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THE PHYTOREMEDIATION POTENTIAL OF NATIVE PLANTS ON NEW ZEALAND DAIRY FARMS

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Ecological restoration of marginal land and riparian zones in agricultural landscapes in New Zealand enhances the provision of above-ground ecosystem services. We investigated whether native endemic plant assemblages have remediation potential, through modifying soil nutrient and trace element mobility. Analysis of native plant foliage in situ indicated that selective uptake of a range of commonly deficient trace elements including Zn, B, Cu, Mn and Co could provide a browse crop to avoid deficiencies of these elements in livestock, although some native plants may enhance the risk of Mo and Cd toxicity. Native plant rhizospheres were found to modify soil physico-chemistry and are likely to influence lateral and vertical fluxes of chemical elements in drainage waters. Native plants on marginal land in agricultural landscapes could add value to dairy production systems whilst helping to resolve topical environmental issues.

KEY WORDS: trace elements, endemic plants, phytoremediation, restoration

INTRODUCTION

As a result of some 80 million years and at least 2,000 km of evolutionary and geographic isolation, more than 80% of the native flora and fauna of New Zealand is endemic and found nowhere else. In a global context, human colonisation of these remote lands by both Polynesians (from about 700 years ago) and Europeans (about 200 years ago) was relatively recent and had profound ecological impacts, as is particularly evident in modern production landscapes. Dairy products are New Zealand's biggest export commodity and conversion of agricultural land to intensive dairy farming is currently prevalent on the Canterbury Plain of South Island. This region has been described as the most modified and biologically depauperate lowland environment in the country (Winterbourne *et al.* 2008). All of the plants used in agricultural and forestry, and most plants in shelterbelts, hedgerows, parks and gardens are introduced species (Meurk 2008).

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There is increasing interest in planting a diverse array of native trees and shrubs particularly in urban areas and on the margins of paddocks, farms and water bodies (Meurk and Swaffield 2000; Meurk and Hall 2006). European gorse, willows, poplars, and macrocarpa in hedgerows are being substantially replaced with native New Zealand plants. Besides the aesthetic and conservation benefits of restoring indigenous plant species to this landscape, increased provision of a range of ecosystems services is becoming clear; for example, hedgerows containing native plant species may provide improved conditions for crop pollination and disease and pest control (Sandhu *et al.* 2008). The potential role of riparian zones in removing nitrogen from vertical and lateral fluxes of water is well documented (Verhoeven *et al.* 2006; Hefting *et al.* 2006) although there appears to be limited supportive factual evidence (Correll 2005; Hill 1996). In particular, there is a paucity of information on the efficacy of different plant species. This paper investigates whether planting native species alongside the edges of dairy paddocks and water races is an opportunity to improve nutrient and trace element management in farming systems in New Zealand.

In dairy pastures there is a complex but well studied relationship between nutrient cycling, grazing effects and plant and soil properties (McDowell and Smith 2012; Mikola *et al.* 2009). Widespread geographical deficiencies of a number of trace elements (Cu, Co, Zn, Mg, Se, I) in plants and animals in New Zealand are well defined; 20–30% of farms are deficient and fertilisers and supplements are routinely provided for both crops and stock. Contamination with non-essential trace elements, especially Cd from phosphate fertilisers (Rothbaum *et al.* 1986) and As from historical sheep-dipping sites (Sarkar *et al.* 2007) may be innocuous but are also frequently contaminative and harmful in an environmental context.

Uptake of nutrients and trace elements from the soil is species dependent (Magesan *et al.* 2012), but there is little knowledge of how this varies in New Zealand's native plants. Palatability of native species has received some attention in the context of cellulose and phenolic content (Bee *et al.* 2011) and it has been found that the most palatable native species of trees have the potential to grow fast and may be in a relatively strong position to recover after grazing (Bee *et al.* 2007). The palatability of New Zealand's native grasses has shown notable differences in the grass species preferred by sheep and red deer (Lloyd *et al.* 2010). There is known to be a wide variation in foliar chemical element concentrations among native species (Lambert *et al.* 1989), and that those with low foliar nutrient concentrations produce more phenolics (including tannins) (Wright *et al.* 2010). However, there has been little exploitation of knowledge from traditional Māori native fodder and food crops, even though some exotic species including willows have been studied in this context (Marmiroli *et al.* 2012).

Any excessive build-up of chemical elements in soils and leakage to water courses may have severe environmental implications (Beare *et al.* 2010; Wilcock *et al.* 2009). With intensification of dairy production, it is now realised that elevated soil macronutrient concentrations in shallow-rooted ryegrass/clover dairy pastures require careful management (Wilcock *et al.* 2009). Modern spray irrigation systems are providing much improved water use efficiency whilst improved fencing of stock is now compulsory; the latter typically consisting of wire fencing and bordering woody vegetation. Nevertheless, intensification of farming and conversion to dairy farms continues to contribute a significant increase in the nutrient loadings of New Zealand's lakes and rivers (Monaghan *et al.* 2007a; Wilcock *et al.* 2007).

The aim of this work was to determine whether there is significant variability associated with native plants foliage and rhizospheres that may be of benefit to agricultural production systems in Canterbury. We have targeted the early spring period that is typified by high soil moisture, substantially raised soil temperatures and early seasonal plant growth.

