PROPERTIES OF RECYCLED PAPER AS A GROWTH SUBSTRATE IN CONTAINER PRODUCTION OF AZALEA AND SPIRAEA

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AND SPIRAEA

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CHAPTER 1

INTRODUCTION

Environmental problems affecting horticultural industries include overuse of slowly renewable resources, groundwater contamination, and solid waste disposal. Opportunities exist in these industries for extensive use of recycled materials which could significantly reduce environmental impacts. Shifting from use of peat to plentiful and readily available organic amendments such as wood and paper waste in container plant growing media would promote conservation of a slowly renewable resource. Compared to peat, many of these alternative materials have also been shown to reduce leachate NO_3 concentrations (Beeson, 1996; Cole and Newell, 1996), and their adoption, especially by large-scale producers, could reduce ground and surface water contamination. Finally, recycling would reduce the demand for landfill space. Because soilless growth substrates, many of which are peat based, are widely used in horticultural products, development of satisfactory peat substitutes would maintain production of high quality plants while contributing to environmental quality.

Soilless Growth Substrates and Container Plant Production

Soilless growth substrates and management practices were developed in response to problems with using soils in container plant production. When placed in containers, the soil:air:water ratio is altered from field conditions, leaving little or no air space. Without adequate oxygen, plant root growth is impeded and plant quality suffers. The acceptable range for container mixes is 20% to 30% air space and 70% to 85% total pore space (Bunt, 1988). Amending soil with lightweight, porous materials can alleviate the problem. However, while soil-based substrates generally have more available plant nutrients, especially micronutrients, than commonly used soilless mixes, they are more costly, heavier, and have less uniform composition (Bunt, 1988). Commonly used soilless substrate components include pine bark, peats, vermiculite and perlite. In correct combination and with proper management, these substrates can provide the physical and chemical properties required for optimal plant growth.

Peat As A Container Growth Substrate

Moss peat (peat) is one of the most widely used components of soilless mixes. Peat has a relatively low bulk density, ($g\cdot cm^{-3}$, about 0.1 compared to 1.0 for sand) and thus increases pore space. On average, peat holds 15 times its dry weight in moisture, is lightweight and easily transported (Hartman et al., 1997). In general, the pH of container mixes should be lower (5.0-6.5) than that of field soils (6.5-7.0) (Warnecke, 1990). With a pH between 3.2 and 4.5, adding peat to growth substrates improves nutrient availability. Peat's effects on substrate physical and chemical properties have made it a favored component of many well established potting mixes (Bunt, 1988). Though several peat substitutes have been researched, peat's relatively low cost and commercial success, especially for high return crops, creates resistance to their use.

Environmental concerns have spurred research into peat substitutes. Global peat reserves have been depleted by draining for agriculture, afforestation and mining for horticultural uses (Barber, 1993; Barkham, 1993). Once removed, peats regenerate at a rate of only about 2 cm per year (Barber, 1993). Peat mining contributes to destruction of wetland habitat, major carbon sinks, and natural filtration systems for waterborne pollutants. Peat deposits constitute approximately 1 billion acres, or 4.4% of the earth's land mass (Cantrell, 1993) and are estimated to contain 3 to 3.5 times the carbon of tropical forests while covering half the area (Barkham, 1993). Mining releases CO_2 and may contribute to global warming. Although it is a subject of controversy, many wetland ecologists feel that current harvest rates exceed sustainable levels (Barber, 1993; Barkland, 1993; Buckland, 1993). Others have focused on peat bogs as preserves of natural history, past climatological data, and human activity (Robertson, 1993). Between 1981 and 1993, U.S. domestic peat production grew at an average annual rate of 2.0% while consumption grew at 3.5%. The excess demand was met by increasing imports accompanied by rising prices (Cantrell, 1993).

Peat Substitutes

A number of nontraditional organic and inorganic materials have been tested as peat substitutes including: composted wood and yard wastes (Beeson, 1996; Lumis, 1976), spent mushroom compost (Rathier, 1982; Wang et al., 1984; and Chong et al., 1987), coir (Meerow, 1994), kenaf stem core (Wang, 1994) and ground automobile tires

(Bowman et al., 1994). Sanderson and Martin (1974) found growth of Burford holly (*Ilex cornuta* Lindl. 'Burfordii') and arborvitae (*Thuja occidentalis* L.) in municipal solid waste superior to peat in nine fertilizer regimes. Many materials are wood-based waste paper (Cole and Newell, 1996; Tripepi, 1996) or papermill wastes (Adamson and Maas, 1971; Chong et al., 1987; Lumis, 1976). Use of locally available supplies of alternative substrates would reduce the use of slowly renewable resources such as peat and bark, and would recycle materials currently being dumped into dwindling landfill space.

Nitrate Leaching In Soilless Growth Substrates

Relative to field production, management practices in container plant production include intensive irrigation and application of fertilizers. When plants are grown in a small volume of media, root growth is limited to a small area, and greater demands are placed on the substrate for air, water and nutrients than exist under field conditions (Hershey, 1990). In addition, most greenhouse mixes provide only a small reservoir of nutrients. Frequent irrigation can result in leaching of nutrients which must be replenished to maintain an adequate nutrient status. Soil solution thus becomes the primary source of nutrients.

Nitrogen is the macronutrient required in the greatest amount by plants, and optimal growth requires a continuous supply of N throughout the growing season (Furuta, 1976). Because nitrate is easily leached from container substrates (Tisdale et al., 1985) it may easily enter the water supply. Concentrations greater than 10 $mg \cdot L^{-1}$ NO_3-N in water exceed limits established by a 1986 amendment to the Safe Drinking Water Act of 1974 (U.S. Environmental Protection Agency, 1990) Nursery and greenhouse operations are often located near surface waters or aquifers, and intensive fertilizer use could result in contamination of groundwater supplies. Groundwater contamination is a concern to environmentalists and large scale growers alike since excessive nitrate translates into environmental damage potential as well as wasted production dollars. For a given irrigation practice, with respect to water quality impacts, substrates that readily retain nutrients are superior to those that do not.

For a given substrate, temperature, humidity, light level and plant species, the nitrate concentration in leachate varies with the amount, type and placement of fertilizer and the irrigation regime (Conover et al., 1994). In response to regulations limiting nitrate levels in drinking water, researchers began to examine how different fertilization practices impact leachate nutrient levels. Yeager et al. (1993) found that controlled release fertilizers (CRF) yielded lower leachate NO_3 concentrations than CRF supplemented with liquid feed (LF). Rathier and Frink (1989) and Broschat (1995) had similar findings for plants amended with only. Meadows and Fuller (1984) found that incorporating CRF in substrates reduced NO_3 in leachate compared to top-dressing. Hicklenton and McRae (1989) found that release occurred at higher rates in dibbled than incorporated CRF and that superior plant growth resulted when CRF was incorporated.

Substantial research has been devoted to determining nutrient levels, rates and methods of application, and irrigation regimes for soilless substrates that maximize yield of quality plants while minimizing fertilizer and water use. However, few of these have examined the effects of substrate composition on nutrient leaching. Comparisons of peat to composted yard waste (Beeson, 1996) and to recycled paper (Cole and Newell, 1996) found peat inferior in terms of leachate NO_3 concentrations. Jarvis et al. (1996) found that NO_3 leachate concentrations were initially reduced in substrates that replaced peat with shredded rubber tire chips, but that NO_3 concentration increased over time to levels comparable to peat-containing substrates.

Recycled Paper As A Potential Peat Substitute

Recycled paper (RP) may be a potential substitute for peat as well as a way to reduce stress on a dwindling supply of available landfill space. Average individual use of paper is 650 pounds per year, contributing to depletion of trees and oil and producing air and water pollution (Kaldjian, 1990). Solid waste generation by Americans increases annually while available landfill space declines. Current paper recycling accounts for only 14% of paper use while paper and paper board comprise about 40% of municipal solid waste generated in the U.S. (Kaldjian, 1990).

Current recycling processes use only "clean papers" which are those without plastic, metallic, or wax coatings and those that are unspoiled by food residues. It is estimated that one ton of paper from recycled pulp creates 74% less air pollution, 35% less water pollution, and 75% less energy than producing paper from virgin fibers (Anonymous, 1995). While markets exist for recycled newspaper, office stationary, computer papers, and cardboard, there are presently no large markets for "garbage" papers.

Recently, CERAD, of Sand Springs, Okla., began developing uses for these unwanted papers. Among the products being tested is Wet Earth, a recycled paper (RP) growth substrate component composed of 80% RP, 18% diatomaceous earth, 1% CaO, and 1% humic acid and nutrients by volume (CERAD Ind., Sand Springs, Okla.). Formulations of Wet Earth include substrate manufactured from paraffin-covered cardboard boxes (RPC) and a recycled paper sludge (RPS) made from waste paper by-products of tissue manufacture. Previous studies (Cole and Newell, 1996) indicate that RPC used in production of Rose-of Sharon (*Hibiscus syracus* L. 'Double Purple') and forsythia (*Forsythia x intermedia* Zab. 'Lynwood Gold') yielded plants of equal or better quality than peat-amended substrates. Evidence also suggested that RP retains nitrates at higher levels than peat.

Objectives

The species selected for this study included *Rhododendron x obtusum* L. 'Hino Crimson' (azalea) and *Spiraea japonica* Planch. 'Froebelii'. Azalea was selected because it requires more acidic soil conditions than most species. Recycled paper sludge was obtained at pH 3.4 (RPS3.4) and 6.6. (RPS6.6) for this portion of the study. Spiraea requires conditions typical for most plants grown in Oklahoma. For both species, objectives of the study were: 1) to compare plant growth, visual quality and shoot leaf N concentration of plants grown in substrates having various ratios of substrate to pine bark (PB), 2) to determine leachate NO_3 concentrations from the different substrates, and 3) to determine the chemical (pH, soluble salts, nutrient status, and CEC) and physical properties (bulk density, percent porosity, percent air space, and shrinkage) at planting and harvest.

The azalea study compared substrates composed of various ratios of peat, RPS3.4, RPS6.6 or RPC (also at pH 6.6) to pine bark. The study was conducted in the summer of 1996 and repeated in the summer of 1997.

Spiraea were similarly tested in RPC only. In addition, spiraea were tested under three different fertilizer regimes. All irrigation water was collected and analyzed for NO_3 and NH_4 concentration to obtain release curves for nitrogen. Partitioning of total N was determined. This portion of the study was conducted in the fall of 1996 and was repeated in the spring of 1997

It is likely that, at some point, government regulations and rising prices of peat will force growers to adopt alternative substrates. Recycled paper has the potential to become a plentiful and environmentally compatible alternative.

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CHAPTER 2

A COMPARISON OF PEAT MOSS AND RECYCLED PAPER IN CONTAINER PRODUCTION OF AZALEAS

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Abbreviations. PB, pine bark, RP, recycled paper, CRF, controlled release fertilizer; LF, liquid fertilizer

Abstract. Recycled paper growth substrates manufactured from either paraffin-coated cardboard with a pH 6.6 (RPC6.6) or from waste paper sludge with a pH 3.4 (RPS3.4) or 6.6 (RPS6.6) were tested as peat substitutes. Experiments compared peat with RPS3.4 (Expt 1), peat, RPS3.4, and RPS6.6 (Expt. 2); and peat, RPS6.6, and RPC6.6 (Expt 3). *Rhododendron x obtusum* Planch.'Hino Crimson' was grown in 3.8 L

containers in RP or peat: pine bark (PB) in ratios of 0:1, 1:3, 1:1, 3:1, and 1:0. Plant growth, substrate chemical and physical properties, and NO_3 and NH_4 leachate concentrations were compared. Peat and RPC yielded similar results in Expt. 3., 1996 with greatest plant growth and quality in 1:3 and 1:1 RPC:PB substrates. Results for 1997 were similar. Comparisons of and NO_3 and NH_4 leachate concentrations in peat and RP-amended substrates were inconclusive. In substrates with over 50% RP, increased bulk density, and reduced volume and air porosity negatively impacted root growth and plant quality. Mortality for plants grown in RPS3.4 was 84% for Expt. 1 and 70% for Expt. 2.

INTRODUCTION

Desirable container growth substrate characteristics include adequate pore and water space, good drainage, and resistance to shrinkage and compaction. Substrate pH, soluble salts, cation exchange capacity (CEC) and nutrient levels should also be within established ranges. The physical and chemical properties of peat make it one of the most widely used substrate inputs in containerized plant production. Peat has a low bulk density, (about 0.1 $g \cdot cm^{-3}$ compared to 1.0 $g \cdot cm^{-3}$ for sand) and, when added to bark or sand-based mixes, improves water holding capacity. Relative to other soilless mixes, peat has a high CEC (Bunt, 1988). Its light weight per unit of volume makes peat easy to handle and reduces transportation costs.

Since the early 1970s, researchers have searched for satisfactory peat alternatives. Environmental concerns over peatland mining and disposal of organic by-products (wood waste, waste paper, municipal solid waste (MSW) and yard wastes) as well as fluctuating peat prices have motivated the search for cheap, readily available container plant substrate materials capable of producing top quality crops.

Several materials have been tested as peat substitutes. Calkins et al. (1997) and Jarvis et al. (1996) tested peat, MSW, composted yard waste and rubber tire chips. The MSW and composted yard waste produced plants of size and quality superior to peat or tire chips. Zinc toxicity and shrinkage of tire chip-amended substrates produced the poorest quality plants. Coir dust also performed well compared to peat, its primary drawback being cost (Meerow, 1994). Shrinkage and low water holding capacity were problems associated with ground kenaf stem core (Wang, 1994).

Beeson (1996) found that azaleas (*Rhododendron indicum* L.) grown in equally spaced ratios of yard waste:sand produced plants of similar or better quality than plants grown in the same ratios of peat:sand. Root mass declined with increasing percentages of yard wastes due to decreases in air space over the growing season.

