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SHORT COMMUNICATION

Plant-soil relationships in a New Caledonian serpentine flora

Summary

Elemental concentrations were studied in two New Caledonian hyperaccumulators of nickel and in the soils supporting these plants. The nickel content of *Hybanthus austrocaledonicus* was directly related to the total nickel content of the soil, and this species may therefore be used for biogeochemical prospecting. Nickel was correlated well with other elements of the iron family in non-lateritic ultrabasic soils but not in laterites. Both *H. austrocaledonicus* and *Homalium kanaliense* contained adequate amounts of potassium despite very low concentrations in the supporting soils. These low nutrient levels were further aggravated by antagonism to potassium uptake caused by other soil elements. Because of the paucity of relationships between nickel in *H. kanaliense* and elements in the soil, it is suggested that the high nickel levels in this plant may be controlled by organic constituents in this species.

Introduction

New Caledonia has a rich and largely endemic flora characterised by some 3000 species growing on a tropical island of only 19000 km^2 in area. The flora is characterized by the number of species adapted to ultrabasic rocks and soils[7] which cover about one third of the island. These species are notable in including several hyperaccumulators of nickel (> 1000 µg/g on a dry-weight basis) belonging to the genera Geissois[8], Homalium,[2,3,8] Hybanthus,[2,3,8,9] Psychotria[8] and Sebertia[6]. To date, only fourteen hyperaccumulators of nickel have been reported in the literature, all of which, except for one in Australia[12] and one in Italy[11], are found in New Caledonia. Seven of these New Caledonian plants belong to the genus Homalium[3] and two to the family Hybanthus. Because of the intense interest generated by the discovery of these hyperaccumulators, a plant soil survey was carried out for two of the most widespread of these plants in order to investigate their potential in biogeochemical prospecting[1] and at the same time to study edaphic factors governing their distributions. The plants studied were: *Homalium kanaliense* Briq. (Flacourtiaceae) and *Hybanthus austrocaledonicus* Schinz. et Guillaumin (Violaceae).

Material and methods

Sampling areas. Plants were collected from three areas in the southern part of the island: Mont Koghi, Rivière Bleue and Plaine des Lacs.

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Specimens of *H. austrocaledonicus* were collected at the first two areas and *H. kanaliense* from the Plaine des Lacs.

At Mont Koghi (rainfall 2000 mm, altitude 600 m) the vegetation cover comprises dense rain forest overlying very humic (29% loss of weight after ashing dried soils at 500°C) ferruginous soils derived from shattered peridotites.

At the Rivière Bleue (rainfall 3000 mm, altitude 200 m) the cover is again dense rain forest overlying residual ferruginous alluvia derived from peridotites and associated rocks.

At the Plaine des Lacs (rainfall 2500 mm, altitude 200 m–300 m) specimens were collected from three separate areas of mainly lateritic soils.

Sampling procedures. Leaves were collected from specimens of *Hybanthus austrocaledonicus* and *Homalium kanaliense.* Samples were taken from various positions on the shrubs and as far as possible were taken from specimens of similar size. Leaves were stored in plastic bags and were washed upon return to the laboratory.

Soil samples were taken from the base of each plant at a point below the humus layer (*i.e.* about 20 cm depth). The soils were dried at 80°C, sieved (−60 mesh), and stored in paper bags.

Chemical analysis. Leaf material was ignited at 500°C in a muffle furnace and the plant ash was pulverised with a glass rod. Subsamples (0.1 g) were dissolved in 10 cm^3 of hot 2*M* hydrochloric acid.

Preliminary analysis of various soil fractions showed no significant differences in elemental concentrations. Samples of −60 mesh size were therefore ignited at 500°C and then ground to about −150 mesh size. Small subsamples (0.1 g) of this ground material were weighed into 50 cm^3 squat polypropylene beakers and digested with 5 cm^3 of a 1:1 mixture of concentrated hydrofluoric and nitric acids. The beakers were suspended in a water bath to evaporate excess acid, and the residues were redissolved in 10 cm^3 of 2*M* hydrochloric acid prepared from redistilled (5*M*) acid.

Plant ash and soil digests were then analysed for a number of elements by atomic absorption spectrophotometry using a background corrector to reduce interference from non-atomic absorption. Phosphorus was analysed separately by a colorimetric technique[13].

