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## of Some Hawaiian Soils and Plants and the Relation of Nickel to Plant Growth

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## INTRODUCTION

Nickel, one of the trace elements in soils, has not been established as essential for plant growth, although there have been occasional reports that minute amounts of nickel have brought about increase in plant growth. Robinson *et al.* (*14*) reported the beneficial effect of nickel on the growth of cereals, beans, and peas in sand and water culture experiments conducted by Scharrer and Schropp. Fifty ppm Ni in sand culture was stimulating to plant growth whereas a higher concentration was toxic. Young (*19*) studied the effects of 35 of the rarer elements in soils on the growth of timothy (*Phleum pratense*). Nickel, one of the elements studied, was added in five concentrations (2,000, 500, 100, 10, 0.10 ppm) to a coarse sandy loam. A concentration of 0.10 ppm Ni showed a slight beneficial effect, but the higher concentrations showed depression in growth. Roach and Barclay (*13*) sprayed manganese, iron, boron, copper, zinc, and nickel solutions on wheat, potatoes, and broad beans, and found an increase in crop yield.

The importance of nickel, however, lies more in its toxic effect on plant growth. Haselhoff (*6*) analyzed a soil after serious complaints from farmers on the ill effects of waste water from a nickel ore crushing plant. Analyses showed the presence of cobalt, nickel, and zinc in the soil. Subsequent water culture studies of the effect of nickel on horse beans and corn showed that plants grown in nutrient solutions without nickel were normal, whereas plants grown in solutions with 2 to 40 ppm Ni turned yellow and finally died within 12 to 72 days. Coupin (*5*) studied the effects of the chlorides, sulfates, and nitrates of nickel and cobalt on wheat germination and found the toxicity of these compounds quite high.

Studies by Robinson *et al.* (*14*) on the chemical composition of infertile soils from certain areas in the United States, Cuba, and Puerto Rico which were derived from rocks high in magnesium, nickel, and chromium showed these soils to have a maximum content of 36.42 percent MgO, 5.23 percent $Cr_2O_3$, and 0.453 percent NiO. The most conspicuous difference between the infertile soils and the fertile soil studied was the absence of chromium and nickel in the fertile soil profile. Poor internal drainage, an excess of magnesium, and lack of elements essential for plant growth may have been causes of infertility in some of the soils studied. However, these investigators believed that the presence of comparatively large quantities of chromium, nickel, and perhaps cobalt may have been the dominant cause of infertility in the serpentine soils which showed favorable physical conditions.

Mitchell (*10*) reported that crops failed to grow in small areas in Aberdeenshire unless the soils were liberally limed. These soils, derived from basic igneous rocks, contained 720 ppm total nickel and 23 ppm ammonium acetate-soluble nickel, whereas soils from adjoining fertile areas contained 410 ppm total nickel and less than 3 ppm ammonium acetate-soluble nickel. Crops grown on the infertile sections after liming contained up to 50 ppm Ni.

Vanselow (*17*), whose studies on microelements in citrus are in progress at the California Agricultural Experiment Station, reported deleterious effects on orange seedlings when 75 ppm, 150 ppm, and 300 ppm Ni were added to the soil. Seedlings grown in soil to which 150 ppm and 300 ppm Ni were added died soon after planting. Plants grown in soil with addition of 75 ppm Ni showed mottled leaves and depressed growth.

Soils derived from basic igneous rocks may be expected to have a nickel content of 50 to 500 ppm or even higher, whereas nickels derived from sandstones, limestones, and acid igneous rocks may have a nickel content less than 50 ppm (*10*). In igneous rocks, mineral lattice replacement of magnesium by nickel occurs normally due to similarity of their ionic radii ($Mg^{++}$ — 0.78 A.°, $Ni^{++}$ — 0.78 A.°). Rocks with basic reaction contain more nickel than the more acidic, silica-rich types, since the parent ferromagnesian minerals such as the olivines, pyroxenes, biotites and amphiboles occur chiefly in these rocks. Olivine, containing as much as 0.5 percent NiO, is the most important of the nickel-bearing silicates (*18*).

The soils of Hawaii, with the exception of small areas near the sea, have developed from basaltic lava and its modifications (*9*). Cross's study of lavas of Hawaii revealed a content of 0 to 0.09 percent NiO in the basalts (*4*). An analysis of olivine, which is contained in amounts to 30 percent of the minerals in the Hawaiian lavas studied, showed a content of 0.34 percent NiO. Hough *et al.* (*8*), in studies of rock weathering and soil profile development, reported the presence of somewhat greater amounts of nickel in the soils of the Hawaiian Islands than in the average soil of the mainland United States. In four soil samples from Hawaii the nickel content ranged from 0.07 to 0.19 percent NiO.

It is therefore reasonable to expect a relatively high nickel content in Hawaiian soils. An investigation of the nickel content of some representative soils from the Great Soil Groups of the Hawaiian Islands and the plants growing on them was made to obtain more information on the distribution of nickel in local soils and plants. Furthermore, since various studies reported in the literature showed contrasting observations of either a stimulating or a toxic effect of nickel on plant growth, this investigation was extended to various water culture and soil pot experiments to determine the actual effect of varying concentrations of nickel on the growth of plants.

## NICKEL CONTENT OF HAWAIIAN SOILS AND PLANTS

### EXPERIMENTAL PROCEDURES

Representative soils from all of the Hawaiian Great Soil Groups from the zonal order, the Dark Magnesium Clay and Gray Hydromorphic groups from the intrazonal order, and the plants growing on them were included in this study. These soils have been classified and described by Cline *et al.** In some instances, more than one family from a Great Soil Group was included to show the variation within the group. The surface soil, ranging from 6 to 10 inches, was air-dried and ground to pass through a 20-mesh sieve. Plant materials were washed, oven-dried at 70° C., ground, and chemically analyzed.

*Determination of nickel in plant tissue:* Two grams of oven-dried plant material were wet-ashed with perchloric acid and nitric acid. The Sandell-Pierlich method (*15, 16*) for the colorimetric determination of nickel was modified to meet the conditions of Hawaiian plants and soils. Sodium citrate, hydroxylamine hydrochloride, and dilute ammonia were added to eliminate interferences by iron, manganese, and copper, respectively. This method is based on the extraction of nickel dimethylglyoxime with chloroform from the ammoniacal citrate solution of the sample. The nickelous dimethylglyoxime is brought to the aqueous phase by shaking with dilute hydrochloric acid and is oxidized with saturated bromine water. The intensity of the brown-red color which develops upon the addition of dimethylglyoxime is read with a Klett-Summerson photoelectric colorimeter, using a green filter with maximum transmission at 530 millimicrons.

