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Endemic Plants as Browse Crops in Agricultural Landscapes of New Zealand

NICHOLAS DICKINSON,[1] MARTA MARMIROLI,[2] BIANCA DAS,[3]
DANIEL MCLAUGHLIN,[1] DAVID LEUNG,[4] and BRETT ROBINSON[3]
[1]*Department of Ecology, Lincoln University, Christchurch, New Zealand*
[2]*Dipartimento di Bioscienze, Università di Parma, Parco Area delle Scienze, Parma, Italy*
[3]*Department of Soil and Physical Sciences, Lincoln University, Christchurch, New Zealand*
[4]*School of Biological Sciences, University of Canterbury, Christchurch, New Zealand*

We investigated the benefits of restoring native plants to intensive agricultural landscapes of New Zealand. As a browse crop on paddock borders, endemic species potentially could add value to more sustainable food systems. Their foliage was found to contain less nitrogen but higher concentrations of a range of trace elements and tannins than both ryegrass and border-planted willows. While native plants could reduce the need for feed supplements, we conclude that the small amount consumed would provide negligible overall nutritional benefits to stock. Nevertheless, this may provide added justification for endemic species and agroecology in landscapes with a depauperate native biodiversity.

KEYWORDS *nutrients, trace elements, native plants, biosolids, agroecology*

INTRODUCTION

Rates of endemism of the native flora of New Zealand are high due to a uniquely long period of geographical and evolutionary isolation (Trewick et al. 2007). More than 80% of New Zealand's native plants are found nowhere else (http://nzpcn.org.nz). The Province of Canterbury on the east coast of South Island is predominantly agricultural; 1.2 m ha of exotic grassland on the plains supports 20% of New Zealand's farmland with a

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Address correspondence to Nicholas Dickinson, Department of Ecology, Lincoln University, Lincoln 7647, Christchurch, New Zealand. E-mail: nicholas.dickinson@lincoln.ac.nz

diverse mix of dairy, sheep and beef, and cropping operations (Dynes et al. 2010). Following European settlement in the early 1850s, sheep farming came to dominate the Canterbury economy, but a recent substantial conversion to intensive dairy is underpinned by availability of a large underground water resource and a substantial increase in spray irrigation. Land cover of native vegetation is particularly poor (Winterbourne et al. 2008) although there have been considerable efforts to reintroduce native species to shelterbelts, hedgerows, riparian zones, and marginal land during the last few decades (Meurk and Swaffield 2000; Meurk 2008). Benefits of restoring indigenous plant species to this landscape include increased provision of a range of ecosystems services, such as improved crop pollination, disease and pest control (Sandhu et al. 2008), riparian zone protection of water quaility (Wilcock et al. 2009) and contributing to New Zealand's commitment to offset CO_2 emissions (Trotter et al. 2005). This article investigates whether selective planting of native species has the additional potential to improve nutrient and trace element management as a component of New Zealand's farming systems.

Sustainable management of crop nutrition, soil fertility, and nutrient cycling requires and receives considerable and ongoing attention within intensive agricultural management systems. Optimal nitrogen and phosphorus management is critical (Di and Cameron 2000, 2007; Condron et al. 2006; McDowell and Smith 2012) but this also extends to other chemical elements. Widespread deficiencies of S, Cu, Co, Zn, Mg, Se, I, B, Mo, Mn, and Fe in plants and animals in New Zealand are also well defined; 20–30% of farms are micronutrient deficient; fertilizers and supplements are routinely provided to crops and stock (Will 1990; Grace 1992; Condron et al. 2000). Contamination from residual nonessential trace elements, especially Cd from phosphate fertilizers and As from sheep dips, also may be harmful in an environmental context (Rothbaum et al. 1986).

Many native plants are palatable to stock and recover well after grazing (Bee et al. 2007; Bee et al. 2011), and there is wide variation in foliar chemical element concentrations among species (Lambert et al. 1989). However, the linkage is poorly defined and 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 the same context (Marmiroli et al. 2012). Little is known of the differences of foliar chemistry between forage crops and potential browse crops amongst the native species commonly planted on the borders of farmland. More detailed studies of Australian plants have shown that differences between exotic and native species reflect differences in the environmental conditions of the site where they occur rather than differences in carbon capture strategies such as leaf area, foliar N or assimilations rate (Leishman et al. 2010). In New Zealand, we know that indigenous woody species are adapted to soils of low phosphorus availability although, in comparison with undisturbed forests, soils of forest fragments in agricultural landscapes have been found to contain 10 times more Inorganic P and Olsen P. This has been found also to be reflected in higher soil Cd, Ca, Mg, and K concentrations (Stevenson 2004). It is also known that species with low foliar nutrient concentrations produce more phenolics, including tannins (Wright et al. 2010).

Recent research has shown the addition of biosolids and biochar mixtures to New Zealand soils results in increased growth and trace element uptake by plants (Gartler et al. 2013). Pasture and willows grown on biosolids amended soil has elevated Zn concentrations, and this Zn is transferred to sheep blood serum, where it may afford protection against fungal-induced facial eczema (Anderson et al. 2012). Potentially, biosolids and biochar additions may also improve the productivity and nutritive value of New Zealand's native plants. The aim of the present work was to elucidate whether there is significant, consistent, and predictable variability in foliar chemistry between native species, of benefit to stock, that may be used to inform the species selection and planting of farm paddock margins.

