91026

Plant and Soil **186**: 255–264, 1996.

Extractability of nickel and its concentration in cultivated plants in Ni rich ultramafic soils of New Caledonia

Laurent L'Huillier and Sylvie Edighoffer
*Agropedology Laboratory, ORSTOM, B.P. A5, 98 848 Noumea cedex, New-Caledonia**

Received 31 January 1996. Accepted in revised form 3 September 1996

Key words: bioavailability, crop plants, DTPA, maize, Ni uptake, toxicity

Abstract

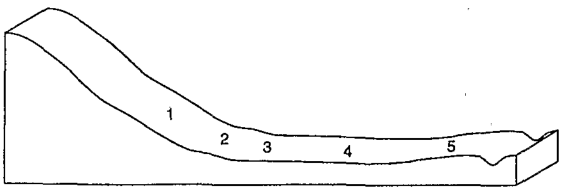
The presence of higher-than-normal quantities of nickel is one of the most general features of ultramafic soils and is often suspected as the reason for their infertility. This study on the bioavailability of Ni in ultramafic soils derived from peridotites in New Caledonia showed important variations depending on the position of the soil in the

Table 1. Chemical and physical properties of the ultramafic soils studied. Values are means ± S.E. (*n* in parenthesis)

Soil	Particle size distribution (%)[a]			pH		C	N	Exchangeable cations (cmol kg^{-1})[e]				CEC	Total elements (%)[f]		
[redacted]															
1. Piedmont	28.9	39.0	31.1	5.1	5.8	1.04	0.06	0.12	0.10	0.06	0.06	1.8	0.4	26.7	0.62
(*n*=6)	±4.6	±7.2	±10.7	±0.1	±0.1	±0.29	±0.01	±0.05	±0.06	±0.03	±0.04	±0.4	±0.2	±0.3	±0.06
2. Colluvio-alluvial soil	50.6	30.9	16.8	6.2	6.3	1.40	0.11	1.50	0.18	0.04	1.36	5.7	0.8	23.9	0.51
(*n*=24)	±6.6	±3.8	±5.3	±0.1	±0.1	±0.11	±0.01	±0.37	±0.07	±0.02	±0.57	±0.8	±0.1	±0.5	±0.03

Table 2. Chemical and physical properties of the ultramafic soils used in the greenhouse experiment

Soil	Horizon	Particle size distribution (%)			pH		C	N	Exchangeable cations ($cmol\ kg^{-1}$)				CEC	Total elements (%)		
	(cm)	Sand	Silt	Clay	(H_2O)	(KCl)	(%)	(%)	Ca	Mg	K	Na	($cmol\ kg^{-1}$)	Si	Fe	Ni
Piedmont	0-20	30.8	45.0	24.1	5.1	5.7	1.83	0.09	0.15	0.21	0.13	0.13	2.5	1.0	25.8	0.76
Piedmont	40-60	35.7	47.3	17.0	4.7	6.1	0.42	0.03	0.02	0.01	0.03	0.03	1.9	0.7	25.9	0.70
Plain	0-20	29.1	49.6	21.3	6.6	6.2	2.10	0.15	1.21	4.48	0.45	0.22	12.1	5.7	16.9	0.85
Plain	40-60	20.9	61.4	17.6	6.6	6.2	1.45	0.11	0.56	4.53	0.16	0.13	11.0	6.4	17.8	0.96



1 : Piedmont.
2 : Colluvio-alluvial soil.

cm and 40-60 cm) and ten repetitions of each. Soils characteristics are given in Table 2. They were sieved through a 6 mm sieve and homogenised before the filling of the pots (5.1 kg of plain soil per pot; 6.2 kg of piedmont soil per pot). They received an addition of nutrients previously determined to alleviate any deficiencies (mg kg^{-1} of soil): 140 N, 1000 P, 69 K, 37 Ca, 23 Mg, 30 S, 0.7 B, 1.1 Zn, 1.6 Cu, 0.2 Mo. After

1925). Nitrogen was determined using the Kjeldahl method.

Statistical analysis

Results obtained from the greenhouse experiment were examined by analysis of variance. The significant differences between means were analysed by Student t test at the 5% confidence limit. Regression equations were performed on all data using step by step regression available on Statview version 4.02, with significance defined at the 1% confidence level.

Results

The geochemical nature of the different soils is relatively homogeneous (Tables 1 and 2). However, the colluvio-alluvial and plain soils possess the highest concentrations of Ni, and exceptionally high concentrations of Si and Mg. Levels of these elements are lower in the piedmont soils, but there is a higher concentration of Fe which corresponds to greater alteration.

