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Paper

MANUSCRIPT III:

Nitrogen and phosphorus recovery by ornamental plants grown in a constructed wetland

ABSTRACT

Constructed wetlands may provide a effective, low-cost, and low technology method for reducing nutrient loading to comply with environmental standards for the discharge of nursery runoff. A part of the cost of the constructed wetland could be recovered from the sale of the plants to wholesale and retail markets. A constructed wetland was built at a commercial nursery in Middletown, Rhode Island, and used to evaluate the growth potential of 9 ornamental plant species and cattail. Plant biomass, tissue nitrogen (N) and phosphorus (P) concentration, N and P recovery, divisions produced, and N and P recovery per division were determined for each planting. N and P recovery of the taxa ranged between 49 to 125 g N•m^{-2} and 6 to 16 g P•m^{-2}. Typha latifolia, Canna x 'Aflame', and Phragmites communis 'Variegata' had the largest biomass and removed the largest amounts of N and P from the constructed wetland. Phragmites and Phalaris produced the most divisons per meter squared. While Iris and Pontederia produced the fewest divisons. Comparisons are made with previous research on wild type non-ornamental taxa.

Index words: non-point source pollution, constructed wetlands, plant production, nursery runoff

Species used in this study: Canna x 'Aflame', Colocasia esculenta, Glyceria maxima 'Variegata', Iris pseudacorus, Phalaris arundinacea 'Feecy', Phalaris arundinacea 'Picta', Pontederia cordata 'Alba', Phragmites australis 'Variegata', Spartina paniculata 'Aureo-marginata', Typha latifolia

Significance to the Nursery Industry

As environmental problems associated with greenhouse and nursery runoff gain more attention, constructed wetlands have emerged as effective, low-cost methods of water treatment that may mitigate agricultural pollutants from nursery runoff. It has been suggested that the expense of using such systems could be offset by growing ornamental aquatic plants in treatment wetlands which, in turn, could be harvested and sold. The potential might exist to incorporate traditional nursery crops into treatment wetlands. For example, several taxa of Canna, Iris and ornamental grasses have been used in treatment wetlands for years. Plants harvested from treatment wetlands could be sold bare root, or potted into containers using traditional potting mixes. Wetlands could be reestablished by the replanting of divisions back into the wetland. Results from this study showed that all of the taxa evaluated were able to grow in a flooded gravel-based wetland.

Introduction

Greenhouse, nursery production, and field crop production represent an industry where fertilizers, insecticides, fungicides, growth regulators, and other chemicals often are used in large quantities (2). According to the National Research Council, agricultural fertilizers are the largest single anthropogenic nitrogen input into freshwater lakes and rivers in the United States (23). It has been estimated that up to 78% of applied irrigation in overhead sprinkler irrigated container or nursery stock may either soak into the ground or end up as surface runoff (2,13).

Several studies have reported nitrogen (N) and phosphorus (P) concentrations from 29 to 224 $mg{\bullet}l^{-1}$ total N and 2 to 16 $mg{\bullet}l^{-1}$ total P in nursery runoff (2, 4, 25). The United States drinking water standard of 10 mg $nitrate\text{-}N{\bullet}l^{-1}$ (12) is often exceeded by nursery runoff (2). The states of California, North Carolina, and Texas are starting to regulate surface runoff from nurseries located in environmentally sensitive watersheds (2, 5).

Constructed wetlands could provide a simple, relatively low-cost method of nutrient reduction from nursery runoff (22). Plants play an important role in constructed wetlands, taking up nutrients and providing an extensive root surface area which, in turn, fosters microbial activity and provides mechanical filtration (7,19). Efficient removal of nutrients bound in plant biomass requires periodic harvesting of plants from the wetland. Otherwise, the wetland reaches a maximum standing biomass which reduces new plant growth and nutrient uptake (6). If plants are not harvested, nutrients also may be re-released during leaf decomposition in winter (19). Since plant harvesting is a potentially costly and laborious process, an economic use for harvested plant material has been sought. Uses include the production of gaseous fuels, cattle feed, fiber, compost and organic soil amendments (10). The sale of harvested plant material to retail and wholesale markets has also been suggested (4).

In recent years water gardening has become a fast-growing specialty in landscape design and home gardening (3). Ornamental emergent and floating aquatic plants, as well as native wetland plants used for mitigation or constructed wetland efforts, are in great demand in nurseries and garden centers. Given the increasing popularity of this commodity, its production could find a profitable niche in the nursery and landscape industry.