SITE AND METHODS

The study site is on a Templeton silt loam which is one of the most fertile, agriculturally-important soils covering 10% of the intermediate terraces of the Canterbury lowlands (Molloy 1998). An area planted with native species, five years before the present study, was located at the south-western corner of a dairy paddock (Figure 1). Five replicate even-aged plants were selected of six of these species at separate locations, semi-randomly distributed within the plot (Table 1); reference plots were selected within the same sampling area at locations with no plants within at least 2 m. Glyphosate weed control had maintained a largely bare ground surface between plantings. Drainage ditches run along two of the three sides of the sampling area, although these remain largely dry during the extended summer period (approximately November–April).

Foliar samples were collected from multiple parts of the canopy of each of the six plant species at the 5 locations. Soil and vegetation samples were taken from the opposite side of each plant from the frames (described below) using a 2 cm diameter corer to a depth of 10 cm. Pasture grass and soils were sampled from patches growing within the plot and from 5 randomized locations in the adjacent dairy paddock.

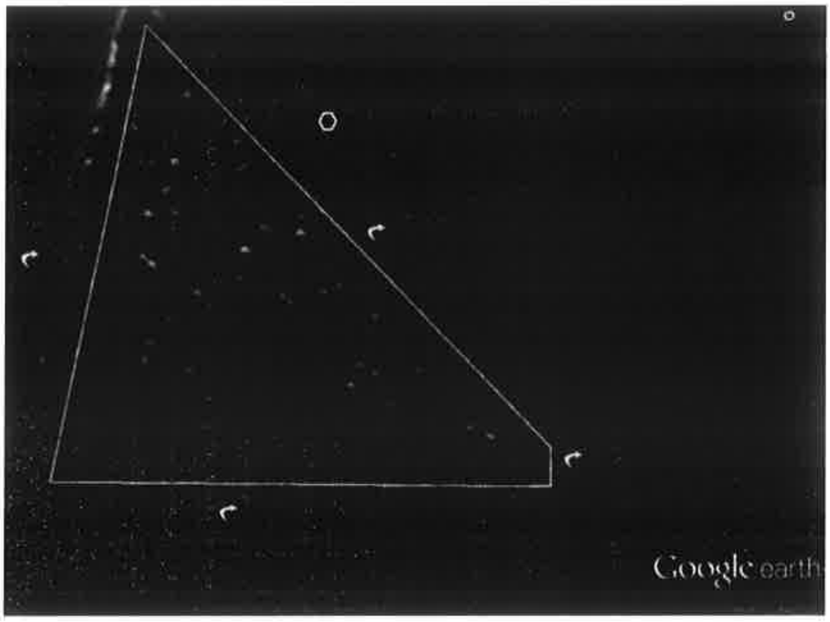


Figure 1 The study site at the Lincoln University Dairy Farm. The sampling plot is located in the corner of the dairy paddock, beyond the reach of the centre-pivot circular irrigator. Native plants were established in 2008. The dairy farm was converted from former dry sheep pasture in 2001, with the irrigation system installed soon after. The sampling plot is bordered by a drainage ditch (west) and a paved road (south). Image from GoogleEarth (2/15/2011, 43°38′38.1″S 172°26′02.19″E).

Table 1 New Zealand native plant species of the present study

Species	Family		English, Māori names
Cordyline australis (G. Forst.) Endl. (1883)	Asparagaceae	monocots	cabbage tree, tī kōuka
Phormium tenax J.R. & G. Forst. (1776)	Haemerocallidaceae		flax, harakeke
Austroderia richardii [1] (Endl.) N.P. Barker and H.P. Linder (2010)	Gramineae		toetoe
Coprosma robusta Raoul (1844)	Rubiaceae	dicots	karamu
Kunzea ericoides [2] (A.Rich.) Joy Thomps.(1983) (A.Rich.) Joy Thomps. (1983)	Myrtaceaea		white tea tree, kānuka
Pittosporum tenuifolium Sol. ex Gaertn. (1788)	Pittosporaceae		black matipo, kōhūhū

[1] Synonym = *Cortaderia richardii*.

Wooden frames (30 cm × 30 cm) were placed as close as practicable against the stems of each of selected plants, and inserted into the soil to a depth of 2.5 cm (Figure 2). Adjacent to each wooden frame, and opposite of the selected plant, a 30 cm × 30 cm pit (50 cm depth) was dug, 10 cm from the inner edge of the frame. Rhizon soil moisture samplers (en.eijkelkamp.com/) 10 cm × 0.25 cm (0.1 micron pore size) were inserted at 15 cm and 30 cm depth. After an equilibration period of 6 days, pore water was sampled. Dairy effluent was collected from the storage pond that services the milking platform, and applied

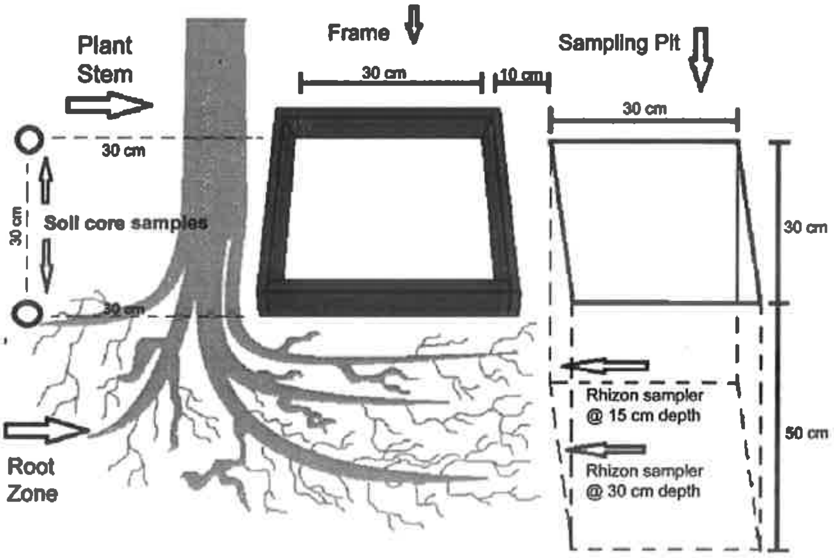


Figure 2 Diagram showing locations of the soil core sampling, wooden frame to contain the slurry application, and positions of the rhizon samplers within the sampling pit.