Greenhouse experiment

The maize grown in the test soils exhibited significant differences in growth (Table 3). Maize showed a weaker root and shoot development in plain soils (0-20 cm

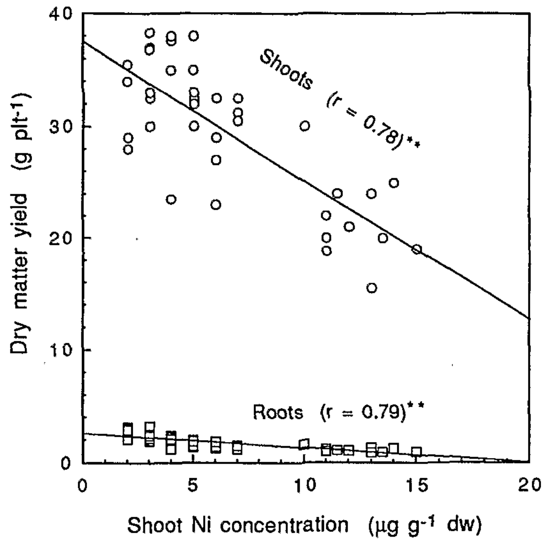


Figure 2. Correlation between shoot dry weight and shoot Ni concentration, and between root dry weight and shoot Ni concentration of maize plants grown in the greenhouse experiment. ** Significant at 1%.

Table 3. Dry matter yield and mineral composition of shoots of maize grown on ultramafic soils used in the greenhouse experiment. Values are means ±SE (n=10)

Soil	Yield (mg plt^{-1})		Si	N	P	K	Ca	Mg	Fe	Mn	Ni
	Shoot	*Root*	(%)						(μg g^{-1} dw)		
Piedmont 0-20 cm	35.1a ±3.9	2.0a ±0.4	1.5a ±0.1	2.8a ±0.3	0.22a ±0.02	1.5a ±0.2	0.54a ±0.05	0.46a ±0.03	121a ±32	115a ±9	4.8a ±0.6
Piedmont 40-60 cm	33.0a ±3.0	2.6a ±0.6	0.7b ±0.1	3.0a ±0.4	0.23a ±0.01	1.4a ±0.3	0.68a ±0.08	0.29b ±0.02	103a ±26	73b ±9	2.9b ±0.3
Plain 0-20 cm	29.8b ±3.1	1.4b ±0.3	2.0c ±0.1	3.1a ±0.3	0.38b ±0.05	2.5b ±0.3	0.24b ±0.02	0.64c ±0.04	134a ±60	56c ±7	6.6c ±1.6
Plain 40-60 cm	21.5c ±2.3	1.1b ±0.3	2.1c ±0.1	3.4a ±0.2	0.37b ±0.03	2.5b ±0.3	0.25b ±0.03	0.82d ±0.07	102a ±50	75b ±6	12.5d ±1.7

Different letters in a column indicate significant difference at the 0.05 confidence level.

Table 4. Ni concentrations in the leaves (μg g^{-1} dw) of some plants cultivated on the ultramafic soils studied. Values are means ± SE (n)

	1. Piedmont	2. Colluvio-alluvial soil	3. Colluvio-alluvial soil with reducing conditions	4. Plain soil with reducing conditions	5. Plain soil
Banana tree				53.5±11.5(2)	22.1±11.0(7)

grown on these types of soil, with Ni concentrations often exceeding 50 μg g^{-1} dw (Table 4). Despite the high levels of fertilization applied by the farmers, crop yields on these soils were much lower than their production potential (about 1.5 to 3 fold low-

plants. The high Ni concentrations recorded for maize grown in the plain soils - especially the horizon 40-60 cm - are probably connected with their poor growth, because they were similar or superior to the concentrations considered toxic in the literature (see Table 6).

