# SOME NEW ZEALAND AND NEW CALEDONIAN PLANT ACCUMULATORS OF NICKEL

By R. R. BROOKS,* J. LEE* and T. JAFFRÉ†

*Department of Chemistry, Biochemistry and Biophysics, Massey University, Palmerston North, New Zealand; and †Section de Biologie Végétale, Centre O.R.S.T.O.M. de Noumea, New Caledonia

## INTRODUCTION

Although plant indicators or accumulators of copper are well represented in the literature (Duvigneaud 1958; Duvigneaud & Denaeyer de Smet 1963; Cole, Provan & Tooms 1968; Howard-Williams 1970), the list of nickel indicators or accumulators is considerably smaller. The term 'accumulator' is here defined as a plant whose mean content of a particular element (expressed on an ash-weight basis) is greater than the content of the same element in the fine earth fraction of the substrate. Table 1 lists all the known nickel accumulators and, as shown, they comprise only six species apart from those first reported in this paper. Of these six, the three *Alyssum* species are very closely related and have all in the past been classified as either *A. alpestre*‡ or *A. argentea*.

The purpose of this paper is to present, for the first time, data on the New Caledonian nickel accumulators which have been found to be characteristic of serpentine areas in that country (Jaffré, Latham & Quantin 1971). The New Caledonian species are compared with the New Zealand serpentine endemic *Pimelea suteri* for which fresh data are presented.

## STUDY AREAS

### *New Zealand*

Specimens of *Pimelea suteri* were collected from sites near the end of the nineteenth century 'ore tramway' in the Dun Mountain serpentine area *c.* 12 km south-east of Nelson City, South Island, New Zealand (latitude 41° 20′ S, longitude 173° 20′ E) described by Lyon *et al.* (1971). The climate is mild with 150–200 cm of rain per year. The pH of the soils is relatively uniform (6·5–7·0). Plants of *P. suteri* are particularly associated with soils derived from shattered pyroxenite boulders.

### *New Caledonia*

Specimens of *Hybanthus caledonicus* were obtained from the Boulinda Massif on the west coast of the island (latitude 21° 19′ S, longitude 165° 6′ E) at an altitude of 300 m (rainfall <180 cm). The base-rich soils are brown and overlay highly serpentinized peridotites. Specimens of *Homalium kanaliense* and *Hybanthus austro-caledonicus* were collected from the Pleine des Lacs and Rivière Bleue areas (latitude 22° 15′ S, longitude 166° 52′ E) in the extreme south of the island in a zone of high rainfall (>180 cm). The plants of *Hybanthus* were growing on humic ferruginous soils over peridotic ancient

‡ Authorities for species mentioned in the text are given in Table 1.

Table 1. *A list of nickel-accumulating plants and their nickel contents*

| Species | Family | Locality | Nickel content (%) Plant ash | Soil | Plant/soil Ni ratio | References |
|---|---|---|---|---|---|---|
| **Alyssum bertolonii* Desv. | Cruciferae | Italy | 8·0 | 0·26 | 30·8 | Minguzzi & Vergnano (1948); Vergnano (1958) |
| **A. murale* Bieb. | Cruciferae | U.S.S.R. | 10·0 | 0·50 | 20·0 | Malyuga (1964) |
| **A. serpyllifolium* Desf. ssp. *lusitanicum* | Cruciferae | Portugal | 10·3 | 0·40 | 25·8 | Menezes de Sequeira (1968) |
| *Dicoma niccolifera* Wild | Compositae | Rhodesia | 2·8 | 0·70 | 4·0 | Wild (1970, 1971); Ernst (1972) |
| *Homalium kanaliense* Briq. | Samydaceae | New Caledonia | 11·0 | 0·46 | 23·9 | This paper |
| *Hybanthus austro-caledonicus* Schinz. et Guillaumin | Violaceae | New Caledonia | 27·0 | 0·50 | 54·0 | This paper |
| *H. caledonicus* (Turcz.) Cretz. | Violaceae | New Caledonia | 10·9 | 0·67 | 16·3 | This paper |
| *H. floribundus* (Lindl.) F. Muell. | Violaceae | W. Australia | 10·0 | 0·07 | 143 | Severne & Brooks (1972) |
| *Pimelea suteri* Kirk | Thymelaeaceae | New Zealand | 0·59 | 0·33 | 1·8 | Lyon *et al.* (1971) |