within each of wooden frame (total 35 locations). Slurry application rates were based on the nitrogen concentration of effluent to reflect recommended realistic slurry application rates of 50 kg N ha^{-1} for grazed pasture systems in Canterbury (Di and Cameron 2000; Monaghan *et al.* 2007b). The slurry contained 450 mg N l^{-1}, thus requiring 1 L of slurry per 30 cm × 30 cm quadrat. The five sampling sites without plants, acting as references to measure natural seasonal variations within the soil were also fitted with wooden frames, but received an equal volume of water in place of effluent. Soil pore water samples were then taken from the rhizon samplers after an equilibration period of 6 days and on 5 subsequent occasions over 11 weeks. Soil moisture and soil temperature data corresponding to the duration of the study was obtained from the NIWA Broadfield Climate Station located approximately 3.5 km NW of the research plot. Soil moisture was recorded (15 cm and 30 cm depth) using a moisture probe at each of the 80 soil pore water sampling sites.

Foliage samples were rinsed with deionized water, separated from stems, then dried (105°C), ground and sieved to 2 mm. Vegetation and soil samples were microwave digested in 5M $HN0_3$ ($+H_20_2$ for soil samples) then analysed using ICP-OES following standard methods. Total C and N were analysed using a LECO CNS-2000 Elemental Analyser. After 4x dilution, ion analysis of soil pore water samples was carried out using a Dionex DX-120 Ion Exchange Chromatograph, suppressed with an Anion Self-Regenerating Suppressor, with detection by conductivity. Ammonia concentrations within the soil pore water samples were analysed using a FS 3000 flow injection analyser. Reference soil and plant material (ISE-921 and IPE-100) was analysed for QA, achieving 91–108% of certified values.

Statistical analysis involved performing one-way Anova with the Fishers individual error rate and a principal components analysis.

RESULTS AND DISCUSSION

Macronutrient and Trace Element Concentration in Plants

Foliar concentrations of N, P, K, S were higher in ryegrass than native plants (Figure 3) and, with the exception of N, ryegrass generally had higher concentrations in the paddock than when it was growing in the native species plot. Significant differences also existed between the native species, with at least two-fold differences in N, P, K and S and a 10-fold difference in Ca. Biomass production is far higher in ryegrass, at about 10–11 t ha^{-1} in this region, and overall uptake would be much higher than by native plants, which are generally slow growing and obviously have less value as stock fodder. With less grazing pressure, however, a large proportion of nutrients in native plant foliage does become incorporated into biomass or returned to soil through leaf fall. Carbon concentrations in foliage ranged from 41.5% to 49.0%, but there were no significant differences between species.

Foliar trace element concentrations (Figure 4) were substantially more variable between species and, in contrast to macronutrients, were often higher in native species than in ryegrass. *Pittosporum tenuifolium* and *Coprosma robusta* often had highest concentrations of both macronutrients and trace elements; these two species took up tenfold more B than did ryegrass. Boron is known to improve fecundity in sheep and cattle (Suttle 2010), and these could be useful supplementary food plants for stock to graze on paddock edges. Manganese and Mo concentrations were high in *Pittosporum*, both are essential elements, involved in N metabolism and cycling. Whilst there was double the concentration of Zn in *Pittosporum* than in pasture grass, this species also accumulated seven-fold more potentially toxic Cd. However, elevated soil Cd is result of its residual co-occurrence in phosphate