*Determination of nickel in soil:* The soil was ground to pass through a 100-mesh sieve and oven-dried at 140° C. One-half gram was fused by the Piper method (*11*) using the mixed carbonates, $2K_2CO_3.Na_2CO_3$. The cold melt was decomposed in hydrochloric acid and the silicic acid was dehydrated. Silica was filtered off after the residue was dissolved in hydrochloric acid. Silica was volatilized with 5 ml. hydrofluoric acid and a few drops of sulfuric acid, and the contents were evaporated to dryness. The residue was re-fused with the mixed carbonates,

* Cline, M. G., *et al.* Soil Survey Report of the Hawaiian Islands. In Press.

dissolved in hydrochloric acid, and then added to the original filtrate. This was made up to 100 ml. and an aliquot of 20 ml. was taken for analysis. Nickel was determined in the same method as described above.

*Determination of exchangeable nickel in soil:* Twenty-five grams of air-dried soil were leached with 500 ml. of 1.0 N. ammonium acetate. The leachate was evaporated to dryness. Organic matter was destroyed with aqua regia. Nickel was determined in the same method as described above.

*Reaction of soil:* A 1:1 water soil suspension was prepared and was allowed to stand for 1 hour. The *p*H of the soil was determined with a Beckman *p*H meter.

## Experimental Results

The nickel content of typical soils of the Hawaiian Great Soil Groups and typical plants growing on each soil were determined. The data obtained are given in table 1.

TABLE 1. The nickel content of some soils and plants from the 10 Great Soil Groups in the Hawaiian Islands.

| SOIL GROUP | LOCATION | *p*H | PPM SOIL Ni | | PLANT MATERIAL | PPM Ni |
|---|---|---|---|---|---|---|
| | | | TOTAL | EXCH. | | |
| Humic Latosol | Haleakala, Maui | 5.70 | 132 | 0.32 | Macadamia leaves | |
| | | | | | *M. ternifolia* | 1.50 |
| | | | | | Mango leaves | |
| | | | | | *Mangifera indica* | 1.80 |
| | Kailua, Oahu | | | | Banana leaves | |
| | | | | | *Musa sapientum* | .83 |
| | Kaneohe, Oahu | 6.00 | 426 | 0.38 | Panicum | |
| | | | | | *P. purpurascens* | 4.00 |
| | | | | | Guava leaves | |
| | | | | | *Psidium guajava* | 2.50 |
| | | | | | Banana leaves | 2.70 |
| | Paauilo, Hawaii | | | | Sugar cane leaves | |
| | | | | | *Saccharum officinarum* | 3.60 |
| | Kona, Hawaii | | | | Tomato leaves | |
| | | | | | *Lycopersicum esculentum* | 6.10 |
| | | | | | Pineapple leaves | |
| | | | | | *Ananas comosus* | 5.50 |
| | | | | | Crotalaria leaves | |
| | | | | | *C. mucronata* | 3.60 |
| | | | | | Guava leaves | 3.00 |
| Hydrol Humic Latosol | S. Hilo, Hawaii | 4.75 | 138 | 0.31 | Guava leaves | 3.50 |
| | | | | | Macadamia leaves | 4.00 |
| | | | | | Tomato leaves | 5.00 |
| | Hilo, Hawaii | | | | Macadamia leaves | 1.80 |
| | | | | | Sugar cane leaves | 3.90 |
| | | | | | Spanish clover | |
| | | | | | *Desmodium uncinatum* | 7.00 |

TABLE 1. *(continued).*

| SOIL GROUP | LOCATION | *p*H | PPM SOIL Ni | | PLANT MATERIAL | PPM Ni |
|---|---|---|---|---|---|---|
| | | | TOTAL | EXCH. | | |
| Low Humic Latosol | Poamoho, Oahu | 5.40 | 661 | 0.73 | Koa haole *Leucaena glauca* | 3.50 |
| | | | | | Mango leaves | 9.75 |
| | | | | | Pineapple leaves | 9.00 |
| | | | | | Lettuce *Lactuca sativa* | 7.00 |
| | | | | | Head cabbage *Brassica oleracea* | 9.50 |
| | | | | | Algaroba leaves *Proposis chilensis* | 7.00 |
| | | | | | Tomato leaves | 15.00 |
| | | | | | Guava leaves | 5.33 |
| | | | | | Macadamia leaves | 14.60 |
| | | | | | Surinam cherry leaves *Eugenia uniflora* | 22.75 |
| | Poamoho, Oahu | 4.80 | 405 | | Kaimi clover *Desmodium canum* | 5.50 |
| | | | | | Wire grass *Eleusine indica* | 5.25 |
| | | | | | Horseweed *Erigeron albidus* | 5.10 |
| | Kahala Heights, Oahu | | | | Koa haole | 3.60 |
| | | | | | Guinea grass *Panicum maximum* | 4.40 |
| | Wahiawa Heights, Oahu | | | | Mango leaves | 4.30 |
| | Hamakuapoko, Maui | | | | Pineapple leaves | 9.00 |
| | Manoa, Oahu | 6.30 | 433 | 1.21 | Rice grass *Paspalum orbiculare* | 9.80 |
| | | | | | Honohono grass *Commelina nudiflora* | 11.00 |
| | | | | | Guava leaves | 5.00 |
| Low Humic Latosol | Waimanalo, Oahu | 6.80 | 353 | 0.46 | Foxtail grass *Seteria verticillata* | 6.10 |
| | | | | | Sugar cane leaves | 3.50 |
| | | | | | Foxtail grass | 2.50 |
| Low Humic Latosol | Waimanalo Exp. Station Farm | | | | Rattle pod leaves *Crotalaria incana* | 2.60 |
| Red Desert (Transitional) | Koko Head, Oahu | 6.05 | 398 | 2.56 | Algaroba leaves | 18.50 |
| | | | | | Passion fruit leaves *Passiflora foetida* | 22.80 |