* Closely related species variously classified in the past as *A. argentea* All. or *A. alpestre* L.

alluvia whereas those of *Homalium* were found on ferruginous residual and hydromorphic soils overlying peridotites.

## MATERIALS AND METHODS

Whole plants and their associated soils (10–20 cm depth) were collected. Plant samples were thoroughly washed in running water for about 30 s, rinsed in distilled water and dried at 110° C. The dried material was placed in 50-ml borosilicate squat beakers and ashed at 450° C in a muffle furnace. The plant ash was then dissolved in one hundred times its weight of 2 M hydrochloric acid and the resultant solution was analysed for various elements (except phosphorus) by means of atomic absorption spectrophotometry.

Soil samples were air-dried, sieved (80 mesh, U.S. standard) and ignited at 450° C. They were then digested in polypropylene beakers with a mixture of concentrated nitric and hydrofluoric acid and taken to dryness over a water bath. The residues were redigested in 2 M hydrochloric acid and the various elements determined by atomic absorption spectrophotometry. Phosphorus in plant ash and soils was determined by the molybdenum blue method (Stanton 1966).

All data in this paper are expressed on an ash-weight basis. For comparison of the present data with those of other workers, whose results may sometimes be on a dry-weight basis, conversion to ash weight has been made by using a factor of ×15 which assumes that ash weight is 7% of dry weight.

An IBM 1620 II computer was used to calculate geometric means, standard deviations and Pearson Product–Moment correlation coefficients ($r$). All concentration data were transformed to logarithms because elemental concentrations in soils and vegetation tended to be distributed log-normally rather than normally.

## RESULTS AND DISCUSSION

It is generally considered that there are three factors mainly responsible for the distinctive flora found on serpentine-derived soils: high concentrations of nickel, chromium and cobalt; low calcium/magnesium ratios; deficiency of macronutrients such as nitrogen, phosphorus, and potassium. The concentrations of all these elements (except nitrogen) are therefore considered in each of the known nickel accumulators with an emphasis on newly reported species. Table 2 summarizes the data available.

The nickel and chromium contents of various species are shown in Table 3. It is clear that both *Pimelea suteri* and the New Caledonian plants are able to restrict chromium uptake at the root systems which contain far more of this element than the aerial parts of each species. The ability of the New Caledonian species to restrict chromium uptake is very striking because their substrate contains considerably more chromium than the New Zealand serpentines.

There is little evidence that either the New Zealand or New Caledonian plants restrict uptake of nickel. Indeed the reverse is true as the aerial parts of the plants have concentrations of nickel as high as those of the roots or higher.

Although excess cobalt can also be toxic to vegetation, the cobalt levels in the New Zealand and New Caledonian serpentines are not sufficiently high to be likely to affect vegetation to any extent. Nevertheless it is clear from Tables 2 and 3 that cobalt is readily accumulated and, like nickel, there is no evidence for precipitation at the root systems.

Table 2. *Mean elemental concentrations in leaves of nickel-accumulating plants and their soils*

