Engineering 5 (2019) 841–848

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Research
Water Pollution Control—Article

Plant Traits for Phytoremediation in the Tropics

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ARTICLE INFO

Article history:
Received 2 November 2018
Revised 15 March 2019
Accepted 11 April 2019
Available online 22 July 2019

Keywords:
Nitrogen
Phosphorus
Plant traits
Bioretention system
Stormwater
Tropical plant
Nutrient pollutant
Native plants

ABSTRACT

Water is a limited and valuable resource. Singapore has four national sources of water supply, one of which is natural precipitation. Pollutants collected in stormwater runoff are deposited into drainage systems and reservoirs. Major nutrient pollutants found in local stormwater runoff include nitrate and phosphate, which may cause eutrophication. Bioretention systems are efficient in removing these pollutants in the presence of plants. This paper discusses plant traits that can enhance the phytoremediation of nutrient pollutants in stormwater runoff for application in bioretention systems. The plant species studied showed variations in chlorophyll florescence, leaf greenness, biomass production, and nitrate and phosphate removal. In general, dry biomass was moderately correlated to nitrate and phosphate removal ($r = 0.339–0.501$). Root, leaf, and total dry biomass of the native tree species showed a moderate to strong correlation with nitrate removal ($r = 0.811$, 0.657, and 0.727, respectively). Leaf dry biomass of fast-growing plants also showed a moderate to strong relationship with the removal of both pollutants ($r = 0.707$ and 0.609, respectively). Root dry biomass of slow-growing plants showed a strong relationship with phosphate removal ($r = 0.707$), but the correlation was weaker for nitrate removal ($r = 0.557$). These results are valuable for choosing plants for application in bioretention systems.

1. Introduction

Urbanization has increased the area of impervious surfaces, replaced natural channels with constructed pipes, drains, or canals, and disrupted the natural equilibrium of organic waterways and the hydrology of a given location [1,2]. As stormwater flows over the surface of developed regions, it washes pollutants from various anthropogenic land uses into downstream water bodies [3]. Stormwater runoff then becomes a major nonpoint source of water pollution. Like most urban cities, Singapore has a traditional stormwater management system that focuses on collecting and channeling stormwater runoff quickly into nearby concretized canals and drains. However, as this infrastructure is aging, there is a need to shift toward improved stormwater management programs that intercept, attenuate, and retain stormwater flows in order to improve or maintain the water quality and flow regime of the runoff to standards similar to pre-urban development [4–6]. Some examples of such systems are rain gardens and bioretention swales that detain and treat stormwater runoff. Precipitation over impervious urban grounds often leads to high runoff volume, shortened peak flow, and high incidence of flash floods. By replacing these impervious landscapes with aesthetically pleasing greenspace with the function of promoting infiltration, reducing peak flow, alleviating storm water runoff pollution, and creating a diverse ecological environment, the installation of rain gardens, bioretention swales, and infiltration wetlands are well considered during urban development. Often, these systems have carefully selected vegetation that enhances the aesthetic value of the urban area while simultaneously increasing biodiversity [7]. Vegetation is important, as it directly or indirectly contributes to pollutant treatment efficiency [8]. Some examples of the direct benefits attributed to vegetation include degradation of organic pollutants, phytoremediation of macronutrients and heavy metals, and maintenance of soil hydraulic conductivity [9–11]. Plants also contribute indirectly through their influence on the soil microbial community by their root exudates or by altering the flow rate [12]. Vegetation in these landscaped bioretention areas also serves to slow down the surface flow and filter sediments, thereby facilitating the physical trapping and biological uptake of nutrients [13].

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https://doi.org/10.1016/j.eng.2019.07.019
2095-8099/

Such bioretention systems aid an urban city to build resilience in its catchments and water supply.

One suggested solution to the negative impacts of excess nutrients on water bodies is phytoremediation [14]. Phytoremediation is the use of plants to decontaminate soil, water, and air in a non-invasive, cost-effective way [14–16]. As improvements in the design of biofilters have started to reach a plateau, plant species selection has been suggested as the best way to maximize pollutant removal in bioretention systems [17]. However, plant species differ in their ability to remove pollutants [4], which can be attributed to their physiological, chemical, and morphological differences [12]. Different species of plants have different root architecture, biomass, transpiration rate, and growth rate, which in turn affect the biochemistry of the soil medium and microbial community [12,18]. In Australia, *Carex appressa* was shown to be the most effective plant for removing nitrogen due to its dense root architecture [4]. This nitrogen removal capability was attributed to the high surface area per volume due to the dense and fine root hairs, which increases the region of soil in which these plants can absorb nutrients [4]. In another study, it was shown that plants with fine root systems were not as favorable for maintaining filter media permeability in comparison with species with thick roots such as *Melaleuca ericifolia* [10]. Yet another study showed that efficient nitrogen removal was correlated to species with long, deep roots, high root biomass, and a fast growth rate [19]. However, the experiments mentioned above were conducted in a temperate region, which gives rise to the question of whether these results can be applied to plants grown in tropical areas such as Singapore. Thus, there is a need to study plant and soil interactions in bioretention systems in the context of urban tropical regions like Singapore.

