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Foliar Nutrient Composition of 19 Tree Species Grown on a Phytocapped Landfill Site

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Abstract

An alternative landfill capping technique 'Phytocapping' (establishment of perennial plants on a layer of soil placed over the waste) was trailed at Rockhampton, Australia, as it is eco-friendly, less expensive and socially acceptable. In this capping, trees are used as 'Bio-pumps and Screens' and soil cover as 'Storage'. They together minimise water percolation leading to reduced leachate production. Twenty one tree species were grown on two depths of soil (700 mm and 1400 mm) and monitored for their growth and their ability to restrict water infiltration through the waste. A very common question raised by most scientist and engineers is growth and survival of tree species in a landfill environment. Hence to determine the conditions and health of the tree species, foliar and foliar litter nutrient concentrations were measured in all the tree species grown on the phytocapped landfill site. The 3 year-old trees showed slightly elevated levels of nutrient and this will continue as the trees mature and develop more roots. The trees in the 700 mm soil cover contained slightly higher leaf concentrations of nutrients due to the possible closer proximity of their roots to the waste.

Keywords: Phytocapping; Landfill; Foliar nutrient; Leaf litter

Introduction

All plants depend on mineral nutrients for survival, good health and growth. There are 18 essential plant nutrients of which 15 are absorbed from the soil and three, oxygen, carbon dioxide and hydrogen, are absorbed from air and water. Table 1 lists the essential nutrients required for plant growth, which are categorised into macronutrients and micronutrients [1]. The first seven elements (Table 1) are classed as macronutrients. These are required in higher concentrations, in the order of >1000 mg kg^{-1} dry matter [2]. The last eight elements are micronutrients or trace elements that are required in lower concentrations in the order of <100 mg kg^{-1} dry matter [2]. All these nutrients are essential for plant growth [3] and transpiration [4]; both macro and micro nutrients play a pivotal role in maintaining the hydrological balance of the phytocapping system.

Plants grown in landfills are affected by surface environmental conditions as well as the nutrient supply from the buried waste [5]. Waste in a typical Municipal Solid Waste (MSW) constitutes more than 50% organics which are the major sources of nutrients for plants established on landfills. Organic wastes in Australian landfills predominantly contain food scraps, green waste, paper and cardboard. The Table 2 below gives the nutrient composition of paper and pulp waste, which can be used as an indicator for MSW composition.

In general, nutrient uptakes by plants are influenced by nutrient retention ability of the soil, nutrient demand of different species, growth rate, and biomass distribution [6]. Organic matter content of the soil and soil temperature [7]. Trees store most nutrients in the leaves [8]. Similarly, trees take up heavy metals and store them in the leaves and branches [9-11] to protect themselves from insects and fungi [12]. Nutrients that are taken up by trees are eventually distributed to the environment via litter fall [13-15]. Nutrient removal through plant uptake and litter fall increases with foliar biomass production [6] and the rate of nutrient supply rate [16].

Class	Subclass	Elements
Macronutrients	Primary nutrients	N, P, K
	Secondary nutrients	S, Ca, Mg, Si,
Micronutrients		Fe, Mn, B, Zn, Cu, Mo, Cl, Ni

Table 1: Essential mineral nutrients for plant growth, from Ref [2].

Element	mg kg^{-1}	Element	mg kg^{-1}
N	4520	B	95
P	3000	Zn	183
K	13,300	Cu	67
S	-	Mo	15
Ca	120000	Pb	72
Mg	7730	Ni	16
Si	-	Cr	75
Fe	6260	Co	14
Mn	2600	Cd	2

Table 2: Nutrient composition of paper and pulp ash, from Ref [38].

Ecosystems differ in nutrient supply rates due to variations in leaf litter decomposition rates, mineral weathering and other processes [17]. Studies show that the leaf litter decomposition rate is more rapid in nutrient rich sites than in nutrient poor sites [18]. A similar situation exists in landfills where the nutrient status of the soil is influenced by composition of the waste, decomposition rates of the waste and the availability of minerals. However, nutrient availability may vary from one landfill to another and also within landfills [19]. Nutrient levels in plants grown on phytocaps were assessed with the view to confirming if the established plants were healthy, and also to test if the same plants accumulate unusual levels of heavy metals that could adversely impact on the environment.

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Foliar chemical analysis is a good method to assess plant nutritional stress [20], which is a good indicator of processes occurring at the ecosystem level [21]. Mineral nutrients are essential for plant growth [2]. However, deficiencies in N, P or K mostly occur in mature leaves [22] as these nutrients are translocated from old to young leaves over time [23]. Differences in nutrient mobilisation may reflect greater internal requirements in young versus old leaves. Pastor and Post (1986) reported that over a period of time plants will affect nutrient availability by producing organic litter of varying chemical and physical properties which may have adverse impact on tree growth. Hence, considering the complex nature of the nutrients, their availability, translocation within plants and within an ecosystem, it is important to evaluate nutrient status of foliage and leaf litter on a phytocapped landfill site.