Studies of papermill wastes conducted independently by Lumis (1976) and Chong et al. (1987) found excessive initial total salt accumulations (electrical conductivity (EC) > 10.0 $dS \cdot m^{-1}$) in wood waste products. High salt accumulations were also found in spent mushroom compost (Rathier, 1982; and Chong et al., 1987). In all cases, however, salts had little affect on plant growth or quality and were readily leached from substrates within the first few irrigations. Tripepi et al. (1996) found that substrates amended with papermill wastes produced taller plants of greater dry mass than peat-amended substrates.

Sanderson and Martin (1974) found that growth of Burford holly (*Ilex cornuta* Lindl. 'Burfordii') and arborvitae (*Thuja occidentalis* L.) in MSW was superior to peat in nine fertilizer regimes.

In addition to studying the effects of peat substitutes on growth, a few researchers have compared leachate NO_3 concentrations for peat-amended and alternative substrates. Comparisons of peat to composted yard waste (Beeson, 1996) and to recycled paper (Cole and Newell, 1996) found greater leachate NO_3 concentrations in peat-amended substrates than in substrates amended with composted yard waste. By adopting recycled container substrates, container producers could reduce their fertilizer costs and the threat of NO_3 contamination to local water supplies

A recycled paper product called Wet Earth, manufactured from paraffin covered cardboard boxes (RPC), has been tested as an alternative substrate by Cole and Newell (1996). Manufactured by CERAD Industries of Sand Springs, Okla., Wet Earth is still in the developmental stages. In addition to RPC, a second formulation of Wet Earth, recycled paper sludge (RPS), uses waste fibers resulting from the manufacture of facial and toilet tissue. Substrates for this study used RPS at pH 6.6, a level desirable for most nursery crops, and at pH 3.4 for plants adapted to acidic growth conditions.

Objectives of this study were: 1) to compare growth, shoot N concentration, and visual quality of *Rhododendron x obtusum* 'Hino Crimson' grown in peat-based substrates to those grown in RPS and RPC; 2) to analyze leachate concentrations of NO_3 and NH_4 from the various substrates; and 3) to determine substrate physical properties (percent air space, percent porosity, bulk density, and shrinkage) and to measure pH and electrical conductivity (EC).

Clearly there are acceptable peat substitutes. Further testing and successful marketing could serve to overcome industry resistance to change. Use of locally available supplies of alternative substrates would reduce the use of slowly renewable resources such as peat, and would recycle materials currently being loaded into dwindling landfill space.

MATERIALS AND METHODS

In May of 1996, the first of three experiments began to compare peat with various formulations of RP. For each experiment, rooted azalea cuttings of uniform height and width were potted into 3.8 L containers filled with 2300 cm^3 of either RP:pine bark (PB) or peat moss (P):PB in ratios of 0:1, 1:3, 1:1 and 1:0 (by volume). Substrate amendments incorporated at planting were ($mg \cdot cm^{-3}$) 0.89 urea (45N-0P-0K), 0.89 triple super phosphate (0N-19.8P-0K), 0.25 KCl (0N-0P-51.5K), 2.23 $CaSO_4$, 0.44 Micromax (Scott's Co., Marysville, Ohio), and 0.59 Crop Mag 58 (Martin Marietta, Baltimore, Md.). Plants were irrigated daily by hand to container capacity.

At monthly intervals, leachate samples were collected as follows. Containers were placed in 20 cm plastic drip pans, and 500 ml water was added to each container.

Containers were allowed to drain for 15 min. Leachate was collected in plastic bottles, filtered, labeled and stored at 4.4 °C until analyzed for NO_3-N and NH_4-N concentration by cadmium reduction (NO_3) and indophenol blue (NH_4) colorimetric methods using a continuous flow analyzer (Lachat Instruments, Milwaukee, Wis.; Soil Water and Forage Laboratory, Oklahoma State University, Stillwater, Okla.).

At planting and at monthly intervals thereafter, for each replicate, plant height and diameter (an average of diameter at the widest point and diameter perpendicular) were measured (cm). Increases in plant height were determined by subtracting height at planting from height at harvest. Increases in plant diameter were determined the same way. Visual quality ratings (1 to 5 scale, 1 = dead plant 1, 5 = highest salable quality) were taken by three independent raters, also at monthly intervals.

At harvest, roots and shoots were separated and washed to remove all substrate, fertilizer and pesticide. Samples were dried at 67 °C for ten days and dry masses recorded. Roots were discarded and shoots were kept for tissue analysis of N. To have sufficient shoot tissue for analysis, shoot tissue samples from two plants were combined. Combined samples were ground to pass through a 917 μm mesh screen and stored in glass jars until analyzed for total N by the macro-Kjeldahl method (Horowitz, 1980).

Bulk density, percent porosity, and percent air space were determined at planting and harvest for peat, RPS (without regard to substrate pH) and RPC using methods described by Ingram et al. (1990). At potting, empty containers were weighed, filled as above, allowed to air dry, and weighed again. Bulk density was calculated as: [(mass of container + substrate) - container mass)]/substrate volume. Container drainage holes were covered with silicone sealant, and water was added to the saturation point. Percent porosity was calculated as ml H_2O added/ substrate volume. Sealant was removed and containers were allowed to drain. Percent air space was calculated as ml H_2O drained/substrate volume. To obtain measurements at harvest, three additional plants were potted as above for each substrate. Plants were irrigated on the same schedule and at the same rate as test plants. Physical properties were determined by the same methods.

Ten replicates of each treatment were arranged in a randomized complete block design. Analysis of variance was performed with GLM in SAS/STAT (SAS Institute, Inc., Cary, N.C.) to determine substrate and ratio main effects and interactions. Where significant substrate by ratio interactions occurred, trend analysis was used to determine linear, quadratic and cubic significance of ratios within substrates using methods outlined in Snedecor and Cochran (1967), and LSD values were calculated for significant substrate main effects.

Expt. 1. Beginning 14 May 1996, this experiment tested peat and RPS3.4. Shadehouse temperatures averaged 31.6/17.4 °C day/night and maximum light intensity [photon flux density (PFD)] was 1025 $\mu mol \cdot m^{-2} \cdot s^{-1}$. An overall plant mortality rate of 84% occurred in RPS3.4 within the first four weeks. The experiment was terminated 10 June 1996, lacking sufficient data for analysis.

Expt. 2. On 14 June 1996, azaleas were planted in peat, RPS3.4 and RPS6.6. The duration of the experiment was 16 weeks. Shadehouse temperatures averaged 34.9/20.9 °C day/night and maximum PFD was 1054 $\mu mol \cdot m^{-2} \cdot s^{-1}$

Expt. 3. Peat, RPS6.6 and RPC6.6 were used. Azaleas were planted 24 June 1996 and harvested after 16 weeks. Shadehouse temperatures averaged 34.7/20.5 °C day/night. Maximum PFD was 1054 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

1997. Analysis of RPC and peat was conducted using procedures similar to those used in Expt. 3 above with the following exceptions. Planting date was 21 May 1997. In addition to analyses for NO_3-N and NH_4-N concentration, leachate samples were analyzed for pH (model 5943-40; Cole-Parmer Inc., Chicago, Ill.) and electrical conductivity (EC) (Solu-Bridge, model SD-B15; Beckman Instruments, Inc., Cedar Grove, N.J.). Substrate pH and EC were determined on three samples of each substrate at planting and harvest using water saturated extraction (Baker, 1992). Plants were grown at an average air temperature of 29.4/18.3 °C day/night, and a maximum PFD of 1034 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Plants were irrigated daily by overhead sprinklers.

RESULTS

Plant Growth

In Expt. 2, 1996 shoot dry mass, shoot N concentration, plant diameter increase, and visual quality had significant substrate by ratio interactions (Table 2.1). Shoot dry mass and shoot N concentration were greatest in a 1:3 ratio of RPS3.4:PB.

When comparing the various substrates within ratio, shoot dry mass, shoot N concentration and diameter growth were greatest in peat-amended substrates. For shoot dry mass, the proportion of substrate to PB was linearly significant in RPS3.4 and RPS6.6, but not in the peat-amended substrates. Substrate proportion significantly affected shoot N concentration in all substrates. Shoot N for RPS6.6-amended substrates increased in ratios up to 1:1 then declined in the 3:1 substrate. There was insufficient shoot dry matter to analyze the 1:0 (100% RPS6.6) for shoot N concentration. In peat-amended substrates, shoot N increased with increasing proportions of peat.

Plant diameter growth was greatest in the 75% and 100% peat substrates and least in the 50% RPS6.6 substrate (Table 2.1). Overall increases in plant width were greatest in the peat-amended substrates and increased with increasing proportions of peat. Visual quality was lowest in substrates containing RPS3.4 and highest in substrates containing peat. Within substrates visual quality increased with increasing proportions of peat and decreased with increasing proportions of RPS3.4 and RPS6.6. The visual quality values reflect 100% plant mortality in RPS3.4:PB of 1:1, 3:1, and 1:0. Plant mortality for all RPS3.4 treatments was 70% compared to 8% in peat:PB substrates, and 38% in RPS6.6:PB. Plant height increase was affected only by the substrate to PB ratio (Figure 2.1). Root mass was not significantly affected by treatment (data not shown).

In Expt 3, which compared RPS to RPC and peat, results were similar to those from Expt. 2 (Table 2.2). Shoot dry mass, shoot N concentration, increase in plant diameter, and visual quality again exhibited significant substrate by ratio interactions. Unlike Expt. 2, peat underperformed RP for the parameters tested. Shoot dry mass was greatest in 1RPS:1PB and highest in RPS overall. In RPC, shoot N concentration was greatest in the 1:1 ratio, but in RPS and peat, shoot N concentration was greatest in the 1:0 ratio. In both RP substrates, 1:1 ratios yielded the highest shoot dry mass and diameter increase; the 1RPC:0PB and the 1RPS:3PB substrates yielded the lowest. Shoot N concentration increased linearly with the proportion of RPC and peat. In RPS, shoot N concentration increased in ratios up to 50% RP and then declined. The effects on visual quality of increasing the substrate to PB ratio were only apparent in peat. Visual quality increased in peat with substrate proportion in media composed of 75% or less peat and then declined in the 100% peat substrate.

Shoot dry mass, shoot N, and plant diameter increase had significant substrate by ratio interactions for the 1997 experiment (Table 2.3). For shoot dry mass and increase in plant diameter, there were no significant differences among substrate ratios in RP:PB. However, both shoot dry mass and changes in width increased linearly with the proportion of peat. Shoot N concentration in both RP and peat substrates increased with increasing proportions of substrate:PB. There were no significant substrate by ratio interactions for root dry mass, but root dry mass in substrates containing peat (0.7 g) were significantly greater ($P \geq 0.01$) than with substrates containing RP (0.5 g). In 1997, visual quality was not significant. Furthermore, the mortality rate was only one plant in 100.

Leachate Analysis

Leachate samples taken 4 and 12 weeks after planting (4 WAP and 12 WAP) were analyzed for NO_3-N and NH_4-N concentrations (mg·L^{-1}). Significant substrate by ratio interactions occurred for NO_3-N at 4 WAP and 12 WAP and for NH_4-N at 4 WAP (Table 2.4). In Expt 2, initial leachate NO_3-N concentrations were highest in peat-amended substrates and lowest in RPS6.6-amended substrates. There were no significant differences in leachate NO_3-N concentrations in the various ratios of RPS6.6. There was an increasing curvilinear relationship between peat ratios and initial leachate NO_3-N concentration. Mortality was 100% in RPS3.4:PB with ratios of 1:1 and above, and only linear significance could be determined for NO_3-N concentrations At 12 WAP, leachate NO_3-N concentrations were highest (4.5 mg·L^{-1}) in RPS6.6:PB of 1:0, and generally increased with the ratio of RP to PB. The NO_3-N concentrations in peat were linearly significant and were inversely related to peat substrate percentage. Substrate NH_4-N concentrations for 4 WAP peaked in 1RP6.6:1PB and in 3peat:1PB at 9.8 and 9.9 mg·L^{-1}, respectively. Leachate NH_4-N concentrations increased with increased RPS6.6 to a proportion of 50% RPS, and then decreased with further increases in RPS. In peat, there was a trend toward increasing NH_4-N concentrations with increasing peat proportions. Leachate NH_4-N concentrations at 12 WAP showed no significant interactions but increased with substrate ratio regardless of material used.

In Expt. 3, there were significant substrate by ratio interactions for NO_3-N at 12 WAP and for NH_4-N concentrations at 4 WAP and 12 WAP (Table 2.5). Ratio was not significant for either form of N on either date in the RPC and peat substrates. In

RPS, concentrations of both forms of N showed curvilinear relationships with ratio at 12 WAP. The NH_4-N leachate concentration for 4 WAP was not significant by ratio. For 4 WAP; there were no significant differences in leachate NO_3-N concentration in any of the treatments. The average NO_3-N concentration at 4 WAP was 3.4 $mg \cdot L^{-1}$ (data not shown).

In 1997, there were significant substrate by ratio interactions for leachate concentrations of NO_3-N at 4 WAP and 12 WAP (Table 2.6). The ratio of RP was significant on both collection dates. At 4 WAP, leachate concentrations of NO_3-N curvilinearly decreased with increasing ratios of RP:PB but were not significantly different in different peat:PB ratios. At 12 WAP leachate NO_3-N concentration increased from 0.6 $mg \cdot L^{-1}$ in 0RP:1PB to 0.9 $mg \cdot L^{-1}$ in 1RP:1PB. At 12 WAP, leachate NO_3-N concentrations declined with increasing peat proportions in substrates containing up to 75% peat. In 100% peat substrates NO_3-N concentrations increased At 4 WAP, NH_4-N leachate concentration was significantly different by substrate only (Table 2.7). At 12 WAP, NH_4-N leachate concentration, at 0.5 $mg \cdot L^{-1}$ was not significantly different regardless of substrate or substrate proportion (data not shown).