MATERIALS AND METHODS

Foliage Sampling

One-year old shrubs were sampled from the Department of Conservation native plant nursery at Motukarara, Canterbury (Table 1). Eleven species were sampled, with five replicates per species, and additional sampling of the potting mixture. All samples were collected in paper bags, then oven-dried (105°C), crushed, and stored prior to analysis for nutrient and trace element composition. Plant and soil samples were also obtained from two field locations, at Tai Tapu (43°42′31.7 S, 172°33′50.1 E, 17m asl) and Kaituna Valley Scenic Reserve (43°44′34.7S, 172°41′19.2E, 15m asl). The Tai Tapu site is a wetland *Salix*-dominated copse (approx. 1 ha), with an emergent understory community of native plants. The Kaituna Valley site is a scenic reserve with well-established native plants within 6 ha of bush (secondary broadleaf forest) dominantly *Alectryon excelsus* (tītoki) and *Melicytus ramiflorus* (mahoe) on lowland alluvium. Both sites are located within a largely pastoral farmed landscape. Five samples of each native species were also sampled from the field sites, collected in the same way. Soils were collected using a 2.5 cm auger after removing any surface litter; five soil samples were collected from each site, but the Tai Tapu soil was bulked due to difficulties of collecting waterlogged samples at the time of sampling.

Biochar and Biosolids Experiments

Biosolids from a regional sewage treatment facility at Kaikoura, described previously (Knowles et al. 2011), were thoroughly mixed and sieved to

TABLE 1 Plant species of the present study (Source of preferred names for native species: www.nzflora.landcareresearch.co.nz). All species are New Zealand native plants, except ryegrass and willows

Species	Family	Vernacular
Olearia paniculata (J.R.Forst. & G.Forst.) Druce (1917)	Compositae	akiraho
Dodonaea viscosa Jacq. (1760)	Sapindaceae	akeake
Cordyline australis (G. Forst.) Endl. (1883)	Asparagaceae	cabbage tree, tī kōuka
Phormium tenax J.R. & G. Forst. (1776)	Haemerocallidaceae	flax, harakeke
Pittosporum eugenioides A.Cunn. (1840)	Pittosporaceae	lemonwood, kīhihi
Griselinia littoralis Raoul (1846)	Griseliniaceae	broadleaf, kāpuka
Hebe salicifolia (G.Forst.) Pennell (1921)	Plantaginaceae	koromiko, kōkōmuka
Pittosporum tenuifolium Sol. ex Gaertn. (1788)	Pittosporaceae	black matipo, kōhūhū
Coprosma robusta Raoul (1844)	Rubiaceae	karamu
Aristotelia serrata (J.R.Forst. & G.Forst.) W.R.B.Oliv. (1921)	Elaeocarpaceae	wineberry, makomako
Chionochloa rigida (Raoul) Zotov (1963)	Gramineae	narrow-leaved snow tussock
Alectryon excelsus Gaertn. (1788)	Sapindaceae	tītoki
Melicytus ramiflorus J.R.Forst. & G.Forst. (1776)	Violaceae	whiteywood, māhoe
Urtica ferox G. Forst (1786)	Urticaceae	tree nettle, ongaonga
Pseudopanax arboreus (Murray) Philipson (1965)	Araliaceae	five-finger, houhou
Kunzea ericoides (A.Rich.) Joy Thomps. (1983)	Myrtaceae	white tea tree, kānuka
Plagianthus regius (Poit.) Hochr. (1907)	Malvaceae	ribbonwood, houi
Lolium perenne (NZ Pasture)	Gramineae	perennial ryegrass
Salix cinerea and *S. fragilis*	Salicaceae	gray willow and crack willow

20 mm. Biochar was manufactured from *Pinus radiata*, as described in Clough et al. (2010) and Taghizadeh-Toosi et al. (2011), was crushed to a maximum diameter of 10 mm. A silt loam topsoil was obtained from a restoration site at Balmoral Forest in Canterbury (42°47′45.24 S, 172°34′08.26 E). The biosolids and biochar were mixed into the soil at rates of 10% and 20% by volume respectively. For each soil type, 75 [5 × 5 × 3] plastic pots (2 liter) were filled to 10 cm depth, arranged in a randomized block design, and left in a glasshouse for two weeks before planting. Five replicates each of five species of one-year old native plants and *Lolium perenne* were planted into each soil treatment and grown for four months, before destructive sampling of aboveground biomass and preparation for analysis as described above. Six soil samples from each treatment were also oven-dried and sieved to <2 mm prior to analysis.