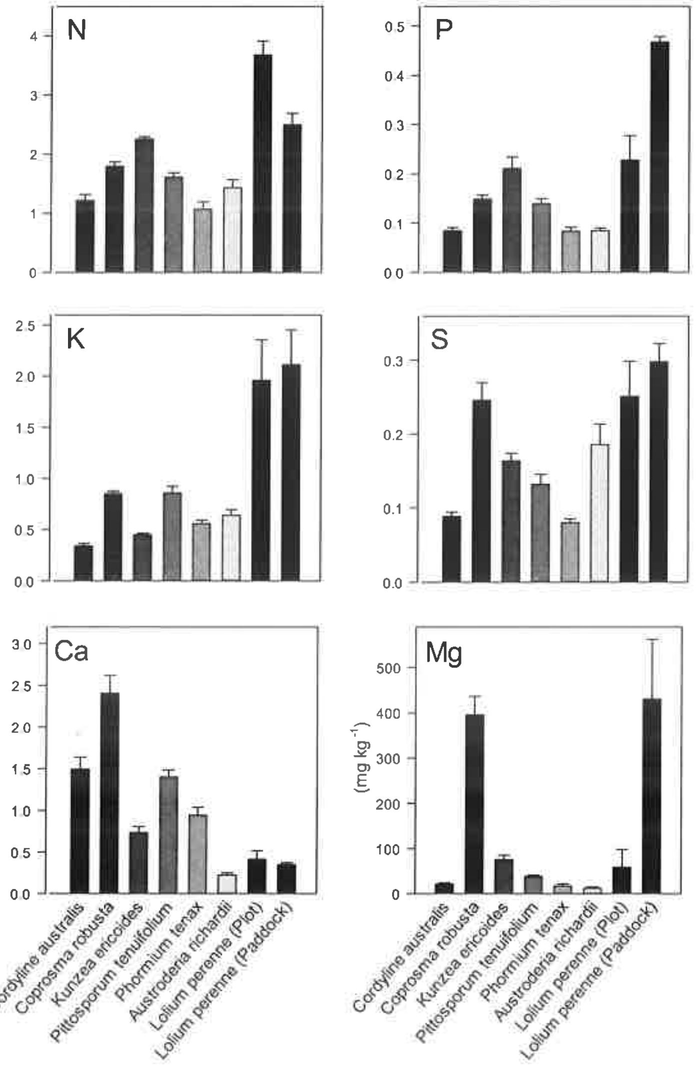


Figure 3 Foliar concentrations of macronutrients. (Values are means ± s.e).

fertilisers and there would normally be less outside the farm paddocks. Zinc deficiency in many New Zealand soils is associated with facial eczema in sheep and cattle, and with cystitis in horses, and is commonly provided a trace element delivered to stock through water trough supplements. Potentially, selective planting of *Pittosporum* around paddock margins and occasional nibbling of its foliage may negate this requirement.

High molybdenum was recorded in flax (*Phormium*); although this element catalyses certain enzymatic reactions and plays an important role in the nitrogen cycle herbage contents approaching toxicity for domestic ruminants (which are particularly sensitive to this element) are not unknown. In the diet of cattle, Cu:Mo ratios of <2:1 are toxic and dietary Mo of >10 mg kg^{-1} can cause toxicity regardless of copper intake (Picco *et al.* 2012); as little as 1 mg kg^{-1} may be hazardous if copper content is <5 mg kg^{-1} (dry-weight

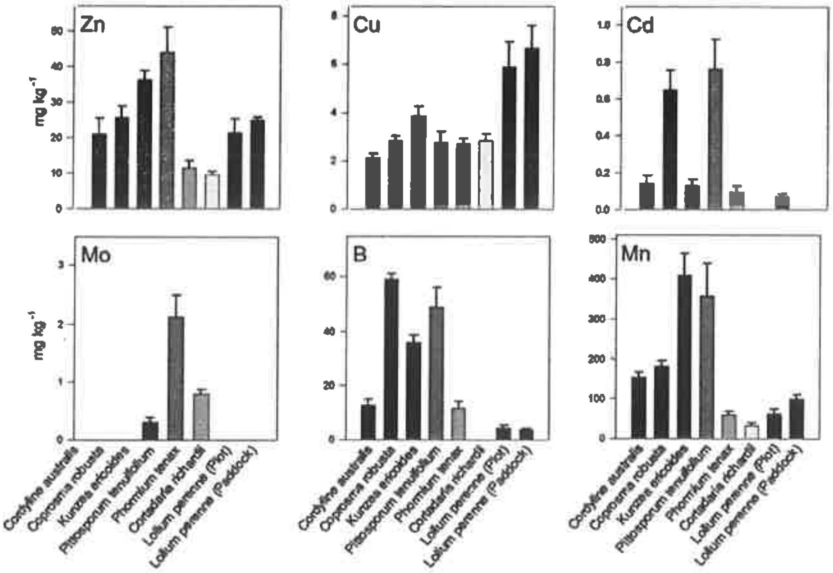
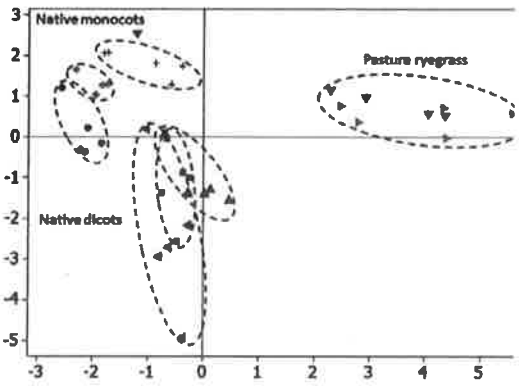


Figure 4 Foliar concentrations (Means ± s.e.) of trace elements. (Values are means ± s.e.).

basis). Integrating New Zealand Flax into Land Management Systems has received some attention and flax leaves can be used to wean cattle through winter (McGruddy 2006) but this may not be wise on NZ soils, many of which are Cu deficient. On the other hand, the occasional browsing of NZ flax may possibly result in Mo-rich faeces which may be a source of bioavailable Mo to leguminous species in the pasture.

There is much current interest in establishing kanuka (*Kunzea ericoides*), a very similar species to manuka (*Leptospermum scoparium*), both of which are valuable crops for high-quality honey production. Although kanuka is better suited to lowland Canterbury environments, they are both dominant early-successional woody shrubs over much of the New Zealand lowlands. The present study shows these species appear to be effectively managing N, P, Zn, Cu and Mn acquisition from the soil. Foliar Mn concentrations, another essential minor nutrient for plants and animals, were extremely variable between plant species, and highest in *Kunzea*, *Pittosporum* and *Coprosma*. There is a strong relationship between Mn and Co in soil; in well-developed New Zealand soils, Mn influences cobalt availability and subsequent uptake by plants (Zheng 2000). Cobalt concentrations in native plant foliar were always below 0.22 ppm (data not shown). Cobalt deficiency is frequent New Zealand soils and vitamin B12 is absorbed from cobalt when it is consumed. There are varying degrees of cobalt deficiency throughout New Zealand and these generally require some additional supplementation in cattle and sheep.

