, K^+, Na^+) and/or organic acid synthesis and dissociation (H^+ donation) (27, 46). The general neutralization pathway involves the formation of a neutral molecule from the reaction of OH^- with the positively charged Ca^{+2}, Mg^{+2}, H^+, K^+, or Na^+ ion (46), and/or the formation of malic acid, which is the predominant organic acid utilized to neutralize NO_3^- (14, 45, 66). Any OH^- not neutralized by organic acids is excreted to the rooting media as HCO_3^- (27, 66). Overall, NO_3^- uptake stimulates increased cation

absorption and organic acid synthesis by the plant (66).

The pattern of NH_4^+ assimilation in crops under low to moderate NH_4^+ regimes differs from NO_3^- assimilation. If the rate of NH_4^+ uptake does not exceed the maximum NH_4^+ assimilation capacity of the roots then NH_4^+ incorporation takes place predominantly in the roots (53, 66). Generally, the organic compounds transported to the shoot in the xylem are amino acids, including glutamine and asparagine, with the corresponding organic acids (37, 53, 66). Abnormally high concentrations of the undissociated NH_4^+ molecule have been noted in the shoots of plants grown with 100% NH_4^+ fertilization or in plants susceptible to NH_4^+ toxicity (8, 9, 76). Raven and Smith (66) conclude that for each NH_4^+ ion taken up and transformed to the NH_3 intermediary one H^+ ion is produced. Under normal conditions, when the majority of the NH_4^+ is assimilated in the roots, the main process of maintaining electroneutrality is by H^+ extrusion to the outside medium, thereby decreasing the pH (46, 66). Uptake of anions ($H_2PO_4^-$, SO_4^{-2}, Cl^-) may also neutralize excess cytosol H^+ (46). A small amount of the H^+ generated may be stored in vacuoles, as noted by Raven and Smith (66). However, the authors suggest that osmotic problems would arise if high quantities of H^+ were compartmentalized in the vacuoles. Overall, evidence indicates NH_4^+ fertilization stimulates anion uptake and decreases organic acid synthesis (46, 66).

Compared to NO_3^- and NH_4^+ fertilization, very little

research has been reported on urea. It is generally believed that urease splits the urea molecule into NH_3 plus CO_2 (46). Electroneutrality is automatically maintained by this conversion without the addition of cations or anions (46).

Varying ratios of NH_4^+ plus NO_3^- can result in diverse plant responses. Generally, plants respond well to the presence of both fertilizers, depending on the concentration of NH_4^+ utilized (35, 43). This is particularly true with reduced light conditions (35). If the plant does not have a preference for one ion over the other, the effects on cation: anion balance should remain at unity, with no major shifts in pH (13). Frith and Nichols (33) reported an NH_4^+ induced inhibition of NO_3^- uptake and reduction in apple seedling roots. They also concluded that the inhibition was not caused by a pH effect. A study by Oaks et al. (52) indicated that the presence of amino acids, particularly glutamine and asparagine, in the roots of corn, partially inhibited the induction of NO_3^- reductase. Evidence indicates when NH_4^+ plus NO_3^- are supplied to certain plants the amino acids produced during NH_4^+ assimilation may suppress NO_3^- utilization (33, 52).

Nitrogen source influences on plant metabolism

The general consensus in the literature indicates that crop variance from the norm occurs under excessive NH_4^+ rather than NO_3^- fertilization (14, 48, 67, 75). The review, therefore, will center around the abnormalities in structure and

metabolism associated with NH_4^+ treated crops.

Vines and Wedding (75) observed reduced oxygen uptake of isolated beet root and excised barley root mitochondria in the presence of NH_3 gas. The authors concluded that the NH_3 inhibited mitochondrial respiration due to a disruption of the electron transport system, specifically inhibiting the oxidation of $NADH_2$. This may lead to an ATP (chemical bond energy) deficiency since terminal oxidation is a major site of ADP phosphorylation (68). Pyruvate kinase, an allosteric controlling enzyme in glucolysis, is activated by the high ADP concentrations induced by NH_3 (60). This results in a drain on photosynthetically incorporated carbon to form amino acids by decreasing sucrose synthesis (14, 48, 67). Vines and Wedding (75) also suggest that the NH_3 induced reduction of respiration was partly brought about by decreased membrane permeability to oxygen.

It is well-established that NH_4^+ may disrupt photosynthesis in susceptible varieties. Izawa et al. (41) reported that high concentrations of NH_3 block the water splitting in photosystem II. This results in the uncoupling of electron flow from phosphorylation (25, 41). Some investigators have reported chloroplast degradation under NH_4^+ fertilization (64). Puritch and Barker (64) concluded that alterations in chloroplast structure were a result of reduced phosphorylation, derangement of protein metabolism, and continuous loss of chlorophyll.

Ammonium fertilization has been shown to decrease water potential (65). Quebedeaux and Ozbun (65), in a study on NH_4^+ treated tomato plants, observed inhibition of water uptake, root exudation, and a decreased leaf water potential. They surmise that the NH_4^+, during brief exposure, directly inhibits water uptake or may cause anatomical and physiological changes during long-term use. Wilcox et al. (76) report similar observations of a rapid decrease in the xylem exudation rate in tomato with NH_4^+ fertilization.

Since there are reports of good yields with NH_4^+ fertilization, in contrast to NO_3^--N, it appears the difference between susceptible and not susceptible species to NH_4^+ toxicity lies in the ability of the plant to assimilate the NH_4^+ into nontoxic metabolites in the roots (8). This root metabolism prevents high concentrations of NH_4^+ and its amides from accumulating in the shoots (8).

High concentrations of organic N and NH_4^+ in the stems and leaves of plants fertilized with NH_4^+ have been associated with reduced Ca, Mg, and K concentrations (1, 3, 7, 18). Holding the NH_4^+:K ratio constant has been shown to inhibit the detrimental effects observed in NH_4^+ treated plants (1, 7). Ajayi et al. (1) indicated that increased K levels enhance NH_4^+ assimilation in the roots, thereby decreasing the NH_4^+ concentration translocated to the shoot. Loss of membrane integrity, as a result of Ca deficiency, may also impair NH_4^+ assimilation (37). The addition of $CaCO_3$, to maintain the pH

near neutrality, has been reported to provide a more favorable environment for NH_4^+ assimilation, consequently reducing the probability of NH_4^+ toxicity in susceptible varieties (54). There is evidence to suggest that some plant species modify the effect of acid forming N fertilizers by altering the excess base/N ratio (57).

One of the major contributing factors to poor yields obtained with NH_4^+ sensitive plants, under NH_4^+ fertilization, is the drain on photosynthetically incorporated carbon to form amino acids by decreasing sucrose synthesis (14, 48, 67). Behrend and Mateles (12) reported that the addition of specific TCA cycle acids can provide the carbon skeletons for synthesis of amino acids necessary for growth under NH_3 treated tobacco cells.

MATERIALS AND METHODS

To test the influence of N source under varying shade regimes and N level on the growth and mineral uptake of P. oxycardium, solution culture experiments were conducted. Three- to ten-leaf, rooted plants were rinsed in distilled water and transplanted into 15 cm (1530 cm^3) plastic pots containing coarse grade perlite[1]. The pots were placed on a corrugated greenhouse bench covered with wire mesh, such that the pots could adequately drain. The plants were mechanically supported by the use of string suspended inside shade cloth enclosures constructed from woven polypropylene shading material.

To determine the shade intensity, light readings were taken in the center of the greenhouse in the vicinity of the bench where the shade enclosures were located. Several light readings per experiment were taken at solar noon on a clear day and averaged. The light intensity was determined using a Lambda light meter with a quantum sensor. Numerous light readings within the shade enclosures were taken at the plant canopy each month during the course of the study and an average light intensity was determined for each shade level. The light readings obtained in the shade enclosures were compared to the greenhouse light intensity to determine

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[1]Contains essentially no available mineral nutrients and has no meaningful cation exchange capacity.

the amount of light each enclosure shaded out.

Experiment 1

A solution culture experiment was established to observe the interaction of N source and shade intensity on the yield of P. oxycardium. A total of 16 plants was placed into each of 3 rectangular shaped shade enclosures of varying shade intensity. The shade enclosures utilized excluded approximately 56 (700 $\mu Em^{-2}s^{-1}$), 79 (333 $\mu Em^{-2}s^{-1}$), and 92% (135 $\mu Em^{-2}s^{-1}$) of the total light intensity (1600 $\mu Em^{-2}s^{-1}$) in the greenhouse. Treatments were initiated March 13 and terminated July 1, 1978. The experimental design was a split plot in which the unreplicated whole plot consisted of the 3 levels of shade and the subplot, comprised of different nitrogen sources. There was a total of 4 nitrogen sources applied, and they were replicated 4 times per block. Treatments were randomized as a 4x4 Latin square in each shade enclosure. Nitrogen was supplied, in complete nutrient solutions, at the rate of 10 meq/liter, as either NO_3^-, NH_4^+, urea, or a 1:1 mixture of $NH_4^+ + NO_3^-$. All other major elements were held constant ($H_2PO_4^{-2}$ at 2 meq/liter, K^+ at 6 meq/liter, Ca^{+2} at 5 meq/liter and Mg^{+2} at 4 meq/liter), except Cl^- (ranged from 1 to 5 meq/liter) and SO_4^{-2} (ranged from 4 to 20 meq/liter) which were varied to balance the nutrient solutions. Sodium was also constant (1 meq/liter) in the 4 nutrient solutions of this experiment. The minor

elements[1] were supplied at the same level and from the same source for each of the 4 different nutrient solutions. Every other day, 3 times per week, 250 ml of complete nutrient solution was applied per pot. Once per week, 300 ml of distilled water was supplied to leach out any accumulated salts.