Materials and Methods

Site establishment

An experimental site of 5000 m^2 area at the Lakes Creek Road Landfill, Rockhampton, Australia was selected for this study.

The experimental site had two soil depths treatments (Thick soil cover, 1400 mm and Thin soil cover, 700 mm; Figures 1 and 2). These treatments were replicated twice. In the Thin soil cover, only 300 mm of sandy loam soil and 100 mm of green waste mulch was placed over the pre-existing 400 mm un-compacted clay soil (total soil cover of 700 mm). In the Thick soil cover, four layers of soil were placed over the pre-existing 400 mm clay soil. This consisted of 200 mm of sandy loam, 300 mm of Yaamba clay and 300 mm of Andersite clay, 200 mm of sandy loam soil and 100 mm of green waste mulch (soil cover of 1400 mm). Both Thick and Thin soil cover treatments were mulched with a layer of shredded green waste (100 mm). Eighteen seedlings of 21 species were planted at 2 m × 1 m spacing in each plot. Two tree species out of the 21 grown did not survive.

Detailed foliar chemical analysis was undertaken to determine nutrient composition of 19 species grown on Thick and Thin phytocapping systems. Foliar analysis was conducted twice during this study; once in 2005 and then in 2006. In the first instance, the youngest fully expanded leaves were analysed for nutrients and heavy metals. Then, in the second instance mature, young and the youngest fully expanded leaves were analysed for nutrients and heavy metals. Foliar chemical analysis was also conducted on leaf litter from the 3 year-old trees.

Figure 1: Thick and Thin soil covers.

Figure 2: Tree species planted at 2 m × 1 m spacing.

Youngest fully expanded leaf (2005)

The youngest fully expanded leaves were collected from 9 plants per species per plot in the trial. Fifty to sixty such leaves were collected randomly from the 2 year-old trees and placed in labelled plastic bags which were placed in on ice in an insulated storage container. To ensure removal of dust from the leaves, the samples were washed subsequently in a series of four buckets of distilled water. Once washed, the samples were blot dried and then oven dried at 70°C for up to 96 hours until they attained a constant dry weight. Once completely dried, the leaf samples were ground to <600 µm using the Mikro-Feinmuhle-Culatti (MFC) grinder. The finely ground samples were then placed in polycarbonate tubes, labelled and sent for chemical analysis. The foliage nutrient concentrations of these samples were compared with the standard nutrient concentrations reported by Ref. [22,24,25] with the view to detecting whether the observed concentrations were low, adequate or excessive for plant growth.

Mature, young and youngest fully expanded leaves (2006)

A mixture of mature, young and the youngest fully expanded leaves were sampled from 9 plants per species per plot. In addition, 50 to 60 leaves were randomly collected from the top, bottom and middle layers of the canopy of the 3 year-old trees. A similar procedure was followed as described above.

Leaf litter

A 50 cm × 50 cm quadrat was used for leaf litter sample collection. Senescing leaves that were about to fall from the plants were also collected during this process. Leaves were collected in the 2 and 3 year-old plantation. The quadrat was thrown randomly between stands of 9 plants in Thick and Thin phytocaps and in both replications and leaf litter samples were collected within those randomly selected quadrats. Un-decomposed leaf litter was collected from three quadrats per species in each replication. The leaf litter was washed free of dust, dried, ground and sent to for chemical analysis.

Statistical analysis

Mineral composition data was statistically tested for outliers, normality and homogeneity of error variances before being subjected to analysis of variance (ANOVA) using Genstat ver. 13 [26,27]. The effects of soil thickness, species and the interactions between soil thickness and species were tested. The effects of time were also tested for the leaf parameters that were measured repeatedly. Least significance differences (l.s.d) are presented where the treatment, capping, species, time or their interactions were significant (P<0.05). Standard errors are provided where there were insufficient data available for ANOVA or when the F test was found not significant (P<0.05).

Results and Discussion

Results from the nutrient analysis were compared to the data of by Ref. [22,24,25] (Table 3) for optimum nutrient concentration. Similarly, results from the heavy metal analysis were compared with the heavy metal concentrations of soils/plants [25,28,29] (Table 4). Foliar and leaf litter compositions were used to determine variability in the performance of each species over two soil thicknesses and over time. Results from ANOVA are presented in Table 5.

Foliar and leaf litter nutrient composition

Foliar nutrient composition in 2 year-old trees: Leaves of trees at 2

years of age contained adequate nutrient levels to support growth. Trees grown in the phytocaps did not show any nutrient deficiency in their early stages of growth (Table 6). This may not be the case when they mature and compete with other species in the stand. The 2 year-old trees showed sufficient concentrations of nitrogen, sulphur, calcium, copper, manganese and magnesium to remain healthy and growing (Table 6). However, a few species contained slightly higher concentration of nitrogen, calcium and magnesium (Figure 3), but these elevated levels were unlikely to have affected their growth as the Australian plants can sustain such variability (Ashwath pers. comm.). Presence of elevated concentrations of potassium, iron, zinc and boron can affect plants [25]. However in this study, although some plants had slightly elevated concentrations of potassium, iron, zinc and boron (Figure 3), present were not at the levels likely to negatively affect plant growth (Table 6). All plants grown in the phytocapping system showed significantly low levels of phosphorus (Figure 3). Overall, in the 2 year-old trees with the exception of phosphorus, all other elements were found to be adequate for plant growth and the sodium content was lower than the threshold limit (except for *A. mangium*). A low level of phosphorus is a concern, but Australian native species have been shown to grow in low phosphorus conditions [30]. The results also suggest that the poor growth of *Salix* and *Populus* species was not due to a lack of excess nutrients (Figure 4) but possibly associated with external and agro-climatic conditions, of the region such as high temperature (>40°C) encountered during some months.