This study aimed to elucidate the plant traits related to the nitrate and phosphate (i.e., nutrient pollutant) phytoremediation potential of species commonly grown in tropical urban Singapore. A wide variety of species was used to allow comparison between growth characteristics and morphologies. The study was conducted in a soil-based filter media to allow practical future application in bioretention systems in Singapore.

2. Materials and methods

2.1. Plant materials and establishment

Table 1 lists the plant species used in this study and their growth forms. For ease of reference, the genus name is used to refer to the plants; where more than one species of a genus is studied, the initials of the species name are included. Potted trials were conducted for 42 species of plants that are common in the horticultural landscape in Singapore. The plants were grown in pots that were 200 mm in height and 280 mm in diameter, containing a filter media comprising a 3:2:7 ratio of top soil, compost, and sand. Ten plants of each species were grown in an open, covered nursery that allowed the unlimited passage of sunlight but shielded the plants from natural precipitation.

2.2. Timeline and watering regime

All the plants were allowed to acclimatize to the new growth environment for 3 weeks after potting, and were irrigated with tap water every 3–4 d during this period. From Week 4 to 7 of the experiments, five randomly selected pots of each species were chosen to be irrigated with nutrient solution every 3–4 d. The nutrient solution consisted of $10\ \text{mg}\cdot\text{L}^{-1}\ \text{NO}_3^-$ and $2\ \text{mg}\cdot\text{L}^{-1}\ \text{PO}_4^{3-}$ added to tap water. This represents the highest range of nitrate and phosphate found in stormwater in Singapore [20,21], and is referred to as "N10 solution" in this study.

2.3. Water quality improvement

During the 4 weeks of N10 solution irrigation, effluents from the pots were collected 12–18 h after irrigation and filtered through sterile 0.45 μm pore sized syringe filters. The water samples were then stored at 4 °C prior to analyses. Nitrate and phosphate concentrations of the influent tap water, influent nutrient solution, and effluents were determined by ion chromatography (Dionex LC20, ThermoFisher). These were used to calculate the amount of nitrate and phosphate removed by the different plant species.

2.4. Plant health

Chlorophyll fluorescence is a sensitive indicator of plant physiological status [22,23]. A hand-held teaching PAM-210 chlorophyll fluorometer (Walz) was used to determine the fluorescence re-emitted by leaves after 30 min of dark adaptation. Chlorophyll fluorescence was determined weekly for all 7 weeks of the experiment.

2.5. Plant growth rate

The plant growth rate was estimated from the new leaf growth after the acclimatization period and during the experimental period. A random growing shoot was selected and tagged, indicating the number of leaves on that branch at the start of the

Table 1
List of plant species used in this study and their growth form in parentheses.

Native species	Native species	Exotic species
Baccaurea minor Hook. f. (t)	*Paederia foetida* L. (c)	*Heliconia psittacorum* L.f. (h)
Barringtonia asiatica (L.) Kurz (t)	*Piper sarmentosum* Roxb. (h)	*Iris domestica* (L.) Goldblatt & Mabb. (h)
Cheilocostus speciosus (J. Koenig) C.D. Specht (h)	*Planchonella obovata* (R.Br.) Pierre (t)	*Lagerstroemia indica* L. (l)
Cleistanthus sumatranus (Miq.) Müll.Arg. (t)	*Plectranthus scutellarioides* (L.) R.Br. (s)	*Lantana camara* L. (s)
Cordyline fruticosa (L.) A. Chev. (s)	*Pluchea indica* (L.) Less. (s)	*Magnolia coco* (Lour.) DC. (t)
Crinum asiaticum L. (h)	*Premna serratifolia* L. (l)	*Pandanus pygmaeus* Thouars (h)
Diospyros discolor Willd. (t)	*Schefflera elliptica* (Blume) Harms (s)	*Schefflera arboricola* (Hayata) Merr. (s)
Dipterocarpus kerrii King (t)	*Sterculia macrophylla* Vent. (t)	*Thunbergia erecta* (Benth.) T. Anderson (s)
Elateriospermum tapos Blume (t)	*Syzygium acuminatissimum* (Blume) DC. (t)	*Trimezia steyermarkii* R.C. Foster (h)
Garcinia cowa Roxb. ex Choisy (t)	*Syzygium antisepticum* (Blume) Merr. & L.M. Perry (t)	*Turnera ulmifolia* L. (s)
Garcinia subelliptica Merr. (t)	*Syzygium myrtifolium* Walp. (t)	*Wrightia antidysenterica* (L.) R.Br. (s)
Gardenia tubifera Wall. ex Roxb. (t)	*Tabernaemontana divaricata* (L.) R.Br. ex Roem. & Schult. (l)	*Xanthostemon youngii* C.T. White & W.D. Francis (t)
Kopsia arborea Blume (t)	*Talipariti tiliaceum* (L.) Fryxell (t)	
Lithocarpus sundaicus (Blume) Rehder (t)	*Tristaniopsis whiteana* (Griff.) Peter G. Wilson & J.T. Waterh. (t)	
Murraya paniculata (L.) Jack (l)	*Vitex trifolia* L. (l)	

c: climber; h: herbaceous; s: small to medium shrub; l: large shrub to small tree; t: tree.