Chemical Analysis

Soil C and N concentrations were measured using an Elementar Vario MAX CN analyzer. Soil pH was determined using 10 g of soil and 25 mL of deionized water. The mixture was shaken, left overnight, and shaken again before pH determination. Pseudo-total elemental analysis was carried out following microwave pressure digestion in 8 mL of nitric acid (±69%), filtered using Whatman 52 filter paper (pore site 7 μm), diluted with water to a volume of 25 ml and stored prior to chemical analyses. Concentrations of Al, As, B, Cd, Cr, Cu, Fe, K, Mn, Ni, P, Pb, and Zn were determined using ICP-OES (Varian 720 ES) using standard methods, with QA reference soil (ISE 921) and plant (IPE 100) material (Houba et al. 1998). Recoverable concentrations were >91% of the certified values. Data were analyzed using Minitab 16. Data sets were analyzed using analysis of variance with Fisher's least-significant-difference post-hoc test to compare means.

RESULTS AND DISCUSSION

Nursery-Plant Foliage

Nitrogen concentrations in the foliage of native plants were substantially lower than those reported for pasture grasses, and there was significant variation in foliar concentrations between natives (Figure 1). Using three different application rates of urine (0, 300, and 700 kg N ha^{-1}) on soil from the same area as the present study Moir and colleagues (Moir, Edwards, et al. 2012; Moir, Malcolm, et al. 2012) recorded comparable mean N concentrations in ryegrass of 2.65–4.55%. Similarly, in extensive field trials of *L. perenne* and *Festuca rubra* in Denmark, Gislum et al. (2004) reported a range of 0.6 to 6.26% N (mean value 2.81%). Clearly, luxury uptake of N is not characteristic of native plants. The foliage of only two native species (*Griselinia* and *Aristotelia*) contained both P and S concentrations as high as ryegrass; concentrations of both of these elements tend to be naturally low in Canterbury soils and this finding may reflect a beneficial uptake trait in these plants. In terms of large amounts of variability between native plant species, there was a 10-fold variation of Ca which is likely to reflect structural characteristics such as leaf thickness and amount of venation; pectins of the middle lamella of the xylem cell wall are significantly associated with Ca composition in leaves (Cobert et al. 2011).

Zinc concentrations were generally higher in native plants, including the native tussock grass *Chionochloa*, than in ryegrass. Hahner et al. (2014) questioned whether stock grazing of *Pittosporum tenuifolium* and *Coprosma robusta* could negate the requirement for water trough supplements of this element (to help combat facial eczema in sheep, hoof rot in cattle, and cystitis in horses). They thought any value as a supplement through stock browsing