TABLE 1. *(continued).*

| SOIL GROUP | LOCATION | *p*H | PPM SOIL Ni | | PLANT MATERIAL | PPM Ni |
|---|---|---|---|---|---|---|
| | | | TOTAL | EXCH. | | |
| | Koko Head, Oahu | 5.35 | 312 | 0.52 | Foxtail grass | 5.00 |
| | | | | | Rice grass | 6.80 |
| | | | | | Swollen finger grass *Chloris inflata* | 5.50 |
| Red Brown | Kona, Hawaii | 6.90 | 144 | 0.68 | Horseweed | 2.55 |
| | | | | | Natal red top grass *Tricholaena repens* | 1.88 |
| Red Brown (Transitional) | Makiki, Oahu | 6.70 | 601 | 0.73 | Rice grass | 2.80 |
| | | | | | Honohono grass | 7.90 |
| | | | | | Panicum | 8.70 |
| Reddish Prairie | Haleakala Junction, Maui | 6.70 | 167 | 0.64 | Kaimi clover | 2.90 |
| | | | | | Rattle pod leaves *Crotalaria longirostrata* | 2.20 |
| | Waimea, Hawaii | | | | Lettuce | 2.35 |
| Brown Forest | Olinda, Maui | 5.50 | 100 | 0.40 | Tomato leaves | 3.10 |
| | | | | | Orchard grass *Dactylis glomerata* | 3.20 |
| | Haleakala, Maui | | | | White dutch clover *Trifolium repens* | 4.10 |
| Ferruginous Humic Latosol | Haiku, Maui | 4.50 | 98 | 0.43 | Guava leaves | 2.40 |
| | | | | | Kaimi clover | 3.20 |
| | Kunia, Oahu | 4.20 | 150 | 0.35 | Natal red top grass | 4.30 |
| | | | | | Pineapple leaves | 3.30 |
| | Kokee, Kauai | 4.00 | 220 | | Japanese tea *Cassia leschenaultiana* | 6.50 |
| | | | | | Paspalum *P. orbiculare* | 9.00 |
| | | | | | Silver oak leaves *Gravillea robusta* | 15.00 |
| Dark Magnesium Clay | Lualualei, Oahu (cultivated) | 7.40 | 211 | 0.54 | Ilima | 3.30 |
| | | | | | *Sida fallax* | 3.30 |
| | | | | | Tomato leaves | 2.90 |
| | Lualualei, Oahu (uncultivated) | 7.70 | 242 | 0.54 | Natal red top grass | 4.30 |
| | | | | | Foxtail grass | 5.50 |
| | | | | | Swollen finger grass | 6.50 |
| | | | | | Algaroba leaves | 5.50 |
| Gray Hydromorphic | Honouliuli, Oahu (cultivated) | 4.90 | 164 | 0.48 | Rice grass | 1.80 |
| | | | | | Sugar cane leaves | 1.50 |
| | Honouliuli, Oahu (uncultivated) | 7.30 | 182 | 0.60 | Algaroba leaves | 7.90 |
| | | | | | Foxtail grass | 6.40 |
| | | | | | Panicum grass | 5.70 |

The nickel content of 75 plant samples analyzed ranged from 0.83 to 22.80 ppm. The plant samples included grasses, vegetables, and leaves of guava, mango, banana, macadamia nut, and silver oak trees. Most of the plants averaged 2 to 5 ppm Ni. Although uniformity in the selection of plant specimens was highly desirable, this was impossible to attain, for in most cases the plants collected were necessarily those growing on that particular soil. Thus, some variation in the nickel content of the plant material was to be expected due to the differences in species of plant, stages of growth, and the parts of the plant analyzed.

Chemical analyses of 20 soil samples from the 10 Great Soil Groups in the Hawaiian Islands showed a total nickel content ranging from 98 to 661 ppm and the exchangeable nickel ranging from 0.31 to 2.56 ppm. The soils of the Low Humic Latosol and the Reddish Brown group (transitional) from Oahu had the highest nickel content. The soils of the Ferruginous Humic Latosol and the Brown Forest group from Maui had the lowest nickel content. The soils of the Red Desert group and the Low Humic Latosol from Oahu had the highest amount of exchangeable nickel.

An attempt was made to show the relationship of the nickel content of the plant to the nickel content of the soil. There was a significant correlation, $r = 0.60$, of plant uptake of nickel with the total nickel content of the soil, and a closer correlation, $r = 0.72$, of plant uptake with the exchangeable nickel of the soil. This was to be expected since exchangeable nickel presumably measures the nickel which is available to the plant. The correlation coefficient was based on the 10 soils which are representative of the different soil groups, and of the plants growing on them.

The *p*H of the soils was determined to see if soil reaction was related to the nickel content of the plants. No conclusive evidence of such a relationship is shown by the data. In some instances, plants from acid soils contained less nickel, but the total nickel content of the soil was also low. A more extensive survey using the same species of plant would perhaps show such a relationship.

A similar relationship is expressed in table 2, where the nickel content of the olivine of the parent rock and the soil which was developed from the parent, the exchangeable nickel of the soil, and the nickel content of the vegetation are reported. The data indicate a close relationship between the exchangeable nickel in the soil and the nickel content of the plants. The relatively high content of nickel in the olivine is also indicated in the data of this table.

TABLE 2. The nickel content of olivine crystals and of the soils and plants from the same vicinity.

| LOCATION | OLIVINE PPM Ni | SOIL GROUP | *p*H | SOIL TOTAL PPM Ni | SOIL EXCH. PPM Ni | PLANT MATERIAL | PPM Ni |
|---|---|---|---|---|---|---|---|
| Manoa, Oahu | 4,000 | Low Humic Latosol | 6.30 | 433 | 1.21 | Rice grass | 9.80 |
| | | | | | | Honohono grass | 11.00 |
| | | | | | | Guava leaves | 5.00 |
| Lower Kunia Road | 3,200 | Low Humic Latosol (surface) | 7.30 | 1,439 | .72 | Sugar cane leaves | 3.50 |
| | | Low Humic Latosol (subsoil) | 6.30 | 1,335 | .68 | Finger grass | 6.75 |
| | | | | | | Wire grass | 15.00 |
| | | | | | | Foxtail grass | 9.00 |
| Hanauma Bay Beach | 1,250 | (olivine and sand mixture) | | | | | |
| Koko Head | | Red Desert | 6.05 | 398 | 2.56 | Kiawe leaves | 18.50 |
| | | | | | | Passion fruit leaves | 22.80 |
| Olaa, Hawaii | 1,880 | Hydrol Humic Latosol | 4.75 | 138 | .31 | Macadamia leaves | 4.00 |
| | | | | | | Tomato leaves | 5.00 |
| | | | | | | Guava leaves | 3.50 |
| Mauna Loa 1949 Flow | 3,158 | | | | | | |
| Mauna Loa | 2,700* | | | | | | |

* Reported in *Lavas of Hawaii and Their Relation,* by Whitman Cross.

This study shows that there is a higher nickel content in Hawaiian soils and plants than in the normal soils and plants reported in the literature from other parts of the world. Bertrand and Mokragnatz (*2*) analyzed samples of cultivated soils (0 to 30 cm. in depth) from France, Germany, Denmark, Italy, Rumania, and Serbia, and found a nickel content of 6 to 37 ppm Ni. Fruits, vegetables, and other plants examined contained very small quantities of nickel. The edible chanterelle, a mushroom, containing 3.5 ppm Ni, gave the highest value (*3*). Beristein (*1*) determined nickel in Argentine vegetables and found a range of 0.13 (watercress) to 4.6 ppm Ni (squash). Mitchell (*10*), in his study of cobalt and nickel in soils and plants, reported 0.10 to 5 ppm Ni in dry plant material. Porfir'ev and Troitskaya (*12*) reported a nickel content of 21 to 130 ppm Ni in soils which had been heated to redness.

The soil profile distribution of nickel is shown in the data presented in table 3. The data were obtained from the analyses of three typical lateritic and laterite soil profiles. The distribution of nickel is uniform throughout the profiles. The nickel content is the highest in the profile of the Low Humic Latosol.