Element	Optimum concentration	Unit	Reference
N	1.48-3.0	%	[24,25]
P	0.1-0.5	%	[22]
K	0.75	%	[24,25]
S	0.20	%	[24,25]
Cl	0.273	%	[22]
Ca	1.60	%	[24,25]
Mg	0.3	%	[24,25]
Na	0.3-0.42	%	[22]
Al	160	mg kg^{-1}	[24,25]
Cu	12	mg kg^{-1}	[24,25]
Zn	18	mg kg^{-1}	[24,25]
Mn	600*	mg kg^{-1}	[24,25]
Fe	110	mg kg^{-1}	[24,25]
B	17	mg kg^{-1}	[24,25]

Note: Concentration of Mn is for tropical species with a range from 28 to 2257 mg kg^{-1}, with most species containing 30 to 500 mg kg^{-1}.

Table 3: Optimum nutrient concentrations in plants.

Elements	Plant/soil	mg kg^{-1}	Reference
As	Soil	7.2	[28]
Pb	Soil	19	[28]
Ni	Soil	19	[28]
Cr	Plant	18	[40]
Co	Plant	2.75	[22]
Cd	Soil/Plant	0.35-0.40	[28,29]
Se	Soil	1	[41]
Mo	Plant	1	[36]
Hg	Plant	0.16	[37]

Table 4: Baseline heavy metal concentrations in soils and plants.

Parameter	ANOVA	d.f.	Significance (P)
Foliar (nutrients)	Cap	1	<0.001
	Species	18	<0.001
	Year	1	<0.001
	Cap.Species	18	0.05
	Cap.Year	1	0.08
	Species.Year	18	<0.001
	Cap.Species.Year	18	0.147
Litter* (nutrients)			
	Cap	1	0.256
	Species	13	<0.001
	Cap. Species	13	0.372

*nutrient (N, P, K, S, Na, Ca, Mg, Cu, Zn, Mn, Fe, B) analysis was conducted in species that had significant quantity of litter in all plots/replications.

Table 5: ANOVA for leaf and litter nutrient compositions (2005 and 2006).

Foliar nutrient composition in 3 year-old trees

At 3 years of age, the trees showed no elevated levels of nutrients (Table 6). Nitrogen concentration was slightly higher in *P. pinnata* at age 3 than at age 2 (Figures 4 and 5), and this may be associated with its nitrogen fixation potential. Sodium, sulphur, calcium, magnesium, copper and manganese concentrations were well within the optimum levels for plant growth (Figure 4). The 3 year-old *A. harpophylla, C. anacardioides*, bamboo, *M. leucadendra* and *P. pinnata* had slightly higher levels of sulphur (Figure 4) but these levels were unlikely to have affected plant growth. Potassium levels were high in most species (Figures 4 and 6), but the levels are not that high to affect their health. *Ficus microcarpa, F. racemosa* and *H. tiliaceus* showed higher concentrations of calcium than other species at the age of 2 and 3 (Figures 3 and 5). Zinc concentrations were slightly higher in *F. racemosa, G. Lobocarpum* and *P. pinnata* (Figure 3). Iron concentrations showed elevated levels in the 3 year-old stand compared to the 2 year-old stand (Figures 3 and 5). Phosphorus was still below the optimum required level (Figure 3). However, trees were growing well in both Thick and Thin phytocaps. It is interesting to note that phosphorus levels were similar in trees growing in Thick and Thin phytocaps (Figure 3). This shows that this element was not governed by the thickness of the soil cover. Boron concentrations were higher than recommended for normal plant growth in most species, except in *C. anacardioides* and *D. latiflorus* (Figure 3).