Canna L., some Iris L. species, and ornamental grasses such as Glyceria maxima (Hartm.) Holmb. ‘Variegata’ and Phalaris arundinacea L.‘Picta’ and ‘Feecy’ are grown in many nurseries. These are selected ornamental cultivars of wetland plants that have been used successfully in treatment wetlands. For these ornamental taxa to function successfully in a constructed wetland, they must be capable of rapid establishment, spread, and growth in high nutrient and anaerobic conditions. However, little or no data exist on the productivity or survival of ornamental wetland plants in treatment wetlands.

For this investigation, ten ornamental plant taxa were grown in a constructed wetland supplied with a commercial fertilizer for the purpose of evaluating growth and N and P recovery. Test species included Canna x generalis L. H. Bail. 'Aflame', Glyceria maxima 'Variegata' (variegated manna grass), Phalaris arundinacea 'Feecy', Phalaris arundinacea 'Picta' (variegated canary reed grass), Phragmites australis (Cav.) Trin. 'Variegata' (variegated common reed), Spartina pectinata Link. 'Aureo-marginata' (variegated prarie cord grass) , Colocasia esculenta (L.) Schott. (green taro), Iris pseudacorus L (yellow flag), Pontederia cordata L. 'Alba' (pickerel weed) and Typha latifolia L. (broad-leaf cattail).

Cattail was included as a test species because of its wide use in constructed wetlands throughout the country and as a point of comparison with the ornamental taxa. Biomass production, tissue N and P concentrations, N and P recovery, and number of divisions produced were determined. The results of this investigation were compared with findings from other studies using the wild type plants from which these ornamental taxa were selected or bred.

Methods and Materials

This experiment was conducted between 1 June 2000 and 11 September 2000 at a commercial nursery in Middletown, Rhode Island (Lat. 41° 44' N, Long. 71o 26' W) in a single wetland cell (4m (13 ft) wide x 30m (98 ft) long x 0.2 m (7.8 in) deep) built outdoors and lined with 45 mil (0.045 in.) butyl rubber (Beacon Co., Cranston, RI). The wetland was filled with gravel (2-6 mm (0.16 to 0.24 in.) dia., 28% pore space) and supplied to a depth of 2 cm (0.8 in) above the gravel surface with a nutrient solution consisting of 20-10-20 Peter's soluble fertilizer (Scotts-Sierra Horticultural Products Company, Marysville, OH) dissolved in tap water to a final concentration of 50 mg N•l^{-1}. Table 3.1 presents a chemical analysis of the nutrient solution. The volume of solution necessary to fill the wetland was approximately 11,300 liters (2,800 gallons). Six polyethylene tubes (0.3 m (12 in.) dia.) were inserted to the bottom of the wetland so that a sump pump could be added for changing the nutrient solution. The nutrient solution was changed every 3 weeks. Tap water was added weekly to replace water lost through evaporation and evapotranspiration.

Plant divisions were purchased from area nurseries and planted in the wetland (Table 3.2). On 1 June 2000 the wetland was planted with 25 divisions per m2 of each species in replicates of 3. Each species block was located within the wetland in a complete randomized design, for a total of 30 blocks. At the time of planting, representative samples were oven dried (70°C for 14 d) and dry weight (DW) and tissue N and P concentrations of the plant material determined (14, 15). These values were used to estimate the biomass and nutrient content of the plants at the beginning of the experiment.

On 11 September 2000, half of each block was harvested. Roots were washed to remove all gravel from the root systems and the plants then divided into divisions appropriately sized for commerical production to determine production increase. Fresh weight (FW) was determined for each replicate and a portion of each replicate was oven dried (70°C for 14 d) to determine FW / DW ratios. Total DW for each block was then calculated. Tabulated data are back calculated to m^2 basis.

Three sub-samples from each replicate of the dried plant material were ground and analyzed for total N by Kjeldahl acid digestion (14), and P determination by molybdate reduction (15). N and P recovery per m^2 was determined by multiplying total biomass by the average tissue N and P concentrations. N and P recovery per division was determined by dividing total recovery by the number of divisions per block. Data collected in June was subtracted from biomass, N and P recovery, and number of divisions data collected in September, so that data would represent net increase over the course of the experiment.

Data were analyzed using Proc GLM method of SPSS (28) and means separated using Duncan's Multiple Range Test to determine significant differences in biomass accumulation, tissue N and P concentration, N and P recovery, and the number of divisions produced per taxa.