TABLE 3. The nickel content of three Hawaiian soil profiles.

| SOIL AND LOCATION | DEPTH (INCHES) | PPM Ni |
|---|---|---|
| Humic Latosol<br>Haleakala, Maui | 0-10 | 132 |
| | 10-20 | 102 |
| | 20-28 | 102 |
| | 28-48 | 152 |
| | (rock) | 198 |
| Low Humic Latosol<br>Makaweli, Kauai | 0- 8 | 609 |
| | 8-17 | 650 |
| | 17-33 | 670 |
| | 33-48 | 782 |
| | 48+ | 726 |
| Hydrol Humic Latosol<br>Waikalu, Molokai | 0-10 | 105 |
| | 10-16 | 200 |
| | 16-24 | 280 |
| | 24-48 | 235 |
| | 48+ | 150 |

## THE RELATION OF NICKEL TO PLANT GROWTH

### WATER CULTURE STUDIES

Tomato seedlings, Lanai variety, *Lycopersicum esculentum,* were grown in glazed 5-gallon crocks, using a Hoagland-Arnon complete nutrient solution (7) made with distilled water. All solutions were aerated continuously by bubbling compressed air through them. The solutions were adjusted to *p*H 6 with 0.5 N NaOH twice a week, using chlorophenol red as indicator. Iron citrate solution was added twice a week and the nutrient solutions were changed after the tenth day.

In the first nutrient culture experiment, 18-day-old seedlings, germinated in vermiculite, were put directly in the nutrient solutions containing 0.002, 0.05, 0.10, 1.0, 2.0, and 3.0 ppm Ni. Nickel was added in the form of the acetate, $Ni(CH_3COO)_2.4H_2O$. There were two crocks for each of the treatments, each crock containing three plants. This experimental study was conducted over a period of 25 days.

Deleterious effects were exhibited within the first week by the seedlings grown in solutions containing nickel in concentrations of 1.0 ppm or more. Another series was conducted in which all the seedlings were first grown in the control solutions to adapt themselves to a new environment. The treatment containing 3.0 ppm Ni was replaced by a treatment containing 0.50 ppm Ni to narrow the wide gap between the toxic (1.0 ppm) and the non-toxic (0.10 ppm) nickel concentrations of the nutrient solutions. The plants were harvested after being subjected to the different treatments for 17 days.

All plants were examined daily for beneficial or injurious effects. At the termination of the experiments, the plants were harvested, weighed, dried, ground, and chemically analyzed.

TABLE 4. Water culture experiments with tomato plants grown in nutrient solutions containing graduated amounts of nickel.

EXPERIMENT I. Seedlings subjected to different treatments for 25 days.

| SOLUTION | TREATMENT | AV. WT. OF PLANT AND ROOTS | PLANT PPM Ni |
|---|---|---|---|
| | *ppm* Ni | *grams* | |
| H-1 (control) | 0.002 | 79 | 0.25 |
| H-2 | 0.05 | 72 | 6.50 |
| H-3 | 0.10 | 87 | 10.50 |
| H-4 | 1.00 | none survived | .... |
| H-5 | 2.00 | none survived | .... |
| H-6 | 3.00 | none survived | .... |

EXPERIMENT II. Seedlings first grown in control solutions for 8 days and then subjected to different treatments for 17 days.

| SOLUTION | TREATMENT | AV. WT. OF PLANT AND ROOTS | PLANT PPM Ni |
|---|---|---|---|
| | *ppm* Ni | *grams* | |
| H-I (control) | 0.002 | 73 | 2.50 |
| H-II | 0.05 | 89 | 8.30 |
| H-III | 0.10 | 58 | 13.00 |
| H-IV | 0.50 | 63 | 50.00 |
| H-V | 1.00 | 13 | 100.00 |
| H-VI | 2.00 | 4 | 126.40 |

The different treatments and the results of plant yield and chemical analysis are tabulated in table 4. Plants grown in treatments H-1, H-2, and H-3, nutrient solutions containing 0.002, 0.05 and 0.10 ppm Ni, respectively, showed excellent growth throughout the experiment. These green, healthy plants showed no effect of the different nickel concentrations, although the plants of treatment H-3 looked larger and gave a slightly larger yield of plant material. The plants of treatments H-4, H-5, and H-6, solutions containing 1.0, 2.0, and 3.0 ppm Ni, respectively, displayed white, chlorotic spots on the leaves and unhealthy, brown, slimy roots at the end of the first week. The tomato seedlings in the 1.0 ppm Ni solution grew about 1 inch, but new leaves and tissue appeared chlorotic and necrotic (fig. 1). There was a cessation of growth in the chlorotic and necrotic plants of treatments H-5 and H-6. Some of these plants died on the twelfth day of the experiment. None of the seedlings of treatments H-4, H-5, and H-6 survived when the first experiment was terminated.

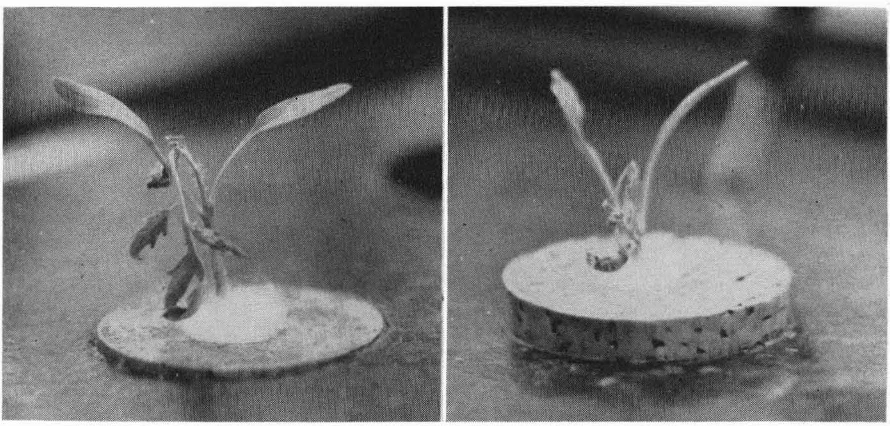

FIG. 1. Injured plant from treatment H-4, solution containing 1.0 ppm Ni (10 days of treatment).

In the second experiment, all plants had a healthy appearance and growth up to the third day of treatment, when yellow, chlorotic spots appeared on the leaves of plants in treatment H-VI, the nutrient solution containing 2.0 ppm Ni. A few days later, bronze and white spots appeared on the leaves, which lost their turgor shortly after. Roots were sparse, brown, and slimy; plants were stunted (figs. 5 and 8). Seedlings in treatment H-V, the solution containing 1.0 ppm Ni, showed good growth during the first week. Leaves developed chlorotic symptoms on the sixth day and new tissues became necrotic. Roots were brown and sparse; growth was retarded (figs. 3, 6, and 7). The growth of plants in treatment H-IV was only slightly retarded. The plants had a normal appearance except for the yellow, mottled pattern which appeared on the leaves during the second week. Plants of treatments H-I, H-II, H-III remained healthy and green throughout the experiment and showed no evidence of the different treatments.