		N %	P%	K%	S%	Ca%	Na%	Mg %	Cu mg/kg	Fe mg/kg	Zn mg/kg	Mn mg/kg	B mg/kg
	Lowest	1.4	0.1	0.7	0.1	0.3	0.016	0.1	3.8	78.4	12.9	27.1	13.4
Leaves (2005)	Highest	3.8	0.2	2.0	0.4	3.0	0.4	0.7	10.9	293	34	535.2	115.5
	Mean	2.1	0.1	1.2	0.2	1.2	0.1	0.3	5.8	157.9	21.3	163.8	47.6
	Lowest	1.5	0.1	0.7	0.1	0.6	0.008	0.2	2.9	145.6	15.0	36.7	14
Leaves (2006)	Highest	3	0.2	2.1	0.4	3.3	0.5	0.6	9.6	455.7	41.4	628.3	109.0
	Mean	2.2	0.1	1.1	0.2	1.5	0.1	0.4	5.1	287.2	21	182.0	54.0
	Lowest	0.8	0.1	0.4	0.3	1.1	0.032	0.2	2.3	316.4	15.4	66.1	26.0
Leaf Litter (2006)	Highest	3.4	0.2	1.6	0.1	3.7	0.3	0.6	8.8	607.2	42.7	645.7	169.0
	Mean	1.4	0.1	0.7	0.2	1.7	0.1	0.3	3.8	388.5	21.1	190.6	63.3

Table 6: The lowest, highest and mean nutrient concentrations in 2 and 3 year-old trees.


Nitrogen
Thick phytocap
Thin phytocap
%
Sulphur
%
Phosphorus
%
Calcium
%
Sodium
%
Magnesium
%
Potassium
%
Copper
mg/kg
Acacia harpophylla
Acacia mangium
Callistemon viminalis
C Cunninghamiana
Casuarina glauca
Cupaniopsis anacardioides
Dendracalamus maroochy
Eucalyptus grandis
Eucalyptus raveretiana
Eucalyptus tereticornis
Ficus micocarpa
Ficus racemosa
Glochidion lobocarpum
Hibiscus tiliaceus
Lophostemon confertus
Melaleuca leucadendra
Melaleuca linariifolia
Pongamia pinnata
Sizigium australis

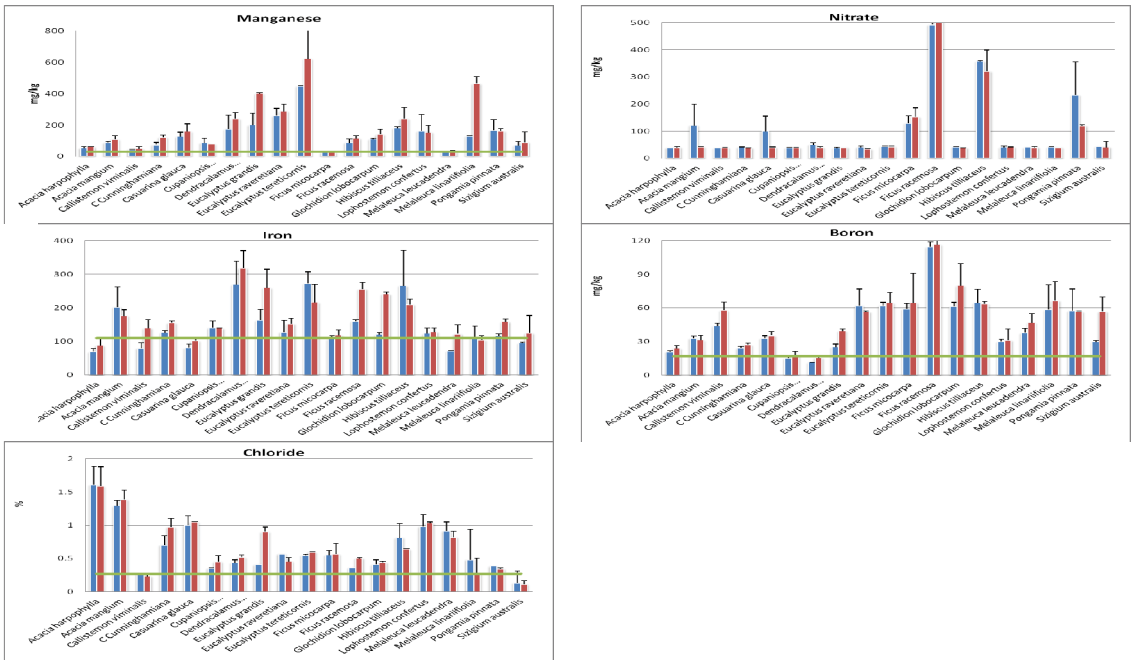


Figure 3: Average foliar nutrient concentrations in 2 year-old species grown in the Thick and Thin phytocapping systems, Bars represent standard errors. The horizontal line shows the optimum levels recommended for normal growth of plants according to Table 3.