Results and Discussion

Desirable characteristics of plants in constructed wetlands and plant production include tolerance of pollutants and waterlogged conditions, quick propagation rates, rapid establishment, spread and growth, and high pollutant removal capacity (32). All of the plant taxa evaluated in this study satisfied these requirements. The test plants grew rapidly in the treatment wetland and after 103 d the mean species biomass (Fig. 3.1) per m2 ranged from 2.1 kg for manna grass to 5.5 kg for cattail. The largest recovery of N per m2 was observed in cattail, followed by canna and common reed (Fig. 3.2). The largest P recovery per m2 was observed in canna, followed by cattail and pickerelweed (Figure 3.3).

Several studies have examined different characteristics of wetland plants to determine which plants have the highest nutrient recovery (1, 10, 11, 31, 32). Nutrient recovery represents the product of two components: plant biomass and tissue nutrient concentration. Wetland plants that are able to recover large quantities of nutrients usually do so through high productivity and large biomass production, rather than through high tissue nutrient concentration. Literature reports of tissue N and P concentration range between 15 - 45 mg N•g DW^{-1} and 1 – 6 mg P•g DW^{-1}. Biomass values range between 1,000 and 60,000 kg•ha^{-1} (27). For example, <u>Lemna</u> <u>minor</u> L. (duckweed) has a relatively high tissue nutrient concentration; however, in side-by-side comparisons with other plants with higher biomass production, duckweed had the poorest nutrient recovery of several species tested due to low biomass (26).

Cattail is used extensively in constructed wetlands in part because of its large biomass production. In the current study, cattail accumulated the most biomass (Fig. 3.1), had the highest N recovery (Fig. 3.2), and the highest recovery of P along with canna (Fig. 3.3). On the other hand cattail had a similar tissue N concentration and one of the lowest P tissue concentrations of the taxa evaluated.

After cattail, canna yeilded the largest biomass (4.1 kg•m^{-2}, Fig. 3.1) and the largest N and P recoveries (95 g N•m^{-2} and 16 g P•m-2, Figs. 3.2 & 3.3). DeBusk and co-workers (11), investigating Canna flaccida Silisb. growth in nutrient enriched and non-enriched dairy wastewater, found tissue N and P concentrations ranging from 15.3 to 29.2 mg N•g $^{-1}$ and 3.6 to 5.0 mg P•g $^{-1}$ at different periods in the summer. They reported a final biomass of 3 kg•m^{-2} in unenriched dairy runoff, and a biomass of 7 kg•m^{-2} in dairy runoff supplemented with N and P fertilizer after 96 d in culture. This study using enriched runoff reported greater biomas than in the current study. This could be attributed to initially denser plantings of 48 rhizome cuttings per m2, warmer growing climate (south Florida), or different growth characteristics between Canna species. Another study using Canna flaccida in a subsurface flow gravel wetland in Texas also had similar results to our study (21).

Variegated manna grass had intermediate tissue N and P concentrations of 24 and 2.8 mg.g-1, respectively (Figs. 3.2 & 3.3). These values were similar to previously reported N and P concentrations of 21.4 mg N•g^{-1} and 2.9 mg P•g^{-1} for Glyceria in wetland cells used to treat dairy waste water (32). In the present study, the biomass of variegated manna grass was 2.1 kg•m^{-2} (Fig. 3.1). This was similar to biomass of manna grass reported for the wild type in ponds in Poland supplied with partially treated sewage (24), and one-half the biomass, N and P recovery, and tissue N and P concentrations reported for manna grass grown in municipal waste water in Sweden (30).

Two cultivars of variegated ribbon grass were grown in the present study. Growth and uptake were very similar with the exception that 'Picta' had a higher tissue N concentration than 'Feecy' (Fig. 3.2). In a constructed wetland treating secondary effluent, located in Manchester, England, ribbon grass yielded 2.5 kg•m^{-2} and N and P tissue concentrations of 41.9 mg•m^{-2} and 6.1 mg•m^{-2}, respectively (20). These biomass yields are similar to our study, but the tissue N and P concentrations are considerably higher than we observed. This might be related to the variegation.

In the current study Pontederia cordata 'Alba' had the largest tissue P concentration (4.5 g N•m^{-2}), and the third largest P recovery (13.8 g P•m^{-2}) of the test species (Fig. 3.3). Field reports of biomass yield for pickerel weed range from 0.5 kg.m-2 for a natural wetland (33) to 5.0 kg•m^{-2} for a nutrient-rich constructed wetland (11). These studies reported tissue N and P concentrations from 14.0 to 25.7 mg•g^{-1} and 2.7 to 3.8 mg•g^{-1}, respectively. This wide range of biomass yields and tissue nutrient concentrations could be due to environmental conditions and ecotypic variations.