Statistical treatment of data. A computer was used to calculate arithmetic means, standard deviations and Pearson product moment correlation coefficients (r) for the data.

Results and discussion

Table 1 shows mean values and standard deviations for elemental concentrations in plants and soils. Both plant species contain considerably higher nickel concentrations then the soil even on a dry weight basis. It is also noteworthy that both species were able to accumulate adequate amounts of potassium (~7000 μg/g) in spite of the very great deficiency of this element in soils.

Interelemental relationships for plants and soils considered separately, are shown in Table 2. Values are based on correlation coefficients denoting

TABLE 1

Concentration data (dry-weight basis) for plants and soils

Element	*H. austrocaledonicus* (72 sites)		*H. kanaliense* (75 sites)	
	Plant	Associated soil	Plant	Associated soil
Ca (%)	0.85 ± 0.25	0.69 ± 0.27	0.76 ± 0.27	0.32 ± 0.20
Co (μg/g)	39 ± 61	877 ± 208	119 ± 99	806 ± 251
Cr (μg/g)	31 ± 27	3612 ± 1048	9.8 ± 6.4	8787 ± 2246
Cu (μg/g)	4.5 ± 1.7	58 ± 36	10.2 ± 5.0	82 ± 51
Fe (%)	0.022 ± 0.018	25.8 ± 4.7	0.027 ± 0.025	35.6 ± 5.1
K (μg/g)	7160 ± 2660	446 ± 758	7750 ± 2443	99 ± 48
Mg (%)	0.67 ± 0.15	4.42 ± 2.55	0.41 ± 0.16	0.59 ± 0.93
Mn (μg/g)	209 ± 91	6078 ± 1459	446 ± 352	4715 ± 2372
Ni (%)	1.36 ± 0.40	0.64 ± 0.14	0.45 ± 0.17	0.52 ± 0.13
P (μg/g)	588 ± 99	349 ± 138	294 ± 84	187 ± 60
Zn (μg/g)	56 ± 23	193 ± 46	213 ± 61	312 ± 57
Extractable Ni (%)	–	0.09 ± 0.03	–	0.03 ± 0.02
Humus (%)	–	23.9 ± 8.0	–	19.3 ± 7.0

relationships significant at the 0.5% level of probabilities ($p \leqslant 0.005$), which by convention[4] are said to be highly significant. Only relationships with at least this level of significance are shown in the table, and positive or negative correlations are indicated by the appropriate symbols.

Inspection of the lower part of Table 2 shows that correlation patterns for soils show some of the expected trends for ultrabasic areas. Nickel is correlated positively with other members of the iron family (Co, Cr, Fe, Mn) in the soils at Mt. Koghi and Rivière Bleue (*i.e.* those supporting *H. austrocaledonicus*). In contrast to this, nickel in the soils from the Plaine des Lacs (upper portion of Table 2) shows no correlation with other members of the iron family. This is almost certainly because these soils reflect the usual lateritic separation of elements such as nickel, iron and cobalt due to heavy leaching.

Correlations between humus and metals are always negative in the forested sites at Rivière Bleue and Mt. Koghi and usually so in the lateritic Plaine des Lacs. The positive association between humus and potassium in this latter area may indicate that humic material is a useful source of potassium in soils that are severely depleted in this element (*i.e.* < 100 μg/g).

In contrast to soils, there are few correlations between pairs of elemental concentrations in plants alone. In *H. austrocaledonicus*, the zinc content of the plant is inversely related to the magnesium content (r is negative) and reflects a relationship already evident in the substrate. No relationship for these elements is apparent in *H. kanaliense*.

Table 3 shows plant-soil relationships for both species.

Highly-significant plant-soil relationships for *H. kanaliense* are fairly numerous, though not for nickel, the most interesting element. The nickel

TABLE 2

Matrix of correlation coefficients for interelemental relationships in plants and soils considered separately (only values for $p \leqslant 0.005$ are shown)

		Soils supporting *H. kanaliense* (Plaine des Lacs)													
		Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Zn	XNi	Humus	
Soils supporting *H. austrocaledonicus* (Mt. Koghi and Rivière Bleue)	Ca			−			+	+	−	+		+			Ca
	Co			−		−	+		+					+	Co
	Cr	−	+			+	−	−			+			−	Cr
	Cu					+				+	+	+		−	Cu
	Fe		+	+			−				+	+		−	Fe
	K						+						+		K
	Mg			−					−	+					Mg
	Mn		+	+		+							+		Mn
	Ni		+	+	+	+		−	+			+		−	Ni
	P	+											+	−	P
	Zn		+	+		+		−		+				−	Zn
	XNi		+	+				−	+	+		+			XNi
	Humus		−	−		−			−	−		−	−		
		Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Zn	XNi	Humus	