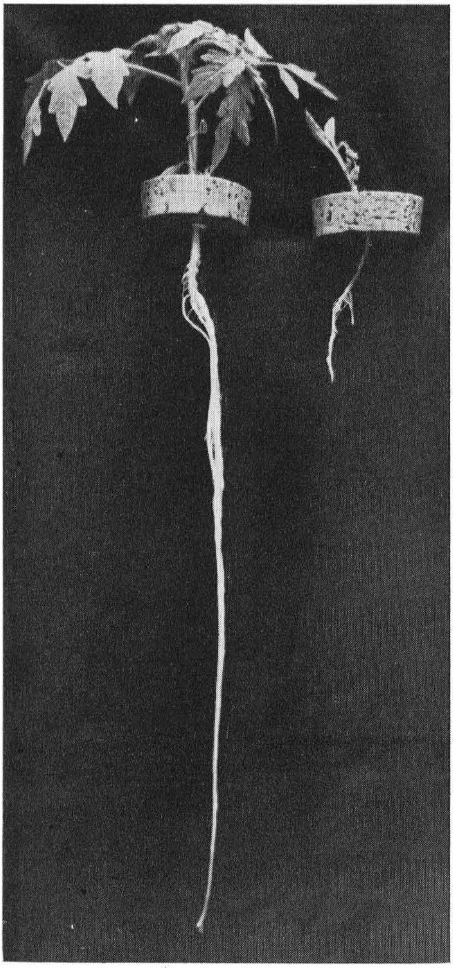

FIG. 2. Comparison of plants from treatments H-1, control solution, left, and H-4, right (10 days of treatment).

Chemical analysis of the tomato plants showed that the plants grown in nutrient solutions containing 1.0 and 2.0 ppm Ni contained over 100 ppm Ni. The chlorotic but otherwise normal plants grown in solution containing 0.50 ppm Ni contained 50 ppm Ni, whereas the healthy plants grown in solutions containing less than 0.50 ppm Ni contained from 0.25 to 13.00 ppm Ni. The yields of the plants affected by the presence of excessive nickel were greatly reduced. The large yield of treatment H-II was due to the presence of one unusually large plant, while the low yield of treatment H-III was due to the two small plants being in that group.

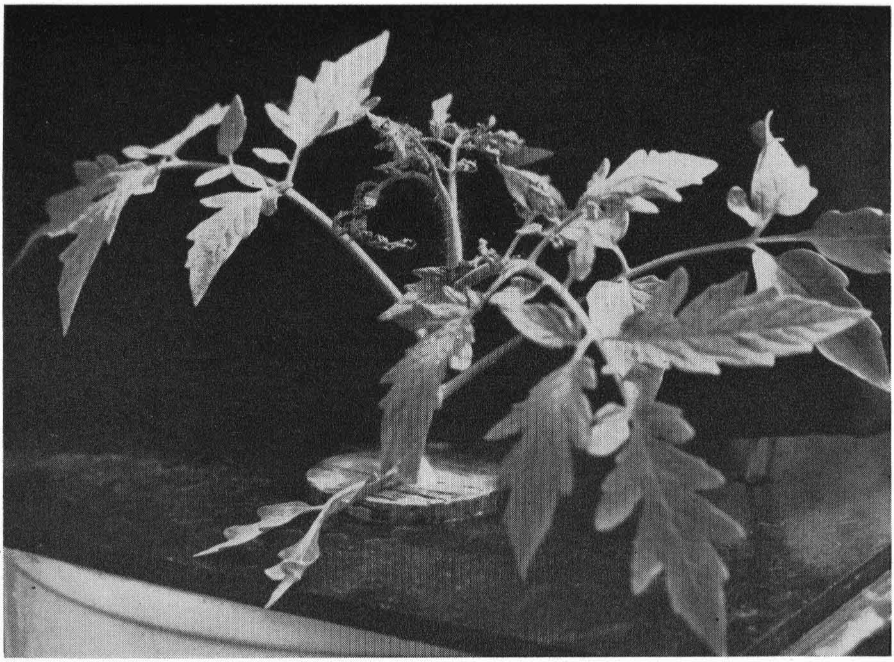

FIG. 3. Chlorotic and necrotic plant from treatment H-V, solution containing 1.0 ppm Ni (7 days of treatment).

SOIL STUDIES

Studies were conducted to determine the effects of applications of increasing increments of a nickel salt to some Hawaiian soils. Several preliminary experiments had shown that the application of 1,000 pounds of nickel sulfate was toxic to plants. A soil of the Kaneohe family of the Humic Latosol group was mixed with 4 percent acid-washed quartz sand, and nickel acetate was applied at rates ranging from 0 to 3,000 pounds per acre. A complete N–P–K fertilizer (7–14–14) was applied at the rate of 600 pounds per acre. Four tons of hydrated lime per acre were added to the soil treatment *g*. There were four Mitscherlich pots to each treatment. Five tomato seeds, Lanai variety, were planted in two pots from each treatment to study the effect of nickel upon seed germination. The seedlings were pulled out after a period of 2 weeks.

Three 18-day-old seedlings, germinated in vermiculite, were then planted in each pot. This experiment was conducted concurrently with experiment H-I. After 37 days of growth, plants were harvested, dried, ground, and analyzed. Soil samples were taken at the start of the experiment for chemical analysis.

The various treatments and results of the chemical analyses are presented in table 5. There was 100 percent seed germination in the soils of treatments *a* and *d*, 60 percent germination in treatments *b*, *c*, and *g*, and none in treatments *e* and *f*. A few of the seeds in treatment *e* sprouted but did not survive. The seedlings of treatments *a*, *b*, and *g* were growing very well when this part of the experiment was terminated. The toxic effect caused by the addition of 2,000 and 3,000 lbs. $Ni(CH_3COO)_2.4H_2O$ per acre to Kaneohe soil, was also exhibited by the green-podded beans of the earlier experiment.

TABLE 5. Pot experiment with tomato plants grown in Kaneohe soil. Experiment P-1.

| POT | TREATMENT | SOIL pH | SOIL PPM Ni | SOIL-EXCH. PPM Ni | AV. YIELD PER POT | PLANT PPM Ni |
|---|---|---|---|---|---|---|
| | *lbs. NiAc/acre* | | | | *grams* | |
| *a* | None (control) | 4.80 | 325 | 0.40 | 76 | 4.60 |
| *b* | 200 | 4.80 | 355 | 2.28 | 81 | 26.00 |
| *c* | 500 | 4.78 | 400 | 3.20 | 36 | 105.00 |
| *d* | 1,000 | 4.77 | 446 | 7.58 | (1 plant) | 208.00 |
| *e* | 2,000 | 4.77 | 504 | 20.08 | none surv. | .... |
| *f* | 3,000 | 4.77 | 668 | 54.40 | none surv. | .... |
| *g* | 3,000 and 4 tons lime | 6.48 | 608 | 14.40 | 64 | 23.00 |

FIG. 4. Comparison of plants from treatment H-IV, solution containing 0.50 ppm Ni, left; treatment H-III, solution containing 1.10 ppm Ni, center; and treatment H-L, control solution, right (7 days of treatment).