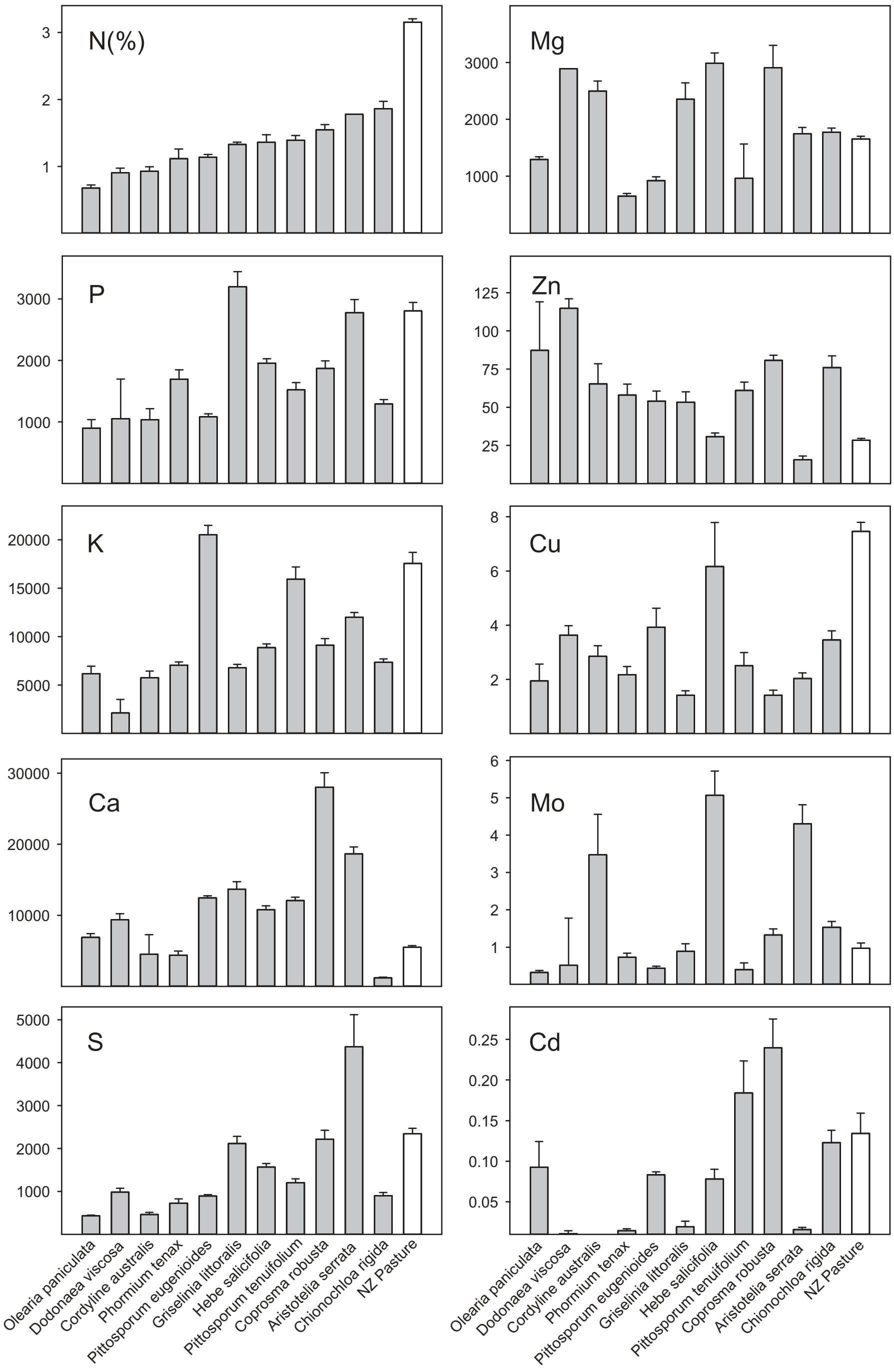

FIGURE 1 Concentrations of 10 elements in foliage sampled from nursery-grown native plants (aged <2 years), compared to published values for NZ pasture ryegrass. Values for N% in ryegrass are a mean of 7 urea and urine ± DCD and control treatments ($n = 16$ for each treatment) in field plots of the same farm from (Moir, Malcolm, et al. 2012). Values are μg g^{-1} (except N) ± standard errors.

of these species would be negated by similarly elevated concentrations of potentially toxic Cd. The earlier findings are supported by data from the present study, which further indicate that *Dodonaea viscosa* may be a better choice, containing high Zn but low Cd. Neither Zn nor Cd was taken up by native plants to the same extent as has been recorded in willows.

The earlier study also recorded high Mo in flax (*Phormium tenax*) which is not supported by the present data, although high Mo was recorded in three natives (*Cordyline, Hebe* and *Aristotelia*). This element catalyzes certain enzymatic reactions and plays an important role in the nitrogen cycle, although domestic ruminants are particularly sensitive to Mo, and herbage contents approaching toxicity are known (Picco et al. 2012). As little as 1 mg Mo kg^{-1} may be hazardous to stock if Cu content is <5 mg kg^{-1}, and Cu:Mo ratios of <2:1 can be toxic (Khan et al. 2012). In the present study Cu was largely below 5 mg kg^{-1} in native species, and it should be noted that Cu concentrations were much higher in the potting mix than in the field sites soils (Table 2). A lower than 2:1 Cu:Mo ratio was recorded in four of the 11 native species [*Cordyline, Griselinia, Hebe, Aristotelia*] (cf. 8:1 in ryegrass). The lowest ratio (0.4:1) was in *Hebe salicifolia*, even though this species contained particularly high concentrations of both elements, as well as Mg. As a browse crop this species potentially could confer both benefits [all three elements are frequently deficient] and problems [toxicity due to low Cu:Mo ratios]. However marginal browse crops, by definition, are likely to from only a minor part of stock diet and concerns about toxicity are unlikely to be realistic.

Field-Sampled Foliage

Sulfur concentrations were particularly high in the Tai Tapu organic wetland soil (Table 2). Foliage S concentrations were high in two species, *Melicytus ramiflorus* and *Pseudopanax arboreus* sampled at both field sites (Figure 2), as also found in *Aristotelia serrata* grown in potting compost (cf. Figure 1). Foliage P concentrations were lower in most species of native plants than in ryegrass (Figure 2), although *Melicytus* foliage at the Tai Tapu site contained phosphorus at similar concentration to paddock pasture grasses (2,805 mg P kg^{-1}), even though soil P concentrations (c. 0.2%) were probably similar to the Kaituna field site. High foliage P in *Griselinia* when grown in nursery soil (as in Figure 1) was not reflected at Kaituna where soil had lower P status, probably reflecting luxury uptake, rather than generally better traits of P acquisition in this species. This contrasts with the situation for S in *Melicytus*, which may be more proficient at acquiring S from deficient soil. Leaf tissues of this species rapidly decompose interveinally following abscission, leaving a distinctive skeletal framework of leaf venation on the soil surface. It is possible this reflects the content and ecological

TABLE 2 Soil properties of the glasshouse experimental treatments and at the field sites of the study. Value are means (± standard errors)