Substrate influence on leachate pH in various ratios was significant early in the experiment (Table 2.6). At 4 WAP, pH was generally higher in RP. Leachate pH declined linearly with increases in peat, while there was no significant difference in pH for different RP ratios. By the end of the experiment (12 WAP), there were no significant substrate by ratio interactions. However, substrate effects were significant, yielding a slightly higher pH in RP than in peat and a tendency for pH to increase with the substrate to PB ratio (Table 2.7).

Electrical conductivity of leachate was significantly higher in RP-amended substrates than in peat-amended substrates at both 4 WAP and 12 WAP (Table 2.6). On both dates, EC linearly declined with increased peat ratio and linearly increased with increased RP ratios.

Substrate Physical Properties

Substrate pH differed slightly from the manufacturers stated pH of 6.6 (Table 2.8). In the control and peat-amended substrates, pH increased from planting to harvest. In both RP substrates there was a slight decline from initial levels. Electrical conductivity was slightly higher at harvest than at planting in all substrates.

At planting, the greater the proportion of RP regardless of source, the greater the bulk density (D_b) and the smaller the percent air space (%AS) (Table 2.8). By harvest, differences in D_b among substrates were more pronounced, ranging from, 0.17 $g \cdot cm^{-3}$ in the 100% PB substrate to 0.49 $g \cdot cm^{-3}$ in the 100% RPC substrate. Volume reductions ranged from 2.0% in the control to 62.3% in the 100% RPC substrate. While %AS was not noticeably reduced in the control from planting to harvest (36.6 to 36.3%), in the RPC only substrate, %AS was reduced by over half (34.7% to 16.7%). Percent porosity showed the same trend as %AS.

DISCUSSION

Plant Growth

Overall, plant growth was best in substrates containing peat while those containing ratios of 50% or less RPC:PB produced slightly smaller plants. Shoot dry mass, visual quality and increases in plant height and width in all experiments were lower than expected. Nearly all plants had visual ratings of 3.5 or below, indicating only an average salable quality. On visual inspection, mature leaves of most plants were chlorotic by the end of the experiments, especially in the 1997 trial, indicating a probable nitrogen deficiency. The roots of most plants failed to extend beyond the original commercial growing medium that surrounded the roots of the young seedlings. Although azaleas have a lower N requirement than many container grown species, shoot N concentration, at less than 2% in all plants, and below 1% in most ratios of 1:3 or less substrate:PB, was likely limiting to growth. Shoot N concentration was lower in plants irrigated by overhead sprinklers in 1996 than in hand watered plants in 1997. In addition, cooler temperatures in 1997 probably caused these plants to use much less water than they received, and it is likely that more nutrients were leached than in the 1996 experiments. Coupled with poor root growth, nutrient availability would have been restricted further in the 1997 experiment. The most telling outcomes in these experiments were rates of plant mortality in the various substrates. The combined effects of substrate pH, physical properties, and problems associated with the root-substrate interface are the most likely contributors to poor plant performance.

In contrast with the findings of this study, Tripepi et al. (1996) found that sand amended with papermill sludge produced lilacs (*Syringa vulgaris* L.) with greater shoot dry mass and height than those in peat or bark-amended sand. They found no differences in leaf N concentration among the media tested. Furthermore, visual inspection of the media at harvest did not indicate substrate shrinkage in the papermill-amended substrates. The papermill sludge used was from a newspaper mill and was composted for six weeks and stored in plastic containers for another two years.

Chong et al., (1987) used uncomposted papermill waste in container production of spiraea (*Spiraea japonica* Planch. 'Bumalda') and found poor growth compared with plants grown in pine bark. Substrate shrinkage was nearly three times greater in sludge substrates compared to controls and initial EC exceeded 10 $dS \cdot m^{-1}$ in sludge substrates. Substrates received no supplemental nutrients, and Chong attributed growth differences to N deficiencies in the papermill substrates. However, Chong (1995) did suggest that composting paper-based substrates might stabilize their chemical and physical properties, making growth outcomes more consistent.

Leachate Analysis

Analyses of NO_3-N and NH_4-N leachate concentrations revealed that NH_4-N was the predominant form. This would be expected since fertilizer N was provided by urea. Ammonium is the predominant form of N absorbed by azalea (Bunt, 1988) and other plants that require a low rhizosphere pH for efficient uptake of micronutrients. In Expt. 2, 1996, NH_4-N leachate concentrations 12 WAP were not significantly different However, NO_3-N concentrations were higher in RPS6.6 than in peat-amended substrates, and within RPS6.6, leachate amounts of NO_3-N increased with increasing proportions of RPS6.6. Because NH_4- N concentrations were not inversely related to NO_3-N, the differential in NO_3-N between RPS6.6 and peat is probably due to decreased water holding capacity of RPS6.6 compared to peat and the top crusting of RPS6.6. Similar results occurred in Expt. 3 except that NO_3-N concentrations were similar for peat and RPC while NH_4-N concentrations were higher in RPC than in peat. The 1997 results also revealed a similar pattern except that there were no significant differences in NO_3-N concentrations by ratio at 4 WAP. Irrigation by overhead sprinklers kept substrates moist without over saturating. Consequently shrinkage was reduced in substrates with a high proportion of RP, and the increasing NO_3-N concentrations with increasing RP seen in the previous summer were not as evident.

The 1997 experiment revealed that pH differed significantly by substrate and by substrate ratio at 12 WAP and that there were significant substrate by ratio interactions at 4 WAP. However, the differences were not likely to have affected plant nutrient availability significantly. For all substrates and substrate ratios, pH was above 7.0. Azaleas require a much more acidic substrate (around 4.5) for optimal nutrient uptake, and the chlorosis and poor growth in these studies may be attributable to the higher substrate pH and resulting lack of nutrient uptake by the plants. In higher pH, NH_4 can dissociate to free ammonium and H^+. Free ammonium is toxic to plants, causing cell membrane damage (Bunt, 1988).

Substrate Physical Properties

Substrate shrinkage and reduced water holding capacity in substrates with more than 50% RP may also have contributed to poor plant performance. Other proposed peat substitutes that have suffered from shrinkage include kenaf stem core (Wang, 1994) and sawdust (Bowman et al., 1994), finely ground rubber tire chips (Jarvis et al., 1996) and recycled cardboard (Chong, 1995). Lack of oxygen in the root zone, especially in the first few weeks of growth, can be a major contributor to low root and shoot dry mass and diminished plant growth in high RP substrates. In addition to their tendency to compact, in 1996, high RP substrates also had a tendency toward surface crusting which decreased water infiltration and led to excessive surface run-off. In the 1997 experiment, shrinkage was reduced in RP substrates by the use of overhead irrigation. Consequently, differences in plant performance were smaller.

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Table 2.1. Shoot dry mass, shoot N concentration, increase in plant diameter, and visual quality ratings of *Rhododendron x obtusum* 'Hino Crimson' grown in various ratios of peat, recycled paper sludge at pH 3.4 (RPS3.4) or RPS at pH 6.6 (RPS6.6) to pine bark (PB) Expt 2, 1996.

Substrate:PB	Shoot dry mass (g)	Shoot N (%)	Plant width increase (cm)	Visual quality[z]
		RPS3.4		
0:1	1.0	0.9	2.8	3.1
1:3	1.7	1.8	3.9	2.6
1:1	--	--	--	1.0
3:1	--	--	--	1.0
1:0	--	--	--	1.0
		RPS6.6		
0:1	1.3	0.9	2.8	3.2
1:3	1.0	1.1	3.9	3.1
1:1	0.8	1.5	2.0	2.6
3:1	1.0	0.9	2.3	1.8

1:0	1.0	--	3 4	1 5
		Peat		
0:1	1.4	0.9	3.8	3.4
1:3	1.5	0.9	3.2	3.5
1:1	1 5	1.0	3.6	3.5
3:1	1.4	1.3	4.3	3.8
1:0	1.5	1.6	4.1	3.7
Substrate (S)*Ratio (R) linear	**	***	NS	***
S*R quadratic	NS	***	NS	NS
S*R cubic	NS	*	*	NS
RPS3.4*R linear	**	**	NS	**
RPS3.4*R quadratic	--	--	--	*
RPS3.4*R cubic	--	--	--	NS
RPS6.6*R linear	*	*	NS	**

RPS6.6*R quadratic	NS	**	NS	NS
RPS6.6*R cubic	NS	*	*	NS
Peat*R linear	NS	**	NS	NS
P*R quadratic	NS	**	NS	NS
P*R cubic	NS	NS	NS	NS

*,**,***, NS Significant at 5%, 1%, 0.1%, nonsignificant.
[z]Visual quality was rated on a scale of 1 to 5 with 1 indicating a dead plant and 5 indicating a high quality plant.

Table 2.2. Shoot dry mass, shoot N concentration, increase in plant diameter, and visual quality ratings of *Rhododendron x obtusum* 'Hino Crimson' grown in various ratios of peat, recycled paper sludge RPS, or recycled cardboard RPC to pine bark (PB). Expt. 3, 1996.

Substrate:PB	Shoot dry mass (g)	Shoot N (%)	Increase in plant diam.(cm)	Visual quality[z]
		RPS		
0:1	1.7	0.9	2.3	2.3
1:3	2.2	0.9	4.3	3.2
1:1	2.7	1.3	3.4	1.7
3:1	1.4	1.2	3.1	2.5
1:0	1.0	1.1	1.1	2.9
		RPC		
0:1	1.6	1.1	3.7	1.9
1:3	1.6	1.4	3.6	2.7
1:1	0.9	1.6	4.2	2.8
3:1	0.9	1.9	1.6	2.3

1·0	1.2	2.0	2.4	2.0
		Peat		
0·1	1 1	0.8	2.4	2.1
1.3	1.3	0.9	2.7	2.4
1·1	1.3	0.9	2.9	2.3
3 1	1.6	1.1	2.5	3 4
1·0	1.5	1.5	2.7	2.8
Substrate*Ratio(R) linear	*	**	*	**
S*R quadratic	NS	*	NS	NS
S*R cubic	NS	NS	NS	NS
RPS*R linear	**	**	NS	NS
RPS*R quadratic	**	*	**	NS
RPS*R cubic	NS	*	NS	NS
RPC*R linear	*	**	*	NS

RPC*R quadratic	NS	NS	NS	NS
RPC*R cubic	NS	NS	NS	NS
Peat*R linear	NS	**	*	**
P*R quadratic	NS	NS	*	NS
P*R cubic	NS	NS	NS	NS

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant.

[z]Visual quality was rated on a scale of 1 to 5 with 1 indicating a dead plant and 5 indicating a high quality plant.

Table 2.3 Growth parameters for *Rhododendron x obtusum* 'Hino Crimson' planted 15 May, 1997. Substrates include various ratios of peat or recycled paper (RP) to pine bark (PB).

Substrate:PB	Shoot dry mass (g)	Shoot N (%)	Increase in plant diam. (cm)
	RP		
0:1	0.9	0.6	1.6
1:3	1.0	0.6	1.0
1:1	1.1	0.7	1.5
3:1	0.8	0.7	1.1
1:0	0.8	0.7	1.0
	Peat		
0:1	1.0	0.6	1.2
1:3	1.1	0.6	1.0
1:1	1.2	0.7	1.8
3:1	1.4	0.7	2.7
1:0	1.7	1.1	3.1
Substrate (S)*Ratio linear	***	***	***
S*R quadratic	*	***	NS
S*R cubic	NS	**	NS
RP linear	NS	**	NS
RP quadratic	NS	NS	NS

RP cubic	NS	NS	NS
Peat linear	**	**	**
Peat quadratic	NS	**	NS
Peat cubic	NS	**	NS

*,**,***, NS. Significant at 5%, 1%, 0 1%, nonsignificant.

Table 2.4. Leachate concentrations of NO_3 and NH_4 for samples taken 4 weeks and 12 weeks after planting (WAP) from growth substrates containing various substrate:pine park (PB) ratios of peat, recycled paper sludge at pH 3.4 (RPS3.4), or RPS at pH 6.6 (RPS 6.6). Expt 2, *Rhododendron x obtusum* 'Hino Crimson', 1996

	NO_3-N ($mg \cdot L^{-1}$)		NH_4-N ($mg \cdot L^{-1}$)
Substrate:PB	4 WAP	12 WAP	4 WAP
	RPS3.4		
0:1	0.5	0.5	1.5
1:3	0.3	1.2	8.0
1:1	--	--	--
3:1	--	--	--
1:0	--	--	--
	RPS6.6		
0:1	0.3	2.2	2.8
1:3	0.2	1.2	9.0
1:1	0.2	3.3	9.8
3:1	0.2	3.6	3.8
1:0	0.2	4.5	1.5
	Peat		
0:1	0.4	2.5	1.4
1:3	0.4	1.6	1.4
1:1	0.5	1.6	4.3
3:1	0.6	1.3	9.9

1:0	1.0	1.6	4.1
Substrate*Ratio (R)*linear	***	***	NS
S*R quadratic	NS	NS	NS
S*R cubic	NS	NS	*
RPS3.4 linear	*	NS	**
RPS3.4 quadratic	--	--	--
RPS3.4 cubic	--	--	--
RPS6.6 linear	NS	**	NS
RPS6.6 quadratic	NS	NS	**
RPS6.6 cubic	NS	*	NS
Peat linear	**	*	*
Peat quadratic	**	NS	NS
Peat cubic	*	NS	*

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant

Table 2.5. Leachate concentrations of NO_3 and NH_4 for samples taken 4 weeks and 12 weeks after planting (WAP) from growth substrates containing various substrate:pine park (PB) ratios of peat, recycled paper sludge (RPS), or recycled cardboard (RPC) at pH 6.6. Expt. 3, *Rhododendron x obtusum* 'Hino Crimson', 1996.