In terms of overall patterns of elemental uptake, multivariate analysis of these data (Figure 5) revealed clear distinctions between pasture grass (both plot and paddock) and native species. PC1 explained 48% of variation, weighted heavily on N, P, K, S and Cu. These elements, with the exception of S, are all phloem mobile in plants. Native species divided clearly into monocots and dicots along PC2 (26% of variation), these also being separated from the ryegrass. PC2 was heavily weighted on phloem-immobile elements (Zn, Mn, Ca, Mg and B].



Principal Component Analysis:		
Variable	PC1	PC2
Ca	-0.17	-0.38
Cu	0.41	0.07
Fe	0.38	0.05
K	0.41	0.07
Mg	0.18	-0.48
Mn	-0.03	-0.54
P	0.42	-0.01
S	0.38	-0.05
Zn	0.11	-0.57
N	0.36	0.03

Figure 5 Principal components analysis describing variation of foliar element concentrations in terms of plants species. The first two PCIs account for 74% of the data variation.

● *C. australis* ◆ *P. tenax* + *A. richardii* ▲ *K. ericoides* ■ *C. robusta* ◀ *P. tenuifolium* ▼ Plot *L. perenne* ▶ Paddock *L. perenne*.

Soil Chemistry and Native Plant Rhizospheres

There was a clear distinction in soil fertility between the sampling site in the fenced-off corner of the paddock and the dairy paddock (Table 2). Dairy pasture management for several years at this site has significantly elevated soil pH, N, P, Ca, S and Cd, although there were no other obvious trace element deficiencies or excesses of metal(oids). Upper nitrate values of about 20 mg l^{-1} are normally expected from soil extractions (Allen 1989), although peak winter concentrations >40 mg l^{-1} are recorded on winter-grazed forage crops on free-draining New Zealand soils (Smith *et al.* 2012). This indicates that background soluble nitrogen as NO_3^- in the plots of the present study was relatively high, representing 1.9–2.4% of total soil N. Both mobile N and Zn were recorded at highest concentrations at 30 cm depth in the research plot. Clearly, liming and fertilisation in the paddock were most likely to be responsible, although native plants themselves may be a small contributory factor to lower pH (Figure 6). Some pore water acidification was evident in the lower layer of the rhizospheres of native plants.

Root systems of native plants suited to riparian zones have distinctly differing morphologies, in terms of rooting depth and root structure, ranging from the fibrous root system of *Austroderia* tussock, through more substantial root systems of *Pittosporum* and *Coprosma* to deep, stout roots of flax and the substantial descending underground stems and long cord-like roots of cabbage trees. This introduces considerable variability into soil profiles through which water percolates, both laterally and vertically. In terms of influencing soil processes, organic exudates from plant root systems introduce substantial soluble carbon to the soil which modifies soil physico-chemistry and directly determines the abundance and functionality of both soil fauna and microbes (Esperschuetz *et al.* 2009; Bardgett and Wardle 2010; Wall *et al.* 2012). It would seem likely that the singular process of lowered soil pH in native plant rhizospheres, as found in the present study, may influence the solubility and mobility of key chemical elements.

There were few differences in soluble leachates in the soil, either between plant species or with reference unplanted plots (Table 3). Exceptions were nitrate and chloride which were significantly higher under *Austroderia* than in reference soil without plant

Table 2 Chemical properties of paddock and research plot soils, and of pore water from two depths in the research plots at t_0. Values are means ± standard deviations. For research plot soil, pH, C and N, $n = 6$ (mean values of the six native species); otherwise $n = 5$. For soluble elements, $n = 10$ (calculated from the reference sites of the research plot). Significant differences (>sd<) between adjacent values are indicated at $P < 0.05$ where they exist. There were no significant differences in soil concentrations between species within the research plot. Blank spaces are undetermined variables

	Paddock Soil		Research Plot Soil	Research Plot Pore Water 15 cm depth		Research Plot Pore Water 30 cm depth
pH	5.25	>sd<	4.71			
C%	3.70 ± 0.47		3.16 ± 0.10			
N%	0.36 ± 0.05	>sd<	0.31 ± 0.01			
	(mg kg^{-1})		(mg kg^{-1})	(mg l^{-1})		(mg l^{-1})
P	1,180 ± 174	>sd<	961 ± 67.3	0.12 ± 0.04		0.03 ± 0.01
K	3,846 ± 162		3,942 ± 202	7.09 ± 2.10		7.75 ± 3.65
Ca	5,270 ± 154	>sd<	4,437 ± 356	43.6 ± 7.60		53.2 ± 7.69
S	426 ± 32.0	>sd<	377 ± 31.4			
NO_3^-				57.6 ± 36.23		72.5 ± 37.09
SO_4^{2-}				10.93 ± 6.21		14.72 ± 6.50
Mg	1,642 ± 18.2		1,657 ± 11.0	9.22 ± 1.68		10.11 ± 1.57
Al	23,460 ± 897		23,420 ± 797	0.22 ± 0.04		0.09 ± 0.02
As	6.85 ± 0.45		8.12 ± 0.47	< 0.01		<0.01
Br				0.93 ± 0.21		1.26 ± 1.17
Cd	0.65 ± 0.03	>sd<	0.55 ± 0.04	<0.001		<0.001
Cl				17.9 ± 8.42		31.9 ± 42.25
Cr	23.9 ± 1.00		23.6 ± 0.83	<0.001		<0.001
Cu	8.57 ± 0.53		7.84 ± 0.29	<0.01		<0.01
Fe	19,659 ± 708		19,802 ± 331	0.06 ± 0.02		0.02 ± 0.001
Li	37.45 ± 1.14		37.11 ± 0.43	<0.01		0.02 ± 0.001
Mn	624 ± 25.8		548 ± 36.8	0.04 ± 0.02		0.03 ± 0.01
Na	271 ± 19.0		278 ± 13.1	8.69 ± 1.13		9.40 ± 1.52
Ni	12.03 ± 0.37		11.70 ± 0.13	<0.01		<0.01
Pb	21.38 ± 0.72		22.79 ± 0.66	<0.001		<0.001
Zn	86.02 ± 1.73		85.45 ± 1.45	0.84 ± 0.16	>sd<	1.30 ± 0.22