FIG. 5. Comparison of plants from treatment H-IV, left; treatment H-V, center; and treatment H-VI, solution containing 2.0 ppm Ni, right (7 days of treatment).

Uniform-sized seedlings were transplanted in all pots. Some of the plants of treatments *d, e,* and *f* withered at the end of the first week. In spite of a second transplanting, none of the seedlings of treatments *e* and *f* and only one seedling of treatment *d* survived after the third week. The lone seedling of treatment *d* was stunted and chlorotic. Chlorotic spots along the areas near the midrib and veins (similar to the toxic plants of the nutrient culture experiments) appeared on the leaves of the plants of treatment *c,* fifteen days after transplanting (fig. 10). These yellow spots later developed into bronze spots. The yield was greatly reduced. The chlorotic plants had an average nickel content of 105 ppm Ni, although the total content of the soil was only 400 ppm Ni. Plants of treatments *a* and *b* showed healthy growth and no effect of the different treatments. The addition of lime to the soil reduced the plant uptake of nickel, for the plants grown in soil with 3,000 lbs. $Ni(CH_3COO)_2.4H_2O$ and 4 tons of lime contained only 23.00 ppm Ni and did not exhibit any toxic symptoms. These plants, however, were slightly smaller than the control plants.

FIG. 6. Chlorotic, necrotic, and stunted plant from treatment H-V, solution containing 1.0 ppm Ni (17 days of treatment).

Figures 9 and 10 show the injurious effect of nickel upon the growth of tomato plants in Kaneohe soil. However, the high acidity of this soil and perhaps the low adsorptive capacity of the added sand may have intensified the toxic effect of the nickel in the soil.

This experiment was carried out to study the growth of tomato plants in a soil which had more favorable physical and chemical properties than the soil from Kaneohe. This soil, a transitional soil of the Red Desert group, was taken from a farm at Koko Head. Nickel concentrations up to 4,000 lbs. $Ni(CH_3COO)_2.4H_2O$ per acre and 900 lbs. of N–P–K (7–14–14) per acre were mixed with the soil. Four tons of hydrated lime per acre were added to treatment 7. There were four replications in each treatment. At the start of the experiment, three tomato seedlings were planted in ½-gallon cans. Two plants from each pot were eliminated after 1 week to obtain uniform-sized seedlings in all cans. During the course of experimentation, yellow cuprocide was added to a few plants which showed symptoms of "damping-off." The experiment was terminated after 38 days. Plants were harvested, weighed, dried, and analyzed. Soil samples were also analyzed.

FIG. 7. Comparison of plants from treatment H-V, left, and treatment H-IV, solution containing 0.5 ppm Ni, right (17 days of treatment).

The various treatments and the results of the chemical analyses are tabulated in table 6. After the elimination of two plants from each pot, all seedlings were of the same size, with the exception of the plants from treatment 6, which were smaller and chlorotic. There were yellow spots on leaves of plants in treatment 5, although growth was normal. Two weeks later these yellow mosaic leaf patterns gradually disappeared, probably due to the leaching of some nickel from the soil through a heavy rain. The plants of treatment 6 remained chlorotic and necrotic throughout the experiment. A slight growth was observed following the rain storm, although the plants remained stunted. The nickel content of these plants and soil were 100 ppm and 844 ppm respectively. Plants of treatments *1, 2, 3, 4,* and *7* showed no evidence of the different treatments, although plant uptake of nickel

TABLE 6. Pot experiment with tomato plants grown in Koko Head soil. Experiment P-2.

| POT | TREATMENT | SOIL *pH* | SOIL PPM Ni | SOIL-EXCH. PPM Ni | AV. YIELD PER PLANT | PLANT PPM Ni |
|---|---|---|---|---|---|---|
| | *lbs. NiAc/acre* | | | | *grams* | |
| 1 | None (control) | 6.95 | 338 | .... | 26.5 | 5.90 |
| 2 | 250 | 6.70 | 350 | 2.85 | 30.0 | 7.50 |
| 3 | 500 | 6.75 | 388 | 9.70 | 28.0 | 9.50 |
| 4 | 1,000 | 6.75 | 439 | 20.40 | 19.5 | 17.00 |
| 5 | 2,500 | 6.55 | 677 | 63.20 | 25.0 | 37.50 |
| 6 | 4,000 | 6.45 | 844 | 115.20 | 7.5 | 100.00 |
| 7 | 4,000 and 4 tons lime | 7.95 | 800 | 56.48 | 19.6 | 16.10 |

FIG. 8. Comparison of plants from treatment H-V, left, and treatment H-VI, solution containing 2.0 ppm Ni, right (17 days of treatment).

increased with increasing nickel concentration in the soil. The addition of lime to the soil to which 4,000 lbs. $Ni(CH_3COO)_2.4H_2O$ had been added, counteracted the toxicity of nickel towards the plants.

TABLE 7. Pot experiment with tomato plants grown in Waimanalo soil. Experiment P-3.

| POT | TREATMENT | SOIL *p*H | SOIL TOTAL PPM Ni | SOIL EXCH. PPM Ni | PLANTS AV. YIELD PER PLANT | PLANT PPM Ni | FRUITS AV. YIELD PER PLANT | FRUIT PPM Ni |
|---|---|---|---|---|---|---|---|---|
| | *lbs. NiAc/acre* | | | | *grams* | | *grams* | |
| I | None (control) | 6.28 | 325 | 0.75 | 27.14 | 2.50 | 632 | 1.0 |
| II | 200 | 6.25 | 405 | 6.30 | 29.00 | 9.50 | 695 | 3.50 |
| III | 500 | 6.20 | 621 | 11.80 | 15.79 | 21.90 | 666 | 12.50 |
| IV | 1,000 | 6.33 | 779 | 40.40 | 13.55 | 53.50 | 465 | 21.50 |
| V | 2,000 | 6.25 | 1,079 | 88.00 | 5.67 | 108.40 | 262 | 31.75 |
| VI | 3,400 | 6.35 | 2,126 | 215.04 | none surv. | .... | .... | .... |
| VII | 3,400 and 4 tons lime | 7.35 | 1,333 | 32.00 | 16.58 | 22.90 | 713 | 6.50 |

Experiment P-3, using Waimanalo soil in 5-gallon cans, was carried out to study the effect of nickel upon the growth of tomato plants and also upon the yield and quality of the fruit. In the previous experiments, plants were harvested at the flowering stage due to the limited size of the cans. The soil, classified as the Waimanalo family of the Low Humic Latosol, was taken from the Hawaii Agricultural Experiment Station farm at Waimanalo. There were four replications in each treatment, with four plants to each pot. The seeds were germinated in vermiculite. Varying concentrations of nickel solution were added to the soil 1 week before the 26-day-old seedlings were transplanted. N–P–K (7–14–14) was added periodically. Four tons of hydrated lime per acre were added to treatment VII.