	Field sites			Experimental treatments			
	Tai Tapu	Kaituna	Motukarara potting mix	Balmoral (BM)	BM + biosolids	BM + biochar	BM+biosolids + biochar
pH	6.4	6.2	5.5–6.6	4.2	4.2	4.4	4.2
Organic C	48	9.0	2.7	2.4 (0.2)	3.9 (0.2)	4.3 (0.3)	7.8 (0.3)
N	n.d.	n.d	0.23	0.2 (0.0)	0.3 (0.0)	0.2 (0.0)	0.4 (0.0)
P	1808 (175)	1355 (94)	1267	612 (82)	717 (21)	548 (26)	846 (46)
K	2033 (53)	1859 (252)	3467	3488 (337)	2879 (532)	2948 (276)	3074 (605)
S	6937 (507)	515 (64)	4945	234 (29)	573 (38)	268 (32)	736 (101)
Ca	25916 (2997)	5541 (751)	10767	1842 (73)	2030 (80)	1966 (81)	2926 (169)
Mg	1621 (39)	1361 (7)	1669	2496 (17)	2438 (22)	2427 (33)	2416 (35)
Cu	21 (1)	18 (0)	169	4.4 (0.1)	36 (5)	5.4 (0.6)	38 (3)
Zn	78 (7)	102 (3)	150	53 (1)	99 (6)	52 (1)	119 (9)
Cd	0.6 (0.0)	1.0 (0.0)	0.2	0.3 (0.0)	0.4 (0.0)	0.3 (0.0)	0.5 (0.0)

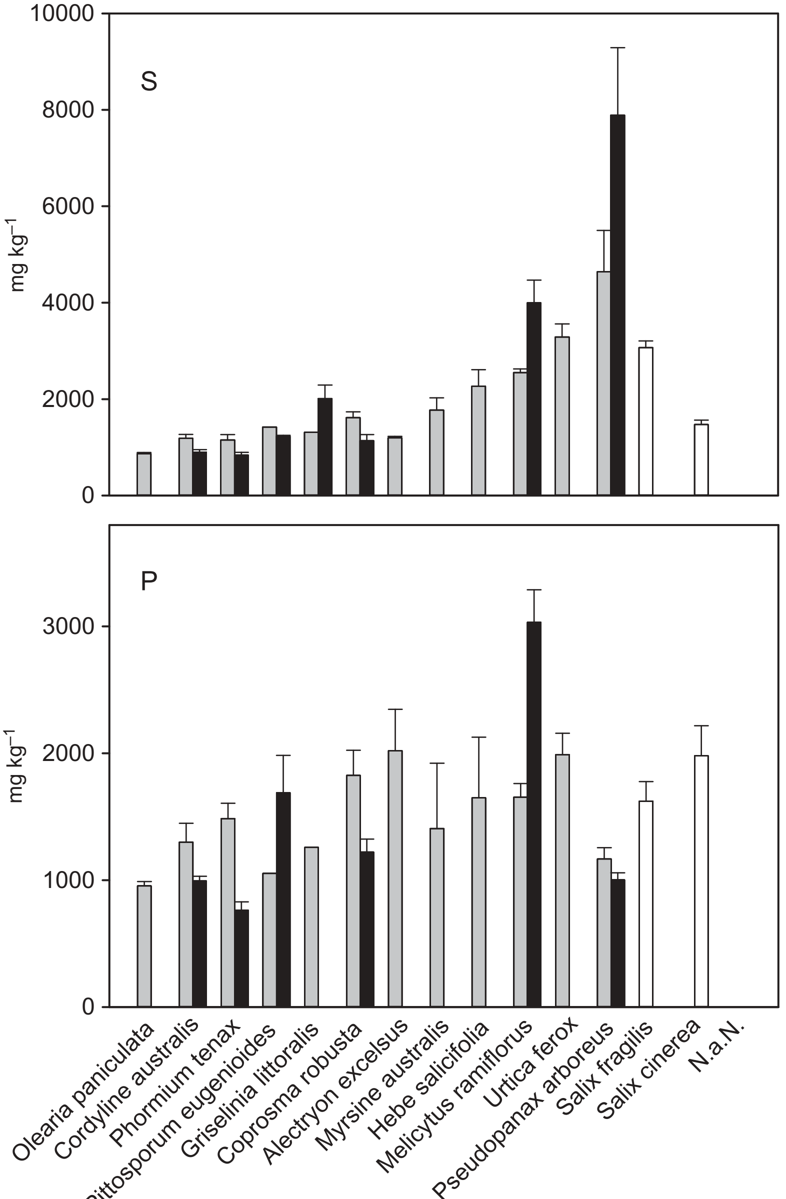

FIGURE 2 Sulfur and phosphorus concentrations in foliage from two Canterbury field sites at Kaituna Valley (light shading) and Tai Tapu (dark shading), compared with *Salix* foliage at Tai Tapu (open bars).

value of key nutrients, particularly as this species has been found elsewhere to also contain variable but sometimes high foliar concentrations of N (Windley 2014).

High Zn concentrations in native plant foliage compared to ryegrass (as above, Figure 1) are less impressive when viewed in perspective of exceptionally high Zn uptake in *Salix* (Figure 3) that is already well documented elsewhere (Robinson et al. 2000; Dickinson and Pulford 2005). However, *Salix* has the potential disadvantage of a simultaneously high uptake of Cd. Compared with this, Cd concentrations in the present study were much lower in the range of native species collected in the field. Copper concentrations in field-collected foliage of native species were similar to ryegrass (cf. Figure 1) but significantly higher than in nursery-collected foliage, despite much higher Cu concentrations in the nursery potting compost (Table 2).