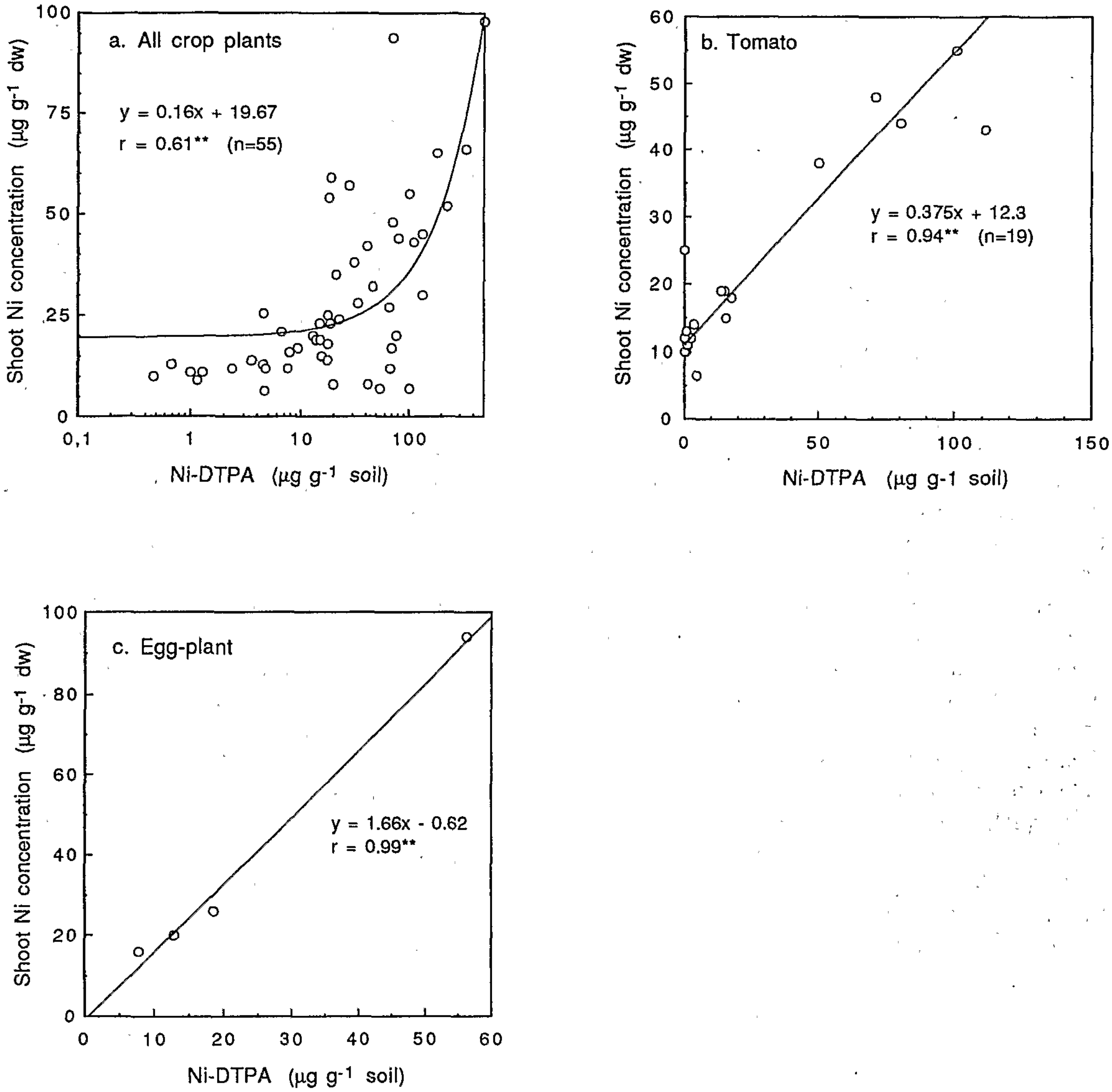


Figure 4. Correlations between DTPA-extractable Ni and shoot Ni concentrations in all crop plants (**a**), in tomato (**b**), or in eggplant (**c**) sampled from the field on ultramafic soils. ** Significant at 1%.

monly used (Haq et al., 1980; Lindsay and Norvell, 1978; Sauerbeck and Hein, 1991). For the soils used in the greenhouse experiment, the correlation between

found with the DTPA extraction. The reasons for that are not clear. Nevertheless, a satisfactory correlation was obtained between Ni concentrations in all crop

Table 6. Toxic Ni concentrations in different crop plants

Plant	Stage	Ni concentration (μg g^{-1} dw)[a]	Effects	Reference
Alfalfa	83 days	44 (S)	Reduced growth	Halstead et al. (1969)
Barley	control at 5 L	12 (S)	Upper critical level	Davis and Beckett (1978)
Bean	75 days	47 (L)	- 60% seeds weight	Piccini and Malavolta (1992)
Citrus	-	40 (L)	Toxic	Vanselow (1966)
Eggplant	4 months	24 (L)	-16% plant dw	Salim et al. (1988)
Maize	18 days	8.4 (S)	-6% shoots dw	Wallace (1989)
	75 cm at 9th L	12 (S)	Upper critical level	L'Huillier (1994)
Oat	adult	42 (L)	Reduced growth	Hunter and Vergnano (1952)
Soya	18 days	13 (L)	-22% shoots dw	Wallace (1989)
Wheat	23 days	25 (L)	-10% leaves dw	Taylor (1988)

[a] Organ analysed: L: Leaves, S: Shoots.