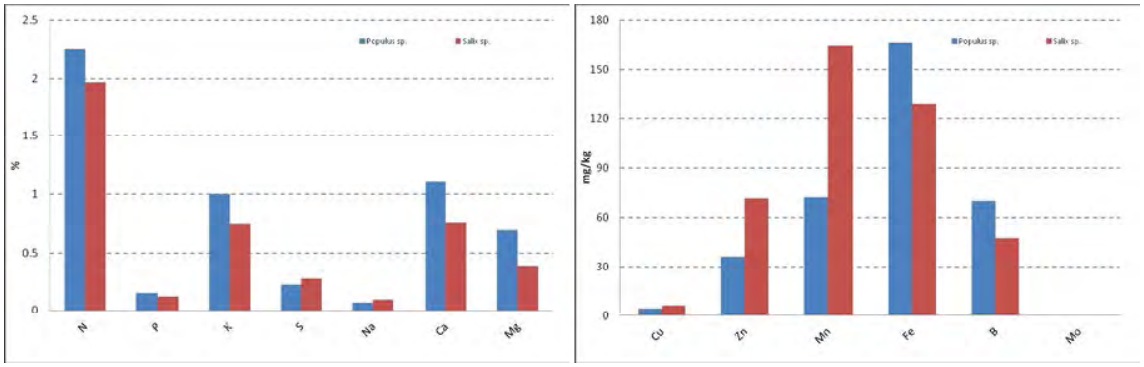
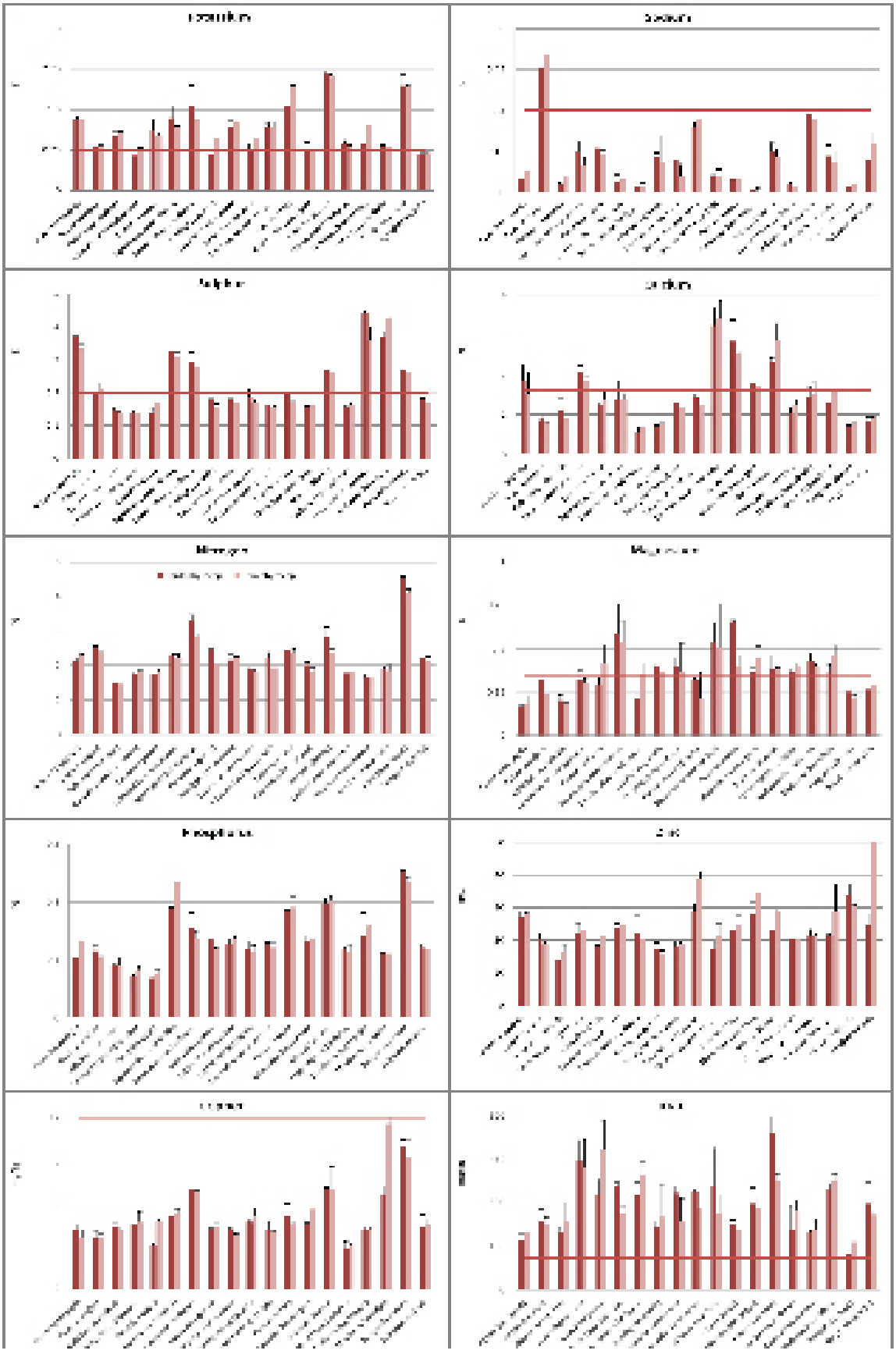


Figure 4: Foliar nutrient concentrations in 2 year-old *Populus* sp. and *Salix* sp. grown in the phytocapping systems at Rockhampton (Average over Thick and Thin phytocap).