Substrate:PB	NO_3-N ($mg \cdot L^{-1}$)	NH_4-N ($mg \cdot L^{-1}$)	
	12 WAP	4 WAP	12 WAP
	RPS		
0:1	1.1	1.6	0.2
1:3	1.4	2.2	0.2
1:1	3.3	6.7	0.8
3:1	4.3	8.0	3.3
1:0	3.1	3.1	0.7
	RPC		
0:1	0.6	8.7	0.1
1:3	0.8	2.5	0.4
1:1	1.6	6.1	0.4
3:1	0.8	3.6	0.2
1:0	0.7	2.1	0.4
	Peat		
0:1	0.6	2.0	0.3
1:3	0.6	1.7	0.3
1:1	0.8	2.2	0.2
3:1	0.8	3.5	0.3

1:0	0.9	3.0	0.3
Substrate (S)*Ratio (R)*linear	NS	*	NS
S*R quadratic	NS	NS	NS
S*R cubic	*	NS	*
RPS linear	**	NS	*
RPS quadratic	NS	NS	NS
RPS cubic	**	NS	*
RPC linear	NS	NS	NS
RPC quadratic	NS	NS	NS
RPC cubic	NS	NS	NS
Peat linear	NS	NS	NS
Peat quadratic	NS	NS	NS
Peat cubic	NS	NS	NS

*,**,***, NS Significant at 5%, 1%, 0.1%, nonsignificant.

Table 2.6. Leachate NO_3 concentrations, pH, and electrical conductivity (EC) for samples taken 4 weeks and 12 weeks after planting (WAP) for growth substrates containing various ratios of peat or recycled paper (RP) to pine bark (PB). *Rhododendron x obtusum* 'Hino Crimson', planted 15 May, 1997

	NO_3-N ($mg \cdot L^{-1}$)		pH	EC ($dS \cdot m^{-1}$)	
Substrate:PB	4 WAP	12 WAP	4 WAP	4 WAP	12 WAP
		RP			
0:1	0.6	0.6	7.6	0.21	0.29
1:3	0.6	0.8	7.5	0.25	0.31
1:1	0.5	0.9	7.5	0.27	0.33
3:1	0.1	0.7	7.6	0.26	0.34
1:0	0.1	0.5	7.5	0.30	0.36
		Peat			
0:1	0.6	0.7	7.6	0.21	0.28
1:3	0.4	0.6	7.4	0.17	0.28
1:1	0.3	0.4	7.3	0.16	0.25
3:1	0.3	0.3	7.2	0.15	0.26

1:0	0.9	0.5	7.1	0.17	0.24
Substrate (S)*Ratio linear	***	NS	**	***	***
S*R quadratic	**	**	NS	*	NS
S*R cubic	NS	NS	NS	NS	NS
RP linear	**	NS	NS	**	**
RP quadratic	NS	**	NS	NS	NS
RP cubic	NS	NS	NS	NS	NS
Peat linear	NS	**	**	**	**
Peat quadratic	NS	*	NS	*	NS
Peat cubic	NS	NS	NS	NS	NS

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant.

Table 2.7. Leachate NH_4 concentrations and pH, for samples taken 4 weeks and 12 weeks after planting (WAP) for various ratios of peat or recycled paper (RP) to pine bark (PB). *Rhododendron x obtusum* 'Hino Crimson', planted 15 May, 1997.

	NH_4 ($mg \cdot L^{-1}$)	pH
	4 WAP	12 WAP
	Substrate main effects	
RP	0.05	7.73
Peat	0.02	7.68
$LSD_{0.05}$	0.029	0.03
	Ratio main effects	
0:1	NS	7.61
1:3	NS	7.62
1:1	NS	7.70
3:1	NS	7.80
1:0	NS	7.80
Ratio linear	NS	***
R quadratic	NS	NS
R cubic	NS	NS

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant.

Table 2.8. Substrate pH, electrical conductivity (EC), and physical properties for various ratios of recycled paper sludge (RPS), recycled paper cardboard (RPC), or peat to pine bark (PB).

	pH		EC ($dS \cdot m^{-1}$)		Bulk Density ($g \cdot cm^{-3}$)		Porosity (%)		Air Space (%)[z]		Shrinkage
Substrate:PB	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	(%)[y]
Control	4.3	5.5	0.1	0.1	0.17	0.17	81.3	79.7	36.6	36.3	2.0
					RPS						
1:3	4.5	5.3	0.6	0.4	0.18	0.22	77.0	77.0	38.3	31.0	4.0
1:1	5.9	6.2	0.9	0.4	0.21	0.28	76.3	72.3	36.0	19.7	25.0
3:1	6.3	6.9	1.1	0.8	0.22	0.36	75.3	68.7	34.0	20.0	40.0
1:0	6.6	7.1	1.4	0.5	0.21	0.43	80.1	63.3	34.7	16.7	51.0
					RPC						
1:3	6.3	5.4	0.6	0.3	0.17	0.20	78.7	69.7	40.3	25.6	15.5
1:1	6.8	5.7	0.6	0.4	0.17	0.25	77.0	66.3	38.3	17.0	29.9
3:1	7.3	6.4	0.6	0.3	0.19	0.33	83.7	61.3	37.0	13.3	44.0

1.0	7.6	7 1	0.9	0.5	0 19	0.49	87.7	58.3	37.0	12.0	62.3
					Peat						
1.3	4.0	5 7	0.1	0.1	0 15	0.17	83 7	80.1	40.3	24.3	11.5
1 1	3.7	6.1	< 0 1	0 1	0.12	0.14	86.7	85.0	42.3	18 7	11 4
3:1	3.7	5.5	< 0.1	0.2	0.12	0 13	86.7	86.3	42.7	17 7	13.4
1:0	3.6	4.4	< 0 1	0.2	0.08	0.09	92.3	91.0	50 1	23.0	8.0

[z] Substrate shrinkage was calcualted as the percentage change between container volume at planting and harvest.

Figure 2.1. Plant height (cm) by substrate ratio. Expt. 2 1996 used *Rhodendendron x obtusum* 'Hino Crimson', and various ratios of peat, recycled paper sludge at pH 3.4 (RPS3.4), or RPS at pH 6.6 (RPS6.6). Ratio linear was significant at the 5% level.

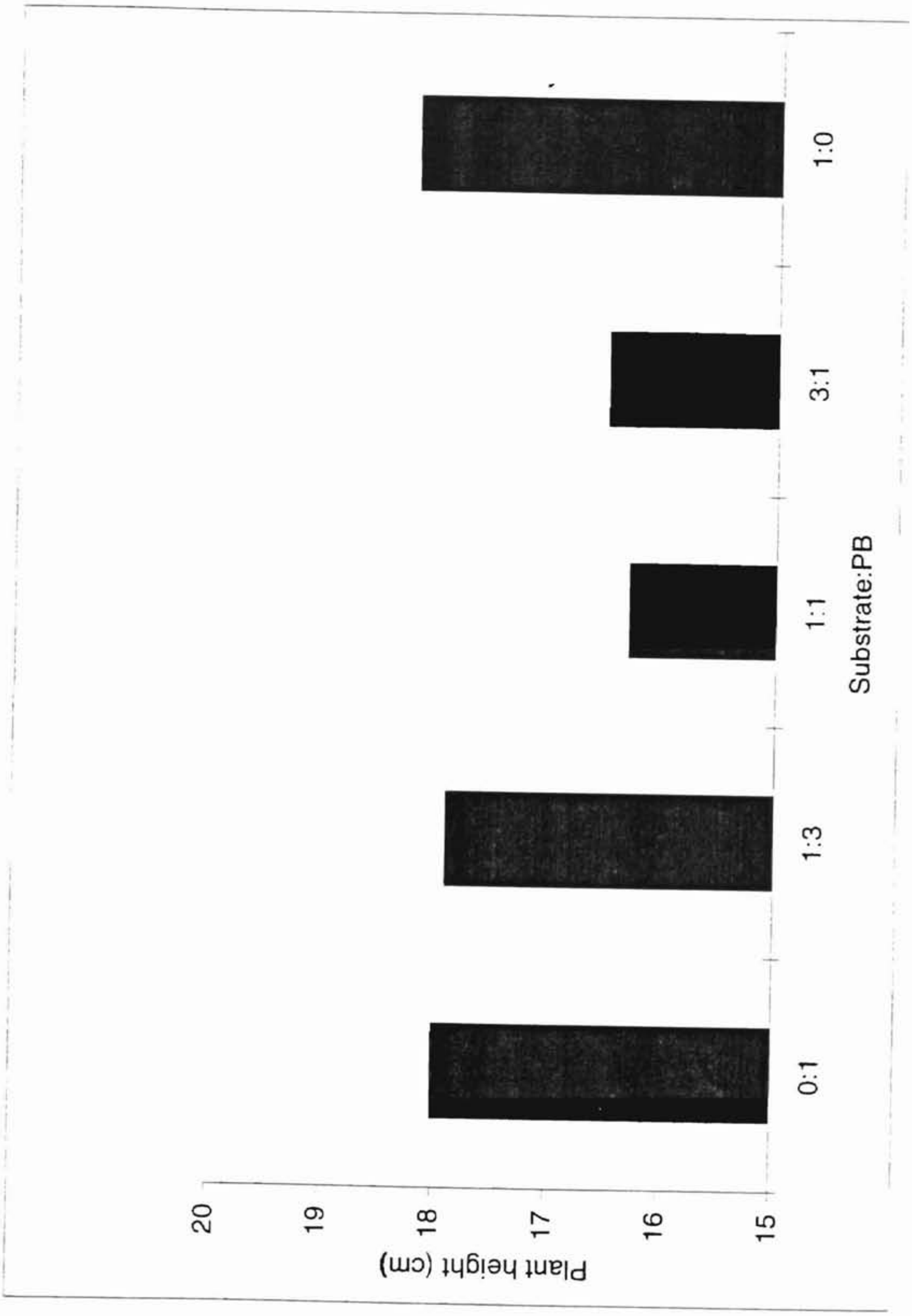

Plant height (cm)
20
19
18
17
16
15
0:1
1:3
1:1
3:1
1:0
Substrate:PB

Figure 2.2. Plant height (cm) by substrate ratio. Expt. 3 1996 used *Rhodendendron x obtusum* 'Hino Crimson', and various ratios of peat, recycled paper sludge (RPS) or recycled cardboard (RPC) at pH 6.6. Ratio linear and quadratic were both significant at the 5% level.

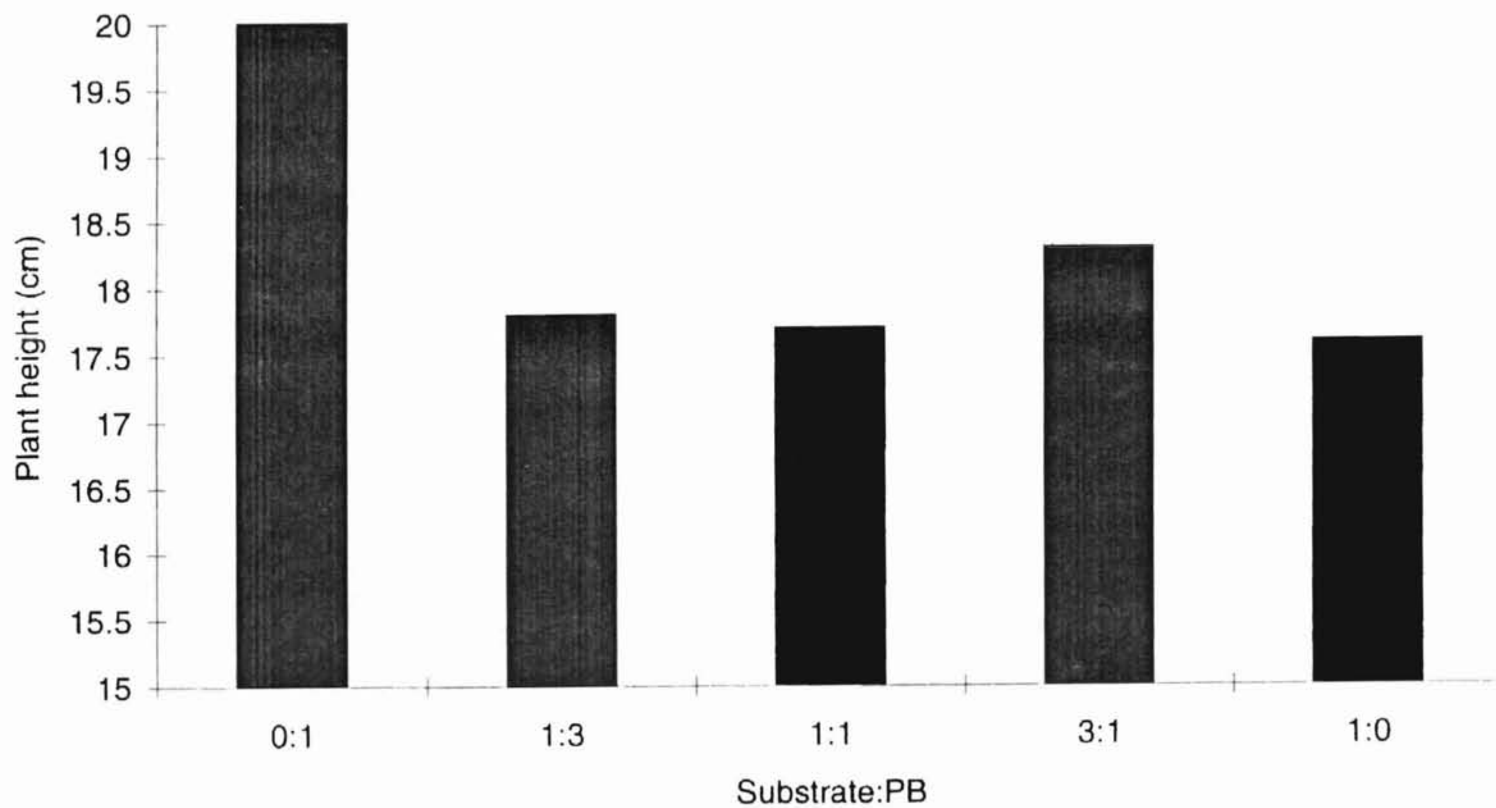

Plant height (cm)
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
0:1
1:3
1:1
3:1
1:0
Substrate:PB