Experiment 2

To establish the effectiveness of N source at various N levels on the production of P. oxycardium a 3x4 factorial experiment of nitrogen level by source was initiated June 7 and terminated September 6, 1978. Nitrogen was supplied at the rate of 5, 10, and 15 meq/liter as NO_3^-, NH_4^+, urea, or a 1:1 NH_4^+ + NO_3^- combination. The pots were placed under a rectangular shaped shade enclosure which excluded 65% (274 $\mu Em^{-2}s^{-1}$) of the total light (784 $\mu Em^{-2}s^{-1}$). The nutrient solutions varied only in N source and level. All the major and minor elements were held constant and supplied at the same rate and in the same manner as experiment 1, except Cl^- (ranged from 1 to 6 meq/liter), SO_4^{-2} (ranged from 4 to 24 meq/liter), and Na^+ (ranged from 1 to 2.3 meq/liter) which were varied to balance the different nutrient solutions.

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[1]The minor elements were .5 ppm B as H_3BO_3, .5 ppm Mn as $MnCl_2 \cdot 4H_2O$, .05 ppm Zn as $ZnSO_4 \cdot 7H_2O$, .02 ppm Cu as $CuSO_4 \cdot 5H_2O$, .01 ppm Mo as $H_2MO_4 \cdot H_2O$, and 5.0 ppm Fe as sequestrene 12%.

Experiment 3

This study was conducted to observe the influence of N source under more uniform shade regimes, on the yield of P. oxycardium during the fall and winter months. A split plot experiment, shade cloth enclosures representing the whole plot and nitrogen source as the subplot, was initiated September 25, 1978 and terminated April 6, 1979. The enclosure was constructed as a hemisphere, rather than a rectangle as in experiment 1, for more uniform light distribution. The shade enclosures utilized excluded approximately 45 (605 $\mu Em^{-2}s^{-1}$), 74 (286 $\mu Em^{-2}s^{-1}$), and 96% (44 $\mu Em^{-2}s^{-1}$) of the total light (1100 $\mu Em^{-2}s^{-1}$) in the greenhouse. A 4x4 Latin square of nitrogen source by replication was employed to randomize treatments within each shade block. Nutrient solutions among treatments differed only in nitrogen source, which was supplied at 10 meq/liter as either NO_3^-, NH_4^+, urea, or a 1:1 combination of $NH_4^+ + NO_3^-$. The other elements, both major and minor, were supplied at the same rate, from the same sources, and in the same manner as in experiment 1.

At the termination of the experiments, plant yield was determined. Beginning at the terminal tip, the total number of leaves produced since the treatments began were counted, internode lengths of the first 5 nodes were averaged, stem diameters of the 1st, 3rd, and 5th internodes were measured and averaged, leaf surface area of the 4th, 5th, and 6th

leaves were averaged, and total stem length was measured. Total fresh weights and the dry weights of the roots, stems, and leaves were also determined.

Leachate pH's were taken several times during the course of each experiment and an average medium pH determined. The leachate pH was taken by applying excess distilled water to the rooting medium and collecting the runoff. Determinations were made following the completion of a week's series of treatment applications once a month during the course of each experiment.

In preparation for mineral analyses, the leaves were rinsed in distilled water, and dried in a force air oven at 60°C. They were then ground in a Wiley mill to pass a 40-mesh screen. To determine total N, .10 g of oven dried leaf tissue was placed into Folin-Wu test tubes, digested and analyzed according to the micro-Kjeldahl procedure reported by Nelson and Sommers (51). To analyze the leaf tissue for P, K, Ca, Mg, Fe, Mn, and Zn, .5 gram samples were placed in porcelain crucibles and ashed for 5 hours in a muffle furnace at 505°C. The residues were dissolved in 5 ml of 1:1 HCl/HOH, brought to a boil, filtered, and brought up to 50 ml volume with distilled water. The Vandomolybdate phosphoric yellow color method in HCl system (42) was used to determine P and was read on a Bausch and Lomb Spectronic 20 Colorimeter. The leaf tissue K, Ca, Mg, Fe, Mn, and Zn concentrations were determined on a Perkin-Elmer Model 403

Atomic Absorption Spectrophotometer.

Analysis of variance and mean separation at the 5% level of Duncan's new multiple range test (71) were computed using the Statistical Analysis System (11).

RESULTS

Experiment 1

pH effects

The initial pH for the nutrient solutions did not vary greatly among N sources but during the course of the experiment changes in the leachate pH became evident (Table 1). A higher pH was associated with the NO_3^- and $NH_4^+ + NO_3^-$ treatments and did not vary with shade intensity. Urea and NH_4^+ treatments resulted in a lower pH with differences associated with shade level. At 56 and 79% shade the leachate pH was lower in the NH_4^+ regime than at 92% shade. Under 79% shade the urea treatment resulted in a lower leachate pH than at 92% shade, while the pH under 56% shade was not different from either. The urea and NH_4^+ regimes produced similar pH values under 92% shade; however, overall urea resulted in an intermediate leachate pH between NO_3^-, $NH_4^+ + NO_3^-$, and NH_4^+.

Philodendron response to N source and shade intensity

Under the 56% shade, taller plants were associated with the NO_3^- and $NH_4^+ + NO_3^-$ treatments compared to NH_4^+ (Table 2). The urea treated plants were not different in height from the $NH_4^+ + NO_3^-$ or the NH_4^+ treatments. Nitrate treated plants were significantly shorter under 79% shade than under 56% shade, while there were no differences in height between these shade

Table 1. Initial nutrient solution pH and the effect of N source x shade intensity on the leachate pH of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	Nutrient solution pH	% shade 56	79	92	Average
			Leachate pH[a]		
NO_3	4.3	6.2 a	6.2 a	6.0 a	6.1 a
NH_4	4.4	3.5 d	3.5 d	4.3 b	3.7 c
Urea	4.6	4.2 bc	3.9 c	4.5 b	4.2 b
$NH_4 + NO_3$	4.3	6.3 a	6.2 a	6.3 a	6.2 a
Average		5.0[b]	4.9	5.2	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

levels for the NH_4^+, urea, and $NH_4^+ + NO_3^-$ regimes. The tallest plants under 79% shade were produced by the $NH_4^+ + NO_3^-$ treatment compared to NO_3^- and urea nutrition, while height in NH_4^+ treated plants was not different from the $NH_4^+ + NO_3^-$ or NO_3^- treatments. Heights produced by NO_3^--N were also similar to urea treated plants. Plant height under 92% shade did not vary among N source and was significantly less than the heights produced under 56 and 79% shade.

An interaction between N source and shade level on

Table 2. The effect of shade level x N source on the height, internode length, and stem diameter of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	% shade 56	79	92	Average
		Height (cm)[a]		
NO_3	91.2 a	69.3 bcd	29.3 e	63.2 a
NH_4	64.1 cd	76.5 abc	27.9 e	56.2 ab
Urea	67.6 bcd	57.3 d	26.4 e	50.4 b
$NH_4 + NO_3$	81.0 ab	87.0 a	26.9 e	64.9 a
Average	76.0[b]	72.5	27.1	
		Internode length (cm)[a]		
NO_3	9.03 a	6.90 bc	2.90 d	6.27 a
NH_4	6.28 c	6.88 bc	2.73 d	5.29 b
Urea	6.75 bc	5.63 c	3.28 d	5.22 b
$NH_4 + NO_3$	7.90 ab	8.18 ab	2.65 d	6.24 a
Average	7.49[b]	6.89	2.89	
		Stem diameter (mm)[a]		
NO_3	4.10	3.08	1.38	2.85 a
NH_4	3.30	3.10	1.45	2.62 ab
Urea	3.40	2.78	1.45	2.54 b
$NH_4 + NO_3$	3.75	3.35	1.45	2.85 a
Average	3.64[b]	3.07	1.43	

[a]Means followed by a different letter within variable groups are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

internode length of P. oxycardium was evident (Table 2). Longer internode lengths under 56% shade were produced by NO_3^--N and $NH_4^+ + NO_3^-$ compared to the NH_4^+ treatment, while urea treated plants had internode lengths not different from the $NH_4^+ + NO_3^-$ or NH_4^+ regimes. There was no difference in internode length between the 56 and 79% shade levels for the NH_4^+, urea, and $NH_4^+ + NO_3^-$ treatments. However, NO_3^- treated plants had shorter internode lengths under 79% shade than at 56% shade. The $NH_4^+ + NO_3^-$ treatment produced longer internode lengths under 79% shade than the urea treatment, while the NO_3^- and NH_4^+ treatments were not different from either. There were no differences in internode lengths among N sources under 92% shade and they were significantly shorter than at the 56 or 79% shade levels.