Effect of maturity on foliar nutrient composition

Results from the analysis conducted in 2 and 3 year-old trees reveal that the foliar nutrients (N, P, K, S, Na, Ca, Mg, Cl, Cu, Zn, Mn, Fe and B) were adequate for their growth in the landfill environment, even though the nutrient content differed significantly ($P<0.001$) (Table 5) between species over a year (Figures 3 and 5). The variation in nutrient levels among trees of the same species may be attributed to composition of the waste [7], soil composition [25] and root distribution [31]. In a fertile soil, concentrations of nutrients in leaves are found at higher levels that those in poor soils [32]. Likewise except copper and phosphorus, all other nutrients were present in adequate levels in most species. Results from this exercise suggest that the trees grown on both Thick and Thin phytocaps had adequate nutrient levels to support their initial growth, and contribute towards the overall performance of the phytocapping system.

The foliar nutrient concentrations differed significantly ($P<0.001$) from year 2 to year 3 (Table 5). The 3 year-old stand contained higher concentrations of nutrients than those sampled in year 2. The concentrations of sulphur and sodium remained the same, but the concentrations of other nutrients showed a gradual increase in uptake (Table 6). The 3 year-old plants contained slightly elevated concentrations of iron, zinc, manganese and boron (Table 6). On the other hand, phosphorus, calcium, magnesium copper and iron levels slightly dropped or remained the same in most species (Figures 3 and 5). Overall there was a marginal increase in certain elements; the levels were well within the threshold to not affect the plants. Nutrient uptake patterns in plants determine the circulation and storage of nutrients. Nutrient concentrations varied with maturity and these variations were related to accumulation of nutrients in the older tissues and mineral shedding (senescence) from one season to the other. Nutrient concentrations decreased from year 2 to year 3 in the cases of potassium, sodium and copper, and this could be associated with exhaustion of nutrients contained in the root zone while new tissues were being produced by the tree [17]. Potassium is easily removed by



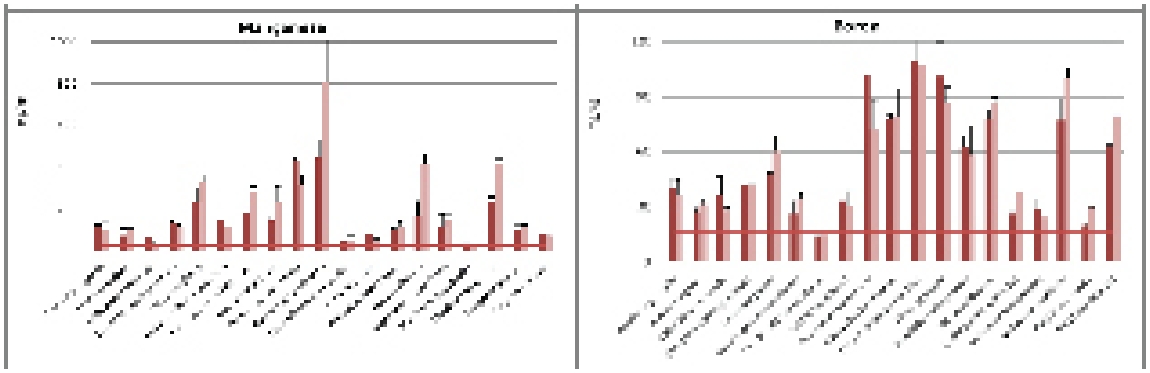
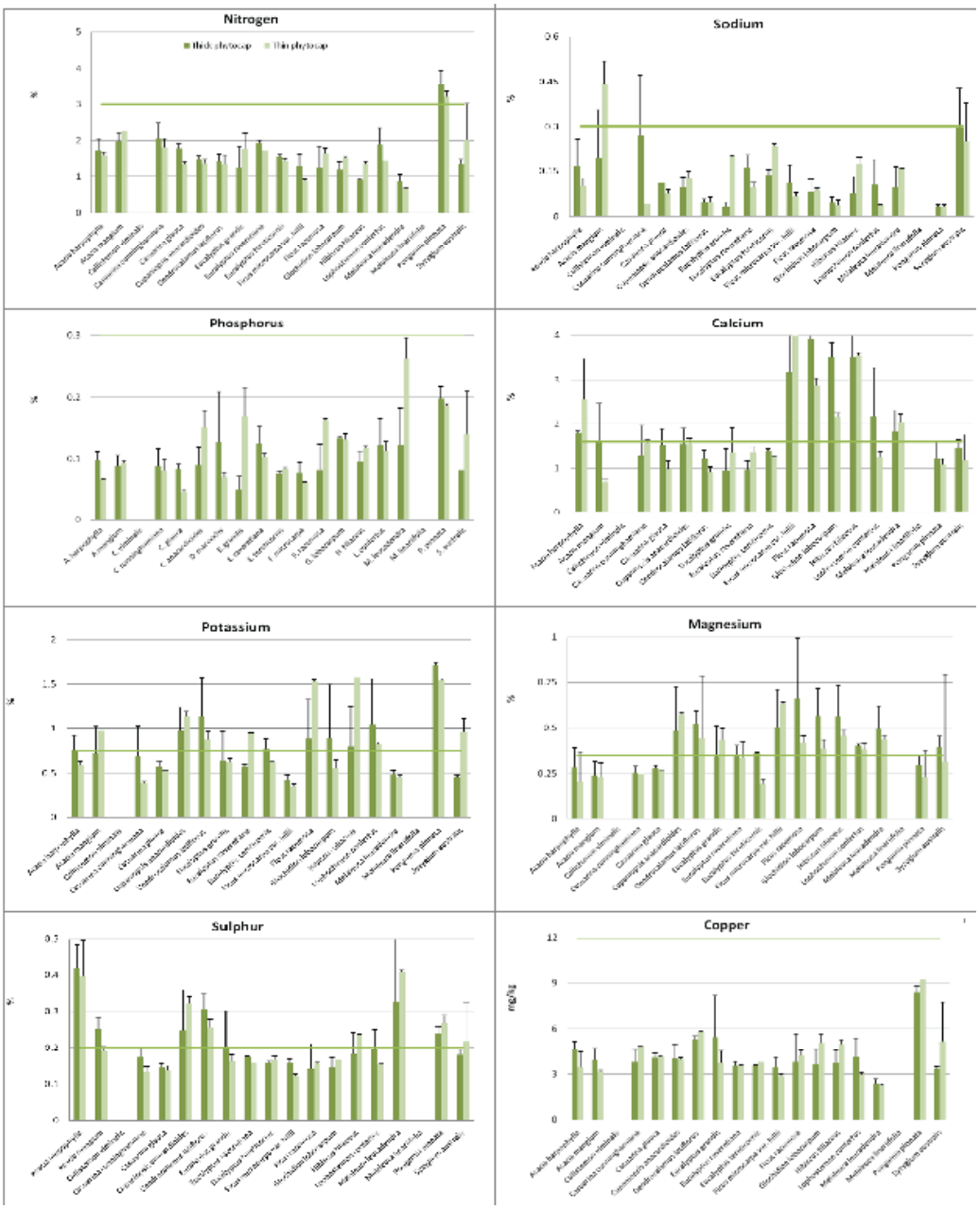