| Sample | No. of analyses | Percentage ash weight | | | | | | | Ca/Mg ratio |
|---|---|---|---|---|---|---|---|---|---|
| | | Co | Cr | K | Ni | P | Ca | Mg | |
| *Alyssum bertolonii** | 2 | 0·001 | 0·0190 | 24·0 | 8·00 | 3·00 | 23·6 | 8·80 | 2·7 |
| Soil | 2 | – | 0·56 | – | 0·260 | – | – | – | – |
| *Homalium kanaliense* | 3 | 0·104 | 0·0054 | 27·0 | 8·87 | 0·57 | 15·5 | 6·15 | 2·5 |
| Soil | 3 | 0·134 | 2·40 | 0·003 | 0·590 | 0·02 | 0·01 | 0·23 | 0·04 |
| *Hybanthus austro-caledonicus* | 2 | 0·042 | 0·0330 | 20·0 | 24·75 | 1·02 | 12·3 | 13·95 | 0·88 |
| Soil | 2 | 0·084 | 2·50 | 0·004 | 0·750 | 0·03 | 0·09 | 2·00 | 0·04 |
| *H. caledonicus* | 2 | 0·073 | 0·0092 | 22·5 | 5·62 | 0·65 | 19·4 | 7·80 | 2·5 |
| Soil | 2 | 0·140 | 3·72 | 0·016 | 0·556 | 0·03 | 0·03 | 1·45 | 0·02 |
| *H. floribundus*† | 2 | 0·040 | 0·0400 | 18·0 | 10·00 | 3·75 | 24·0 | 4·80 | 5·00 |
| Soil | 2 | 0·004 | 0·40 | – | 0·070 | – | 0·60 | 1·20 | 0·50 |
| *Pimelea suteri* | 34 | 0·0043 | 0·0089 | 9·3 | 0·230 | 0·60 | 6·90 | 16·98 | 0·41 |
| Soil | 34 | 0·027 | 0·10 | 0·320 | 0·260 | 0·04 | 0·94 | 14·45 | 0·07 |

* Data from Minguzzi & Vergnano (1948) and Vergnano (1958).
† Data for cobalt and nickel from Severne & Brooks (1972).

Table 3. *Elemental concentrations in various organs of representative individual nickel-accumulating plants and their soils*

| | Percentage ash weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Co | Cr | K | Ni | P | Ca | Mg | Ca/Mg ratio |
| *Alyssum bertolonii** | | | | | | | | |
| Seeds | – | – | – | 7·20 | – | 17·3 | 4·6 | 3·76 |
| Flowers | 0·0300 | 0·0001 | – | 6·40 | – | 20·3 | 4·5 | 4·51 |
| Mature leaves | 0·0010 | 0·0190 | – | 8·00 | – | 23·3 | 4·6 | 5·07 |
| Roots | – | – | – | 4·60 | – | 13·7 | 6·0 | 2·28 |
| Soil | – | 0·560 | – | 0·26 | – | – | – | – |
| *Homalium kanaliense* | | | | | | | | |
| Flowers | 0·0202 | 0·0066 | 39·75 | 2·93 | 1·12 | 13·05 | 6·0 | 2·18 |
| Mature leaves | 0·0420 | 0·0120 | 36·00 | 7·48 | 0·56 | 13·95 | 3·6 | 3·87 |
| Bark | 0·0060 | 0·0060 | 6·45 | 1·01 | 0·15 | 3·45 | 0·9 | 3·83 |
| Soil | 0·054 | 2·964 | 0·005 | 0·49 | 0·003 | 0·001 | 0·10 | 0·01 |
| *Hybanthus austro-caledonicus* | | | | | | | | |
| Flowers | 0·0087 | 0·0165 | 46·50 | 0·90 | 3·75 | 8·40 | 12·90 | 0·65 |
| Old leaves | 0·0480 | 0·0795 | 17·25 | 24·0 | 0·84 | 10·50 | 13·80 | 0·76 |
| Mature leaves | 0·0270 | 0·0360 | 19·80 | 22·5 | 1·14 | 9·60 | 14·25 | 0·67 |
| Twigs (2-year) | 0·0042 | 0·0142 | 16·20 | 6·75 | 0·53 | 7·65 | 3·00 | 2·55 |
| Bark | 0·0165 | 0·0165 | – | 21·00 | 0·51 | 6·90 | 2·25 | 3·07 |
| Thick roots | 0·0042 | 0·0285 | 5·40 | 6·67 | 0·32 | 6·75 | 2·10 | 3·21 |
| Fine roots | 0·0081 | 0·1080 | 5·40 | 18·00 | 0·51 | 2·70 | 3·45 | 0·78 |
| Soil | 0·062 | 2·128 | 0·005 | 0·80 | 0·003 | 0·08 | 1·68 | 0·05 |
| *Pimelea suteri* | | | | | | | | |
| Mature leaves | 0·0095 | 0·0150 | 14·00 | 0·59 | 0·60 | 7·0 | 28·0 | 0·25 |
| Twigs | 0·0250 | 0·0337 | 12·00 | 0·75 | 0·88 | 5·4 | 24·0 | 0·22 |
| Roots | 0·0151 | 0·0671 | 1·86 | 0·53 | 5·26 | 3·5 | 17·5 | 0·20 |
| Soil | 0·040 | 0·160 | 0·320 | 0·35 | 0·043 | 0·47 | 15·0 | 0·03 |