cover or beneath other plant species. This corresponded to drier soil beneath this large tussock grass (Figure 7), and is therefore likely to simply be a resultant concentration effect (rather than due to increased nitrification, for example). Higher Cl^- in the rhizosphere of *Pittosporum* (lemonwood) and *Kunzea* (Kanuka) may have a similar explanation. No account was made of seasonal differences.

Slurry Application

Soil pore water NO_3^- and NH_4^+ at 15 and 30 cm were not significantly elevated above baseline concentrations following slurry application to the soil surface, beneath any plants or even in the case of where slurry was applied to the bare soil surface. There were no differences in NH_4^+, NO_3^-, Cl^-, Br^- or SO_4^{2-}, and PO_4^{3-} was below detection limits [data are not shown for non-significant variables]. Soil beneath *Austroderia* presented the only situation where NO_3^- was significantly elevated in soil pore water samples (Figure 8), whilst NO_3^- beneath *Coprosma* was significantly lower than other treatments. This was

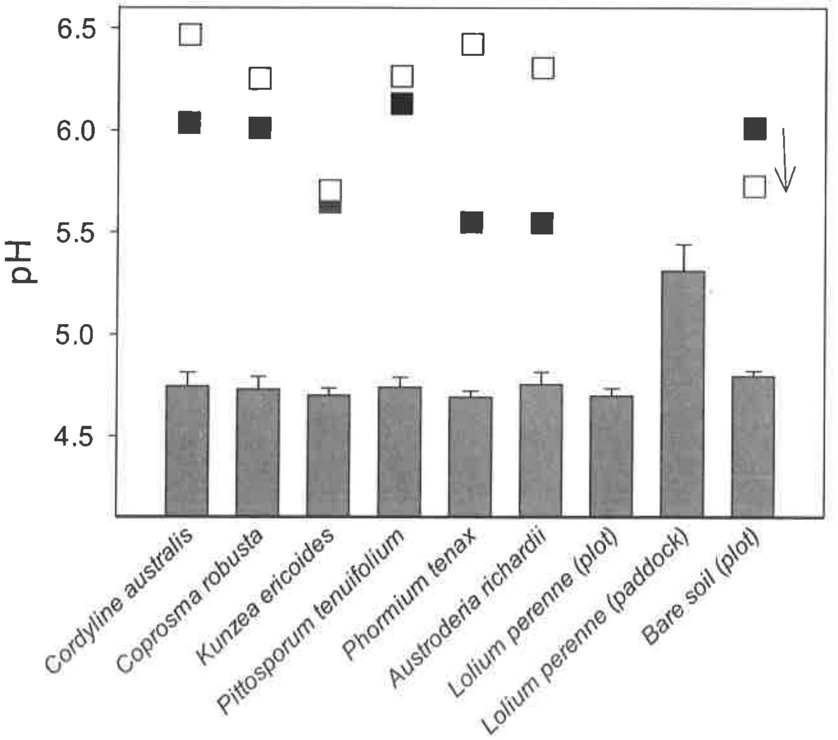


Figure 6 Soil pH (0–10 cm) beneath native species compared to ryegrass in the research plot and paddock and bare soil in the plot (histogram bars, n = 10 for the bare soil, n = 5 all others). Symbols show pore water pH at the two depth of sampling (■15 cm, □30 cm, n = 5). Arrow indicates falling pH with depth beneath bare soil.

Table 3 Soil and Plant species beneath which soil chemical concentrations (mg l^{-1}) were significantly higher or lower than in bare soil reference plots (n = 10, reference sites; n = 5 plant species).