experiments. Subsequently, the number of leaves on that branch was counted weekly to determine how many new leaves had grown. Plants that showed a significant increase in new leaves were considered to have fast growth, whereas plants that showed no leaf growth were considered to have slow growth. Plants whose growth fell between these limits were considered to have moderate growth.

2.6. Plant dry biomass

At the end of 7 weeks, all the plants were harvested and separated according to their organs—that is, roots, leaves, and stems—and dried at 60 °C for a week or until a constant weight was obtained.

2.7. Statistical analysis

The means were compared via the Fisher's least significant difference (LSD) test (one way for analysis of variance (ANOVA) and multivariance analyses) at a 5% level of significance. The biomass data and growth data were correlated to the nitrate and phosphate removal using Pearson correlation, and the results of the simple linear regression were also presented. For all analyses, data were transformed where necessary to meet assumptions of normality and homogeneity of variance.

3. Results

Chlorophyll fluorescence was monitored throughout the experiments as a non-destructive parameter to determine plant health and to assess whether the plants could tolerate the harsh conditions in a bioretention system. The chlorophyll fluorescence results (Fig. 1) showed that there was no significant difference in the physiological health of plants irrigated with tap water versus N10 solution.

The root, leaf, and total dry biomass of the harvested plants were log10-transformed to make the distribution normal. The relationship between the dry plant biomass traits and the nitrate and phosphate removed as recorded for all species was described with a simple linear regression; the results are summarized in Table 2. In general, the plants native to Singapore showed a statistically significant relationship between nitrate and phosphate removal and root and total mass ($p < 0.01$ and 0.05, respectively), but the leaf