In the present study, variegated common reed yielded a biomass of 3.7 kg•m^{-2} (Fig. 3.1) with tissue N and P concentrations of 24 mg N•g^{-1} and 2.3 mg P•g^{-1} (Figs. 3.2 & 3.3). A study evaluating the biomass of wild type Phragmites grown in a wetland treating dairy waste water reported yields of 4.2 kg•m^{-2} and tissue N and P concentrations of 32.0 and 2.6 mg•g^{-1}, respectively (32). Variegated common reed in the present study had similar biomass and slightly lower tissue N and P concentrations. However, similar tissue N concentrations have been reported for common reed grown in a subsurface flow wetland (18). Lower tissue nitrogen levels but similar phosphorus levels have also been recorded for common reed growing in gravel-bed wetlands treating secondary domestic sewage (1) and settled domestic sewage (8).

Of all the ornamental grasses evaluated in the present study, Variegated prairie cordgrass yielded the lowest tissue N and P concentrations (Figs. 3.2 & 3.3), but had a relatively high biomass yield (3.2 kg•m^{-2}). Several extensive studies of biomass production among Spartina species have been conducted in salt marshes along the Atlantic and Gulf Coasts of the United States. Two such studies reported above-ground biomass production in the range of 1.4 to 3.7 kg•m^{-2} (16, 17).

On the basis of number of divisions produced, canna and cattail removed the most N, while canna and pickerelweed removed the most P (Fig. 3.4). Cattail and canna had high nutrient recovery because of their large biomass per division (33 g•div^{-1} and 28 g•div^{-1}, respectively). A division of canna and cattail frequently included a single stem up to 2 m in height. An exception to the correlation of high biomass and high nutrient recovery was found with pickerelweed. Despite lacking a large biomass (23 g•div^{-1}) , the high tissue P concentration per division of pickerelweed resulted in a recovery of 0.11 g P•div^{-1}. Iris also removed a relatively large amount of N and P per division (Fig. 3.4).

The two cultivars of variegated ribbon grass and variegated common reed produced the most divisions per m^2, followed in rank by variegated manna grass, variegated prairie cord grass, and cattail (Fig. 3.1). Many of the taxa that produced the most divisions per m^2 had low biomass per division and hence, low nutrient recovery per division.

In traditional nursery practice it is common to plant a single division in a container and allow one or two years growth before sale (9). In this investigation we estimated that constructed wetlands could yield from 112 to 239 div•m^{-2} while recovering from 49 to 125 g N•m^{-2} and 5.9 to 16 g P•m^{-2} depending upon the taxa planted. Because of the abundance of divisions produced, several divisions could be planted into a container to produce a finished plant in much shorter time.

Typically, constructed wetlands are planted initially with only a few divisons per m^{2}. Wetlands planted at this density usually require 1 or 2 seasons of growth to function at full capacity. A wetland designed to treat nursery runoff while producing plants for resale might be planted, initially, at a higher density to ensure full coverage by the end of the first growing season. A production schedule then could be developed to harvest new biomass as a part of the propagation operation, after periods of spring fertilization. A portion of the divisions harvested could then be replanted at a density that would yield 100% coverage for the onset of the next year's fertilization.

Many types of wetland substrates have been used in constructed wetlands. This investigation used gravel, which is often used in subsurface flow wetlands. In preliminary trials it was found that ornamental wetland plants grew well in a 2-6 mm gravel, which is also washes easily from the roots and rhizomes for evaluation of plant growth. Larger treatment wetlands designed for long-term use would typically use larger diameter (e.g.1.3 cm (0.5 in.) to 5 cm (2 in.)) gravel to avoid reduced flow or clogging from sediment build up.(29).

The ornamental taxa evaluated here performed similarly to reports of wild type wetland plants grown in constructed wetlands. However, many of the variegated grasses had lower biomass and tissue N and P concentrations than that reported for the wild type taxa. Future research is needed to determine if these differences are due to the genetics of the plant material or to environmental conditions. Studies are needed to determine what runoff nutrient concentrations and retention times would maximize nutrient removal and plant production. Other areas of future research include varying planting densities to determine optimum density for maximum nutrient removal. In this study, divisions were planted at an initial density of 25 divisions per m^2. It is anticipated that planting densities could effect growth rates. In the current study, yellow flag and pickerelweed might have been planted at higher densities to yield higher nutrient recovery and more divisions per m^2.