Overall, the stem diameter of P. oxycardium followed the main effect of shade level and N source (Table 2). Larger stem diameters were produced under 56% shade than at 79% shade, but differences between these shade levels were slight. Stem diameter was severely restricted under 92% shade compared to the other shade intensities. The NO_3^- and $NH_4^+ + NO_3^-$ treated plants had larger stem diameters than the urea treatment, while stem diameter under NH_4^+ nutrition was not different from the other N sources.

As shade intensity increased from 56 to 79% slightly fewer leaves were produced by the plants with each N source (Table 3). The number of leaves produced under 92% shade was

Table 3. The effect of N source x shade level on the number of leaves produced and leaf surface area of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	% shade 56	79	92	Average
	No. of leaves[a]			
NO_3	10.50	9.50	5.75	8.58 a
NH_4	9.50	8.75	5.00	7.75 b
Urea	9.25	9.00	5.50	7.92 b
$NH_4 + NO_3$	9.50	9.25	5.25	8.00 ab
Average	9.69[b]	9.12	5.37	
	Leaf surface area (cm^2)[a]			
NO_3	83.2	69.7	28.4	60.4 a
NH_4	67.9	65.9	26.4	53.4 b
Urea	72.9	61.0	26.9	53.6 b
$NH_4 + NO_3$	73.8	79.0	25.9	59.6 ab
Average	74.5[b]	68.9	26.9	

[a]Means followed by a different letter within any group are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

considerably less than that obtained at the other shade levels. Overall NO_3^--N produced more leaves than the NH_4^+ and urea treatments, while the number of leaves produced under $NH_4^+ + NO_3^-$ was not different from the other N sources.

The influence of N source and shade level on leaf surface area showed a similar trend as the number of leaves produced (Table 3). The leaf surface area decreased slightly as shade intensity increased from 56 to 79% with the NO_3^-, NH_4^+, and urea treatments. Although not significant, there was a slightly greater leaf surface area at 79% shade than at 56% shade associated with the $NH_4^+ + NO_3^-$ treatment. Under 92% shade the leaf surface area was severely restricted with each N source. Nitrate-N produced a larger leaf surface area than NH_4^+ and urea, but $NH_4^+ + NO_3^-$ was not different from the other sources.

The interaction of N source and shade level on the fresh weight of P. oxycardium was significant (Table 4). Nitrate-N, under 56% shade, produced a larger fresh weight than the other N sources which had similar weights. The fresh weight at 79% shade in NO_3^- treated plants was less than the weight obtained under 56% shade, while fresh weight did not vary between these shade levels for the other N sources. Higher fresh weights were obtained with $NH_4^+ + NO_3^-$ at 79% shade than with NO_3^-, NH_4^+, and urea, which were not different in weight. Fresh weight did not vary among N source under 92% shade and was significantly less than the weight at the 56 and 79% shade levels.

Table 4. The effect of N source x shade level on the fresh weight and dry weight of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	% shade 56	79	92	Average
	Fresh weight (g)[a]			
NO_3	70.4 a	48.6 c	14.8 d	44.6 a
NH_4	44.4 c	46.1 c	14.2 d	34.9 b
Urea	49.8 c	41.2 c	14.4 d	35.1 b
$NH_4 + NO_3$	54.1 bc	62.3 ab	13.9 d	43.4 a
Average	54.7[b]	49.5	14.3	
	Dry weight (g)[a]			
NO_3	7.86 a	4.75 cd	1.21 e	4.60 a
NH_4	5.33 bcd	4.63 cd	1.20 e	3.72 ab
Urea	5.39 bcd	3.97 d	1.19 e	3.51 b
$NH_4 + NO_3$	6.06 bc	6.45 ab	1.12 e	4.54 a
Average	6.16[b]	4.95	1.18	

[a]Means within variable groups followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

The interaction of N source and shade level on plant dry weight showed a similar trend as the fresh weight (Table 4). Under 56% shade NO_3^- treated plants had larger dry weights than the NH_4^+, urea, and $NH_4^+ + NO_3^-$ treatments, which had similar weights. The dry weight at 79% shade was significantly lower than at 56% shade with NO_3^--N, while there was no difference between these shade levels with the other N sources. Ammonium plus nitrate produced higher dry weights under 79% shade than the NO_3^-, NH_4^+, and urea sources, which were not different in weight. There were no differences in dry weight among N sources under 92% shade, and these were significantly less than those at the 56 and 79% shade levels.

Effect of N source and shade level on elemental composition

Shade level did not appear to affect leaf N concentration when averaged over the 4 N sources (Table 5). Higher N concentrations were associated with urea, while $NH_4^+ + NO_3^-$ treated plants were greater than NO_3^-. The N concentration under NH_4^+ nutrition was not different from those obtained with urea or $NH_4^+ + NO_3^-$.

There were no differences in P concentration between the 56 and 79% shade levels (Table 5). However, P concentration under 92% shade was somewhat higher for each N source compared to the other shade intensities. A higher P concentration was associated with the NH_4^+, urea, and $NH_4^+ + NO_3^-$ treated plants and did not differ between sources.

Table 5. The effect of N source x shade level on the N, P, and K concentration of P. oxycardium leaf tissue

Nitrogen source 10 meq/liter	% shade 56	79	92	Average
	% N (dry wt)[a]			
NO_3	2.80	2.66	2.75	2.73 c
NH_4	3.14	2.89	2.98	3.00 ab
Urea	3.11	3.03	3.03	3.06 a
$NH_4 + NO_3$	2.81	2.83	3.10	2.91 b
Average	2.96[b]	2.85	2.96	
	% P (dry wt)[a]			
NO_3	.145	.144	.162	.150 b
NH_4	.148	.152	.194	.166 a
Urea	.166	.168	.191	.175 a
$NH_4 + NO_3$	.167	.155	.178	.167 a
Average	.156[a]	.155	.182	
	% K (dry wt)[a]			
NO_3	4.21	3.55	2.99	3.58 a
NH_4	4.18	3.62	2.81	3.53 a
Urea	4.53	3.29	2.29	3.37 a
$NH_4 + NO_3$	3.46	3.21	2.95	3.20 a
Average	4.09[b]	3.42	2.76	

[a]Means within any group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

A drop in K concentration with each rise in shade level for each N source was noted (Table 5). Generally, N source did not influence K concentration in the leaf tissue of P. oxycardium. However, under 56% shade there was a trend of reduced K concentration associated with $NH_4^+ + NO_3^-$.

An interaction between N source and shade level on Ca concentration was evident (Table 6). Highest Ca concentrations under 56% shade were associated with the NO_3^- treatment compared to NH_4^+ and urea treated plants, which had similar Ca levels. The Ca concentration in the $NH_4^+ + NO_3^-$ regime was not different from that obtained by NO_3^- and NH_4^+. As shade level increased from 56 to 79% the Ca concentration remained stable in the NO_3^-, urea, and $NH_4^+ + NO_3^-$ treated plants, while under NH_4^+ nutrition Ca concentration increased at 79% shade. Higher Ca concentrations at 79% shade were associated with the NO_3^- and NH_4^+ treatments compared to urea and $NH_4^+ + NO_3^-$ treated plants. Under 92% shade, the Ca concentration decreased with the NO_3^- and urea treatments compared to the other shade levels. The Ca concentration under 92% shade also decreased using NH_4^+ compared to 79% shade, but it did not differ from 56% shade. Ammonium plus nitrate treated plants had a lower Ca concentration under 92% shade compared to 56% shade, but it did not differ from 79% shade. The Ca concentration under 92% shade was not different in NO_3^-, NH_4^+, and $NH_4^+ + NO_3^-$ treated plants, while urea resulted in a lower Ca concentration.

Higher Mg concentrations, under 56% shade, were associated

Table 6. The influence of N source x shade intensity on the Ca, Mg, and Fe concentration of P. oxycardium leaf tissue

Nitrogen source 10 meq/liter	% shade 56	79	92	Average
	% Ca (dry wt)[a]			
NO_3	2.59 a	2.44 a	2.08 c	2.37 a
NH_4	2.16 bc	2.48 a	1.98 c	2.21 b
Urea	1.99 c	2.03 c	1.53 d	1.85 c
$NH_4 + NO_3$	2.36 ab	2.14 bc	1.99 c	2.16 b
Average	2.27[b]	2.27	1.89	
	% Mg (dry wt)[a]			
NO_3	.378 ab	.368 ab	.395 a	.380 a
NH_4	.335 bc	.330 bc	.285 c	.317 b
Urea	.298 c	.300 c	.375 ab	.324 b
$NH_4 + NO_3$	.315 bc	.275 c	.333 bc	.308 b
Average	.331[b]	.318	.347	
	ppm Fe (dry wt)[a]			
NO_3	131 de	183 abc	220 a	177 a
NH_4	138 de	146 cde	191 ab	158 ab
Urea	136 de	160 bcd	193 ab	162 ab
$NH_4 + NO_3$	128 de	113 e	217 a	152 b
Average	133[b]	150	205	

[a]Means within variable groups followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

with NO_3^--N compared to urea, while NH_4^+ and $NH_4^+ + NO_3^-$ treated plants were not different from either (Table 6). As shade intensity increased to 79% the Mg concentration remained stable for all 4 N sources. However, $NH_4^+ + NO_3^-$ treated plants accumulated a significantly lower Mg concentration than under NO_3^--N. At 92% shade the Mg concentration did not differ from the other shade levels with the NO_3^-, NH_4^+, and $NH_4^+ + NO_3^-$ treatments while an increase was associated with urea. Higher Mg concentrations at 92% shade were associated with the NO_3^- treatment compared to the NH_4^+ and $NH_4^+ + NO_3^-$ regimes, which had a similar Mg concentration. The Mg concentration with urea nutrition was not different from NO_3^- and $NH_4^+ + NO_3^-$ treated plants.