Table 7. Regression equations for the prediction of Ni concentrations in Tomato developed with DTPA-extractable Ni and other soil characteristics as independent variables (n=19)

Regression step	R^2	Variable added	Final equation Coefficient	Standard error	F
1	0.88	Ni-DTPA (Constant: 12.3±1.5)	0.375	0.035	113.2**

** Significant at the 0.01 confidence level.

relation coefficient (R^2) did not significantly improve when other soil characteristics were included into the regression equation. The data from Table 7 can be presented in equation form as follows:

Ni in Tomato (μg g^{-1} dw) = 12.3 + 0.375 Ni-DTPA (μg g^{-1} soil) ($R^2 = 0.88$, $n = 19$)

DTPA is therefore a chemical extractant that by itself is a good indicator of Ni bioavailability and toxicity risks in ultramafic soils. Hughes and Noble (1991) are among the few who have tested chemical extractants in ultramafic soils. They showed that none of the ten single extractants they tested were capable of indicating Ni availability for the flora of ultramafic soils in the Eastern Transvaal. However, the correlations with the vegetation they studied probably lacked some precision and DTPA was not tested.

The regression equations for the prediction of Ni extractability by DTPA (Table 8) allowed us to highlight soil characteristics which may play a significant role in Ni extractability. The levels of CEC, pH(KCl), silica, iron and carbon in the soil explained 89% of the variation in Ni extractability by DTPA with significant probabilities at 1%. This suggests that Ni was more extractable - and probably more bioavailable - in soils with a high level of silica, iron and probably organic matter (for CEC and carbon). The negative coefficient for pH(KCl) suggests that Ni was more extractable in low pH soils. CEC in these soils mainly originates from organic matter, so this one might be a significant source of bioavailable Ni, especially in the surface horizons of these soils as already shown (Becquer et al., 1995). Silicates might constitute an important source of bioavailable Ni as they can originate from easily weatherable primary minerals (rich in Ni and Si), which can be transported by alluviation and colluviation in colluvio-alluvial and plain soils. Nickel has also been shown to occur in association with iron oxides in mafic soils (Schwertmann and Latham, 1986; Singh and Gilkes, 1992; Uren, 1992) which may represent another significant source of Ni for plants, in particular goethite which is more abundant in plain oxisols (Schwertmann and Latham, 1986). These results are in accordance with Jenne (1968) who showed the important effect of hydrous Fe oxides on Ni availability and emphasised the crucial role of redox potential and pH in determining the availability of these hydrous oxides.

In conclusion, our results show that Ni bioavailability in ultramafic soils is very variable. The levels are low in non hydromorphic colluvio-alluvial and piedmont soils, as previously observed by Angelone et al.

Table 8. Regression equations for the prediction of DTPA-extractable Ni developed with soil characteristics as independent variables (n=60)

			Final equation		
Regression step	R^2	Variable added	Coefficient	Standard error	F
1	0.76	CEC	4.8	1.2	16.0**
2	0.81	pH(KCl)	-36.2	10.5	11.8**
3	0.85	Si	31.1	5.6	30.6**
4	0.87	Fe	11.6	2.9	15.8**
5	0.89	C	2.3	0.9	5.6**
		(Constant: -126.2±106.4)			

**Significant at the 0.01 confidence level.

(1993) on ultramafic soils. In contrast, Ni bioavailability is high in plain soils and especially in colluvio-alluvial and plain soils subject to temporary reducing conditions. Crops cultivated on these soils probably suffer from an excess in Ni uptake. Extraction by DTPA gives a good estimation of Ni bioavailability in ultramafic soils.

The regulations concerning the maximum concen-

Becquer T, Bourdon E and Pétard J 1995 Disponibilité du nickel le long d'une toposéquence de sols développés sur roches ultramafiques de Nouvelle-Calédonie. C. R. Acad., Sci. Paris 321, 585–592.

Bourdon E and Becquer T 1992 Etude de l'organisation pédologique des sols ferrallitiques des massifs du Sud de la Grande Terre: zones de la Coulée et de la Lembi. Caractérisation physico-chimique des sols. Nouméa, ORSTOM, Agropédol. 16. 88 p.

Brooks R R 1987 Serpentine and Its Vegetation. A Multidisciplinary Approach. Diocorides Press, Portland, OR.

oxides. *In* Trace Inorganics in Water. Ed. R F Gould. pp 337–387. Adv. Chem. Series 73. Am. Chem. Soc., Washington, DC, USA.

Robertson A I 1992 The relation of nickel toxicity to certain physiological aspects of serpentine ecology: some facts and a