Points 1 and 2 are made evident by the radiographs in Fig. 1. Comparison of the radiograph of potassium in a tomato leaf (Fig. 1A) with the radiographs of molybdenum (B, C) shows that molybdenum is accumulated in interveinal areas in direct contrast with the potassium pattern. It is not accumulated by stem tissue to any great degree—another point of direct contrast with potassium.

It is evident, from the characteristic patterns of molybdenum accumulation, that this element, unlike other mineral nutrient elements of which we have knowledge, is not rapidly accumulated by actively metabolizing plant cells adjacent to the vascular tissue in the upper parts of the plant. Areas within the leaf where the molybdenum does accumulate are also the areas having the greatest number of stomatal openings. Accumulation could therefore result from molybdenum being left at points of greatest water loss.

In the absence of molybdenum, loss of chlorophyll takes place in the same interveinal regions. This may be seen by comparing the photographs of molybdenum-deficient leaflets (D, E) showing the chlorotic areas caused by molybdenum deficiency with the molybdenum radiographs (B, C). Accumulation of molybdenum in the chlorotic areas after it is supplied to the culture solution suggests an alternate possibility of molybdenum being tightly held in these areas by plant compounds directly involved in metabolic processes which are either peculiar to, or more active within, the interveinal areas of the leaf—for example, the reduction of nitrates referred to earlier, which could be considered as one step in the metabolic cycle.

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Molybdenum Deficiency in Serpentine Barren Soils

Richard B. Walker[1]

Department of Botany, University of California, Berkeley

The infertility and unique plant distribution patterns of serpentine barren soils recently prompted an investigation of the mineral nutrition of certain native and agricultural species grown on such soils. As a part of this study, tomato plants were grown in pot culture experiments designed to test the effect of variations in the soil calcium level. Marked responses to increased calcium were obtained, similar to those already reported for serpentine soil (*10*), but anomalous symptoms remained. The type of abnormality appeared to be identical with that characterizing molybdenum-deficient plants grown in water cultures in the Division of Plant Nutrition at this University.

The first abnormalities were yellowing and curling of the leaflets of the first or second pair of true leaves. Development of typical molybdenum-deficiency symptoms, as described by Arnon and Stout (*3*) using water cultures and Hewitt and Jones (*7*) in water and sand cultures, followed these initial signs. Pronounced mottling appeared in all true leaves, the veins remaining light green and shading into the chlorotic interveinal areas. Advanced symptoms were puffing of the chlorotic areas and marked upcurling of the leaflet margins. Finally, the tips of the leaflets and areas along the margins began to shrivel and later die. Newly formed leaves were green, but during expansion became mottled and curled.

Molybdenum deficiencies in higher plants grown on soils in Australia, New Zealand, and Central Europe have been reported (*1, 4, 5, 6*), but the writer knows of no previous observation of molybdenum deficiency on soils in the Western Hemisphere. In Australia, legumes grown on certain pasture soils showed marked response to molybdenum in both field and pot tests (*1, 2, 6, 9*), and perennial rye grass responded in pot cultures (*9*). Davies (*5*) observed characteristic molybdenum-deficiency symptoms in cauliflower growing on an acid New Zealand soil and was able to bring about rapid recovery of the plants with molybdate fertilization. Mitchell (*8*), also working in New Zealand, prevented the occurrence of the whiptail disease in cauliflower and broccoli by applications of ammonium molybdate in field plots.

In order to substantiate the symptomatic diagnosis of molybdenum deficiency in the affected tomato plants of this study, chemical analyses were made in the Division of Plant Nutrition to establish their molybdenum content. These showed that the level was less than 0.1 ppm on a dry weight basis (see Table 1), which was lower than any previous assay for molybdenum made in those laboratories on soil-grown plant material.

Molybdenum was then supplied to affected plants in order to check further the indications that they were molybdenum deficient. Direct corroborative evidence was obtained through the recovery of the affected plants after supplying them with molybdenum. Three methods were used: (1) application of small amounts of molybdate salts to the soils, (2) painting of leaflets with a dilute solution of Na_2MoO_4, and (3) direct infiltration of Na_2MoO_4 into cut leaflet tips. Also, a few treatments were made with manganese without success. Specific procedures with results obtained are outlined below.

(1) *Fertilization.* (a) Application of Na_2MoO_4 in solution to the top of the soil at the rate of 0.81 lb of Mo/acre to young mottled plants caused definite greening up in 48 hrs and complete loss of leaf mottling in 4 days. Of 30

[1] Now of the Botany Department, University of Washington, Seattle.

mottled plants in one experiment, 26 were fertilized with molybdenum and 4 held out as untreated checks. *Every one of the fertilized plants lost the yellowish mottled appearance and assumed a normal green color within 4 days,* while the unfertilized plants became more yellowish and mottled.

TABLE 1

MOLYBDENUM ASSAYS OF TOMATO TISSUE

Tissue analyzed	Dry weight (gm)	Mo present (μg)	Mo in dry tissue (ppm)
Older, chlorotic leaflets	4.45	0.50	0.11
Younger, nonchlorotic leaflets	1.20	< 0.07	< 0.06
Stems (including petioles and rachises)	2.76	0.17	0.06
Total of above fractions	8.41	0.74	0.09

(b) Similar fertilizer applications, as $(NH_4)_6Mo_7O_{24}$ at the rate of 1.00 lb of Mo/acre to older plants having severely chlorotic and curled leaves, gave essential recovery in 7 days. Mottling disappeared, and growth was accelerated, although some curling and necrosis persisted in the older, heavily damaged leaves.