Figure 2.3. Root mass (g) by substrate ratio. Expt. 3 1996 used *Rhodendendron x obtusum* 'Hino Crimson', and various ratios of peat, recycled paper sludge (RPS), or recycled paper cardboard (RPC) at pH 6.6 Ratio quadratic was significant at the 5% level. n = 5

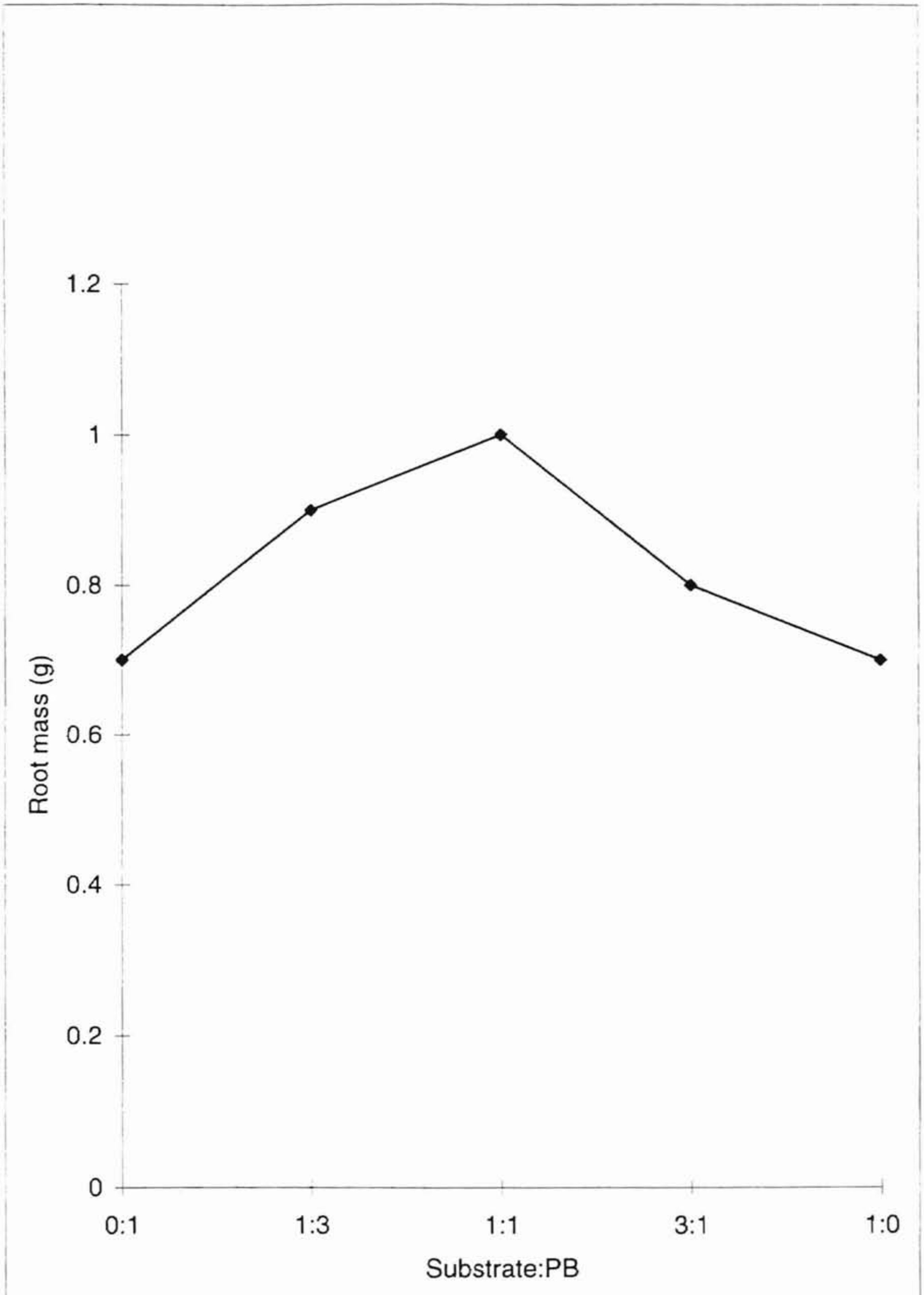

1.2
1
0.8
0.6
0.4
0.2
0
Root mass (g)
0:1
1:3
1:1
3:1
1:0
Substrate:PB

Figure 2.4. Leachate NH_4 concentration ($mg \cdot L^{-1}$) at harvest by substrate ratio. Expt. 2 1996 used *Rhodendendron x obtusum* 'Hino Crimson', and various ratios of peat, recycled paper sludge (RPS), or recycled cardboard (RPC) at pH 6.6. Ratio linear was significant at the 1% level. n=10.

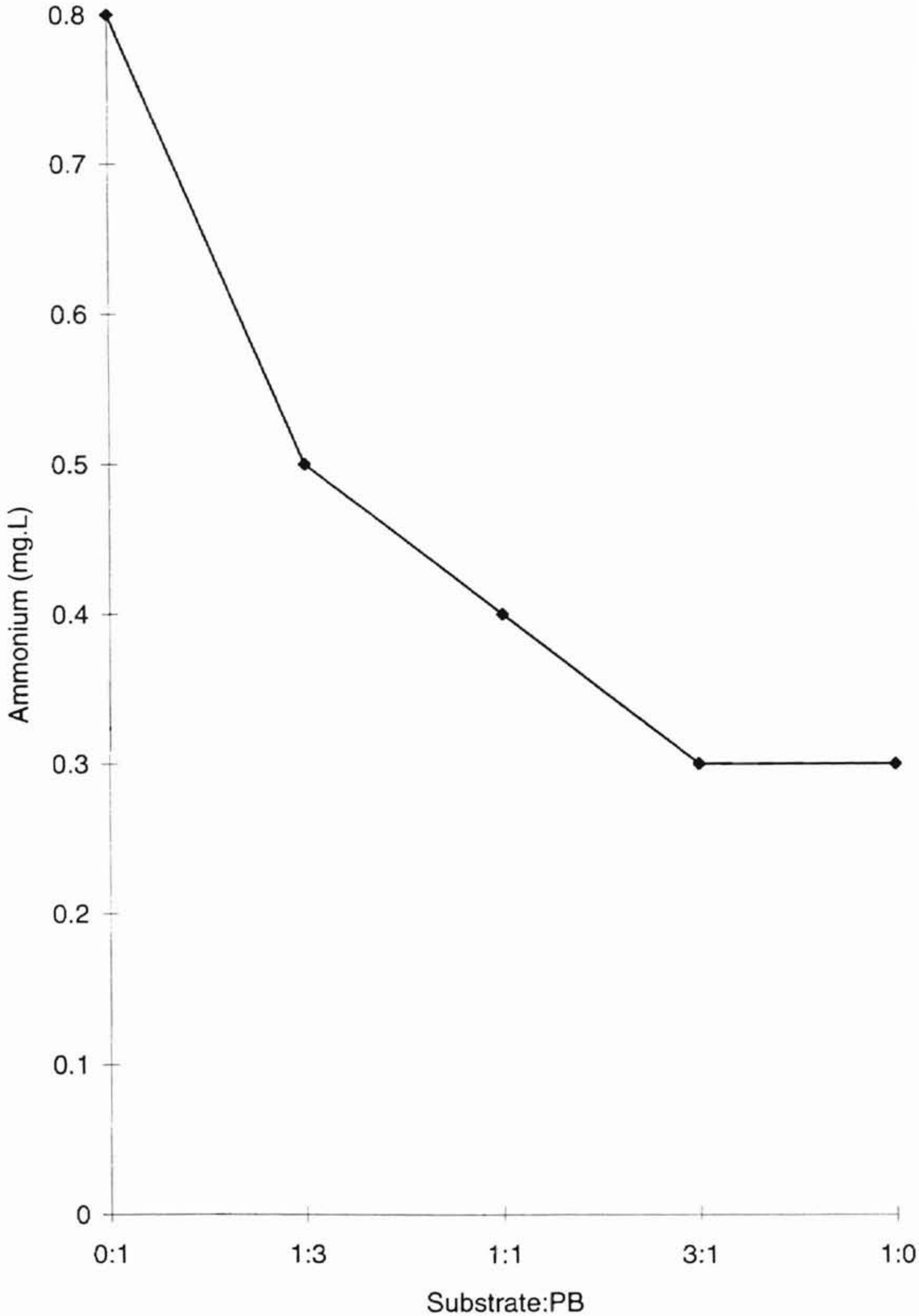
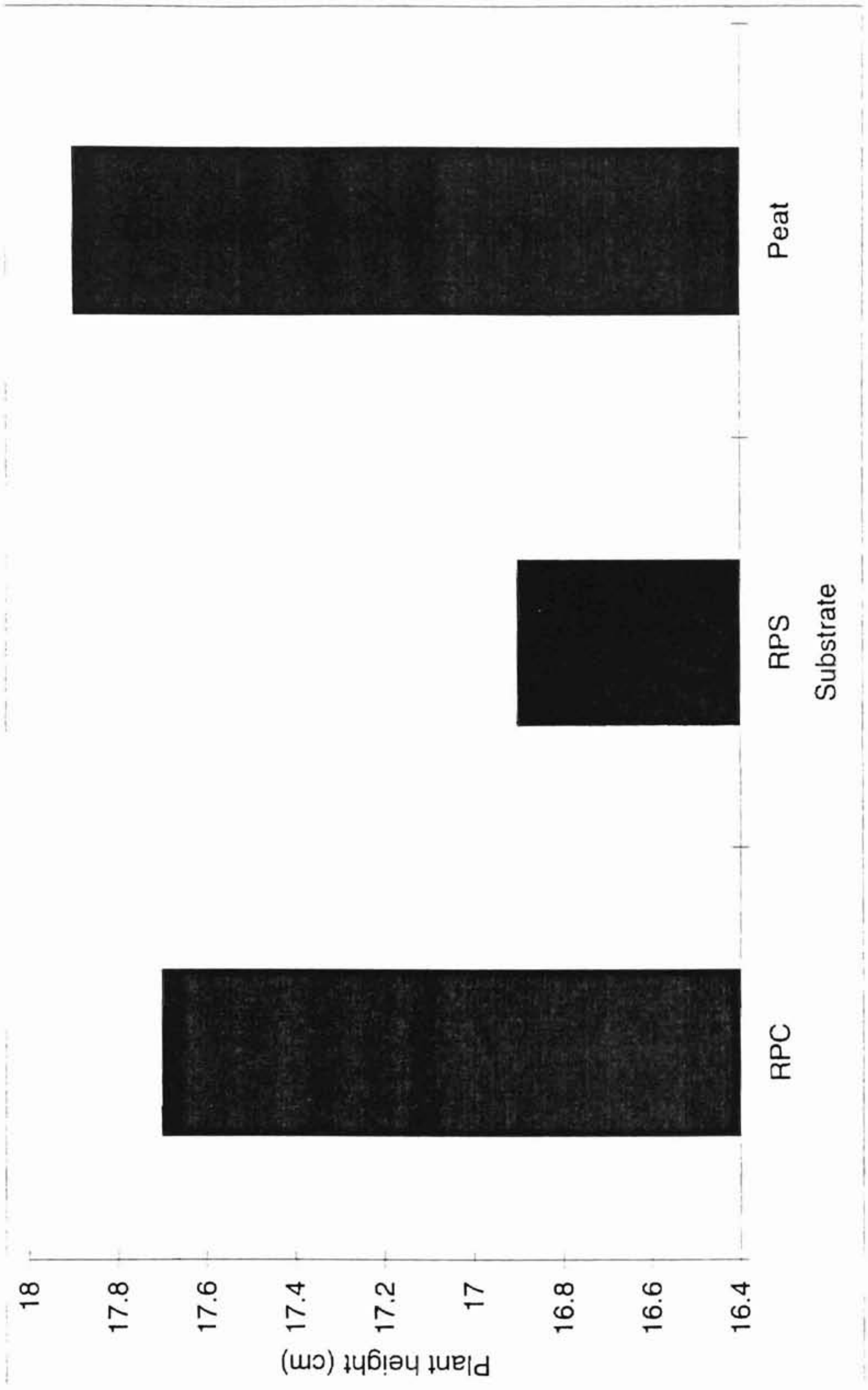

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Ammonium (mg.L)
0:1
1:3
1:1
3:1
1:0
Substrate:PB

Figure 2.5. Plant height (cm) by substrate. Expt. 3 1996 used *Rhodendendron x obtusum* 'Hino Crimson', and various ratios of peat, recycled paper sludge (RPS), or recycled cardboard (RPC) at pH 6.6. Substrate quadratic was significant at the 1% level. Averages were based on live plants remaining out of 50. For RPS, n=24; RPC, n=29; peat, n=34. LSD = $\pm$ 0.95.


Plant height (cm)
18
17.8
17.6
17.4
17.2
17
16.8
16.6
16.4
RPC
RPS
Peat
Substrate

CHAPTER 3

RECYCLED PAPER AS A GROWTH SUBSTRATE IN CONTAINER PRODUCTION OF SPIRAEA

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Additional index words. *Spiraea japonica* 'Froebelii', nitrate, ammonium.