The leaf Fe concentration under 56% shade did not vary with N source (Table 6). As the shade intensity increased from 56 to 79% the Fe concentration increased in NO_3^- treated plants, while it remained stable between these shade levels with the NH_4^+, urea, and $NH_4^+ + NO_3^-$ treatments. Higher Fe concentrations at 79% shade were associated with the NO_3^- and urea treatments compared to the $NH_4^+ + NO_3^-$ regime. Ammonium N resulted in Fe concentrations not different from any other N source. Under 92% shade the Mg concentration remained stable for the NO_3^- and urea N sources compared to 79% shade, but was significantly higher than at 56% shade. The NH_4^+ and $NH_4^+ + NO_3^-$ N sources at 92% shade resulted in higher Mg concentrations than levels obtained under 56 and 79% shade.

Nitrogen source did not influence Fe concentration at 92% shade.

The leaf Mn concentration at 56% shade was higher in plants treated with NO_3^- and urea, than those receiving NH_4^+ or $NH_4^+ + NO_3^-$ (Table 7). There were no differences between NO_3^- and urea or NH_4^+ and $NH_4^+ + NO_3^-$. The Mn concentration did not differ under 79% shade from that found at 56% shade with each N source. The highest Mn concentration at 79% shade was associated with the NO_3^- treatment compared to the other N sources. Urea treated plants had a higher Mn concentration than the NH_4^+ regime, but the $NH_4^+ + NO_3^-$ treatment did not differ from either. At 92% shade Mn concentration increased with the NO_3^-, NH_4^+, and $NH_4^+ + NO_3^-$ treatments compared to the other shade levels. Whereas, the urea regime had similar Mn concentrations at each shade level. Nitrate N produced the highest Mn concentration at 92% shade, while the urea treatment was the lowest. An intermediate Mn concentration was associated with the NH_4^+ and $NH_4^+ + NO_3^-$ regimes.

Small differences in Zn concentration were evident between the 56 and 79% shade levels for all N sources (Table 7). Under 92% shade Zn concentration was higher than at the other shade levels for each N source. Higher Zn concentrations, averaged over the 3 shade levels, were associated with NO_3^--N compared to NH_4^+ and $NH_4^+ + NO_3^-$, which had similar Zn concentrations. The Zn concentration of urea treated plants was not different from the other N sources.

Table 7. The effect of N source x shade level on the Mn and Zn concentration of P. oxycardium leaf tissue

Nitrogen source 10 meq/liter	% shade 56	79	92	Average
	ppm Mn (dry wt)[a]			
NO_3	141 bc	158 b	214 a	170 a
NH_4	78 e	74 e	164 b	105 c
Urea	134 bc	121 cd	120 cd	125 b
$NH_4 + NO_3$	88 de	92 de	161 b	113 bc
Average	110[b]	111	164	
	ppm Zn (dry wt)[a]			
NO_3	22.5	30.3	31.6	28.0 a
NH_4	20.3	22.3	29.6	24.0 b
Urea	23.0	24.8	28.7	25.5 ab
$NH_4 + NO_3$	22.5	22.3	29.8	24.8 b
Average	22.1[b]	24.1	29.8	

[a]Means within variable groups followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

Experiment 2

pH effects

The initial pH did not vary greatly among N levels (Table 8). Nitrate, NH_4^+, and NO_3^- N sources had similar nutrient solution pH values, while urea had a substantially higher pH.

The interaction between N source and N level on leachate pH was significant (Table 9). A higher leachate pH was associated with NO_3^--N at the 5 meq/liter N level compared to the other N sources. Urea produced a higher pH than $NH_4^+ + NO_3^-$ and NH_4^+, while NH_4^+ resulted in the lowest leachate pH. As the N level increased to 10 meq/liter the leachate pH remained stable for all N sources. The NO_3^- and urea treatments affected the leachate pH in a similar fashion to 5 meq/liter N. Ammonium and $NH_4^+ + NO_3^-$, however, resulted in the lowest leachate pH and did not differ. At the 15 meq/liter N level the leachate pH was not different than the pH at the other N levels for the NH_4^+ and $NH_4^+ + NO_3^-$ treatments. The leachate pH decreased in the NO_3^- regime at the 15 meq/liter N level compared to the other N levels. Conversely, the leachate pH under 15 meq/liter N urea treatment was significantly higher than at 5 and 10 meq/liter N. Higher leachate pH values at the 15 meq/liter N level were associated with the urea and NO_3^- treatments, which did not differ. Ammonium plus nitrate resulted in an intermediate leachate pH, while NH_4^+ produced the most acidic media.

Table 8. Initial nutrient solution pH as influenced by N source and concentration

Nitrogen source	Nitrogen level (meq/liter)		
	5	10	15
	Nutrient solution pH		
NO_3	4.8	4.4	4.3
NH_4	4.8	4.4	4.9
Urea	5.6	5.6	6.0
$NH_4 + NO_3$	4.2	4.8	5.0

Table 9. The leachate pH as influenced by N source and N concentration of P. oxycardium grown in solution culture

Nitrogen source	Nitrogen level (meq/liter)			
	5	10	15	Average
	Leachate pH[a]			
NO_3	6.0 a	6.0 a	5.5 bc	5.8 a
NH_4	3.1 e	3.3 de	3.1 e	3.2 d
Urea	5.1 c	5.1 c	5.6 ab	5.3 b
$NH_4 + NO_3$	3.7 d	3.5 de	3.6 d	3.6 c
Average	4.5 a	4.5 a	4.5 a	

[a]Means within each group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Influence of N source and N level on P. oxycardium growth

The yield responses of Philodendron to N source and varying N levels generally followed the trends of the main effects (Appendix Tables A1, A2, A3). There was no difference between the NO_3^- and urea N sources in any of the categories of plant growth determined (Table 10). Nitrogen source did not affect leaf surface area, stem diameter, fresh weight, and dry weight. Ammonium and $NH_4^+ + NO_3^-$ treated plants, however, were significantly shorter and had smaller internode lengths compared to NO_3^--N, but they did not differ from urea. The number of leaves produced with the NO_3^- treatment was greater than with the $NH_4^+ + NO_3^-$ regime, while NH_4^+ and urea were not different from either.

The influence of N level on the growth of P. oxycardium is presented in Table 11. There were no differences in plant growth between the 5, 10, or 15 meq/liter N levels.

Influence of N source and N level on elemental composition

An interaction between N source and N level on Zn concentration was evident (Table 12). Higher Zn concentrations were associated with the urea treatment at the 5 meq/liter N level compared to the NH_4^+ and $NH_4^+ + NO_3^-$ regimes, which had a similar Zn concentration. Nitrate treated plants had Zn concentrations no different from urea, NH_4^+, and $NH_4^+ + NO_3^-$. At 10 meq/liter, the Zn concentration decreased in the urea treatment, while the NO_3^-, NH_4^+, and $NH_4^+ + NO_3^-$ regimes had

Table 10. The influence of N source, averaged over 3 N levels, on the growth of *P. oxycardium* grown in solution culture[a]

Nitrogen source	Height (cm)	Leaf surface area (cm^2)	No. of leaves	Internode length (cm)	Stem diameter (mm)	Fresh weight (g)	Dry weight (g)
NO_3	94.3 a	85.8 a	10.2 a	7.45 a	2.12 a	62.9 a	5.52 a
NH_4	80.5 b	78.7 a	9.7 ab	6.32 b	1.86 a	50.3 a	5.01 a
Urea	85.1 ab	77.3 a	10.1 ab	6.63 ab	1.99 a	53.8 a	4.77 a
$NH_4 + NO_3$	77.0 b	80.1 a	9.4 b	6.40 b	1.87 a	51.1 a	4.71 a

[a]Means within any column followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Table 11. The influence of N level, averaged over 4 N sources, on the growth of *P. oxycardium* grown in solution culture[a]

Nitrogen level meq/liter	Height (cm)	Leaf surface area (cm^2)	No. of leaves	Internode length (cm)	Stem diameter (mm)	Fresh weight (g)	Dry weight (g)
5	80.0 a	79.1 a	9.75 a	6.29 a	1.90 a	51.5 a	4.59 a
10	87.2 a	84.3 a	9.94 a	6.96 a	2.02 a	57.3 a	5.23 a
15	85.5 a	77.9 a	9.87 a	6.86 a	1.96 a	54.8 a	5.19 a

[a]Means within any column followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test.