Biosolids and Biochar Amendments

Addition of biosolids initially improved growth of ryegrass (Figure 4), although this fertilization effect diminished with time. A marginally beneficial growth response was found in only two of the five native species tested. The biochar amendment tended to reduce growth, unless applied in conjunction with biosolids. *Plagianthus regius*, a small tree which had not been sampled previously, had higher rates of P uptake than ryegrass with all treatments, and higher rates of S uptake than other native species (Figure 5). In this experiment, higher uptake of P and S in *Griselinia* found in the pot-grown nursery specimens (Figure 1) was not recorded (agreeing with data from field sites, Figure 2).

There was a reduced growth response of *Dodonaea viscosa* with biochar (Figure 4) and these data do not support the earlier findings from nursery specimens of high Zn and low Cd in this species (Figure 1); both elements are generally elevated in biosolids, although there is little evidence for this in the present study (Table 2). This is contrary to earlier suggestions that *Dodonaea* may be a preferred browse crop due to lower uptake of Cd into foliage. Native plant foliage contained higher concentrations of tannins, which could be beneficial in terms of reducing both nitrogen content in urine and NH_3 and CH_4 emissions from stock, dairy barn floors and soil (Powell and Broderick 2011; Grainger et al. 2013); leaf browsing of *Dodonaea* and *Kunzea* may add value in this context. *Kunzea* was not otherwise included in the present study although, in earlier work, we found that this species had potential advantages in terms of influencing mobility of N, P, Zn, Cu, and Mn in soil (Hahner et al. 2014).

Potential for Species Selection

Physiological traits responsible for differential uptake of chemical elements in plants are both genetically and environmentally determined (Baker 1981),

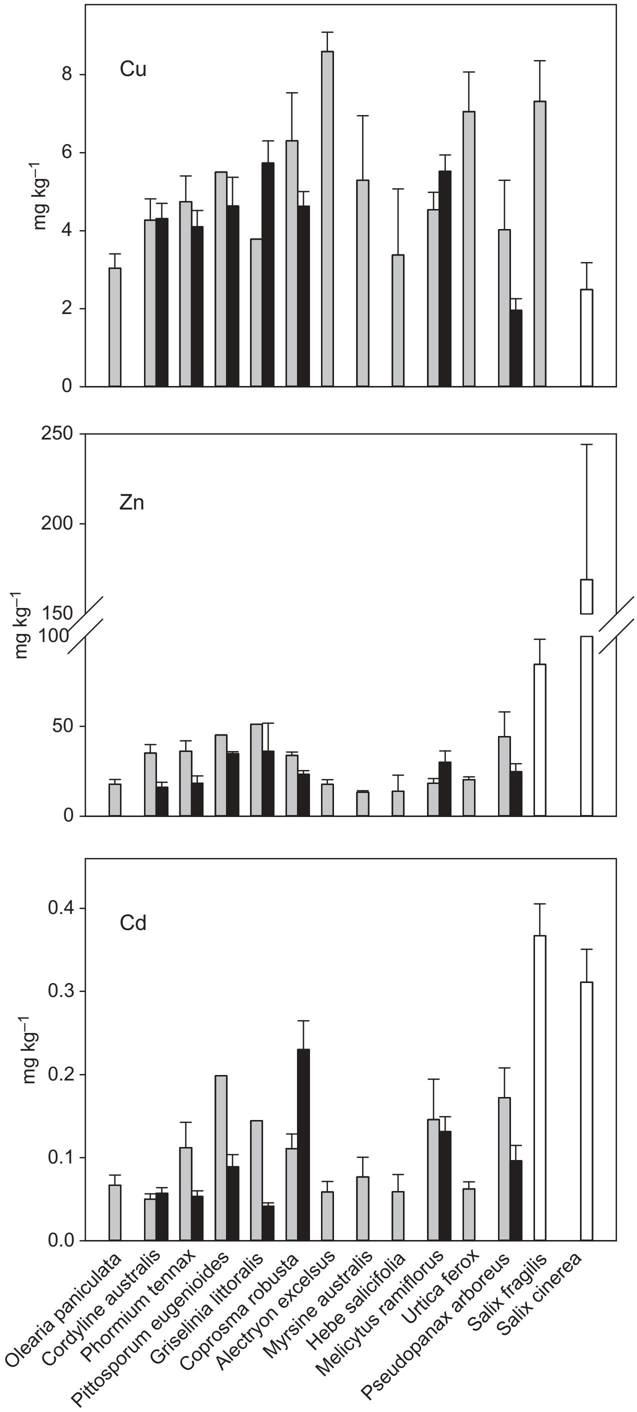

FIGURE 3 Trace element concentrations in foliage from two Canterbury field sites at Kaituna Valley (light shading) and Tai Tapu (dark shading), compared with *Salix* foliage at Tai Tapu (open bars).