		15 cm depth	30 cm depth
NO_3^-	Reference	57.55	
	A. richardii	202.4	
B^-	Reference	0.05	0.05
	P. tenax	0.04	
	A. richardii		0.03
	C. australis	0.03	0.04
	P. tenuifolium	0.04	
	C. robusta		0.04
Cl^-	Reference	10.06	10.68
	A. richardii	20.53	
	P. tenuifolium		18.36
	K. ericoides	17.87	21.78
Fe	Reference		0.02
	A. richardii		0.01
	C. australis		0.01
Cu^{2+}	Reference		0.003
	C. robusta		0.005

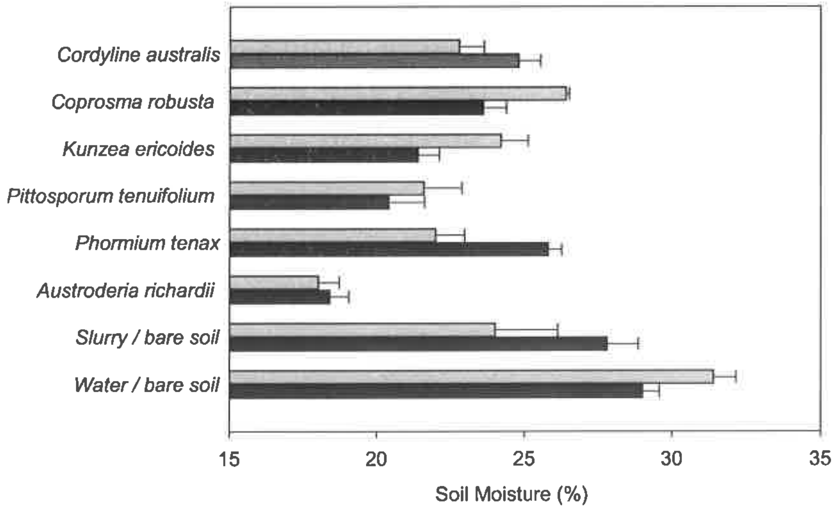


Figure 7 Soil moisture beneath different plant species and reference locations on the plot at depths of 15 cm (▨ upper bars) and 30 cm depth (■ lower bars). Values are means ± s.e. (n = 5).

apparently unrelated to slurry application however. Soil temperature at 20cm depth increased from 6–12.5°C over the 11 week sampling period during which time soil moisture was relatively high (Figure 9). Clearly this had no significant effect on soil pore water concentrations of these elements.

Little difference in soluble elements in pore water may have been due to high spring rainfall raising soil moisture, or of course may reflect a limitation of our study. Despite the targeting of sampling over the early summer period of high soil moisture and increasing soil

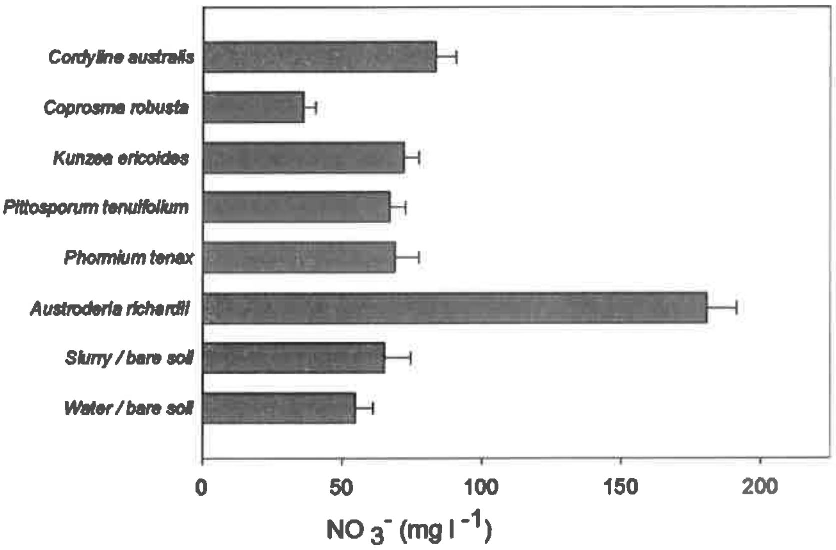


Figure 8 Nitrate concentrations in rhizon leachate samples from 15 cm depth during the six sampling events over 11 weeks. Values are means ± s.e. (duplicate samples at each sampling event at each location).

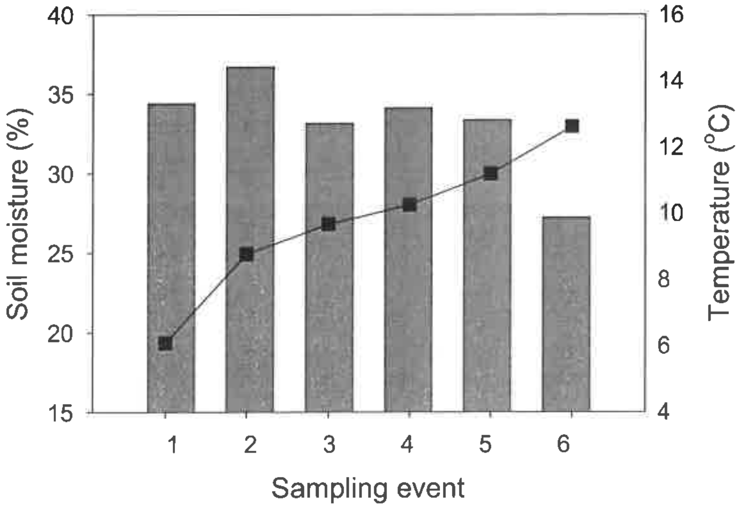


Figure 9 Soil moisture (bars) and temperature during sampling events over the 11 week period.