Table 12. The effect of N level and N source on Zn concentration in leaf tissues of P. oxycardium

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
	ppm Zn[a]			
NO_3	33.3 ab	32.5 ab	32.5 ab	32.7 a
NH_4	27.0 b	27.8 b	29.0 b	27.9 b
Urea	37.0 a	26.8 b	30.3 b	31.3 ab
$NH_4 + NO_3$	28.0 b	32.8 ab	29.5 b	30.1 ab
Average	31.3 a	29.9 a	30.3 a	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

similar Zn concentrations to those at 5 meq/liter N. There were no differences among N source on Zn concentration at the 10 meq/liter N rate. At the 15 meq/liter N level the Zn concentration for NO_3^-, NH_4^+, and $NH_4^+ + NO_3^-$ treated plants was not different than at the other N levels. Urea resulted in a similar Zn concentration at 15 meq/liter N as at 10 meq/liter N; however, it was significantly lower than the 5 meq/liter N level. There were no differences among N sources on Zn concentration at the 15 meq/liter N rate.

Slight variations in the leaf N, P, K, Ca, Mg, Fe, and Mn concentrations as influenced by N source and N level were

noted, but overall they followed the same trends as the main effects (Appendix Tables A4, A5, A6). Nitrate treated plants accumulated higher Ca, Mg, and Mn concentrations than plants supplied with NH_4^+, urea, and $NH_4^+ + NO_3^-$ (Table 13). The Ca concentration in the NH_4^+, urea, and $NH_4^+ + NO_3^-$ regimes was similar. The Mg concentration was intermediate between NO_3^- and urea under NH_4^+ nutrition, while $NH_4^+ + NO_3^-$ was not different from NH_4^+ or urea. Manganese concentration was lowest with the $NH_4^+ + NO_3^-$ treatment and intermediate in urea treated plants. The NH_4^+ treated plants had similar Mn concentrations as under urea and $NH_4^+ + NO_3^-$ nutrition.

Highest N concentrations were associated with the urea treatment compared to NO_3^- and NH_4^+-N, while $NH_4^+ + NO_3^-$ was not different from the other N sources (Table 13). Urea and $NH_4^+ + NO_3^-$ treated plants had similar P concentrations which were significantly higher than under NH_4^+ nutrition (Table 13). The P concentration of NO_3^- treated plants was not different than the urea and NH_4^+ regimes. Nitrate treated plants had a significantly higher K concentration than those treated with $NH_4^+ + NO_3^-$, while the NH_4^+ and urea treatments were not different from either (Table 13). Iron concentration was higher under NO_3^--N than under the urea and $NH_4^+ + NO_3^-$ regimes whereas NH_4^+ was not different from the other sources (Table 13).

Nitrogen concentration, averaged over the 4 N sources, was enhanced at the 15 meq/liter N level compared to 5 meq/

Table 13. The influence of N source, averaged over 3 N levels, on the N, P, K, Ca, Mg, Fe, and Mn leaf concentration of *P. oxycardium*[a]

Nitrogen source	N	P	K	Ca	Mg	Fe	Mn
	% dry wt					ppm	
NO_3	2.84 b	.180 bc	5.82 a	2.16 a	.372 a	188 a	138 a
NH_4	2.80 b	.173 c	5.57 ab	1.91 b	.338 b	168 ab	103 bc
Urea	3.01 a	.190 ab	5.58 ab	1.92 b	.306 c	156 b	108 b
$NH_4 + NO_3$	2.90 ab	.193 a	5.51 b	1.99 b	.317 bc	154 b	91 c

[a]Means within any column followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Table 14. The influence of N level, averaged over 4 N sources, on the N, P, K, Ca, Mg, Fe, and Mn concentration of P. oxycardium leaf tissues[a]

Nitrogen level meq/liter	N	P	K	Ca	Mg	Fe	Mn
	% dry wt					ppm	
5	2.81 b	.181 a	5.73 a	2.04 a	3.31 a	167 a	110 a
10	2.89 ab	.183 a	5.59 a	1.96 a	.334 a	163 a	110 a
15	2.96 a	.186 a	5.55 a	2.00 a	.334 a	169 a	110 a

[a]Means within any column followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

liter N, while the 10 meq/liter N level was not different from either (Table 14). Nitrogen level did not influence P, K, Ca, Mg, Fe, and Mn concentration.

Experiment 3

pH effects

The initial pH for the nutrient solutions did not vary greatly among the NO_3^-, NH_4^+, and $NH_4^+ + NO_3^-$ sources, while the nutrient solution pH for urea was higher (Table 15). Although shade intensity did not appear to influence leachate pH differences in pH were noted among N sources. The pH of the leachate was significantly higher under NO_3^- nutrition than the other N sources. The leachate pH in the urea regime was intermediate while the pH under the NH_4^+ and $NH_4^+ + NO_3^-$ treatments was significantly lower and did not vary between these sources.

Philodendron response to N source and shade intensity

As shade intensity increased from 45 to 74% there was a slight decrease in Philodendron height (Table 16). Height under 96% shade was severely restricted with each N source compared to the other shade levels. Nitrogen source, averaged over the 3 shade intensities did not influence height.

The effect of shade level on internode length showed a similar trend as plant height (Table 16). Overall, differences in internode length between the 45 and 74% shade levels for the 4 N sources were small, while measurements were substan-

Table 15. The initial nutrient solution pH and the effect of N source x shade intensity on the leachate pH of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	Nutrient solution pH	% shade			Average[a]
		45	74	96	
		Leachate pH			
NO_3	5.3	5.8	5.6	5.9	5.8 a
NH_4	5.0	3.5	3.6	4.5	3.9 c
Urea	6.0	4.5	4.8	4.8	4.7 b
$NH_4 + NO_3$	5.0	3.8	3.7	4.2	3.9 c
Average		4.4[b]	4.4	4.8	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

tially less under 96% shade. Nitrate-N resulted in longer internode lengths than NH_4^+, whereas urea and $NH_4^+ + NO_3^-$ were not different from either.

Stem diameter, averaged over the 3 shade levels, was not influenced by N source (Table 16). As shade intensity increased from 45 to 96% stem diameter decreased for each N source. However, measurements between 45 and 74% shade were closer in range than at 96% shade.

There was a slight decrease in the number of leaves

Table 16. The influence of shade level and N source on the height, internode length and stem diameter of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	% shade 45	74	96	Average[a]
	Height (cm)			
NO_3	148	138	42	109 a
NH_4	111	98	34	81 a
Urea	137	132	36	101 a
$NH_4 + NO_3$	159	121	34	105 a
Average	139[b]	122	37	
	Internode length (cm)			
NO_3	11.7	12.4	3.2	9.1 a
NH_4	8.3	9.2	3.0	6.9 b
Urea	10.7	11.6	3.7	8.7 ab
$NH_4 + NO_3$	11.3	10.7	3.0	8.3 ab
Average	10.5[b]	11.0	3.2	
	Stem diameter (mm)			
NO_3	5.95	4.98	1.37	4.10 a
NH_4	4.75	3.68	1.25	3.23 a
Urea	6.08	5.18	1.35	4.20 a
$NH_4 + NO_3$	5.33	4.70	1.25	3.76 a
Average	5.53[b]	4.64	1.31	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

produced between the 45 and 74% shade levels, while the number was severely restricted under 96% shade (Table 17). Nitrogen source did not influence the number of leaves produced.

Urea treated plants, overall, had a larger leaf surface area than those under NH_4^+ nutrition, while the NO_3^- and NH_4^+ + NO_3^- treatments were not different from either (Table 17). Leaf surface area was restricted under 96% shade compared to 45 and 74% shade, which had similar measurements.

The influence of N source and shade level on the fresh and dry weight of P. oxycardium showed a similar trend (Table 18). The differences in fresh and dry weight between the 45 and 74% shade levels were slight compared to 96% shade, which produced substantially lower weights. Nitrogen source, averaged over the 3 shade levels, did not influence fresh or dry weight.

Effect of N source and shade level on elemental composition

As shade intensity increased from 45 to 96% there was a small increase in leaf tissue N concentration for each N source (Table 19). Urea treated plants accumulated more N than the NO_3^- and NH_4^+ treatments, while the NH_4^+ + NO_3^- treatment was not different from any other N source.