Research on biomass and nutrient recovery is needed in pilot scale wetlands, where large blocks of plant material have been planted. This investigation establishes the ability of certain test species to grow in flooded wetland conditions, and identifies potential biomass yields and N and P recovery of ornamental cultivars of several taxa grown in constructed wetlands.

Table 3.1. Chemical composition and of nutrient solution applied to wetlands. Town of Newport, RI water ammended with 50 ppm-N of Peter's 20-10-20 souble fertilizer.

Mineral Element	Concentration (mg.l-1)
Ammonium-N	13.0
Nitrate-N	37.0
Phosphorus	10.5
Potassium	41.0
Magnesium	8.7
Sulfur	25.0
Calcium	30.6
Boron	0.02
Copper	0.1
Iron	1.08
Manganese	0.1
Molybdenum	0.003
Zinc	0.009
Chloride	31.9
Sodium	18.2

Chemical concentrations reported above are the sum of the fertilizer chemical analysis supplied by Scotts-Sierra Horticultural Products Company and the chemical concentrations of City of Newport Public Works Department..

Table 3.2. Common names and division description for test species grown in constructed wetland trial.

Species	Common name	Division description
Canna x generalis 'Aflame'	yellow-orange canna	single rhizome with two stems
Colocasia esculenta	green taro	single stem
Glyceria maxima 'Variegata'	variegated manna grass	basal clump with 5 shoots
Iris pseudacorus	yellow flag iris	single stem
Phalaris arundinacea 'Feecy'	tricolored ribbon grass basal	clump with 10-12 stems
Phalaris arundinacea 'Picta'	variegated ribbon grass	basal clump with 10-12 stems
Pontederia cordata 'Alba'	pickerelweed	single stem
Phragmites australis 'Variegata'	variegated common grass	basal clump with 8-10 stems
Spartina paniculata 'Aureo-marginata'	variegated cordgrass	basal clump with 6-8 stems
Typha latifolia	broadleaf cattail	single stem