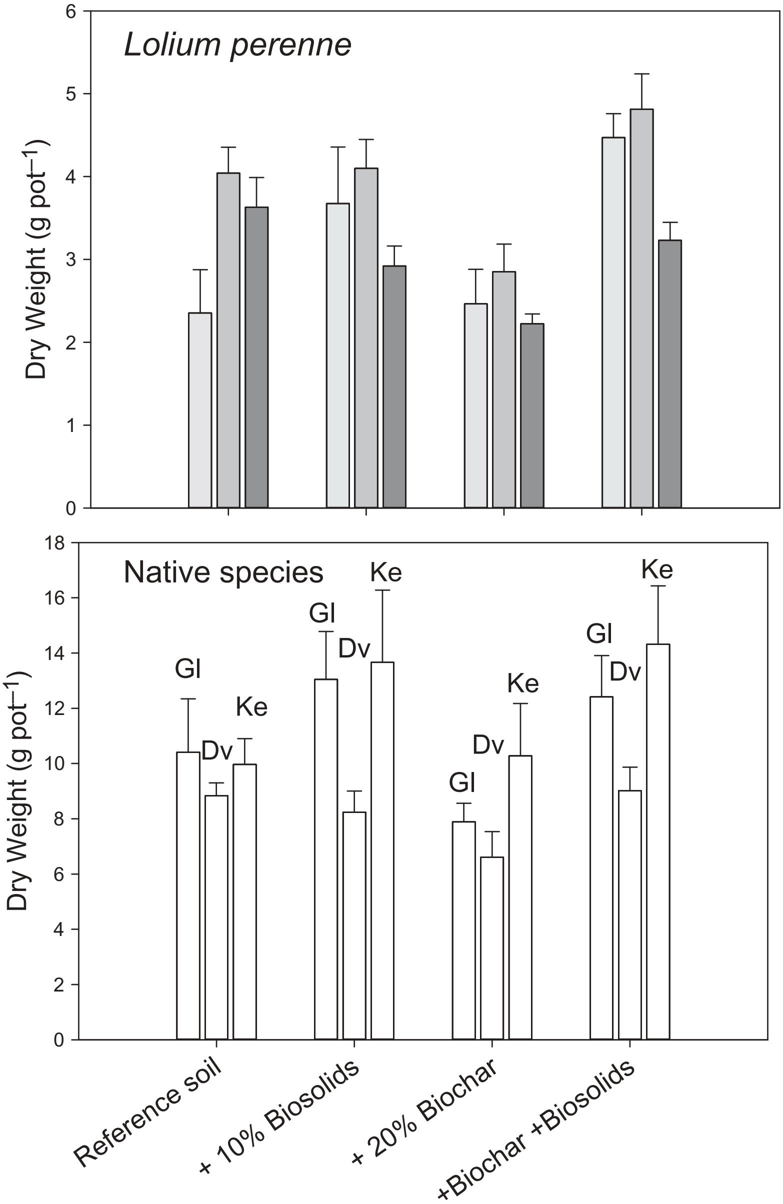

FIGURE 4 Yields of ryegrass on three sequential sampling events over 4 months (upper figure), and of three native species (lower figure) [*Griselinia littoralis* (Gl), *Dodonaea viscosa* (Dv), and *Kunzea ericoides* (Ke)] after 4 months growth in the pot experiment containing biosolid and biochar amendments. (Data for other species not shown.)