Phosphorus concentration was higher under urea and NH_4^+ + NO_3^- nutrition compared to the NO_3^- and NH_4^+ treatments

Table 17. The influence of shade intensity x N source on the number of leaves produced and leaf surface area of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	% shade 45	74	96	Average[a]
	No. of leaves			
NO_3	16.3	15.5	7.3	13.0 a
NH_4	14.5	12.8	6.0	11.1 a
Urea	15.5	15.3	6.5	12.4 a
$NH_4 + NO_3$	17.8	14.5	7.3	13.2 a
Average	16.0[b]	14.5	6.8	
	Leaf surface area (cm^2)			
NO_3	80.5	86.8	25.1	64.1 ab
NH_4	69.2	71.3	22.4	54.3 b
Urea	96.1	91.6	23.0	70.2 a
$NH_4 + NO_3$	72.9	81.8	21.3	58.7 ab
Average	79.7[b]	82.9	22.9	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

Table 18. The effect of N source x shade level on the fresh and dry weight of P. oxycardium grown in solution culture

Nitrogen source 10 meq/liter	% shade 45	74	96	Average[a]
	Fresh weight (g)			
NO_3	104	93	14	70 a
NH_4	70	50	11	44 a
Urea	103	85	12	67 a
$NH_4 + NO_3$	98	76	11	62 a
Average	94[b]	76	12	
	Dry weight (g)			
NO_3	13.3	10.8	1.1	8.4 a
NH_4	10.1	6.1	1.0	5.7 a
Urea	13.7	9.5	1.0	8.1 a
$NH_4 + NO_3$	14.2	9.4	.9	8.2 a
Average	12.8[b]	9.0	1.0	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

Table 19. The influence of N source and shade level on the N, P, and K concentration of P. oxycardium leaf tissue

Nitrogen source 10 meq/liter	% shade 45	74	96	Average[a]
		% N (dry wt)		
NO_3	2.30	2.34	2.63	2.43 b
NH_4	2.25	2.50	2.52	2.42 b
Urea	2.36	2.63	2.97	2.65 a
$NH_4 + NO_3$	2.36	2.44	2.82	2.54 ab
Average	2.32[b]	2.48	2.74	
		% P (dry wt)		
NO_3	.151	.162	.213	.175 b
NH_4	.122	.149	.219	.163 b
Urea	.179	.190	.238	.203 a
$NH_4 + NO_3$	.166	.209	.243	.206 a
Average	.154[b]	.177	.228	
		% K (dry wt)		
NO_3	3.41	3.43	4.64	3.83 a
NH_4	3.42	3.55	4.51	3.83 a
Urea	3.44	3.48	4.56	3.83 a
$NH_4 + NO_3$	3.28	3.57	4.67	3.84 a
Average	3.39[b]	3.51	4.60	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

(Table 19). There were no differences between urea and $NH_4^+ + NO_3^-$ or NO_3^- and NH_4^+. With each increase in shade intensity an increase in P concentration was noted for each N source.

The influence of shade intensity on K concentration showed the same trend as P concentration (Table 19). As shade intensity increased from 45 to 96% the K concentration increased for each N source. Nitrogen sources, averaged over the 3 shade intensities, did not influence K concentration.

The interaction of N source and shade intensity on Ca concentration was evident (Table 20). Higher Ca concentrations at 45% shade were associated with the NO_3^- and urea treatments and did not differ among these sources. The lowest Ca concentration was associated with NH_4^+, while $NH_4^+ + NO_3^-$ treated plants were intermediate. The Ca concentration remained stable as shade intensity increased to 74% with the NO_3^-, urea, and $NH_4^+ + NO_3^-$ treatments. However, Ca concentration increased under 74% shade with NH_4^+ compared to the 45% shade level. Nitrate, urea, and $NH_4^+ + NO_3^-$ treated plants were not different in Ca concentration under 74% shade, while NH_4^+ nutrition was significantly lower. The Ca concentration decreased with the NO_3^-, urea, and $NH_4^+ + NO_3^-$ treatments under 96% shade compared to the 45 and 74% shade levels. Whereas the Ca concentration was lower under 96% shade for NH_4^+-N compared to 74% shade,

Table 20. The effect of N source and shade level on the Ca, Mg, and Fe concentration of P. oxycardium leaf tissue

Nitrogen source 10 meq/liter	% shade 45	74	96	Average
		% Ca (dry wt)[a]		
NO_3	3.25 a	3.18 ab	2.32 e	2.92 a
NH_4	2.37 e	2.70 d	2.24 ef	2.44 c
Urea	3.18 ab	3.01 abc	1.92 g	2.70 b
$NH_4 + NO_3$	2.83 cd	2.98 bc	2.00 fg	2.60 b
Average	2.91[b]	2.97	2.12	
		% Mg (dry wt)[a]		
NO_3	.420	.365	.295	.360 a
NH_4	.348	.313	.255	.305 c
Urea	.385	.338	.265	.329 b
$NH_4 + NO_3$	.393	.328	.273	.331 b
Average	.386[b]	.336	.272	
		ppm Fe (dry wt)[a]		
NO_3	103	107	164	124 a
NH_4	101	122	151	124 a
Urea	107	124	162	131 a
$NH_4 + NO_3$	93	107	165	122 a
Average	101[b]	115	160	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

it was not different than 45% shade. Nitrate and NH_4^+-N resulted in a higher Ca concentration at 96% shade than urea, while $NH_4^+ + NO_3^-$ was not different from the NH_4^+ and urea treatments.

The Mg concentration decreased with each N source as shade intensity increased from 45 to 96% (Table 20). Higher Mg concentrations were associated with NO_3^--N compared to the other N sources. The urea and $NH_4^+ + NO_3^-$ treatments resulted in intermediate Mg concentrations and did not differ between these sources. Ammonium nutrition resulted in a significantly lower Mg concentration.

Nitrogen source did not influence Fe concentration in P. oxycardium leaf tissue (Table 20). As shade intensity increased the Fe concentration for each N source increased.

Nitrate nutrition resulted in a higher overall Mn concentration than the other N sources (Table 21). The lowest Mn concentration was associated with the NH_4^+ and $NH_4^+ + NO_3^-$ treatments, while urea was intermediate. As shade intensity increased there was a general trend of increasing Mn concentrations for each N source.

The Zn concentration under 45% shade was substantially lower than at the 74 and 96% shade levels for each N source (Table 21). Differences in Zn concentration between the 74 and 96% shade intensities were small. Nitrate and urea treated plants had higher Zn concentrations than the NH_4^+ treatment, while $NH_4^+ + NO_3^-$ was not different from any other source.

Table 21. The effect of N source and shade level on the Mn and Zn concentration in P. oxycardium leaf tissue

Nitrogen source 10 meq/liter	% shade 45	74	96	Average[a]
	ppm Mn (dry wt)			
NO_3	159	161	272	197 a
NH_4	70	74	161	101 c
Urea	125	130	193	150 b
$NH_4 + NO_3$	77	97	165	113 c
Average	108[b]	115	198	
	ppm Zn (dry wt)			
NO_3	26.3	39.0	43.5	36.2 a
NH_4	19.8	36.0	32.5	29.4 b
Urea	23.0	47.5	37.6	36.0 a
$NH_4 + NO_3$	24.3	31.5	36.6	30.8 ab
Average	23.3[b]	38.5	37.5	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

[b]Valid testing among shade levels is prohibited by the experimental design employed.

DISCUSSION

Treatment Effects on *Philodendron* Growth

The influence of shade level by N source on the height, internode length, fresh weight, and dry weight in experiment 1 was similar. As shade intensity increased these categories of plant growth decreased under NO_3^- nutrition, whereas the NH_4^+, urea, and $NH_4^+ + NO_3^-$ treatments were not different between 56 and 79% shade or 700 and 333 $\mu Em^{-2}s^{-1}$, respectively. This would seem to indicate that the difference in light intensity between the 56 and 79% shade levels was great enough to stimulate increased plant growth when NO_3^- was used as the N source. Perhaps at the higher light intensity of 56% shade the *Philodendron* was better able to utilize NO_3^- in comparison to the other N sources. This could explain the increased yields at the 56% shade level in contrast to 79% shade. These results concur with those of Green et al. (35) who observed maximum carnation growth under high light intensity when 100% NO_3^--N was supplied.

Philodendron height, stem diameter, number of leaves produced, fresh weight, and dry weight in experiment 3 did not show the same trend as experiment 1. Generally, as shade intensity increased the measurements in these categories decreased with each N source. In experiment 3, the light intensity (605 $\mu Em^{-2}s^{-1}$) of the 45% shade level might not have been high enough to stimulate increased growth under NO_3^-

nutrition, whereas in experiment 1 the 56% shade level had sufficient light (700 $\mu Em^{-2}s^{-1}$) to enhance P. oxycardium growth.

In all these experiments, the leachate pH of those pots treated with NO_3^--N shifted toward alkalinity and was in agreement with previous reports (46, 66). However, in experiments 1 and 3 there were no differences between shade levels. One might expect with the greater plant growth associated with NO_3^--N under the low shade level in experiment 1, there would be greater absorption of NO_3^- and a corresponding increase in pH.

The greatest variability among N sources on plant growth occurred in experiment 1. Overall, there were no differences in Philodendron yield between the NO_3^- and $NH_4^+ + NO_3^-$ regimes. Both sources resulted in adequate plant development. However, in looking at the interaction of N source and shade level on plant growth a trend becomes evident. Generally, NO_3^--N resulted in slightly higher measurements than $NH_4^+ + NO_3^-$ under 56% shade, while $NH_4^+ + NO_3^-$ was higher at 79% shade. Ammonium and urea produced lower yields under 56% shade in experiment 1; however, at 79% shade NH_4^+ was not different than any other source. These results strengthen the suggestion that the Philodendron may have a preference for NO_3^--N under higher light intensities and NH_4^+ sources or a combination of NO_3^- and NH_4^+ at lower light intensities.