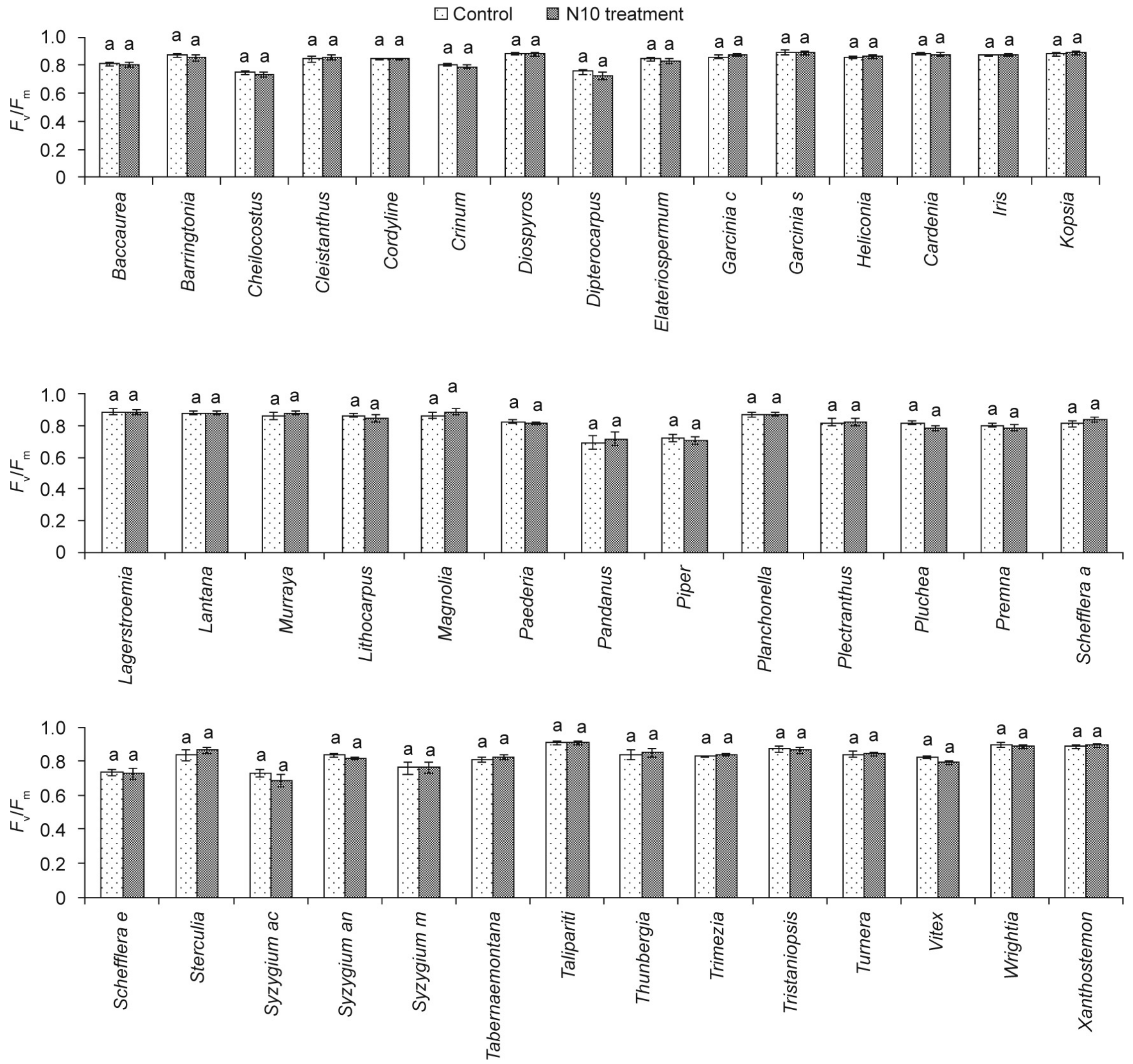

Fig. 1. Maximum chlorophyll photochemical efficiency of photosystem II in dark-adapted leaves (F_v/F_m) readings of control plants and plants irrigated with N10 solution. Each bar represents the mean of five replicates over a 7 week period. The error bars represent the standard error and the letters above each bar represent the statistical group after conducting a Fisher's LSD test. F_m: maximal chlorophyll fluorescence intensity in dark-adapted state during the application of a saturating pulse of light; F_v: variable chlorophyll fluorescence ($F_m - F_0$) measured in the dark-adapted state, when non-photochemical processes are minimum; F_0: minimal chlorophyll fluorescence intensity measured in the dark-adapted state.

mass of plants native to Singapore was only significantly related to nitrate removal ($p < 0.01$). Further analysis of the native plants according to the plant habit revealed that this trait also influences the pollutant-removal capacity. Native trees showed a significant relationship between nitrate and phosphate removal and root, leaf, and total plant biomass (Table 2, Figs. 2 and 3). However, native non-tree species showed no such significant relationship (sample size n, $n = 10$; p-values for the correlation between nitrate removal and root, leaf, and total mass, respectively, are 0.8269, 0.1403, 0.5071; p-values for the correlation between phosphate removal and root, leaf, and total mass, respectively, are 0.4071, 0.8490, 0.5292); thus, those results were not included in Table 2, Figs. 2 and 3. Nitrate removal was more strongly related to native plant leaf biomass than phosphate removal, the latter of which showed no highly significant relationship at the 99% confidence level.

Plants with fast growth showed a significant relationship between nitrate removal and leaf and total mass, and between phosphate removal and leaf mass. In comparison, plants with moderate and slow growth showed opposite significant relationships. Plants with moderate growth showed a relationship between nitrate removal and root and total mass whereas plants with slow growth showing a relationship between phosphate removal and root and total mass.

The coefficient of determination (R^2) results (Fig. 2) revealed that most plant traits showed a moderate to strong correlation with nitrate removal. When all the 42 species studied in this project were considered, root biomass, leaf biomass, and total biomass accounted for 21.75%, 25.11%, and 22.77% of the variation in nitrate removal, respectively (Fig. 2(a)). Exotic plants showed the poorest correlation to nitrate removal, where root biomass only explained 8.79% of nitrate removal (Fig. 2(c)). The roots of native tree species showed the strongest correlation, contributing to 65.83% of the nitrate removal (Fig. 2(d)). Plants with fast growth showed a strong correlation between nitrate removal and leaf mass, where leaf mass explained 49.99% of the nitrate removal (Fig. 2(e)). Plants with moderate and slow growth did not show as strong a correlation as those with fast growth (Figs. 2(f) and (g)).

In general, the correlation between phosphate removal and plant traits was not as high as that reported for nitrate removal. However, although it was reported that nitrate removal in exotic plants was poorly correlated to the different plant parts, phosphate removal showed moderately strong correlation with leaf and total biomass, with 43.39% and 44.03% of the variation explained, respectively (Fig. 3(c)). Native tree species showed similar correlation results for phosphate compared with nitrate, where correlation was high for root biomass (Fig. 3(d)). Plants with fast growth also showed similar results for phosphate removal compared with nitrate removal, where leaf biomass showed high correlation (Fig. 3(e)). However, plants with slow growth showed the highest correlation between phosphate removal and root mass (Fig. 3(g)).

Table 2
Dry plant biomass traits that showed significant correlation with nitrate and phosphate removed (mg).