temperatures, this may not have been optimal. Higher nitrate recorded under the tussock grass *Austroderia* was unlikely to be due to increased nitrification since Cl^- was similarly high, but more likely due to less water flow beneath this species. Thus, an important difference between varying plant morphologies may be related to above-ground canopy interception of rainfall or its effect on infiltration of rainfall into the soil. Preliminary work applying dairy slurry to soil did not raise soluble N concentration in pore water over the subsequent 11 week sampling period, with no evidence of nitrification producing NO_3^-. It is possible that acidification in the surface layers of native plant rhizosphere may be related to the release of H^+ from nitrification processes. Work is continuing to establish the fate of this applied N but, at this stage we are unable to comment on whether the explanation for low pore-water mobility is rapid binding and immobilization of organic N in soil, volatilization of NH_3 or denitrification through N_2O release. It is known that NH_3 emissions from land-spread slurries can account for more than 40% of Total Ammoniacal N (Nyord *et al.* 2012). Lesser amounts of N_2O production have been found previously to progressively increase over a 10 week period following slurry application, accounting for 2 to 10% of applied N (Oenema *et al.* 2007; Sherlock *et al.* 2002). Our own data suggest that time of year of is a critical factor in terms of its influence of soil moisture and rhizosphere dynamics, and subsequent impacts on chemical speciation and mobility. This requires further attention.

Highly variable rooting profiles of New Zealand native plants have been previously described (Marden *et al.* 2005) [*also see* www.landcareresearch.co.nz]. Most of the species in the present study are recognised as riverbank protection plants and have extensive root systems that have considerable potential to modify soil physico-chemistry. For example 38% of the biomass of *Cordyline australis* (cabbage tree) is below-ground, with a root spread of 3 m to depths of 1.75–2.00 m after 25 years (Czernin and Phillips 2005). *Phormium tenax* has a similarly extensive adventitious root system with particularly stout fleshy roots (Wehi and Clarkson 2007) that are likely to alter patterns of vertical water flow through soil. Both rooting systems differ substantially from the rhizomes and fibrous rooting mass of the tussock grass *Cortedaria richardii* which has an overall substantially longer total root length (Phillips *et al.* 2008). Clearly the rhizospheres of native species will have differential effects on the ingress, flow and discharge of water, and also on the speciation and mobility of chemical constituents of the soil.

CONCLUSION

The foliage of native plants contained highly variable concentrations of nutrients and trace elements and there is an opportunity to provide species for occasional grazing on paddock margins that may address trace element deficiencies in stock and remove the need for supplements. *Coprosma robusta* contained high foliar concentration of B and *Kunzea ericoides* contained high Zn, Cu and Mn. *Pittosporum tenuifolium* contained high B, Mn, Mo and Zn, although its high uptake of Cd where this is elevated in soils may make this an unwise choice due to potentially toxicity. High concentration of Mo in *Phormium tenax* is potentially useful, but may create toxicity issues if flax is planted on Cu-deficient soils. Differences in uptake of chemical elements between species were clearly related to the mode of transport within the plant, in terms of whether there is significant phloem mobility. The potential of these plant species as supplementary sources for contending against dietary deficiencies in stock requires further investigation.

Without agricultural inputs and with the influence of deeper and more extensive rhizospheres of native plants, soil physico-chemistry on the margins of paddocks and adjacent to water courses differs substantially to managed pasture. Differences, for example in terms of soil pH, NO_3^- and mobile Zn, were also evident in deeper layers of the rooting profiles of native plants. However, the most significant influence on nutrient and trace element profiles appeared to be associated with the morphology of different species of plants, their interception or deflection of rainfall and the resultant wetness of underlying soil. Selective planting of the large native tussock grass, *Austroderia richardii*, may be particularly useful for intercepting lateral flow of nutrient-enriched drainage waters. A tussock-forming sedge, *Carex secta*, that thrives alongside waterways in Canterbury deserved further attention in this context.

Plant roots modify soil physico-chemistry, in turn regulating aboveground productivity, biodiversity and other essential life processes including storage and filtration of water (Bezemer *et al.* 2010; McNeill and Winwiarter 2004). Dependent on widely different morphologies of plant root systems (Marden *et al.* 2005; Dickinson *et al.* 2009; Robinson *et al.* 2009), the rhizosphere is likely to substantially modify the ingress and discharge of water and dissolved substances. There is a generally held belief that riparian planting helps to protect water bodies from polluted run-off and drainage effluents. However, in the present study, slurry application beneath the canopy of native plants did not lead to increased fluxes of nutrient or trace elements through the soil profile; in the case of nitrogen, this was probably due to some combination of immobilization, volatilization, denitrification or lack of nitrification. Further investigation, perhaps with higher application rates, may be worthwhile; an equivalent amount of 1200 kg N ha^{-1} is typical of dairy farm urine patches (Di and Cameron 2000; Moir *et al.* 2012) to understand the mobility of chemical elements in native plant rhizospheres; potential benefits have not been proven in the present study. Streamside riparian vegetation is known to influence the health of waterways and how they function, but influences and explanations are complex involving a range of factors from the benefits of shading, livestock exclusion and upstream landscape management. Over the last 10 to 15 years, there has been a surge in stream-restoration projects in Canterbury by a range of agencies, community groups, and rural landowners (www.niwa.co.nz).

Overall, the results of this study indicate that planting native species on productive agricultural land in New Zealand offers potential advantages in terms of nutrient and trace element management. This could be of benefit to both agriculture and environment. There is sufficient evidence to show that soil conditions differ beneath native species of plants and with soil planted with shallow-rooted pasture grass. It is a reasonable assumption that this is likely to modify lateral and vertical fluxes of nutrient-enriched drainage water in riparian zones. Trace element uptake differs significantly between native plant species to the extent that selective planting on paddock borders may also add value through avoidance of deficiency diseases in stock. These potentially useful findings justify further research.

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