Three plants from each pot were harvested after 38 days, weighed, dried, and chemically analyzed. A soil sample was taken from each pot and a composite sample was made from the four pots of each treatment. The composite samples were air-dried, ground, and chemically analyzed. The tomatoes from the remaining plant in each pot were harvested when ripe and weighed. The experiment was terminated at the end of 90 days.

The results of the plant and fruit yields and chemical analyses are tabulated in table 7. The plants in treatments I and II remained normal and healthy throughout the experiment. The plants of treatment II looked better and larger than the control plants of treatment I. Slightly larger yields of tomato fruits and plants were harvested in treatment II, but the results are not significant.

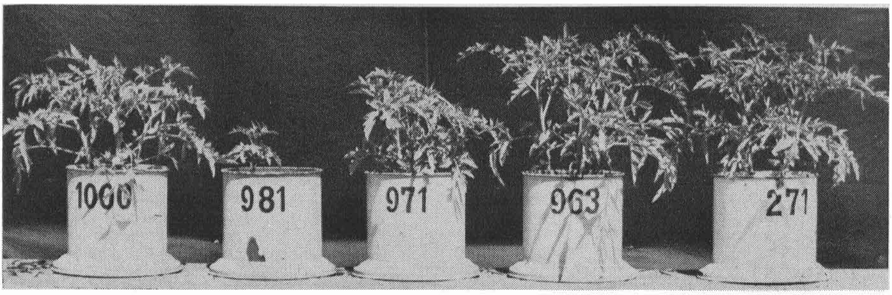


FIG. 9. Tomato plants grown in Kaneohe soil for 37 days. Pot 271 = control soil; 963 = 200 lbs. NiAc; 971 = 500 lbs. NiAc; 981 = 1,000 lbs. NiAc; and 1,000 = 3,000 lbs. NiAc and 4 tons lime.

"Damping-off" caused the death of two plants from treatment II and one plant each from treatments I and IV. One plant in treatment II was afflicted with "early blight," a virus disease, but the effect was negligible since most of the tomatoes were mature at that time. Blossom-end rot was noticed in a few fruits of the various treatments.

A depressing effect on the growth of the plants was noticed in treatment III, although no effect was noticed on the quality and yield of the fruits. Symptoms of toxicity developed in the plants of treatment IV a week after transplanting. Plants remained stunted and chlorotic. The yield of fruits was reduced. Some of the plants in treatment V and all of the plants in treatment VI died during the first 2 weeks. A second transplanting was attempted, but none of the seedlings survived. The plants which survived in treatment V were stunted, chlorotic, and necrotic. Tomato plants grown in the toxic soils contained 53.50 ppm Ni and more. Chlorotic and stunted foxtail grass, *Seteria verticillata,* and rattle-pod plant, *Crotalaria incana,* grew in the toxic soil of treatment VI. These plants contained 24.75 and 20.10 ppm Ni, while similar plants from the same area at Waimanalo contained 2.50 and 2.60 ppm Ni, respectively.

The addition of lime to the nickel-treated soil greatly reduced the plant uptake of nickel. The tomato plants of treatment VII, containing 22.90 ppm Ni, were green and healthy, although somewhat smaller than the control plants. A better yield of tomatoes, however, was harvested.

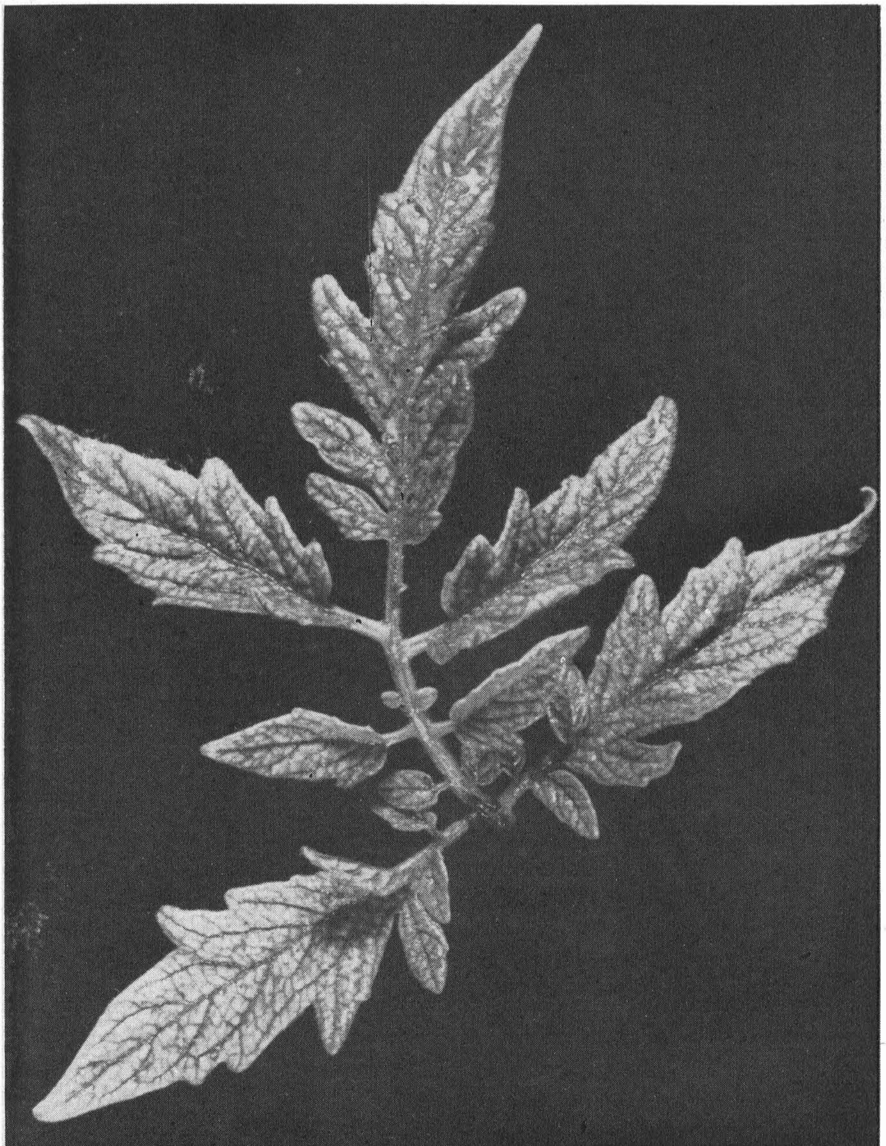

FIG. 10. Yellow- and bronze-spotted leaf of stunted tomato plant grown in Kaneohe soil with 500 lbs. NiAc.