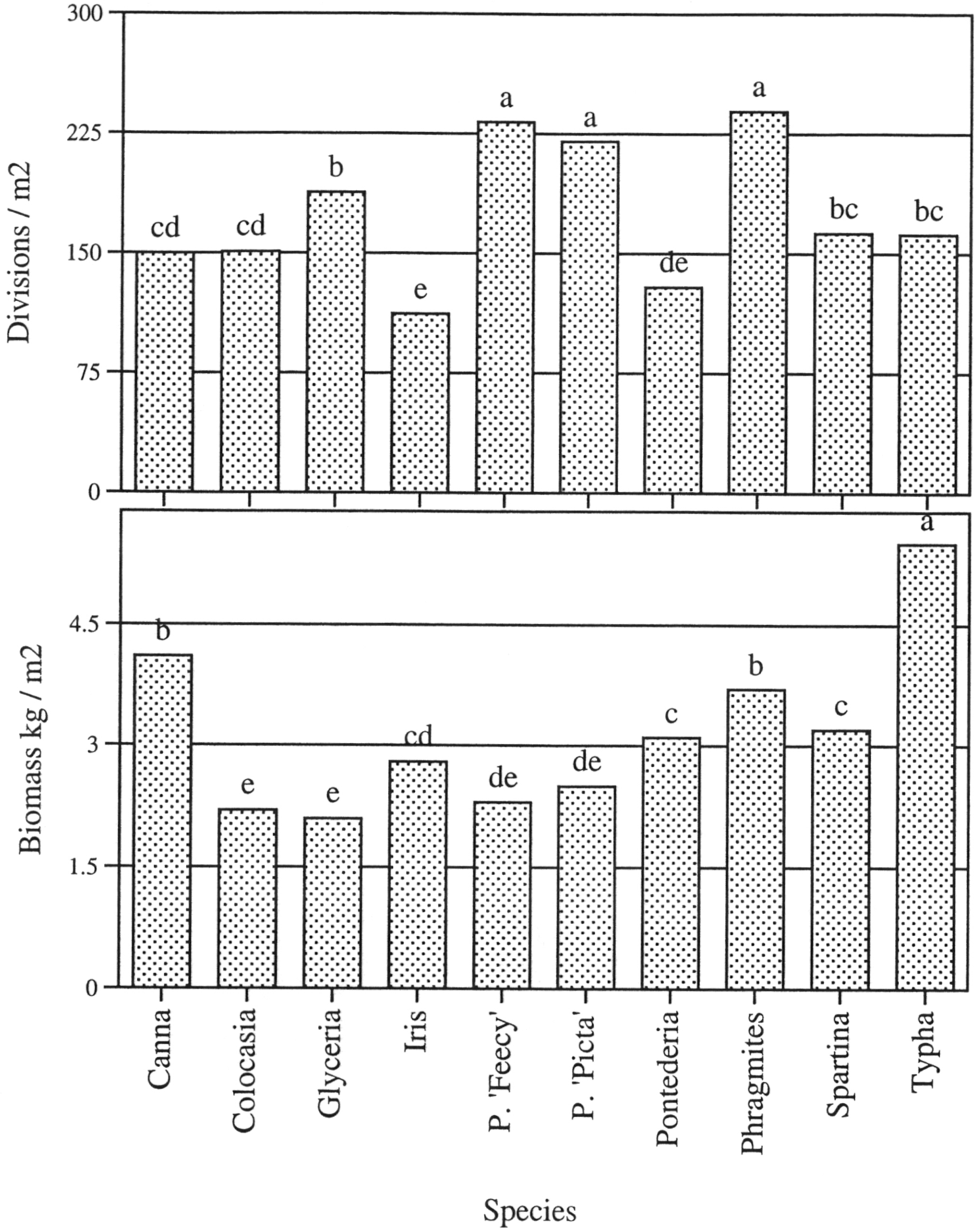

Figure 3.1. Test plant biomass (means) and divisions (means) produced per 1 m2 planting after 103 days in a constructed wetland (n=3). Bars with different subscripts are significantly different at $p < 0.05$.