Item	NO_3^-	PO_4^{3-}
All plants ($n = 42$)	Root mass**	Root mass**
	Leaf mass***	Leaf mass*
	Total mass**	Total mass**
Plants native to Singapore ($n = 30$)	Root mass**	Root mass*
	Leaf mass**	Total mass*
	Total mass**	–
Plants exotic to Singapore ($n = 12$)	–	Root mass*
	–	Leaf mass*
	–	Total mass*
Trees native to Singapore ($n = 19$)	Root mass***	Root mass**
	Leaf mass**	Leaf mass*
	Total mass***	Total mass**
Plants with fast growth ($n = 15$)	Leaf mass**	Leaf mass*
	Total mass*	–
Plants with moderate growth ($n = 17$)	Root mass*	–
	Total mass*	–
Plants with slow growth ($n = 12$)	–	Root mass*
	–	Total mass*

n: number; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

4. Discussion

The suitability of plants for bioretention systems depends not only on the ability of the plants to remove pollutants and maintain the filter medium, but also on their ability to tolerate the abiotic conditions in the bioretention system. Bioretention systems have harsh abiotic conditions, as they are usually situated in open areas to receive stormwater runoff, as well as being exposed to high light levels and unpredictable precipitation. The practice of minimum maintenance for bioretention systems means that the selected plants must withstand periods of stormwater runoff influx to the system and periods of dryness. Plants employed in such bioretention systems must adapt to these harsh environmental conditions. The present study was conducted to test the suitability of 42 species for planting in bioretention systems for the phytoremediation of nitrate and phosphate. Their selection was based on their extensive horticultural use and nativity to Singapore. Before starting the experiments on phytoremediation, the plants were allowed to adapt to the new growth environment for 3 weeks, and their health was monitored through chlorophyll fluorescence. The chlorophyll fluorescence results showed that the plants were not physiologically stressed when irrigated with N10 solution (Fig. 1), indicating that the addition of 10 $mg \cdot L^{-1}$ NO_3^- and 2 $mg \cdot L^{-1}$ PO_4^{3-} into the system would pose no negative impact on plant health.

Easy-to-identify traits such as plant growth rates were observed in order to obtain insight into whether the traits would affect nutrient removal. Shoot growth is easily observable and correlates to the plant's assimilation of available nutrients; hence, this parameter can act as a marker for inferring nutrient uptake and pollutant-removal efficiency [24]. Plants with fast growth showed significant correlation ($p < 0.01$ and 0.05, respectively) between nitrate removal and leaf and total mass ($r = 0.707$ and 0.570, respectively) (Fig. 2), and significant correlation ($p < 0.05$) between phosphate removal and leaf mass ($r = 0.460$) (Fig. 3). It has been commonly thought that fast-growing plants will enhance nutrient uptake [25], and a strong, significant correlation between the leaf mass of fast-growing plants and nitrate removal showed that fast-growing plants with higher leaf biomass would remove more nitrate. As it is difficult to estimate the root size of plants planted in soil medium, leaf mass may be an easier indicator to monitor with regards to estimating the nutrient uptake capacity of the plants. Improved nitrate removal by plant uptake is related to leaf production and biomass, since there is an adequate supply of nitrate stimulating leaf growth and photosynthesis. This is also related to fast growth, as increased photosynthesis in the leaves is related to the assimilation of nitrate into components of the light reaction and carbon dioxide assimilation processes [24]. In photosynthesis, light energy is converted into chemical energy, and reduced metabolic intermediates, such as nicotinamide adenine dinucleotide phosphate, are used in the synthesis of biomolecules, such as carbohydrates and amino acids [26]. These biomolecules are used in the synthesis of different plant organs and ultimately the structure of the whole plant [27], thus linking fast growth, leaf biomass, and plant nitrate uptake.

In a model simulation of nutrient uptake by Agren et al. [28], increasing the external nitrogen was found to increase the plant nitrogen concentration and, subsequently, the growth rate; however, the phosphorus uptake remained unchanged and the phosphorus concentration in the plant decreased. Our results confirmed the