## SUMMARY

1. A study of the distribution of nickel in Hawaiian soils and plants was made. There is a higher nickel content in Hawaiian soils and plants than in the normal soils and plants reported in the literature from other parts of the world.

a. Chemical analyses of 20 soil samples from the ten Great Soil Groups in the Hawaiian Islands gave total nickel contents ranging from 98–661 ppm and exchangeable nickel ranging from 0.31–2.56 ppm.

b. The soils of the Low Humic Latosol and the Reddish Brown soil (transitional) from Oahu had the highest amount of nickel.

c. The nickel content in plants ranged from 0.83–22.80 ppm, with most of the plants containing between 2–5 ppm Ni.

2. Nickel has been reported to have a stimulating as well as a toxic effect upon plant growth. Soil and water culture experiments with varying concentrations of nickel were conducted to study the effect of nickel on the growth of plants.

a. Symptoms of toxicity (chlorosis, necrosis, stunted growth, and sparse, brown, slimy roots) were exhibited by tomato plants grown in nutrient solutions containing 1.0 ppm Ni and more. The leaves of plants affected by excessive nickel displayed white, yellow, and bronze spots along areas near the midrib and veins, which remained dark green. A yellow, mottled pattern was manifested on the leaves of plants grown in solution containing 0.50 ppm Ni. These plants otherwise appeared normal and healthy, although growth was slightly retarded.

b. The chlorosis, necrosis, and stunted growth exhibited by the injured plants in the water culture experiments were also manifested by the plants in the soil pot experiments. Toxic effects were observed on tomato plants grown on Kaneohe soil (4 percent quartz sand) with 400 ppm total Ni, on Koko Head soil with 844 ppm total Ni, and on Waimanalo soil with 779 ppm total Ni.

c. The nickel content of tomato plants injured by excessive nickel was over 50 ppm.

d. The addition of lime to nickel-treated soil counteracted the toxic effect of nickel on plant growth. The plants grown in soil to which nickel and lime were added did not exhibit the injurious effects of the plants grown in nickel-treated soil without lime. Plant uptake of nickel in the limed soils was greatly reduced.

e. The addition of very small amounts of nickel to Waimanalo soil and water culture experiments brought about a slight increase in yield of tomato plants, but the increase was not significant.

## LITERATURE CITED

(1) BERISTEIN, A.
1943. THE NORMAL OCCURRENCE OF NICKEL IN VEGETABLE FOODSTUFFS OF ARGENTINA. Rev. Facultad Cienc. Quim., 18: 139–145. (Abstract in Chem. Abs. 40: 3535.)

(2) BERTRAND, G., and M. MOKRAGNATZ.
1924. GENERAL PRESENCE OF NICKEL AND COBALT IN ARABLE SOIL. Compt. Rend. Acad. Sci., Paris, 179: 1566–1569.

(3) ———— and ————
1930. ON THE DISTRIBUTION OF NICKEL AND COBALT IN PLANTS. Bul. Soc. Chim. France 4: Ser. 47, No. 3: 326–331. (Abstract in Exp. Sta. Record 64: 10.)

(4) CROSS, W.
1915. LAVAS OF HAWAII AND THEIR RELATIONS. U. S. Geol. Survey Prof. Paper 88.

(5) COUPIN, H.
1901. ON THE COMPARATIVE POISONOUS PROPERTIES OF COMPOUNDS OF NICKEL AND COBALT WHEN APPLIED TO THE HIGHER PLANTS. Compt. Rend. Soc. Biol. Paris 53: 489–490. (Abstract in Exp. Sta. Record 13: 620.)

(6) HASELHOFF, E.
1893. EXPERIMENT ON THE INJURIOUS EFFECT ON VEGETABLES OF WATER CONTAINING NICKEL. Landw. Jahrb. 22: 862–868. (Abstract in Exp. Sta. Record 5: 697–698.)

(7) HOAGLAND, D. R., and D. I. ARNON.
1938. THE WATER-CULTURE METHOD FOR GROWING PLANTS WITHOUT SOIL. Calif. Agr. Exp. Sta. Cir. 347.

(8) HOUGH, J., Z. C. FOSTER, and P. L. GILE.
1941. ROCK WEATHERING AND SOIL PROFILE DEVELOPMENT IN THE HAWAIIAN ISLANDS. U. S. Dept. Agr. Tech. Bul. 752.

(9) KELLEY, W. P., W. MCGEORGE, and A. THOMPSON.
1915. THE SOILS OF THE HAWAIIAN ISLANDS. Hawaii Agr. Exp. Sta. Bul. 40.

(10) MITCHELL, R. L.
1945. COBALT AND NICKEL IN SOILS AND PLANTS. Soil Sci. 60: 63–70.

(11) PIPER, C. S.
1944. SOIL AND PLANT ANALYSIS. Interscience Publishers, Inc., New York.

(12) PORFIR'EV, N. A., and K. V. TROITSKAYA.
1937. THE NICKEL CONTENT OF VARIOUS TYPES OF SOILS. Uchenye Zapiski Kazan Gosudarst Univ. 97: 51–66. (Abstract in Chem. Abs. 33: 7459.)

(13) ROACH, W. A., and C. BARCLAY.
1946. NICKEL AND MULTIPLE TRACE ELEMENT DEFICIENCIES IN AGRICULTURAL CROPS. Nature 157: 696.

(14) ROBINSON, W. O., G. EDINGTON, and H. G. BYERS.
1935. CHEMICAL STUDIES OF INFERTILE SOILS DERIVED FROM ROCKS HIGH IN MAGNESIUM AND GENERALLY HIGH IN CHROMIUM AND NICKEL. U. S. Dept. Agr. Tech. Bul. 471.

(15) SANDELL, E. B.
1944. COLORIMETRIC DETERMINATION OF TRACES OF METALS. Interscience Publishers, Inc., New York.

(16) ———— and R. W. PIERLICH.
1939. DETERMINATION OF NICKEL AND COBALT IN SILICATE ROCKS. Indus. and Eng. Chem., Anal. Ed., 11: 309–311.

(17) VANSELOW, A. P.
1952. MICROELEMENTS IN CITRUS. Calif. Agr. Exp. Sta. Prog. Rpt. 6, No. 1

(18) VOGT, J. H. L.
1923. NICKEL IN IGNEOUS ROCKS. Econ. Geol. 18: 307–353.

(19) YOUNG, R. S.
1935. CERTAIN RARER ELEMENTS IN SOILS AND FERTILIZER, AND THEIR ROLE IN PLANT GROWTH. Cornell Agr. Expt. Sta. Mem. 174.

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