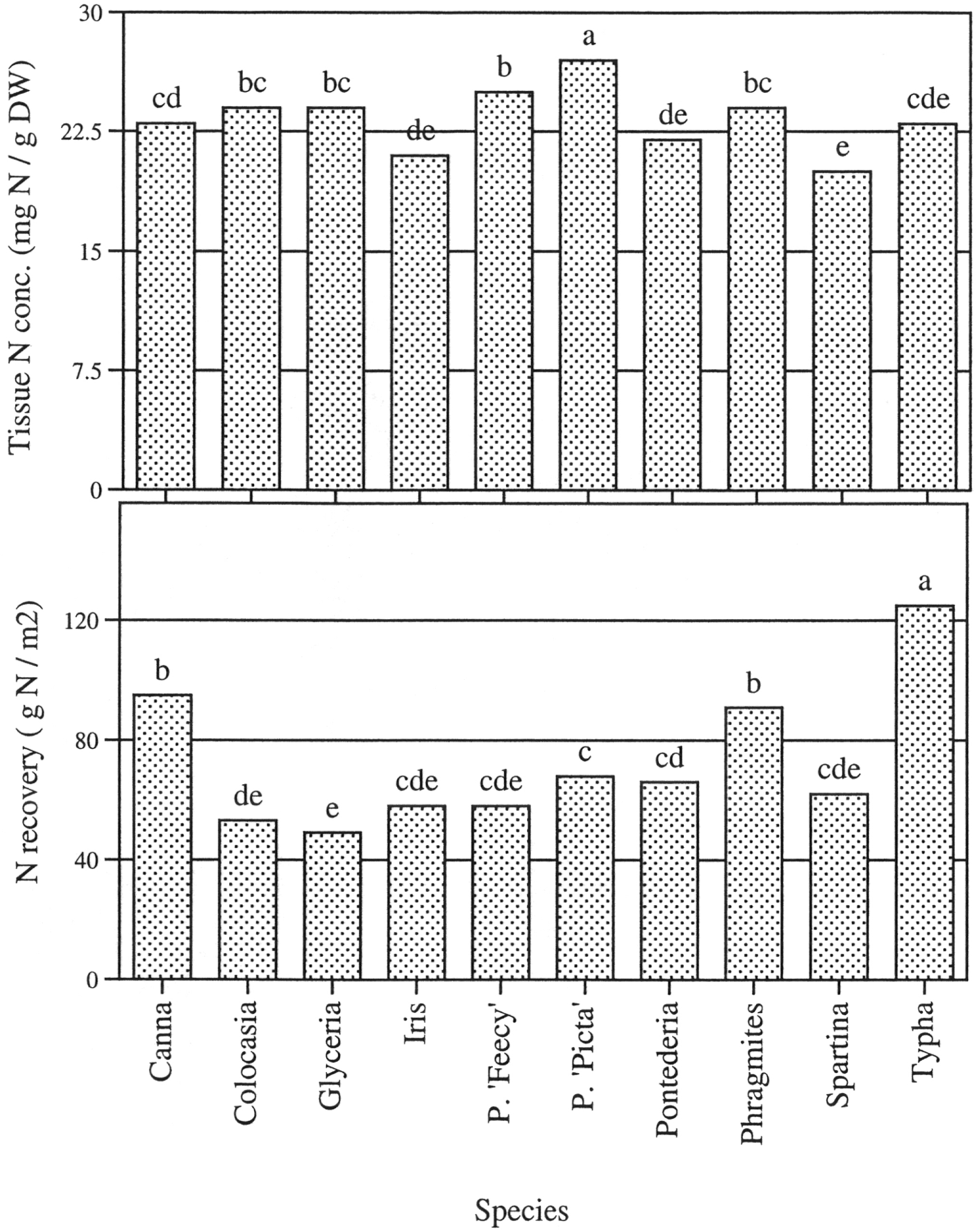

Figure 3.2. Test plant tissue nitrogen concentration (means) and nitrogen recovered per m2 after 103 days in a constructed wetland (n=3). Bars with different subscripts are significantly different at $p < 0.05$.

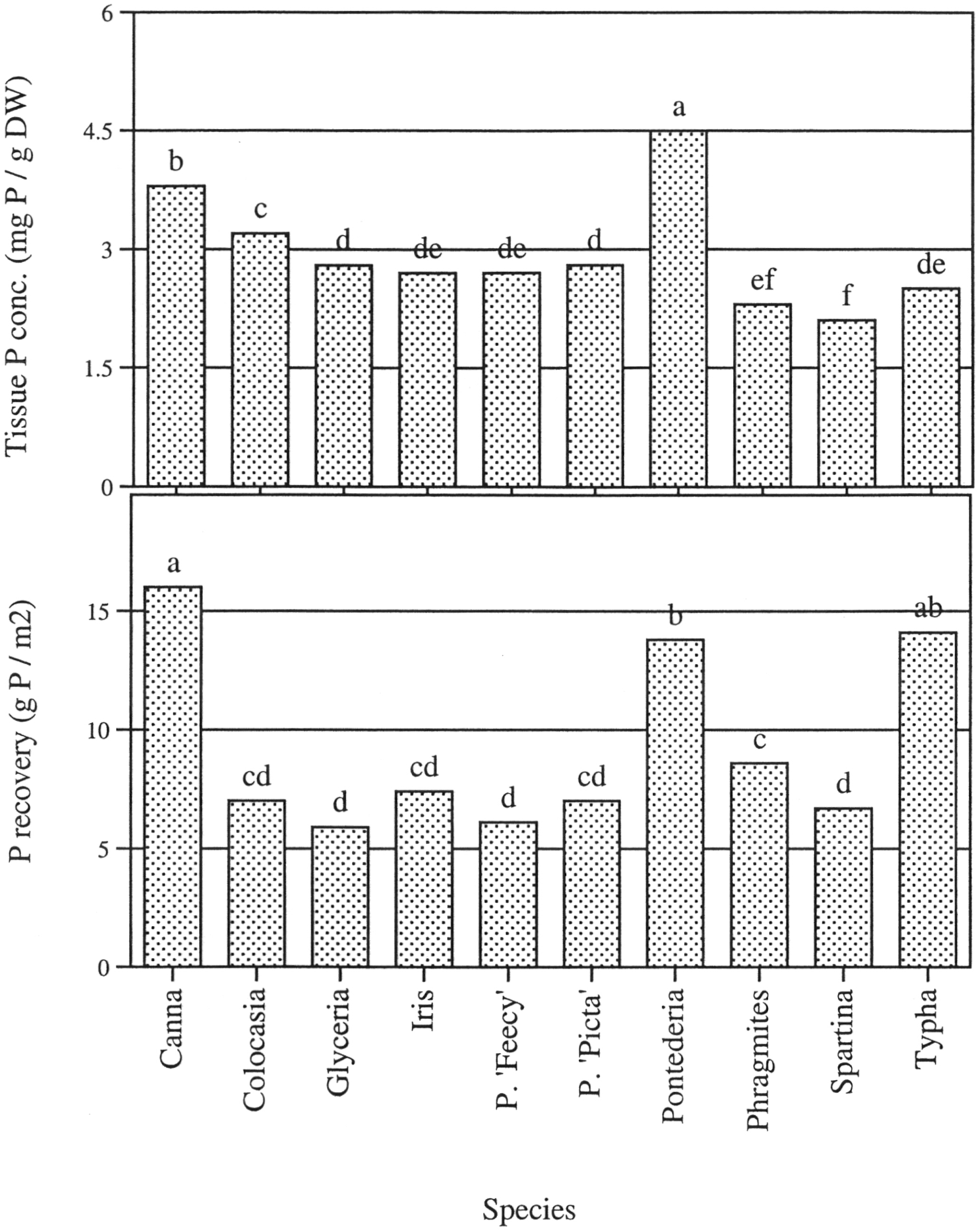

Figure 3.3. Test plant tissue phosphorus concentration (means) and phosphorus recovered per planting (means) per m2 planting after 103 days in a constructed wetland (n=3). Bars with different subscripts are significantly different at $p < 0.05$.