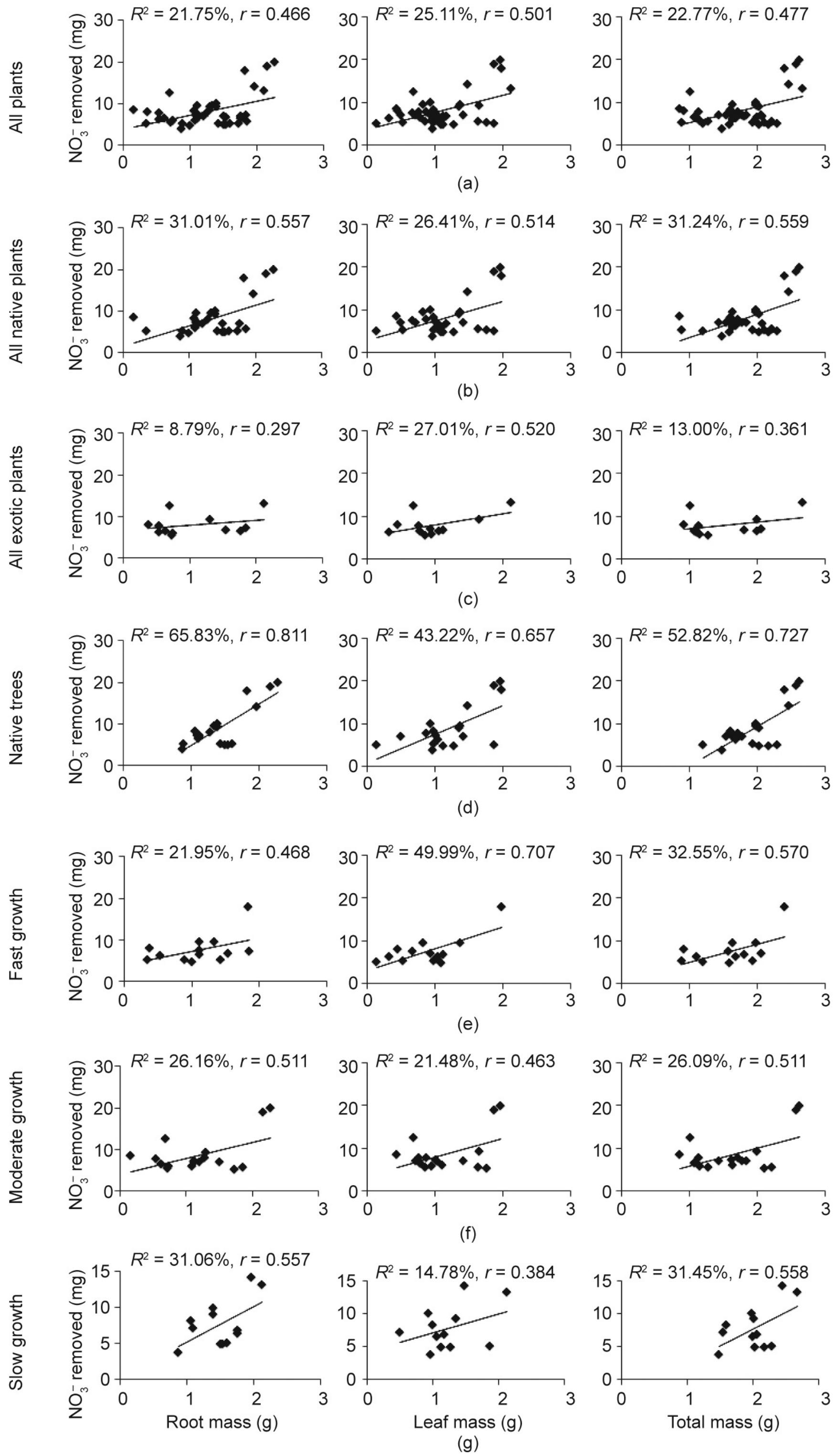

Fig. 2. Linear regression and Pearson correlation of biomass traits with nitrate removed. (a) Root, leaf, and total biomass of all plants; (b) root, leaf, and total biomass of all native plants; (c) root, leaf, and total biomass of all exotic plants; (d) root, leaf, and total biomass of native trees; (e) root, leaf, and total biomass of plants with fast growth; (f) root, leaf, and total biomass of plants with moderate growth; (g) root, leaf, and total biomass of plants with slow growth. R^2: coefficient of determination; r: correlation coefficient of determination of linear regression.

simulation, as fast-growing plants showed greater nitrate uptake while the correlation with phosphate removal was not as strong. The sensitive response in leaf phosphorus concentration to growth rate was also reflected in the responses to specific leaf area and photosynthetic rate [29]. Although the photosynthetic rate was not measured in the current study, the increase in phosphorus removal in relation to leaf biomass in fast-growing plants may have been a result of the greater photosynthetic rate of the plants in this group, which is related to nitrate uptake, as mentioned above.

Native plants have been studied for stormwater treatment in bioretention systems [12,19], whereas in the similar area of wastewater treatment in constructed wetlands, research has