Abbreviations. PB, pine bark, RP, recycled paper, CRF, controlled release fertilizer; LF, liquid fertilizer

Abstract. Spiraea japonica Planch. 'Froebelii', were grown in 3.8 L containers in substrates consisting of recycled paper (RP):pine bark (PB) of 0:1, 1:3, 1:1, 3:1, and 1:0 by volume. Fertilizer treatments included: 100% of the recommended rate of controlled release fertilizer (CRF), 50% CRF plus 50% liquid fertilizer (LF) and 100% LF. Plant growth and quality, leachate NO_3 and NH_4 , and chemical and physical properties of substrates were tested. Plant size and quality varied significantly between

substrate mixes. Mortality was significantly higher in mixes containing 75% and 100% RP. Changes in volume, bulk density, and percent air space were also significant and inversely related to RP concentration. Poor plant quality in 3RP:1PB and 1RP:0PB was attributed to substrate shrinkage and reductions in substrate air space.

INTRODUCTION

A number of nontraditional organic and inorganic materials have been tested as container growth substrates including: coir (Meerow, 1994), spent mushroom compost (Chong et al., 1987) kenaf stem core (Wang, 1994) and ground automobile tires (Bowman et al., 1994). Many materials are wood-based waste paper (Cole and Newell, 1996) or papermill wastes (Adamson and Maas, 1971; Chong, 1995; Lumis, 1976). Much of the interest in these substrates stems from concerns over current use of slowly renewable resources such as peat and the desire to find methods of recycling waste materials. Adoption of plentiful substrates by container producers could reduce depletion of natural resources and amounts of disposable waste.

In addition to an ample supply, to be considered as an alternative to current substrates, a material must exhibit properties conducive to production of high quality plant stock. A suitable substrate is well drained, has adequate pore space, water holding capacity, and resistance to shrinkage (Bunt, 1988). In addition, substrate pH, electrical conductivity (EC), cation exchange capacity (CEC) and nutrient levels should fall within established ranges. Substrates should also be free of substances toxic to plants.

Soilless media came into use originally because of problems encountered when soil is placed in containers. Container soil physics differs from field conditions. For example, Hershey (1990) found that a silt loam having 2 soil:1 air:1 water at field capacity is altered to 2:0:2 at container capacity in a 15-cm deep pot. Without adequate oxygen, plant root growth is impeded and plant quality suffers. The ideal ratio for container mixes has 20-30% air space and 70-85% total pore space (Bunt, 1988).

Relative to field production, management practices in container growing include intensive irrigation and application of fertilizers. Most container growing mixes provide low nutrient holding capacity and the needs for air and drainage result in leaching of nutrients that are present. Soil solution thus becomes the primary source of nutrients. Further, to assure adequate nutrient availability, pH of container mixes should be lower (5.0-6.5) than that of field soils (6.5-7.0) (Warnecke, 1990).

Intensive fertilizer use can result in excessive leaching of nutrients into groundwater supplies. Enactment of regulations governing acceptable nutrient concentrations in leachate that enters ground and surface waters have led researchers to examine how different irrigation practices impact leachate nutrient levels. For a given irrigation practice, with respect to water quality impacts, substrates that retain more nutrients are superior to those that retain fewer nutrients.

CERAD Industries of Sand Springs, Okla. developed the technology for reusing food contaminated paper and paraffin-covered cardboard in a recycled paper (RP) substrate called Wet Earth. Previous studies (Cole and Newell, 1996) indicate that RP may be a suitable peat substitute and may retain more nitrates than peat-based substrates.

Objectives of this research are to determine the effects of RP on plant quality and growth, to compare NO_3 and NH_4 in leachate for substrates containing various ratios of RP to composted pine bark (PB) under three fertilizer treatments (100% controlled release (CRF), 100% liquid feed (LF), and 50% CRF plus 50% LF (50-50), and to characterize the physical and chemical properties of the substrates. If RP proves to be a feasible container substrate, large-scale container producers would have an alternative, environmentally compatible substrate to incorporate into their best management practices.

MATERIALS AND METHODS

1996. On 14 August 1996, *Spiraea japonica* 'Froebelii' rooted cuttings of uniform height and width were potted into 3.8 L containers filled with 2300 cm^3 of RP:PB in ratios 0:1, 1:3, 1:1 and 1:0 (by volume). Plants were grown in a polyethylene covered greenhouse operated at 32.5/15.5 °C day/night under long-day conditions induced by night interruption (incandescent light from 0000 HR to 0300 HR). Maximum light intensity (photon flux density) was 924 $\mu mol \cdot m^{-2} \cdot s^{-1}$

Substrates were amended with equal amounts ($mg \cdot cm^{-3}$) of N, P, and K in combinations of CRF ($mg \cdot cm^{-3}$ incorporated at planting) and LF (total $mg \cdot cm^{-3}$ applied over the course of the experiment): CRF = 5.2 Osmocote 14-14-14 (14N-6.2P-11.6K, 3 to 4 month duration; Scott's Co., Marysville, Ohio)], 50-50 = 2.6 Osmocote plus 0.87 NH_4NO_3 and 0.29 $(NH_4)_2HPO_4$ applied during irrigation, plus 0.4 TSP (0N-19.8P-0K), and 0.79 controlled release K_2SO_4 incorporated at planting, and LF = 1.74 NH_4NO_3 and 0.58 $(NH_4)_2HPO_4$ applied during irrigation, plus 0.8 TSP and 1.58 controlled release K_2SO_4 incorporated at planting. Liquid fertilizer concentrations ($mg \cdot L^{-1}$) varied by irrigation and substrate according to amount of water added per irrigation and the estimated number of irrigations. Slight periodic adjustments were made to ensure that each plant received the same total amount of each nutrient over the course of the experiment. Additional amendments of 1.74 gypsum and 0.65 Micromax (Scott's) were incorporated at planting.

All plants within a substrate treatment were irrigated when a pre-selected test plant reached a target irrigation mass. Target mass was determined by planting an additional six plants per substrate as described above. Plants were irrigated to container capacity and allowed to dry to the permanent wilting point. The mass of containers was recorded. Plants were again irrigated to container capacity and weighed. Target irrigation mass was calculated as a six-container average of: [(50%)(container capacity mass - wilting point mass)] + wilting point mass = container mass at 50% available water. The time to permanent wilting point was used to estimate the number of irrigations and application rates of LF over the 16-week duration of the experiment. Plants were irrigated to capacity plus 10% or more to allow for collection of sufficient leachate for analysis. Because of the greater water holding capacity of RP compared to PB, fewer irrigations and more water per irrigation was required as the proportion of RP increased.

All plants in a given substrate received the same measured volume (400 to 700 ml) of water at irrigation. The amount was determined by the initial water holding capacity of the substrate. In the LF treatments, all replicates of a given fertilizer and substrate received equal amounts of fertilizer ($mg \cdot L^{-1}$) and were leached with clear water every fourth irrigation. At irrigation, containers were nested in plastic funnels seated in the propagation benches. All leachate was collected in 500 ml volumetric cylinders placed beneath each funnel and volumes were recorded. Clear water samples were also taken at each irrigation. A portion of each leachate sample was filtered, labeled and stored at 4.4 °C until analyzed for NO_3 and NH_4 concentration by cadmium reduction (NO_3) and indophenol blue (NH_4) colorimetric methods using a continuous flow analyzer (Lachat Instruments, Milwaukee, Wis., Soil Water and Forage Laboratory, Oklahoma State University, Stillwater, Okla.)

The remainder of each sample was stored at 4.4 °C until analyzed for pH (model 5943-40; Cole-Parmer Inc., Chicago, Ill.) and EC (Solu-Bridge, model SD-B15, Beckman Instruments, Inc., Cedar Grove, N.J.)

For each replicate, shoot height and diameter (an average of diameter at the widest point and diameter perpendicular) were measured (cm) at planting and at monthly intervals thereafter. Visual quality ratings (1 to 5 scale, 1 = dead plant 1, 5 =

highest salable quality) were taken at the same intervals Three independent raters were used to ensure objectivity.

Root balls and shoots (five each) were taken at planting, dried, and stored for later analysis of total N. At harvest, roots and shoots were washed to remove all substrates, fertilizer and pesticide. Root balls, initial shoots, harvested roots and shoots were dried at 67 °C for ten days and dry masses recorded. Growth substrates were dried; samples were taken and weighed All root, shoot, and substrate samples were ground to pass through a 917 µm mesh screen and stored in glass jars until analyzed for total N by the macro-Kjeldahl method (Horowitz, 1980).

Growth substrate bulk density, percent porosity, and percent air space were determined at planting and harvest using methods described in Ingram et al (1990). At potting, empty containers were weighed and filled as above, allowed to air dry and weighed again. Bulk density was calculated as. [(mass of container + substrate) - container mass]/substrate volume. Container drainage holes were covered with silicone sealant, and water was added to the saturation point Percent porosity was calculated as ml H_2O added/substrate volume. Sealant was removed and containers were allowed to drain Percent air space was calculated as ml H_2O drained/volume An average of the measurements was calculated for each substrate. To obtain measurements of media physical properties at harvest, three additional plants were potted as above for each substrate. Plants were irrigated on the same schedule and at the same rate as test plants. Media physical properties were determined by the methods described above.

Five replicates of each treatment were arranged in a split-plot design with fertilizer as the main plot, and growth substrate as the subplot. Analysis of variance and trend analysis were performed using GLM in SAS/STAT (SAS Institute, Inc., Cary, N.C.) Regression models were determined for leachate volume and N released (Tablecurve, Jandel Scientific, Corte Madera, Calif.).

1997. Procedures were similar to those used in 1996 with the following exceptions. Dormant rooted cuttings of uniform height and width were planted 25 February 1997 and grown at an average air temperature of 33.3/12 °C day/night, and maximum light intensity (photon flux density) of 1010 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In addition to height and width measurements, maximum stem length was recorded, and substrate mass for each treatment was recorded at harvest. Along with root and shoot tissues, substrates were analyzed at planting and harvest for total N concentration by the previously described method.

RESULTS

Leachate Analysis

In 1996, there was a significant substrate by fertilizer interaction for initial and final pH and EC (Table 3.1). Initial pH was lowest for 0RP:1PB with 100CRF and for 3RP:1PB with 100LF and highest for 1RP:3PB with 100CRF. At harvest, the 1RP:0PB with 100CRF had the lowest leachate pH and 1RP:0PB with 50-50 and with 100LF were highest. The lowest initial EC ($dS \cdot m^{-1}$) occurred in 1RP:3PB for both

100CRF (1 4) and 50-50 (1 5) treatments. Within fertilizer treatments, initial and final EC increased with the proportion of RP. Leachate for a given substrate ratio tended to increase from CRF to 50-50 to LF fertilizer treatments.

In 1996, there was also a significant substrate by fertilizer interaction for leachate N (Table 3 1). The total amount of N in the leachate decreased as the proportion of RP increased in all fertilizer treatments, but the total amount of N in the leachate increased with the ratio of LF to CRF. Release curves showing the cumulative N in the leachate over the duration of the experiment appear in Fig. 3 1. As shown, the rate of accumulation of N in leachate is lowest in the 100CRF fertilizer treatments and highest in the 100LF. Further, the rate of accumulation of N in leachate in the 100CRF fertilizer treatments increases at a lower rate that in the 50-50 or 100LF treatments.

In 1997, there were also significant interactions between substrate and fertilizer for initial and final pH and EC (Table 3.2). Generally, pH was lowest for the 0RP:1PB regardless of fertilizer treatment at planting. At harvest, however, pH was higher than at planting in all substrate and fertilizer treatments. As was apparent in 1996, EC generally increased with increased proportions of RP regardless of fertilizer treatment (Table 3 2). Leachate EC was generally lower at harvest than at planting and followed the same trend, increasing with the proportion of RP for 100CRF and 50-50. There was, however, little difference in leachate EC at harvest among the substrates in the LF treatment.

There was also a significant fertilizer by substrate interaction for the total amount of N in leachate and the total amount of N in the substrate at harvest in 1997

(Table 3.3). The amount of N in the leachate was lowest with 100CRF and greatest with 100LF regardless of substrate. Within the 100CRF and 100LF treatments, the total amount of N in the leachate generally decreased with increasing proportions of RP in the substrate. Release curves reveal a similar accumulation pattern in 1997 (Fig. 3.2) and in 1996 (Fig. 3.1). In contrast, there was a tendency for substrate N to increase as the proportion of RP in the substrate increased in the 50-50 fertilizer treatments (Table 3.3). At harvest, substrate N increased as RP increased.

Plant Growth

In 1996, there were significant substrate by fertilizer interactions for all growth parameters measured (Table 3.4). Visual quality was lowest in 1RP:0PB with 100CRF and 100LF. Regardless of fertilizer treatment, plants in the substrate consisting of only RP (no PB) were smaller in diameter, height, and shoot and root dry mass. Plants in 1RP:3PB and 1RP:1PB treatments tended to have larger diameters and heights than those in the other substrate proportions within each fertilizer treatment.

Shoot and root N concentrations also showed significant fertilizer by substrate interactions (Table 3.4). Overall shoot N concentration was highest in the 100CRF fertilizer treatment. Both root and shoot N concentrations were lowest in 1RP:0PB in the 100LF fertilizer treatment.

In 1997, visual quality, plant diameter, and root dry mass results were similar to those of 1996, generally declining with increased proportions of RP (Table 3.5). Maximum stem length followed the same trend and showed a significant fertilizer-substrate interaction. The greatest stem lengths occurred in the 50-50 and 100LF treatments

Shoot and root N concentrations were generally highest in substrates containing 50% or less RP. The highest shoot and root N concentrations occurred in the 50-50 fertilizer treatment in the 1RP:1PB substrate and in the 100LF fertilizer treatment in the control substrate, respectively.