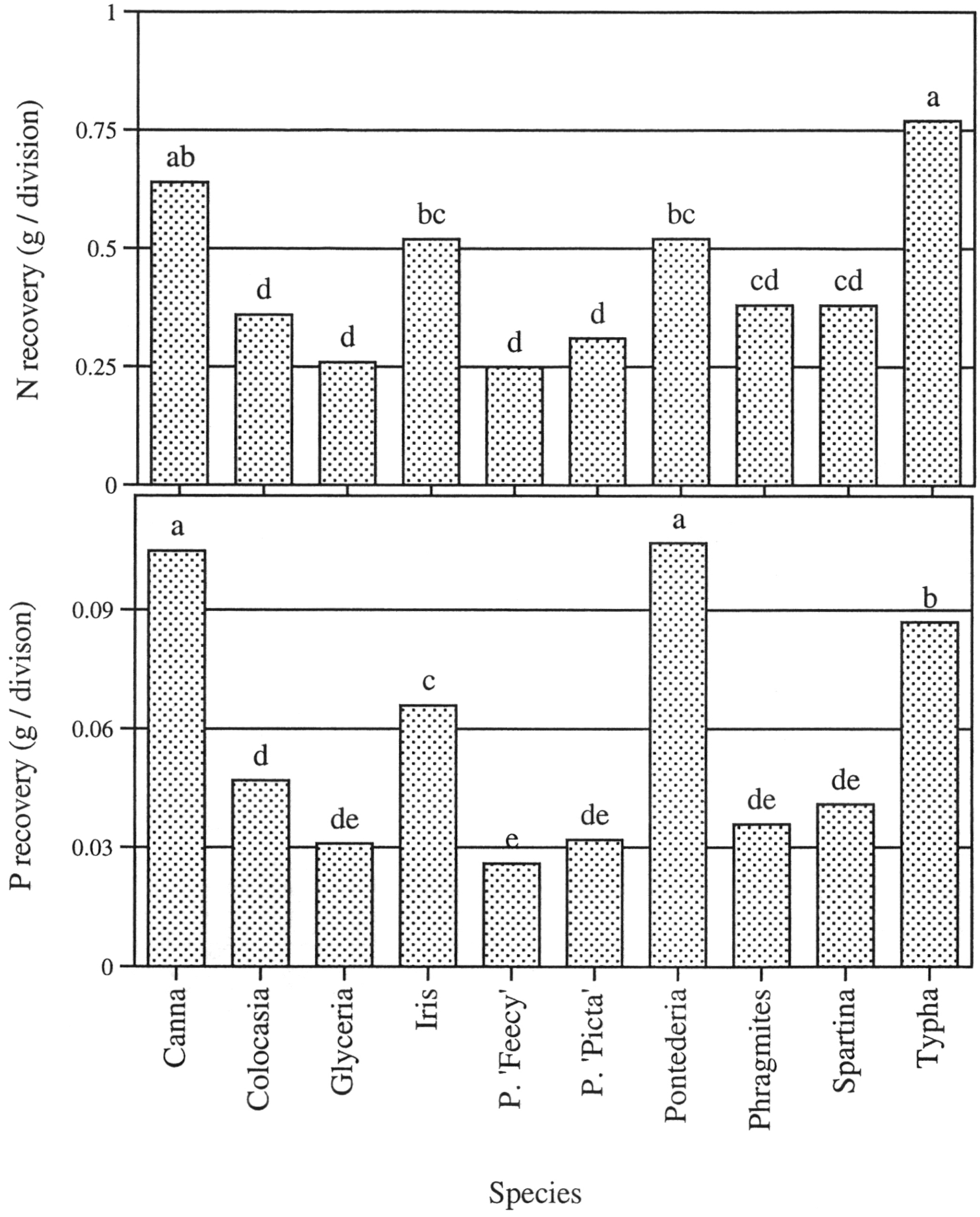

Figure 3.4. Test plant nitrogen and phosphorus recovery (means) per division after 103 days in a constructed wetland (n=3). Bars with different subscripts are significantly different at $p < 0.05$.