Overall, the data of experiments 2 and 3 indicated that

there were no differences between the N sources on plant yield. Apparently, the absorption and incorporation of NH_4^+ and urea into organic compounds proceeded at a rate similar to NO_3^- and $NH_4^+ + NO_3^-$ under the environmental conditions that persisted through the duration of these experiments.

Of the 4 N sources tested, $NH_4^+ + NO_3^-$ behaved the least consistently among the experiments. In experiment 1, $NH_4^+ + NO_3^-$ behaved more like NO_3^--N in its effects on plant growth, while in experiments 2 and 3 it acted more like NH_4^+. The leachate pH values correlate well with this observation. Raven and Smith (66) reported that NO_3^--N generates OH^- which shifts the media pH toward alkalinity, while NH_4^+ produces an abundance of H^+, thereby decreasing the pH. The leachate pH values obtained with the NO_3^- and NH_4^+ treatments in each experiment concur with those reported. Since the $NH_4^+ + NO_3^-$ was supplied from the same source and provided at similar rates (5-15 meq/liter N), the variable pH response might have been attributed to a differential preference for N source during the growing season. Experiment 1 was conducted in the spring (1600 $\mu Em^{-2}s^{-1}$), experiment 2 in the summer (784 $\mu Em^{-2}s^{-1}$), and experiment 3 in the fall and winter (1100 $\mu Em^{-2}s^{-1}$), suggesting that light intensity may have been involved. However, this argument was disaffirmed by the observation that the leachate pH with $NH_4^+ + NO_3^-$ in experiment 1 under 79 and 92% shade or 333 and 135 $\mu Em^{-2}s^{-1}$, respectively, was substantially higher than at the 45 and 74% shade levels or 605 and 286 $\mu Em^{-2}s^{-1}$, respectively, in experiment 3. Therefore, even

though the total light intensity of the spring was higher, the 79 and 92% shade levels in experiment 1 were lower in light intensity than the 45 and 74% shade levels, respectively, in experiment 3. However, the pH was more alkaline in experiment 1 and did not vary between the shade levels. Perhaps the deviation in leachate pH with $NH_4^+ + NO_3^-$ among the experiments could be due to the temperature change in the greenhouse associated with the various seasons. Generally, the greenhouse was cooler in the spring, hot in the summer and fall, and intermediate in the winter due to the fluctuations in the heating and vent systems. Black (13) reported that temperature has a definite influence on soil pH. To determine if P. oxycardium utilizes NO_3^- sources more efficiently than NH_4^+ sources under high light intensities additional research needs to be conducted. Furthermore, to maximize yields under low light intensities various ratios of $NH_4^+ + NO_3^-$ should be tested.

Matsumoto et al. (48) report reduced starch synthesis under NH_4^+ nutrition. Blackwood and Miflin (14) attributed the reduced sucrose and starch in NH_4^+ treated plants to the drain of photosynthetically derived carbon to form amino acids at the expense of starch and free sugar production. Such a drain on starch synthesis associated with NH_4^+ might cause a reduced growth rate. This could perhaps, in part, explain the reduced growth rate of the plants grown under NH_4^+ nutrition in comparison to the NO_3^- and $NH_4^+ + NO_3^-$ treated plants under 56% shade in experiment 1. Since the yields of the urea

treated plants were not different from the NH_4^+ treated plants in experiment 1 it might be assumed that the urea was being converted to NH_3 and CO_2 internally, as suggested by Kirkby and Mengel (46). Ultimately the urea behaves like NH_4^+, after its conversion to NH_3, in terms of plant metabolism. The leachate pH with urea in experiment 1 correlates well with the previous reports.

Most foliage plants are commercially produced under 80 to 90% shade (17, 20). Taylor et al. (72) and Conover and Poole (21) report higher quality and increased yields of P. oxycardium when shade intensity decreased from 80 or 90% to 30, 40, or 60% shade. The results of P. oxycardium growth in experiments 1 and 3 at the varying shade intensities concur with the previous reports. Overall, the low and intermediate shade levels produced higher yields than the highest shade intensities, which resulted in severely restricted plant growth for all the N sources. Taylor et al. (72) noted no differences in yield between 30 and 60% shade on P. oxycardium but a significant decrease in growth at 90% shade. They surmised that the increased yields at 30 and 60% shade were due to increased photosynthetic activity and hence increased carbohydrate accumulation compared to the plants grown under 90% shade. In addition to reduced photosynthesis the restricted growth under the highest shade levels in experiments 1 and 3 might be due to a depleted ATP (chemical bond energy) supply. The ATP is required for the assimilation of NH_3 into amino

acids (68). Since ATP synthesis is a light dependent reaction (68), the light intensity under the highest shade level might have been too low to generate enough ATP to stimulate growth.

Taylor et al. (72) observed no yield enhancement in P. oxycardium as N levels were increased from 6.4 to 25.7 meq/liter N. They attributed the lack of response to the low light intensities which prevailed during the experiment. In another study (73), they observed increased plant growth of P. oxycardium at higher light intensities with increased N levels. They concluded under low light conditions plants are less metabolically active than under high light intensities and, therefore, do not require a high level of nutrition to sustain growth. Since there were no differences between the 5, 10, and 15 meq/liter N levels on plant yield in experiment 2 it must be concluded that at 65% shade the light intensity (274 $\mu Em^{-2}s^{-1}$) was insufficient to obtain growth promotion at higher N levels. Additional research needs to be conducted using increased N fertilization with the 4 N sources tested at varying light intensities.

No visual toxicity symptoms were observed with any of the N sources in the experiments, even at the 15 meq/liter N rate supplied in experiment 2. This observation might suggest that P. oxycardium is not sensitive to NH_4^+ fertilization, whereas many plant species have been shown to be sensitive to NH_4^+. Therefore, NH_4^+ sources of N might be considered a

viable N alternative to NO_3^--N sources. However, the light intensity the plants will be grown under must be taken into consideration.

Treatment Effects on Elemental Composition

Dijkshoorn (27) states that electroneutrality must be maintained in plant tissues. Since it is known that the source of N influences cytosol pH, the plant must have a regulatory process by which charge balance is maintained. Furthermore, Kirkby and Mengel (46) stated that the total cations are fairly well-balanced by total anions in plant tissues independent of the form of nitrogen nutrition. This would indicate that plants that take up N as an inorganic anion, such as NO_3^-, should compensate by absorbing increased cations to maintain charge balance without changing the total cation:anion ratio. Conversely, cationic N sources, such as NH_4^+, should bring about decreased cation and increased anion uptake to maintain charge balance without changing the total cation:anion ratio. This observation has been reported by numerous investigators studying the effects of NO_3^- versus NH_4^+ nutrition (14, 45, 66). The leaf tissue analysis results obtained in all 3 experiments correlate well with this explanation. Generally, the leaf tissues of those plants treated with NO_3^--N had reduced anion (P) and increased cation (Ca, Mg, Zn) concentrations. Ammonium nutrition resulted in similar or enhanced N and P leaf tissue concentrations relative to those obtained under NO_3^--N in each

of the experiments. There were no differences in K or Fe concentrations between the NO_3^- and NH_4^+-N sources and generally NH_4^+-N resulted in reduced Ca, Mg, Mn, and Zn levels in contrast to NO_3^--N. These results agree with the charge balance theory.

Kirkby and Mengel (46) state that since urea is taken up as a whole neutral molecule in soilless media, there is no need for it to be balanced by other ions. They further state that the total cations and organic anions should be intermediate between the NO_3^- and NH_4^+ results. Generally, urea behaved consistently in each of the 3 experiments in terms of leaf tissue elemental composition. However, there were no clear cation/anion balance ratios. In comparison to NO_3^- nutrition, urea treated plants had increased N and P levels but reduced Ca, Mg, and Mn concentrations. It appeared that in the majority of elements analyzed urea behaved more like NH_4^+ than NO_3^-; however, in some cases intermediate results between NO_3^- and NH_4^+ were observed.

It was previously reported that in experiment 1, the $NH_4^+ + NO_3^-$ treatment produced similar results as NO_3^--N in terms of Philodendron yield, while in experiments 2 and 3, $NH_4^+ + NO_3^-$ resulted in similar growth as NH_4^+. The leachate pH values for $NH_4^+ + NO_3^-$ in the experiments helped substantiate this observation. Yet, in terms of elemental composition, $NH_4^+ + NO_3^-$ appeared more similar to NH_4^+ in each experiment. Ideally, the elemental composition of $NH_4^+ + NO_3^-$ treated plants should

be intermediate between the NO_3^- and NH_4^+ treatments. Perhaps since the source was a 1:1 combination of NH_4^+ + NO_3^- it could produce similar yields as NO_3^- in experiment 1, but due to the cationic NH_4^+ it resulted in similar charge balance effects as NH_4^+.