The 1997 data revealed no substrate by fertilizer interactions for shoot height or shoot dry mass. However, both parameters were linearly related to substrate, decreasing with increased proportions of RP.

Substrate Physical Properties

At planting, the greater the proportion of RP, the greater the bulk density (D_b) and the smaller the percent air space (%AS) (Table 3.7). By harvest, differences in D_b among substrates were more pronounced, ranging from, 0.257 $g \cdot cm^{-3}$ in the control to 0.589 $g \cdot cm^{-3}$ in the RP only substrate. Volume reductions ranged from 14.4% in the control to 52.6% in the RP only substrate. While %AS was reduced somewhat in the control from planting to harvest (51.3% to 45.9%), in the RP only substrate, %AS was reduced by nearly a third (28.8% to 19.9%) Percent porosity showed the same trend as %AS. Cation exchange capacity of substrates increased with increasing proportions of RP.

DISCUSSION

Recycled paper can be used to produce high quality plants when used as 50% or less of the growth substrate. Electrical conductivity and pH of all substrates were within the acceptable range for adequate nutrient availability (0.1-1.8 $dS \cdot m^{-1}$ and 5.0-6.5, respectively) over most of the experiment duration (Warnecke, 1990). While 1997 initial pH values were below 5.0, values increased by the second to third irrigation (data not shown). Furthermore, higher pH values at harvest were not accompanied by observable symptoms of nutrient deficiency. Ammonium nitrate and diammonium phosphate fertilizer sources, both having relatively high salt indices (Tisdale et al., 1993), may have contributed to higher EC readings in LF treatments. In addition, in 1996, plants grown in higher proportions of RP were irrigated less frequently and at higher fertilizer concentrations that those with less RP. This would also contribute to higher EC in media containing more RP, indicating that alternative fertilizer sources may be desirable when RP is used as a substrate.

Studies of CRF versus LF indicate that nitrate leaching is reduced with the former (Broschat, 1995; Furuta, 1976; Rathier and Frink, 1989; Yeager et al., 1993). Those findings are supported in this study. Determination of RP effects on nitrate leaching suggest that there may be some benefits to its use where excessive nitrate leaching is of concern.

An examination of N partitioning between plants, substrate and leachate indicated that total plant N did not significantly differ by substrate or fertilizer treatment. Of the total input of N into each container (about 4 g), the amount N in shoots and roots was highest in the 100% PB treatments and decreased with increased proportions of RP. Amounts of N in each substrate ratio were similar regardless of fertilizer regime. Of the remaining N, the portion in substrates at harvest and in leachate depended on the fertilizer regime used. Substrate percentages of total N were lowest in the LF fertilizer treatment and highest in the 100CRF treatment. Leachate percentage of total N had the opposite pattern with more N in leachate from the LF treatment than from CRF treatment.

Shoot dry masses and maximum stem lengths declined with increasing proportions of RP in the growth substrate both years. Since production of larger plants is a primary goal of growers, the trade-off between environmental impacts and plant growth must be considered when evaluating the use of RP as a potential component of growth substrates.

For optimal growth, container substrates should have a total pore space of 70% or greater and air space of 20% to 30% (Bunt, 1988; Hershey, 1990). Physical properties of substrates containing 50% or less RP were within the acceptable range. Substrates containing more than 50% RP suffered from lower initial air space that decreased further over time. Lack of oxygen in the root zone, especially in the first few weeks of growth, was likely a major contributor to low root and shoot dry masses and diminished plant growth in high RP substrates. In addition to their tendency to compact, high RP substrates also had a tendency toward surface crusting which decreased infiltration and led to excessive surface run-off. Total leachate volumes decreased with increasing RP in 1996, however, this was likely due to the lower irrigation rates in the higher RP substrates. This is supported by the lack of significant differences between substrate leachate amounts in 1997 where irrigation rates were uniform across substrates (data not shown).

In measuring air and water filled porosity, drainage holes were sealed and substrates were allowed to stand in water until saturated. Under this experiment's watering conditions, drainage holes were intact and much of the liquid was lost before the substrate could become saturated. Under conditions of luxury water consumption, as may exist in commercial plant production, crusting of the high RP substrates would not likely occur For this reason, estimates of water and air filled porosity at harvest most likely reflect luxury consumption of water However, for this experiment, water filled porosity may be slightly overstated while air filled porosity may be slightly understated

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Table 3.2. Initial and final pH and electrical conductivity (EC) of leachate from *Spiraea japonica* 'Froebelii' grown in substrates containing various ratios of recycled paper (RP) to pine bark (PB) and receiving various fertilizer treatments in 1997. n = 5

	pH		EC ($dS \cdot m^{-1}$)	
RP:PB	Initial	Final	Initial	Final
	100% CRF			
0:1	4.0	7.2	1.9	0.7
1:3	4.7	6.8	2.4	0.8
1:1	4.5	6.4	3.7	1.0
3:1	5.0	6.4	3.7	1.1
1:0	4.3	--	3.9	--
	50% CRF, 50% LF			
0:1	3.8	6.8	2.0	0.8
1:3	5.2	6.3	2.5	1.2
1:1	4.6	6.8	3.7	1.5
3:1	4.4	6.7	3.6	1.9
1:0	4.3	6.8	4.7	0.9
	100% LF			
0:1	3.9	6.5	1.9	1.1
1:3	3.9	6.4	1.9	1.0
1:1	4.6	6.4	3.9	1.1
3:1	4.5	6.3	3.8	1.1
1:0	4.3	6.6	5.1	0.9

Fertilizer (F) *Substrate (S)	NS	**	***	*
F linear (L)*S quadratic (Q)	NS	NS	**	NS
FL*S cubic (C)	NS	NS	NS	NS
FQ*SL	*	**	NS	***
FQ*SQ	*	NS	NS	***
FQ*SC	***	*	NS	*

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant

Table 3.3. Total amount of N in leachate in substrate at harvest of *Spiraea japonica* 'Froebelii' grown in substrates containing various proportions of recycled paper (RP) to pine bark (PB) and receiving various fertilizer treatments in 1997. n = 5.

RP:PB	Leachate N (g)	Substrate N (g) at harvest
	100% CRF	
0:1	0.30	2.83
1:3	0.16	3.17
1:1	0.23	3.16
3:1	0.19	3.96
1:0	.	
	50% CRF, 50% LF	
0:1	0.60	2.33
1:3	0.54	2.88
1:1	0.59	2.76
3:1	0.62	3.01
1:0	0.69	2.87
	100% LF	
0:1	0.98	1.92
1:3	0.91	2.26
1:1	0.78	2.51
3:1	0.85	2.62
1:0	0.81	2.73

Fertilizer (F) *Substrate (S)	NS	*
F linear (L)*S quadratic (Q)	NS	*
FL*S cubic (C)	NS	NS
FQ*SL	***	*
FQ*SQ	NS	*
FQ*SC	NS	NS

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant

Table 3.4. Plant quality, height, diameter, root and shoot dry mass, and N concentration in roots and shoots at harvest of *Spiraea japonica* 'Froebelii' grown in substrates containing various proportions of recycled paper (RP) to pine bark (PB) and receiving various fertilizer treatments in 1996. n = 5.

RP:PB	Visual quality[z]	Plant diam. (cm)	Plant ht (cm)	N (%) Shoot	N (%) Root	Dry mass (g) Shoot	Dry mass (g) Root
			100% CRF				
0:1	3.3	30.3	21.5	4.3	2.6	6.5	5.0
1:3	3.6	37.0	30.2	4.4	2.8	6.0	4.3
1:1	4.3	37.8	27.0	4.3	3.1	7.3	4.5
3:1	3.4	32.1	26.6	3.6	2.9	5.9	4.5
1:0	1.8	21.8	18.8	4.6	3.0	4.1	3.8
			50% CRF, 50% LF				
0:1	3.0	34.2	21.3	3.6	2.8	5.6	4.2
1:3	3.5	44.6	32.2	3.8	2.9	7.3	5.5
1:1	2.9	37.3	24.7	4.1	3.0	7.6	4.8

3:1	3.6	35.7	22.4	4.1	2.4	8.0	5.3
1:0	3.1	19.1	19.3	3.8	2.3	3.9	1.9
			100% LF				
0:1	4.2	40.3	34.4	4.0	3.4	7.3	5.9
1:3	3.9	46.9	25.3	3.9	3.8	8.7	5.5
1:1	3.9	48.8	32.8	4.0	3.6	8.0	4.3
3:1	2.5	16.2	20.7	3.5	2.4	3.4	2.4
1:0	1.9	14.0	19.5	2.8	2.3	1.9	1.6
Fertilizer (F) *Substrate (S)	NS	*	*	NS	*	*	*
F linear (L)*S quadratic (Q)	NS	NS	NS	*	NS	NS	NS
FL*S cubic (C)	NS	NS	NS	*	NS	NS	NS
FQ*SL	*	NS	NS	*	NS	*	NS
FQ*SQ	NS	NS	NS	NS	NS	NS	NS
FQ*SC	NS	NS	NS	NS	NS	NS	NS

*,**,***, NS Significant at 5%, 1%, 0.1%, nonsignificant.

[z]Visual quality was rated on a scale of 1 to 5 with 1 indicating a dead plant and 5 indicating a high quality plant.

Table 3.5. Plant quality, height, diameter, maximum stem length, N concentration in roots and shoots, and root dry mass at harvest of *Spiraea japonica* 'Froebelii' grown in substrates containing various proportions of recycled paper (RP) to pine bark (PB) and receiving various fertilizer treatments in 1997. n = 5.

RP:PB	Visual quality[z]	Plant diam (cm)	Maximum stem length (cm)	N (%) Shoots	N (%) Roots	Root dry mass (g)
			100% CRF			
0:1	4.1	53.3	46.0	2.85	2.00	4.9
1:3	3.5	47.9	45.7	2.64	1.95	3.3
1:1	3.9	58.5	42.5	3.19	2.49	3.7
3:1	4.5	35.1	36.8	2.92	2.30	2.2
1:0	1.0	.	.			
			50% CRF, 50% LF			
0:1	4.7	58.5	51.2	2.90	2.75	7.6
1:3	4.7	55.2	50.8	3.19	2.55	4.5
1:1	4.4	49.1	44.4	2.85	2.45	3.2

3:1	4.5	38.1	35.4	2.34	2.13	2.1
1:0	3.6	27.1	23.2	2.48	2.29	1.2
			100% LF			
0:1	5.0	59.6	51.0	3.00	2.85	8.2
1:3	4.8	52.2	49.2	2.83	2.40	4.4
1:1	4.6	45.7	46.0	2.46	2.02	2.6
3:1	3.5	20.6	21.2	2.08	2.08	1.4
1:0	3.5	27.8	24.0	2.26	2.06	1.4
Fertilizer (F)*Substrate (S)	NS	*	*	*	***	**
F linear (L)*S quadratic (Q)	NS	*	NS	NS	NS	*
FL*S cubic (C)	*	*	*	*	NS	NS
FQ*SL	NS	NS	NS	NS	***	NS
FQ*SQ	NS	NS	NS	NS	***	NS
FQ*SC	NS	NS	NS	NS	NS	NS

*,**,***, NS Significant at 5%, 1%, 0.1%, nonsignificant

[z]Visual quality was rated on a scale of 1 to 5 with 1 indicating a dead plant and 5 indicating a high quality plant

Table 3.6. Plant height and shoot dry mass for *Spiraea japonica* 'Froebelii' grown in substrates containing various proportions of recycled paper (RP) to pine bark (PB) and receiving various fertilizer treatments in 1997. n = 5.