Figure 5: Average foliar nutrient concentrations in 3 year-old species grown in Thick and Thin phytocapping systems, Bars represent standard errors. The horizontal line shows the optimum levels recommended for normal growth of plants according to Table 3.



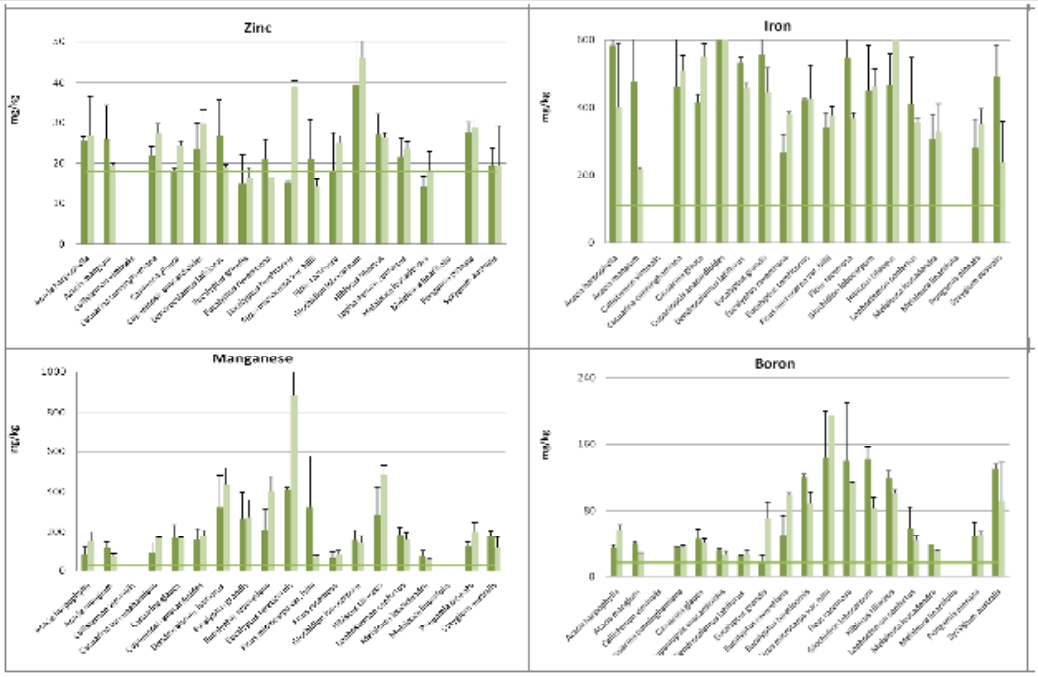


Figure 6: Average values of leaf litter nutrient concentrations in 3 year old plants grown in the Thick and Thin phytocapping systems, Bars represent standard errors. The horizontal line shows the optimum levels recommended for normal growth of plants according to Table 3.

leaching [17]. While nitrogen, calcium, zinc, magnesium, manganese, iron and boron are gradually accumulated over one year. Differences in nutrient concentrations in the established trees can be attributed to individual species having nutrient storage-pool turnover times ranging from one year to several hundred years [33]. Seasonal variation in nutrients within individual species can also be caused by caterpillars feeding on these trees [34].