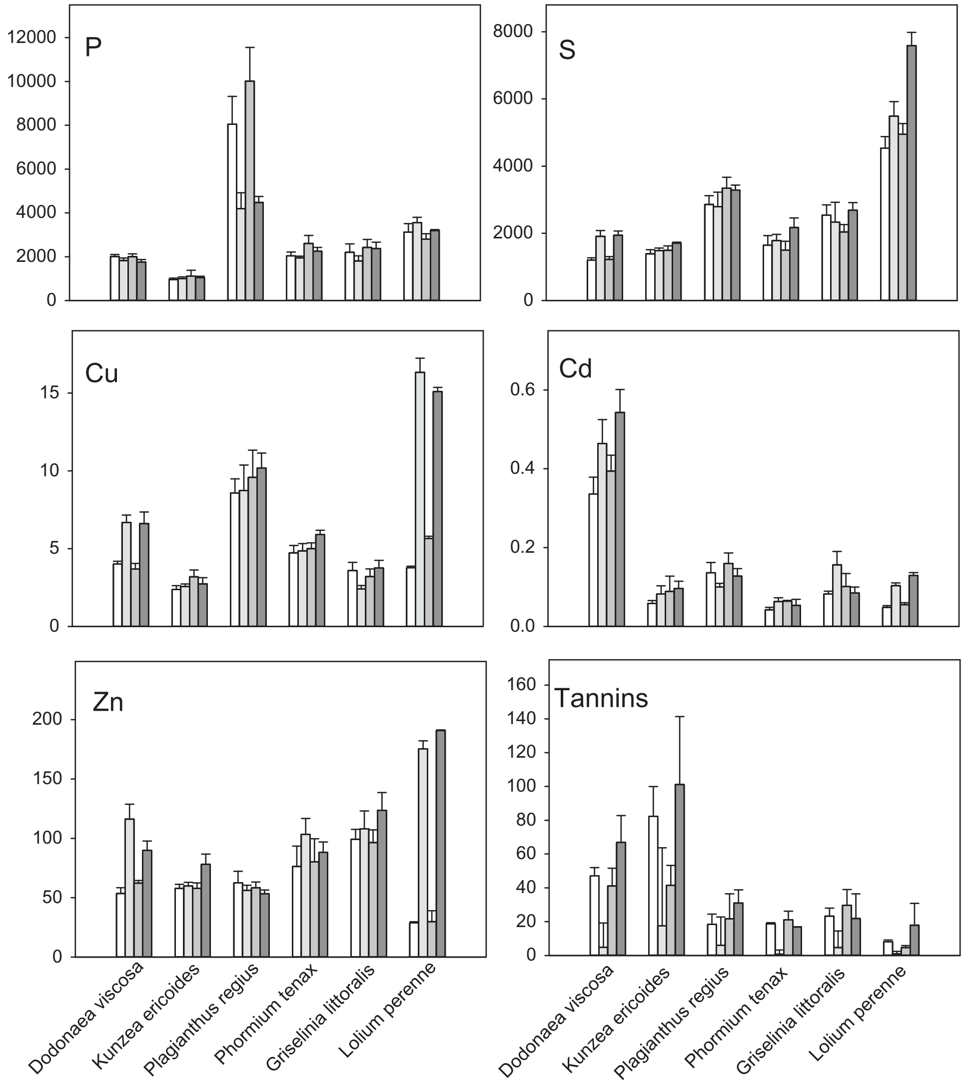

FIGURE 5 Elemental and tannin concentrations in plant foliage after growth in reference soil (open bars), soil with 10% biosoilid amendment (lightest gray bar), soil with 20% biochar amendment (medium gray bars) and both amendments (dark gray bars),after 4 months growth in the pot experiment.

the former effectively providing scope for a range of foliar concentrations between taxa, individual plants and different leaves of the same plant (Bradshaw 1991). Thus phenotypic plasticity responds to environmental variables that include a multitude of physicochemical soil variables combined with the effects of associated biota (microorganisms, soil fauna), both above- and belowground (Bardgett and Wardle 2010). There were substantial differences in chemical element concentrations in the soils of the present study, and wide-ranging differences would likely occur on the margins of agricultural land. Clearly, reliable and confident prediction of the concentration range within any species is fraught with difficulty, except in extreme cases (e.g., in extreme soils [Martínez-Sánchez et al. 2012) and in hyperaccumulator species [Baker and Brooks 1989]) or where there is a substantial knowledge base. Such a body of evidence exists for ryegrass, as described above, but otherwise is unusual outside major crop species. Confidence intervals associated with means in the present study obviously relate solely to the material sampled. Consequently, any further interpretation of these data should be viewed cautiously; at best the outcomes may provide focus of which species are worthy of future research (Table 3).

Benefits in terms of potentially providing a trace element feed supplement through stock browsing would rely on foliar trace element concentrations substantially higher than in ryegrass. The total amount of the trace element delivered to the animal is a balance of the total amount of biomass eaten and the concentrations of the trace elements in biomass; it may be assumed that a chemical concentration in native foliage must be, say, a factor of 10 or 100 times higher than ryegrass. In fact, concentrations differences measured in the present study seldom varied by a factor of more than 5, with a substantially higher concentration differential only recorded for tannins. Six native species provided simultaneously beneficial concentrations of at least four chemical elements, with substantially elevated tannins in only two other species.

CONCLUSIONS

The findings of the present study show that concentration of major nutrients (N,P, K, Ca) in the foliage of native plants were frequently substantially higher than in soil, reflecting selective acquisition of these resources. A tentative overview of the findings (Table 3) suggests there is potential to use 15 of the 17 species to influence the management of chemical elements that are important in the context of stock grazing. Two species could provide benefits of tannins reducing nitrogen in the urine of stock. In view of the lesser amounts of native plants that would be likely to be consumed by stock, in proportion to consumption of ryegrass, any benefits in terms of potentially providing a trace element feed supplement are probably negligible. Biosolid and biochar soil amendments had negligible effects on growth, nutrient, and trace element content of foliage of native plants. Planting of native species in production landscapes has only limited potential to add value to agroecology and sustainable food systems through providing a trace element supplement.

TABLE 3 Tentative description of situations where native New Zealand plant species may be beneficial (√) or detrimental (X) as a browse crop in agricultural landscapes. [1] Potentially beneficial to environmental management of nitrogen, rather than through nutritional advantages. [2] Potentially beneficial or detrimental dependent on concentration (see text)

Species	N[1]	P	K	S	Ca	Mg	Zn	Cd	Cu	Mo	Cu:Mo	Tannin
Olearia paniculata							√					
Dodonaea viscosa	√	√				√	√	X				√
Cordyline australis						√				√	X	
Pittosporum eugenioides		√			√							
Griselinia littoralis		√		√	√	√				√	X	
Hebe salicifolia					√	√			√	√	√X [2]	
Pittosporum tenuifolium				√	√			X				
Coprosma robusta				√	√	√	√	X				
Aristotelia serrata		√	√	√	√				√		X	
Chionochloa rigida							√					
Alectryon excelsus									√			
Melicytus ramiflorus				√								
Pseudopanax arboreus				√								
Kunzea ericoides	√											√
Plagianthus regius								X	√			

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