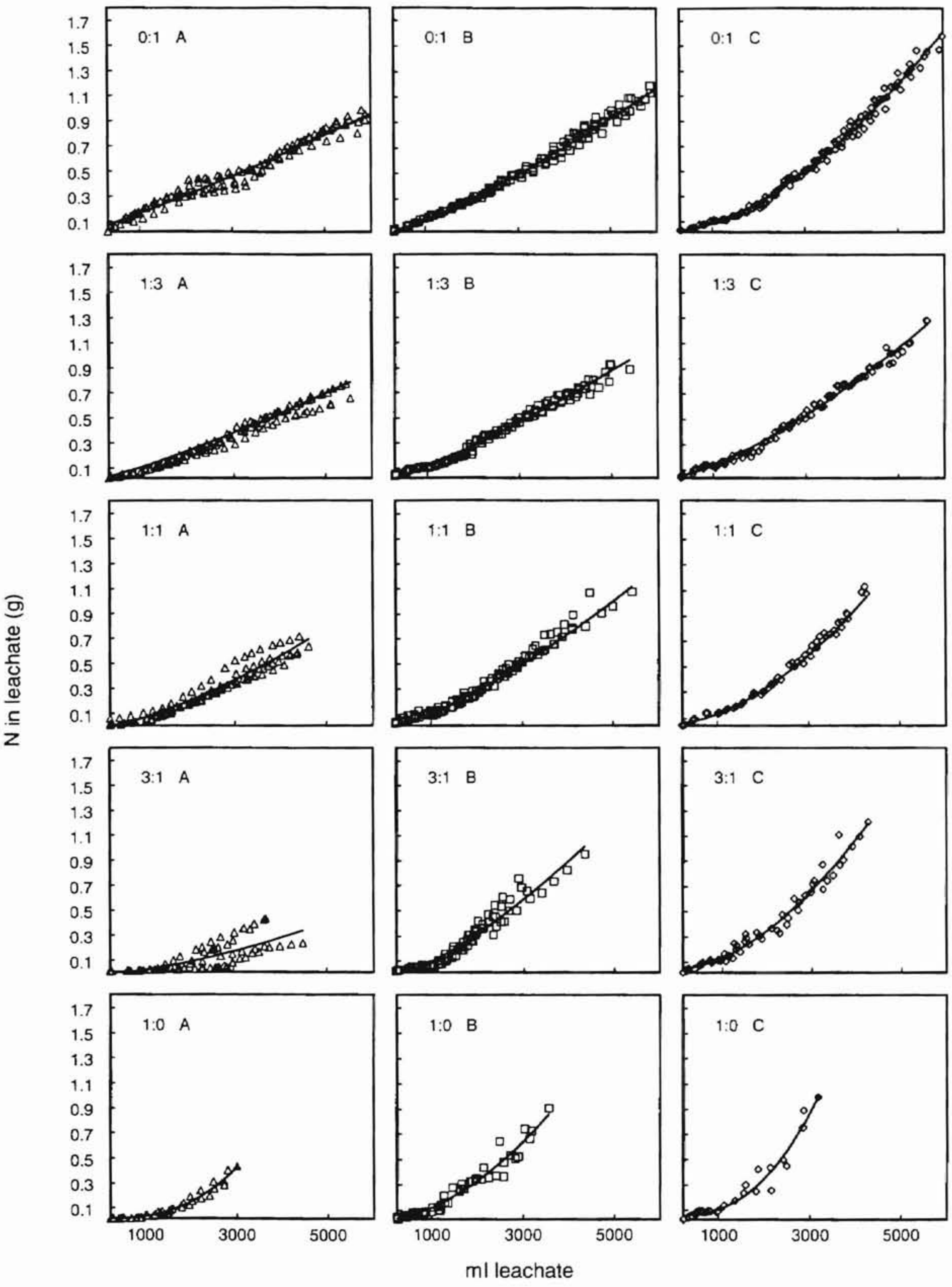
RP:PB	Plant ht. (cm)	Shoot dry mass (g)
0:1	38.1	17.4
1:3	36.2	11.3
1:1	31.3	9.5
3:1	25.3	3.8
1:0	21.7	2.2
Substrate (S) linear	***	***
S quadratic	NS	NS
S cubic	NS	NS

*,**,***, NS. Significant at 5%, 1%, 0.1%, nonsignificant.

Table 3.7 Physical characteristics of substrates containing various proportions of recycled paper (RP) and pine bark (PB). n= 6 ± standard deviation.

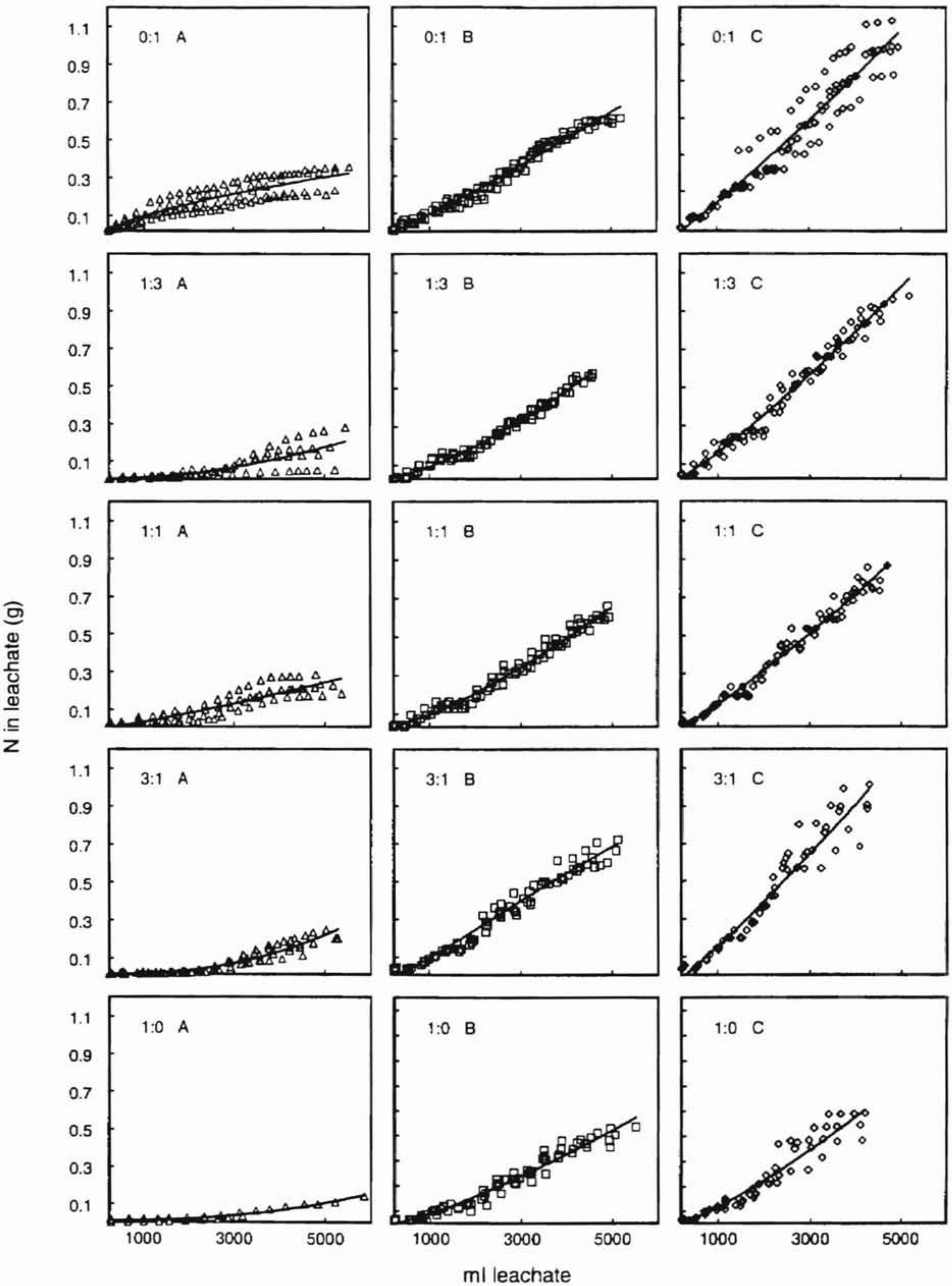
RP:PB	Bulk density ($g\,cm^{-3}$) Initial	Bulk density ($g\,cm^{-3}$) Final	Change in volume (%)	Air space (%) Initial	Air space (%) Final	Pore space (%) Initial	Pore space (%) Final
0:1	0.208 ± 0.009	0.257 ± 0.009	15.4 ± 0.6	51.3 ± 6.9	45.9 ± 1.4	76.5 ± 4.7	78.8 ± 1.3
1:3	0.221 ± 0.002	0.269 ± 0.003	14.2 ± 0.1	40.8 ± 2.9	46.2 ± 1.3	72.6 ± 5.4	76.2 ± 0.1
1:1	0.257 ± 0.001	0.351 ± 0.023	23.4 ± 5.5	35.4 ± 3.4	37.2 ± 2.6	71.9 ± 6.8	69.0 ± 3.6
3:1	0.275 ± 0.02	0.448 ± 0.029	35.8 ± 0.5	31.9 ± 6.6	25.1 ± 7.8	74.1 ± 5.5	65.8 ± 3.3
1:0	0.266 ± 0.006	0.589 ± 0.026	52.6 ± 3.1	28.8 ± 1.1	16.9 ± 9.8	74.7 ± 0.8	54.7 ± 4.8

Figure 3 1. Total amount of N in leachate from substrates containing ratios of recycled paper (RP) to pine bark (PB) of 0:1, 1:3, 1:1, 3:1 and 1:0 and amended with 100% controlled release fertilizer (CRF) (**A**), 50% CRF and 50% liquid fertilizer (LF) (**B**), or 100% LF (**C**) in 1996 The regression equations were as follows: 0:1 with CRF y = a + bxlnx, a= 0.041, b = 1.75e-05 (r^2 = 0.97); for all others, y = a + bx^c: 0:1 with 50-50 a = 0.024, b = 1.56e-05, and c = 1.29 (r^2 = 0.99), with LF a = 0.009, b = e-076.25, and c = 1.69 (r^2 = 0.99), 1.3 with CRF a = -0.131, b = 2.11e-05, and c = 1.22 (r^2 = 0.97), with 50-50 a = -0.007, b = 2.65e-05, and c = 1.22 (r^2 = 0.98), with LF a = 0.031, b = 6.20e-06, and c = 1.41 (r^2 = 0.99); 1:1 with CRF a = -0.007, b = 2.95e-06, and c = 1.47 (r^2 = 0.93), with 50-50 a = -0.004, b = 9.68e-06, and c = 1.36 (r^2 = 0.99), with LF a = 0.054, b = 4.56e-07, and c = 1.75; 3:1 with CRF a = -0.015, b = 5.17e-07, and c = 1 60 (r^2 = 0.57), with 50-50 a = -0.040, b = 1.20e-05, and c = 1.36 (r^2 = 0.94), with LF a = 0.04, b = 4 96e-07, and c = 1.75 (r^2 = 0.98); 1.0 with CRF a = 0.013, b = 1.32e-10, and c = 2.73 (r^2 = 0.96), with 50-50 a = 0.026, b = 5.63e-07, and c = 1.74 (r^2 = 0.95), with LF a = 0.053, b = 1.65e-09, amd c = 2.50 (r^2 = 0.96)



0:1 A
0:1 B
0:1 C
1:3 A
1:3 B
1:3 C
1:1 A
1:1 B
1:1 C
3:1 A
3:1 B
3:1 C
1:0 A
1:0 B
1:0 C
N in leachate (g)
ml leachate
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1000
3000
5000

Figure 3.2. Total amount of N in leachate from substrates containing ratios of recycled paper (RP) to pine bark (PB) of 0:1, 1:3, 1:1, 3:1 and 1:0 and amended with 100% controlled release fertilizer (CRF) (**A**), 50% CRF and 50% liquid fertilizer (LF) (**B**), or 100% LF (**C**) in 1997. The regression equations were as follows. **0:1**: $y = a + bx^{0.05}\ln x$, a= -0.019 and b = 0.0005 ($r^2 = 0.76$) with CRF; $y = a + bx\ln x$, a = -0.010 and b = 1.53e-05, ($r^2 = 0.98$), and a = -0.047 and b = 2.63e-05 ($r^2 = 0.75$) with LF; **1:3**: $y = a + bx^2$, a = 0.007 and b = 6.61 ($r^2 = 0.65$) with CRF; $y = a + bx^c$, a = 0.028, b = 3.23e-06, and c = 1.43 ($r^2 = 0.99$) with 50-50 and a = -0.002, b = 5.42e-05, and c = 1.57 ($r^2 = 0.99$) with LF; **1:1**: $y = ax^b$, a = 9.39e-06 and b = 1.19 ($r^2 = 0.79$) with CRF; $y = a + bx^c$, a = 0.025, b = 6.67e-06, and c = 1.34 ($r^2 = 0.98$) with 50-50 and a = -0.0005, b = 4.10, and c = 1.17 with LF; **3:1**. $y = a + bx^{2.5}$, a = 0.016 and b = 1.16e-10 ($r^2 = 0.89$) with CRF, $\ln y = a + b/\ln x$, a = 8.06 and b = -71.87 ($r^2 = 0.97$) with 50-50; $y = a + bx\ln x$ a = -0.048 and b = 2.88e-05 ($r^2 = 0.94$) with LF; **1:0:** $y = a + bx^c$, a = 0.009, b = 1.56e-10, and c = 2.37 ($r^2 = 0.91$) with CRF; $y = a + b/\ln x$, a = 9.19, b = -80.89 ($r^2 = 0.96$) with 50-50,; $y = a + bx^c$, a = -0.019, b = 1.60e-05, and c = 1.27 ($r^2 = 0.96$) with LF.



N in leachate (g)
ml leachate
0:1 A
0:1 B
0:1 C
1:3 A
1:3 B
1:3 C
1:1 A
1:1 B
1:1 C
3:1 A
3:1 B
3:1 C
1:0 A
1:0 B
1:0 C
1.1
0.9
0.7
0.5
0.3
0.1
1000
3000
5000

CHAPTER 4

SUMMARY

Recycled paper manufactured from paraffin-covered cardboard is an acceptable peat substitute when used as 50% or less of a container substrate. In experiments with azalea, plants of similar quality were grown in peat RPC-amended substrates. Plants grown in RPC and peat-amended substrates had greater shoot dry and root mass, visual quality ratings, shoot N concentration, height and diameter than plants grown in RPS-amended substrates. Performance of azaleas grown in all substrates was likely reduced by substrate pH above 7 0. However, plant mortality rate of 84% in RPS3.4 indicates that perhaps another means of acidification should be found. In experiments with spiraea, substrate pH remained in the range 5.5 to 6.5 for the duration of the experiment which was adequate for the species.

In azalea experiments, the failure of roots in all substrates to move beyond the original commercial media may also have contributed to poor plant performance. The phenomena did not occur in experiments with spiraea and suggests that azaleas rooted in one media may be more sensitive than spiraea to being placed in a different media.

Evidence of greater NO_3 leaching in peat-amended substrates compared with RP-amended substrates was inconclusive in experiments with azalea. Many factors influence leachate NO_3 concentrations including mineralization rates, temperature, pH and substrate water holding capacity. Sampling on any particular day may provide insufficient data on average release of NO_3 from a substrate. Experiments with spiraea, in which all leachate was captured, indicate that NO_3 leaching decreased with increasing proportions of RP.

In experiments with both azalea and spiraea, poor growth and visual quality in substrates containing more than 50% RP probably resulted from media shrinkage and loss of air porosity. Chong (1995) suggested that composting paper-based substrates might stabilize their physical properties and improve growth.

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