* Data from Minguzzi & Vergnano (1948) and Vergnano (1958).

From Table 2 it is apparent that the calcium and magnesium content of the heavily-leached tropical New Caledonian serpentine soils is much lower than that of the New Zealand ultrabasic area. The New Caledonian plants might therefore have been expected to suffer a deficiency of both elements rather than a deficiency of calcium caused by excessive uptake of magnesium as could be expected for the New Zealand plant. All the New Caledonian nickel accumulators, however, have not only a favourable (high) calcium/magnesium ratio but also (in common with *Alyssum bertolonii*) have quite high concentrations of calcium (~15%) compared with *Pimelea suteri*, which contains only about 7% calcium although it grows in a substrate with much more of this element than the New Caledonian soils. It seems therefore that the major difference between the New Caledonian species and the New Zealand plant is that in the former case there must be some mechanism to allow for adequate uptake of calcium which is deficient in the soil, whereas in the case of *P. suteri* this mechanism is either less evident or is hindered by the depressant effect of magnesium on uptake of calcium. The favourable calcium/magnesium ratio in *Hybanthus floribundus* probably results from a combination of adequate calcium levels in the soils coupled with a relatively low magnesium content so that uptake of calcium is not hindered.

With regard to the macronutrients phosphorus and potassium, it is evident (Table 2) that, as in the case of calcium and magnesium, the New Caledonian environment is extremely hostile to plant growth in comparison with the New Zealand area where the concentrations of both phosphorus and potassium are at least twenty times greater. The deficiency of these nutrients in the New Caledonian soils represents perhaps the greatest single difference in the two localities and yet, in spite of this, the New Caledonian species have unusually high levels of these two elements (and calcium also). There is a correlation between higher Ni content and higher contents of P, K and Ca in the New Caledonian plants compared as a whole with the New Zealand plants.

Correlation analysis of thirty-four samples of leaves of *Pimelea suteri* showed highly significant ($P<0{\cdot}01$) correlations for the following element pairs: nickel–cobalt ($r$ = 0·66), nickel–zinc ($r$ = 0·57), nickel–calcium ($r$ = 0·53). There was also a significant ($P$ = 0·02) value for the nickel–phosphorus pair ($r$ = 0·38) and a possibly significant ($P$ = 0·06) relationship for the nickel–potassium pair ($r$ = 0·30).

Two possible hypotheses may account for the correlations obtained. Firstly there is the possibility that some nickel accumulators use extensive uptake of this element as a means of obtaining adequate amounts of nutrients whose concentrations in the substrate are exceedingly low. A second possibility is that growth of the plant is inhibited to an extent proportional to the foliar nickel content so that, the higher the nickel, the longer the period needed for the plant or organ to attain maturity and the greater the consequent uptake of macronutrients. Whichever of these two mechanisms is operative, the end result is apparently the same: the greater the nickel content, the higher the ultimate concentration of macronutrients.