		Leaves of *H. kanaliense*										
		Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Zn	
Leaves of *H. austrocaledonicus*	Ca								+			+	Ca
	Co											+	Co
	Cr					+							Cr
	Cu	+								+			Cu
	K							−					K
	Mg								−		+		Mg
	Ni											+	Ni
	Zn							−					Zn
		Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Zn	

XNi = extractable nickel
+ = positive correlation
− = negative correlation

content of dried leaves (0.45%) is related only to the manganese and extractable nickel in the soil. The lack of interelemental relationships is perhaps the most significant factor involving *H. kanaliense* and raises the possibility of an accumulation mechanism dependent on the presence of organic, rather than inorganic constituents in the plant. It is also clear that the nickel content of *H. kanaliense* is of little use in biogeochemical prospecting since it is not related to the total nickel content of the substrate, although it is found only in soils with a high nickel content.

Successful serpentine species are those which are able to adapt to unfavourable (mainly edaphic) factors in the substrate. The principal factor is often excess levels of magnesium which results in lower uptake of nutrients such as calcium, potassium and phosphorus. Table 3 shows that calcium

TABLE 3

Matrix of correlation coefficients for plant *vs* soil relationships (only values for $p \leqslant 0.005$ are shown)

		Soils												
		Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Zn	XNi	Humus
Leaves of *H. kanaliense*	Ca									+				−
	Co	+		−					−				−	
	Cr	−						−		−		−		+
	Cu			+										−
	Fe	−								−		−		+
	K	−	−	+	+	+	−	−			+			
	Mg	+	+	−		−	+	+	−	+				
	Mn	−	−	+		+	−	−						−
	Ni	−							+				+	
	P			−		−								+
Leaves of *H. austrocaledonicus*	Ca							+				−	−	
	Co		+											
	Cr							−				+		
	Mg							+				−		
	Mn				+				+					
	Ni							−		+		+	+	
	P												+	
	Zn												+	

XNi = extractable nickel
\+ = positive correlation
− = negative correlation

uptake is apparently unaffected by unfavourable mineralogical edaphic factors, since calcium is related inversely only to the humus content. This represents a significance departure from trends in other serpentine areas[10] and on brown hypermagnesian soils of New Caledonia[5], where high magnesium levels depress calcium uptake. The potassium levels in the plants are however inversely related to the concentration of several elements in the supporting soil, notably calcium and magnesium.

The most striking feature of the chemical composition of *H. kanaliense*, is that this plant is able to attain an adequate potassium content (0.78%) in spite of the compoinding disadvantages of antagonism to uptake which is caused by several soil elements, and a very low concentration of potassium (0.01%) in the soil.

The same is true, though to a lesser extent, for phosphorus whose uptake is affected (*i.e.* negative plant-soil correlations) by the iron and chromium content of the soil. The low phosphorus content of the soil (187 μg/g) is another unfavourable factor since it is about one fifth that of normal soils.

In the case of *H. austrocaledonicus*, there is again no evidence for a reduced calcium uptake due to antagonism from magnesium or other elements in the soil. This again is probably due to the fact that the magnesium content of its substrate, though appreciable, is well below that of brown hypermagnesian New Caledonian soils and that of many other ultrabasic areas, particularly those in temperate regions[10] of the world. In contrast to *H. kanaliense*, the nickel content of *H. austrocaledonicus* is related not only to the extractable nickel in the soil but also to the total nickel content. This species therefore shows potential for biogeochemical prospecting. There are no significant plant-soil relationships involving potassium, and the phosphorus content is correlated only with zinc (positive relationship). The lack of any relationship involving the potassium content of the plant, may be explained by the fact that the soils supporting this species are less hostile than those associated with *H. kanaliense*. Not only is the potassium concentration (446 μg/g) fourfold higher, but the phosphorus content is also twice as high.

It is hoped that the results presented in this paper will prove to be of use for other workers in this field, and it is suggested that future studies could be concerned with possibility of organic constituents of these species having a role in the uptake of nickel.

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