Leaf litter nutrient concentration

In this study leaf litter was used to determine the nutrient flux from the aboveground vegetation to the soils. Results from the analysis conducted on 3 year-old trees suggested that considerable amount of nutrients were cycled within the phytocaps irrespective of the soil thickness (Figure 4). Species differed significantly (P<0.001) in their litter nutrient composition (Table 5) as they were diverse in morphology, growth patterns and physiology. The lower concentrations of nitrogen, potassium, copper and zinc in the leaf litter compared to the live tissues of leaves (Table 6) can be attributed to nutrient withdrawal from leaves of many species [17]. Phosphorus, sulphur, sodium and magnesium levels were the same as observed in the live tissues of the leaves (Figure 4). Manganese, iron and boron concentrations were elevated in leaf litter compared to the live tissues of the leaves (Figure 4).

In this study, the leaf litter from the 3 year-old trees contained lower levels of nitrogen, sodium, phosphorus potassium and copper compared to the levels in the live tissues of the leaves (Figures 3 and 4). The leaf litter from *P. pinnata* showed high level of nitrogen (Figure 4). *Ficus microcarpa, F. racemosa, G. lobocarpum* and *H. tiliaceus* showed slightly higher levels of calcium (Figure 4) and *E. tereticornis* and *G. lobocarpum* showed slightly elevated levels of zinc (Figure 4). *Pongamia pinnata* showed slightly more elevated levels of potassium in the leaf litter than in the live tissues of its leaves (Figure 4). Magnesium levels remained the same in the majority of the species (Figure 4). *Acacia hapophylla* contained slightly higher levels of calcium and sulphur in the leaf litter than in the live tissues of its leaves (Figures 3 and 4). Zinc, manganese, iron and boron were at higher levels in the leaf litter than the live tissues of leaves (Figure 4). The variation in different elements among different species may be associated with differing ability of species to translocate and re-translocate elements within the tree. This would in turn contribute to species differences in nutrient recycling [17]. Overall, adequate (90% to 100%) levels of nutrients were being recycled into the soil, which is beneficial for plant growth and the longer sustainability of the phytocaps [35-37]. This attests that the soil being moderately fertile (Appendix A) and able to support plant growth without any health deficits. Some species showed slightly elevated levels of leaf nutrients, which in this instance were insignificant to their health and growth.

Effect of soil depth on foliar nutrient composition

There was a significant (P<0.001) influence of soil thickness on foliar nutrient levels (Table 5). Trees grown in Thin soil cover accumulated more nutrients than those grown in Thick soil cover (Figures 1 and 2). This could potentially be due to proximity of roots to the waste in Thin phytocap than in Thick phytocap. The Thin cap had only 700 mm of soil cover as compared to the Thick cap which had 1400 mm of soil cover [38-41]. However, root depth in Thin and Thick phytocaps was in the range of 500 mm to 700 mm, with a few species showing a root depth on 600 mm in both Thick and Thin soil covers, which in thin soil cover is very close to the underlying waste. Difference in the nutrient levels between the trees grown in Thick and thin phytocaps are likely to diminish as trees mature and send their roots deep down to the waste as indicated by these observations.

Overall Trend

An overall trend in nutrient concentrations in foliage and leaf litter of 2 and 3 year-old trees established in the phytocapping system is summarised in Table 7. In this study, the exotic species such as bamboo showed good growth; were healthier and grew faster than many

	Foliar (2005)			Foliar 2006			Leaf litter (2006)			Remark
Element	Normal	Low	High	Normal	Low	High	Normal	Low	High	
N	*			*			*			Slightly high in P. pinnata
P		*			*			*		
K	*			*			*			
S	*			*			*			Slightly high in A. harpophylla and M. leucadendra
Ca	*			*			*			Slightly high in four species
Mg	*			*			*			
Na	*			*			*			Slightly high in A. mangium foliar (2005)
Cu	*			*			*			
Zn	*			*			*			Slightly elevated in G. lobocarpum leaf litter
Mn	*			*			*			
Fe	*			*			*			
B			*			*			*	

Table 7: Overall trends in foliar and leaf litter nutrient concentrations in the phytocapping system (at 2 and 3 years).

Australian native species. Similar observations were made in a study conducted by Ref. [35] in China.

Conclusions

Overall, trees grown in two phytocapping systems contained adequate levels of nutrients to support growth. Low phosphorus levels are a concern and can be overcome by fertilizing trees at regular intervals. However, Australian trees are known to withstand phosphorus deficient conditions [30]. Significant quantities of nutrients are recycled into the soil via leaf litter which will enhance the supply of nutrients to the trees over time. The 3 year-old trees showed slightly elevated levels of nutrient and this will continue as the trees mature and develop more roots. The trees in the thin soil cover contained slightly higher leaf concentrations of nutrients due to the possible closer proximity of their roots to the waste.

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