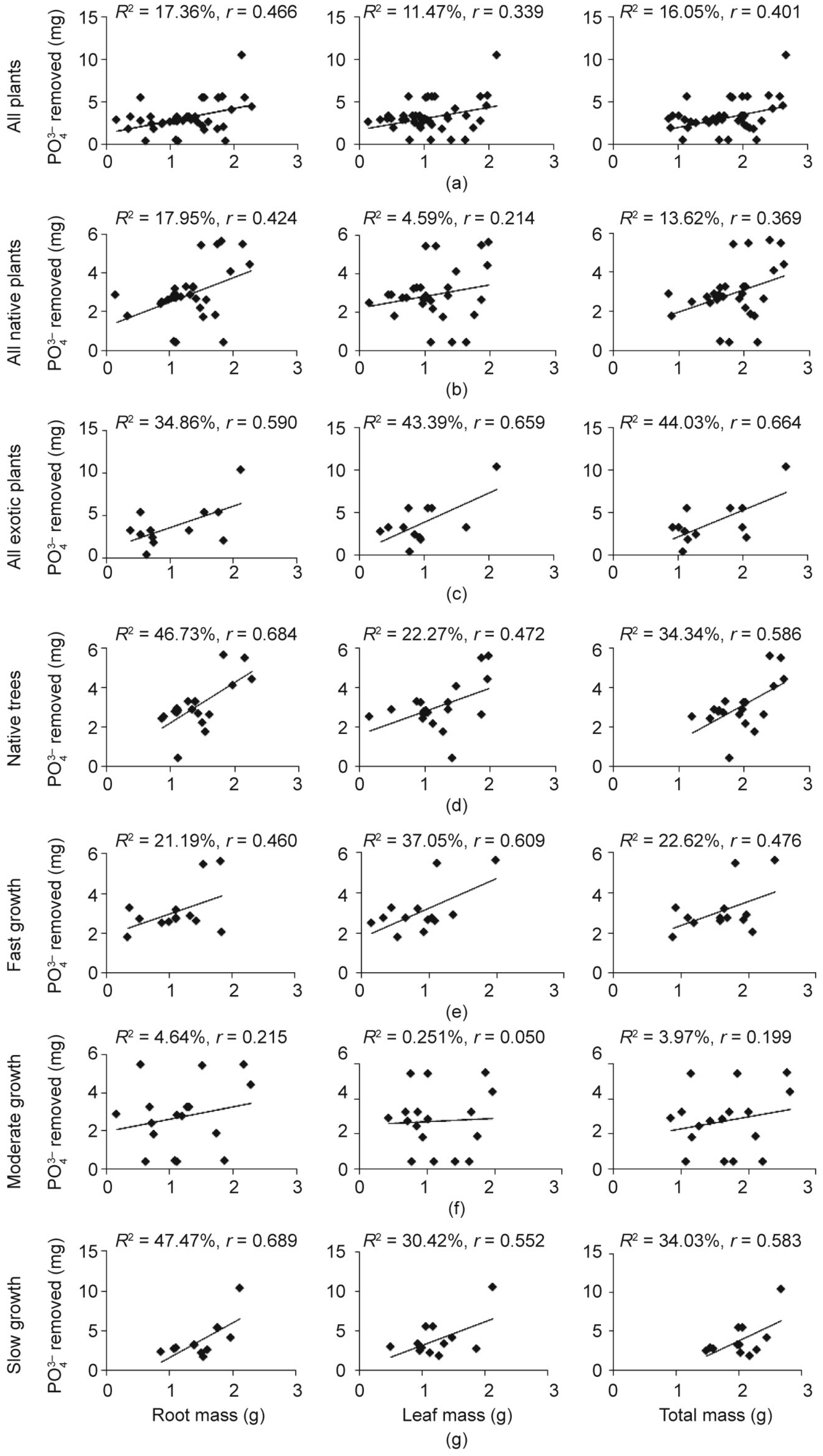

Fig. 3. Linear regression and Pearson correlation of biomass traits with phosphate removed. (a) Root, leaf, and total biomass of all plants; (b) root, leaf, and total biomass of all native plants; (c) root, leaf, and total biomass of all exotic plants; (d) root, leaf, and total biomass of native trees; (e) root, leaf, and total biomass of plants with fast growth; (f) root, leaf, and total biomass of plants with moderate growth; (g) root, leaf, and total biomass of plants with slow growth.

expanded into ornamental plants, especially in tropical countries where ornamental plants would not be negatively affected by cold weather [30,31]. In our study, most of the exotic plants used were ornamental plants that could be purchased from a local nursery. Using exotic plants may pose a threat to native biodiversity, and such concerns make it important to use native plants instead [32]. In a constructed wetland study using both a native and exotic subspecies of *Phragmites*, the native subspecies was shown to be an effective alternative to the more commonly used exotic subspecies [33]. Because our present study included both native and exotic species, the correlation results were separated in order to understand whether the relationship between nutrient pollutant removal and species' nativity would affect pollutant removal effectiveness. In our study, native plants and exotic plants showed different effects on nitrate and phosphate removal. In addition, the effects of nativity, growth form, and characteristics on pollutant removal were analyzed in this paper. Native plants showed a statistically significant ($p < 0.01$) moderate correlation between nitrate removal and root, leaf, and total mass ($r = 0.557$, 0.514, and 0.559, respectively). Nitrate removal—but not phosphate removal—was found to be significantly correlated to the leaf mass of native plants. In contrast, when exotic plants were studied, none of the plant traits were significantly correlated to nitrate removal ($r = 0.297$, 0.520, and 0.361, respectively). In addition, the studies on exotic plants showed that only phosphate removal had a significant relationship ($p < 0.05$) with the root, leaf, and total plant dry mass ($r = 0.590$, 0.659, and 0.664, respectively). Our results showed that native plants could be selected for nitrate removal traits by evaluating the plant root, leaf, and total biomass, whereas exotic plants could be selected for their phosphate removal traits by evaluating these same parameters. The relationship between pollutant removal and plant trait varies with nativity, which indicates that the relationship is not universal for all species. The determined relationships could be highly beneficial to bioretention system users and landscape planners. Our findings could serve as a useful quick guide for choosing plants for use in bioretention system based on their physical traits, without having to go through the rigor of lengthy scientific experiments.