The plant response to shade intensity and N source on leaf Ca in experiments 1 and 3 was similar. In both experiments Ca concentration in the leaf tissues of P. oxycardium remained unaltered between the lowest and intermediate shade intensities when NO_3^-, urea, and NH_4^+ + NO_3^- were applied. However, Ca concentration was lower under 92% shade. Epstein (31) noted that Ca is required for cell wall formation and growth. Apparently, the light at the intermediate shade level was sufficient for adequate growth under urea and NH_4^+ + NO_3^- nutrition, hence similar Ca concentrations. It was previously reported that NO_3^- resulted in increased Philodendron growth at the low shade level compared to intermediate shade in experiment 1. However, this trend was not evident in experiment 3. As a result of the enhanced growth, an increased Ca concentration with NO_3^--N at the low shade level in experiment 1 should have been apparent, but this was not observed. The restricted growth at the highest shade intensity with each N source was substantiated by the lower Ca concentration in the leaf tissue.

The Ca concentration in the leaf tissue of plants supplied with NH_4^+ was higher at the intermediate light intensity in

comparison to the low and high shade levels in both experiments 1 and 3. Claassen and Wilcox (18) reported that NH_4^+ nutrition reduces Ca concentration in corn tissue. Perhaps at the lower light intensity of the intermediate shade level, in contrast to the higher light intensity of the lowest shade level, Ca is better able to compete with NH_4^+ for absorption, hence the increased Ca concentration.

The effects of shade on the leaf tissue elemental composition obtained in experiment 1 were varied. There were no clear trends for N, P, and Mg concentrations as shade intensity increased, whereas K concentration decreased as shade intensity increased from 56 to 92%. Epstein (31) states that K is required for sugar and starch formation, synthesis of proteins, and for cell division. As previously noted, the growth rate of P. oxycardium decreased from 56 to 92% shade. The reduced K at 92% shade in contrast to the K concentration at 56% may have been an energy related phenomenon whereby the plants under the highest shade intensity had the lowest chemical energy available for active K uptake. This interpretation must be viewed with a degree of discretion, as this trend of K uptake over increasing shade levels was not evident in experiment 3.

Iron, Mn, and Zn concentrations increased as shade level increased from 56 to 92% in experiment 1. Each of these elements is involved with chlorophyll or chloroplast formation as activators of enzymes or components thereof, along with

many other diverse functions (31). The increased Fe, Mn, and Zn concentrations in the smaller leaves of plants grown at 92% shade may be the manifestation of a dilution effect, in that the small leaves have less total dry matter to dilute the total accumulated quantities of these elements.

Magnesium concentration decreased as shade intensity increased in experiment 3. Magnesium is an essential part of the chlorophyll molecule, and serves as an enzyme cofactor for amino acid formation, and synthesis of fats and sugar (31). The reduced Mg concentration in leaf tissues of plants grown under 96% shade may be due to less chlorophyll, less sugar synthesis under the reduced photosynthesis induced by lower light conditions, or reduced energy available for Mg uptake.

The N, P, K, Fe, Mn, and Zn concentrations increased as shade level increased from 45 to 96% in experiment 3. These results partially contradict uptake trends observed in experiment 1, where the N and P concentrations remained static and K concentration decreased as shade intensity was increased. The increased N, P, K, Fe, Mn, and Zn concentrations under 96% shade could be attributed to a dilution of these elements in the larger leaf mass produced at 45% shade compared to the smaller leaf mass produced at 96% shade.

Overall, the N levels tested did not influence the P, K, Ca, Mg, Fe, Mn, and Zn leaf tissue concentrations in experiment 2. This observation correlates with the previous report

that N level did not influence Philodendron growth. The lack of response was attributed to the low light intensity (274 $\mu Em^{-2}s^{-1}$) of the 65% shade level under which the plants were grown. The leaf N concentration was higher at the 15 meq/liter N level in contrast to the 5 meq/liter N rate. This was presumably due to a concentration effect, in that the plants absorbed increased N in the presence of the higher external N concentration.

In general, the treatments did influence the leaf tissue elemental composition. However, the assayed elements of P. oxycardium in each of the 3 experiments were equal to or higher than the minimum recommended contents for healthy plants with each of the 4 N sources (63).

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APPENDIX

Table A1. The effect of N source and N level on the height, internode length, and stem diameter of P. oxycardium grown in solution culture

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
		Height (cm)[a]		
NO_3	96.7	93.1	93.3	94.3 a
NH_4	82.3	76.5	82.6	80.5 b
Urea	81.5	92.9	81.0	85.1 ab
$NH_4 + NO_3$	59.7	86.3	85.0	77.0 b
Average	80.0 a	87.2 a	85.5 a	
		Internode length (cm)[a]		
NO_3	7.35	7.30	7.70	7.45 a
NH_4	6.30	6.30	6.38	6.32 b
Urea	6.08	7.38	6.45	6.63 ab
$NH_4 + NO_3$	5.45	6.85	6.90	6.40 b
Average	6.29 a	6.96 a	6.86 a	
		Stem diameter (mm)[a]		
NO_3	2.10	2.15	2.10	2.12 a
NH_4	1.98	1.75	1.85	1.86 a
Urea	1.95	2.20	1.82	1.99 a
$NH_4 + NO_3$	1.58	1.97	2.08	1.87 a
Average	1.90 a	2.02 a	1.96 a	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Table A2. The influence of N source and N level on the number of leaves produced and leaf surface area of P. oxycardium grown in solution culture

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
		No. of leaves[a]		
NO_3	10.0	10.5	10.3	10.2 a
NH_4	9.7	10.0	9.3	9.7 ab
Urea	10.3	10.3	9.8	10.1 ab
$NH_4 + NO_3$	9.0	9.0	10.3	9.4 b
Average	9.8 a	9.9 a	9.9 a	
		Leaf surface area (cm^2)[a]		
NO_3	90.2	88.5	78.7	85.8 a
NH_4	83.0	74.3	78.7	78.7 a
Urea	76.7	87.4	67.8	77.3 a
$NH_4 + NO_3$	66.6	87.0	86.5	80.1 a
Average	79.1 a	84.3 a	77.9 a	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Table A3. The influence of N source x N level on the fresh and dry weight of P. oxycardium grown in solution culture

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
		Fresh weight (g)[a]		
NO_3	63.4	60.8	64.7	62.9 a
NH_4	53.3	45.9	51.9	50.3 a
Urea	52.9	60.8	47.7	53.8 a
$NH_4 + NO_3$	36.3	62.0	55.0	51.1 a
Average	51.5 a	57.3 a	54.8 a	
		Dry weight (g)[a]		
NO_3	5.55	5.24	5.79	5.52 a
NH_4	5.30	4.32	5.41	5.01 a
Urea	4.58	5.49	4.25	4.77 a
$NH_4 + NO_3$	2.92	5.87	5.33	4.71 a
Average	4.59 a	5.23 a	5.19 a	

[a]Means followed by a different letter within the group are significantly different ($P \leq .05$ Duncan's multiple range test).

Table A4. The effect of N source and N level on the N, P, and K concentration in P. oxycardium leaf tissue

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
		% N (dry wt)[a]		
NO_3	2.77	2.89	2.88	2.84 b
NH_4	2.65	2.85	2.92	2.80 b
Urea	2.94	2.94	3.14	3.01 a
$NH_4 + NO_3$	2.89	2.88	2.93	2.90 ab
Average	2.81 b	2.89 ab	2.96 a	
		% P (dry wt)[a]		
NO_3	.176	.176	.187	.180 bc
NH_4	.174	.168	.175	.173 c
Urea	.185	.191	.193	.190 ab
$NH_4 + NO_3$	.191	.198	.191	.193 a
Average	.181 a	.183 a	.186 a	
		% K (dry wt)[a]		
NO_3	5.87	5.84	5.76	5.82 a
NH_4	5.67	5.55	5.50	5.57 ab
Urea	5.49	5.60	5.67	5.58 ab
$NH_4 + NO_3$	5.90	5.36	5.28	5.51 b
Average	5.73 a	5.59 a	5.55 a	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Table A5. The effect of N source and N level on the Ca and Mg concentration in P. oxycardium leaf tissue

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
	% Ca (dry wt)[a]			
NO_3	2.19	1.99	2.32	2.16 a
NH_4	2.05	1.85	1.85	1.91 b
Urea	1.92	1.96	1.90	1.92 b
$NH_4 + NO_3$	1.98	2.04	1.95	1.99 b
Average	2.04 a	1.96 a	2.00 a	
	% Mg (dry wt)[a]			
NO_3	.370	.363	.383	.372 a
NH_4	.340	.340	.335	.338 b
Urea	.313	.295	.310	.306 c
$NH_4 + NO_3$	.303	.338	.310	.317 bc
Average	.331 a	.334 a	.334 a	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).

Table A6. The effect of N source and N level on the Fe and Mn concentration in P. oxycardium leaf tissue

Nitrogen source	Nitrogen level (meq/liter) 5	10	15	Average
		ppm Fe (dry wt)[a]		
NO_3	192	198	174	188 a
NH_4	153	166	186	168 ab
Urea	163	136	170	156 b
$NH_4 + NO_3$	161	153	149	154 b
Average	167 a	163 a	169 a	
		ppm Mn (dry wt)[a]		
NO_3	146	136	134	138 a
NH_4	116	96	98	103 bc
Urea	98	106	121	108 b
$NH_4 + NO_3$	82	102	90	91 c
Average	110 a	110 a	110 a	

[a]Means within the group followed by a different letter are significantly different ($P \leq .05$ Duncan's multiple range test).