Although this work has been primarily concerned with reporting new data for nickel accumulators, it is hoped that it will stimulate further research into these species. In particular it seems probable that investigation of other species of *Hybanthus* may lead to the discovery of further nickel accumulators.

## SUMMARY

Three species of New Caledonian serpentine plants: *Homalium kanaliense* Briq., *Hyban-*

*thus austro-caledonicus* Schinz. et Guillaumin, and *H. caledonicus* (Turcz.) Cretz., have unusually high accumulations of nickel. These species are compared with the New Zealand accumulator, *Pimelea suteri* Kirk.

The New Caledonian species contained higher-than-average contents of the nutrients, calcium, phosphorus and potassium, in spite of the particularly low concentrations of these elements in New Caledonian serpentine soils. It was also found that there were strong correlations between foliar levels of nickel and those of calcium, phosphorus and potassium in the New Zealand plant *P. suteri*. It is postulated that the very high uptake of nickel may be linked to the concomitant accumulation of macronutrients and that nickel may have a stimulating effect on this uptake. The same effect can be explained by inhibition of growth by the high nickel content and a consequent increase of macronutrient values owing to the longer time needed for the plant or organ to attain maturity.

## REFERENCES

**Cole, M. M., Provan, D. M. J. & Tooms, J. S. (1968).** Geobotany, biogeochemistry, and geochemistry in the Bulman–Waimuna Springs area, Northern Territory, Australia. *Trans. Instn Min. Metall.* Sect. B, 77, 81–104.

**Duvigneaud, P. (1958).** La végétation du Katanga et de ses sols métallifères. *Bull. Soc. r. Bot. Belg.* **90,** 127–286.

**Duvigneaud, P. & Denaeyer de Smet, S. (1963).** Cuivre et végétation au Katanga. *Bull. Soc. r. Bot. Belg.* **96,** 93–231.

**Ernst, W. (1972).** Ecophysiological studies on heavy metal plants in South Central Africa. *Kirkia,* **8,** 125–45.

**Howard-Williams, C. (1970).** The ecology of *Becium homblei* in Central Africa with special reference to metalliferous soils. *J. Ecol.* **58,** 745–63.

**Jaffré, T., Latham, M. & Quantin, P. (1971).** Soils of mining massifs of New Caledonia and their relation to vegetation. *Spec. Rep. O.R.S.T.O.M.*, Noumea.

**Lyon, G. L., Peterson, P. J., Brooks, R. R. & Butler, G. W. (1971).** Calcium, magnesium and trace elements in a New Zealand serpentine flora. *J. Ecol.* **59,** 421–9.

**Malyuga, D. P. (1964).** *Biogeochemical Methods of Prospecting.* Consultants Bureau, New York.

**Menezes de Sequeira, E. (1968).** Toxicity and movement of heavy metals in serpentine soils (North-eastern Portugal). *Agronomia lusit.* **30,** 115–54.

**Minguzzi, C. & Vergnano, O. (1948).** Il contenuto di nichel nelle ceneri di *Alyssum bertolonii* Desv. *Memorie Soc. tosc. Sci. nat.* **55,** 49–74.

**Severne, B. C. & Brooks, R. R. (1972).** A nickel accumulating plant from Western Australia. *Planta,* **103,** 91–4.

**Stanton, R. E. (1966).** *Rapid Methods of Trace Analysis.* Arnold, London.

**Vergnano, O. (1958).** Il contenuto di elementi inorganici delle piante della formazione ofiolotica dell' Impruneta (Firenze). II. Nichelio, cromo e cobalto nel dinamismo nutritivo delle piante serpentinicole. *Nuovo G. bot. ital.* **65,** 133–62.

**Wild, H. (1970).** The vegetation of nickel-bearing soils. *Kirkia,* **7** (Suppl.), 1–62.

**Wild, H. (1971).** The taxonomy, ecology and possible method of evolution of a new metalliferous species of *Dicoma* Cass. (Compositae). *Mitt. bot. StSamml., München.* **10,** 266–74.

(*Received* 9 *August* 1973)