Although it is assumed that native plants are more susceptible to diseases and pests than exotic species [34], there have also been studies in which herbivory on exotic plants was higher, as they have lower physical and chemical defenses against pests in comparison with the native plants sharing a co-evolutionary history with native herbivores [35]. While native and exotic species may not share the same relationship between nitrate or phosphate removal and biomass traits, a combination of species is still recommended in bioretention systems to ensure optimal water quality and resistance against pest and disease.

Another consideration when selecting suitable plants for use in a bioretention system could be based on the plants' growth form. Shrubs have been shown to prefer nitrate in comparison with grasses, which prefer ammonium [36]. These findings may explain the lack of significance in the relationship between non-tree species and pollutant removal in this study. On the other hand, native tree species showed a strong and significant correlation between both nitrate and phosphate removal and all dry biomass traits analyzed (Table 2, Figs. 2 and 3). Our results differed from those reported by Read et al. [19], who found that the growth form of the plants (climbers, shrubs, or trees) did not influence the effectiveness of nitrate or phosphate removal in comparison with the longest root length and root soil depth. Thus, in Singapore, the growth form and nativity of the plant seem to play a more important role in influencing the nutrient pollutant removal in comparison with the study conducted on Australia species such as *Juncus amabilis*, *Banksia marginata*, *Correa alba*, *Hibbertia scandens*, and *Kunzea ericoides* [19]. Although the study by Read et al. [19] showed that the length of the longest root and root soil depth contributed strongly to pollutant removal, our present study did not focus on the root length and depth, as ours was a pot study with plants planted in pots of limited depth. Moreover, in the case of lined bioretention systems, the plants would also have a limited growth area, albeit not as small as the pots. Indeed, previous studies have demonstrated that plants with a deeper root system are effective in taking up soil nitrate, whereas soil nitrate to phosphate ratio could influence the phosphate uptake [37,38]. Further studies on the effect of the root depth of tropical plant species on soil nitrate uptake may be of value.

Our results have added to the understanding and selection of plants traits that can enhance nutrient pollutant removal in a bioretention system. Planting tree species is feasible even in bioretention systems, as trees hold vast potential to remove large amounts of pollutants due to their extensive root systems and biomass. A tree's large biomass, both above and below ground, makes it a strategic method for the phytoremediation of soil [19]. In addition, trees are generally long-lived and have a long growing period. Tree species may be preferred for phytoremediation over annual crops because of their large biomass, root system, and long growing season [39].

Whereas much of the above discussion focused on the influence of plant growth forms and nativity on pollutant-removal capability in the tropics, little is known on the influence of the climatic environment on the phytoremediation potential in a bioretention system. Plant growth rate is sensitive to temperature changes, and soil nutrient availability is also largely dependent on temperature. Low soil temperature is associated with low nitrogen diffusion rates (for both organic and inorganic nitrogen) [40,41], and low translocation of nitrate from roots to leaves [42]; therefore, root architecture and root biomass allocation may be altered due to climatic adaptations. Hence, further research would be valuable in examining the effects of temperature on plants' ability to remove nutrient pollutants.

5. Conclusions

The following conclusions can be formed from this study:

(1) For the native species examined in this study, nitrate and phosphate removal were significantly related to root and total plant biomass.

(2) Exotic and native plants showed different relationships between biomass traits and nutrient pollutant removal; these relationships can be used to make informed decisions on species selection in bioretention systems.

(3) The root biomass of native tree species showed the strongest correlation to nitrate removal, whereas the correlations of phosphate removal to plant traits were not as high as those reported for nitrate removal.

(4) Plants with a fast growth rate contributed to a higher removal of nitrate and phosphate.

(5) The growth form and nativity of Singapore plants influenced their nutrient-removal capabilities.

Acknowledgements

This project was funded by the Public Utilities Board, Singapore (R-706-000-020-490). The authors thank the Office of Estate Development, National University of Singapore, for their support.

Compliance with ethics guidelines

Xiangting Cleo Chen, Liling Huang, Tze Hsien Agnes Chang, Bee Lian Ong, Say Leong Ong, and Jiangyong Hu declare that they have no conflict of interest or financial conflicts to disclose.

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