(2) *Leaf painting.* Young mottled leaves painted with a water solution of Na_2MoO_4 containing 100 ppm of Mo appeared to be fully recovered after 4 days, and the adjacent leaves greened up as well. Similar painting of other leaves with $MnSO_4$, 100 ppm in manganese, did not remedy the mottled condition.

(3) *Leaf infiltration.* The terminal leaflet of a lower leaf on a severely affected plant was cut transversely and the cut end dipped into a vial containing Na_2MoO_4 solution, 10 ppm with respect to Mo. Greening up was noticeable even in the most chlorotic leaflets after 3 days, and the entire plant was essentially recovered in 5 days. Treatment of another plant in a like manner using 10 ppm of manganese had no beneficial effect.

The same symptoms have been observed in tomato and corrected through molybdenum fertilization on two other serpentine soils, with results similar to those indicated under "fertilization" above. No exceptions to recovery after soil fertilization have been noted in 51 separate treatments of affected tomato plants.

Limited evidence also indicates that Romaine lettuce suffers from molybdenum deficiency on the one soil tested. The symptoms are a pale yellowish color, spindliness, and retarded growth. Plants showing such symptoms in one experiment were fertilized with Na_2MoO_4 at the rate of 1 lb of Mo/acre, which restored the normal green color of the plants in 5 days and markedly improved their vigor.

The three soils involved are shallow, primary hillside soils overlying crystalline serpentine rock in Lake and Marin Counties, California. The areas are sharply delimited serpentine barrens with characteristically sparse endemic floras. These soils are:

(1) A red, gravelly loam from Lake County, classified in the Henecke soil series. Its pH is 6.8 as read on the saturation paste with a glass electrode; the calcium-magnesium ratio in the base exchange complex is 0.176; content of organic matter is low; and X-ray powder diagrams of the 2-μ clay fraction show only characteristic lines of kaolinite.

(2) A brown, gravelly loam of the Montara series from the south slope of Mt. Tamalpais, Marin County. The pH is 6.3; the calcium-magnesium ratio in the base exchange complex is 0.286; and the organic matter content is low.

(3) An unclassified, gray, stony loam from the northwest slope of Mt. Tamalpais, Marin County. The pH is 6.7; the calcium-magnesium ratio in the base exchange complex is 0.148; and the organic matter content is high.

Plants were grown from April through June 1948 and began to show deficiency symptoms about two weeks after transplanting. In similar experiments conducted during the winter months this condition was not so obvious, although, particularly in the case of the lettuce, it is believed that the deficiency existed but was not properly diagnosed. Rapid growth which occurred during the spring season apparently accentuated the deficiency.

No particular precautions were taken to prevent contamination with micronutrient elements in these greenhouse experiments. Marglobe tomato seeds were germinated in sand for most of the experiments and the seedlings transplanted to potted soils when the first true leaf was 1½ to 2 cm long, while lettuce seedlings were grown on loam soil and transplanted when the first true leaf was 3 to 3½ cm in length. A few tomato seedlings were germinated directly on the Henecke soil and then transplanted to the 6″ pots when the first true leaf was 2 cm long. These plants exhibited deficiency symptoms at an earlier stage of growth than those which were germinated on the sand. The 6″ red clay pots were covered with two coats of black asphalt varnish. All pots were uniformly fertilized with C.P. chemicals (154 ppm N, 205 ppm P_2O_5, and 154 ppm K_2O in the air-dry soil) and irrigated with distilled water, but calcium levels varied from 11% to 80% calcium in the base exchange complex. The same symptoms were present, however, on the unaltered field soils having 13%, 14%, and 22% exchangeable calcium, respectively, for the unclassified gray loam, the Henecke, and the Montara soils.

Presence of molybdenum deficiency in the three primary serpentine soils so far subjected to test, coming as they do from different areas and varying widely in organic matter content, suggests that low available molybdenum may be a general chemical characteristic of primary soils weathered on serpentine parent material. In addition to probable peculiarities in their calcium-magnesium nutrition, plant species native to the serpentine barrens may also have a lower molybdenum requirement than that of the crop plants used in these tests.

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X Irradiation of the Hypophysectomized Rat

H. M. PATT, M. N. SWIFT, E. B. TYREE, and R. L. STRAUBE

Biology Division, Argonne National Laboratory

In a previous communication we reported that X radiation, in common with other types of stress, appeared to result in an increased demand for the adrenal-cortical hormone (*3*). In general, the pattern of the adrenal response to irradiation in the lethal range consisted of a reduction in adrenal cholesterol initially, a normal or elevated cholesterol concentration associated with adrenal hypertrophy in the intermediate period, and a second marked fall in adrenal cholesterol terminally. Subsequent studies revealed that the initial reduction in adrenal cholesterol observed 3 hrs after X irradiation could be prevented by suitable administration of adrenal-cortical extract (*9*). This substantiates the findings of Sayers and Sayers (*5*), who found that the previous administration of cortical hormone prevented the rather similar fall in adrenal ascorbic acid seen in rats stressed by exposure to cold. The intermediate and terminal adrenal responses to irradiation, however, were not modified by the daily administration of cortical extract in an amount sufficient to prevent the initial cholesterol change, nor was the survival of irradiated rats altered by such treatment (*9*). Even when the dose of extract was increased 5-fold, the usual adrenal changes were observed 4 days after irradiation (*4*).

It is generally agreed that the early depletion in adrenal lipids and ascorbic acid seen after a variety of stressing stimuli, as well as the subsequent adrenal hypertrophy, are mediated through the pituitary adrenotropic hormone (*1, 2, 7, 10*). Since the possibility exists that the adrenal glands may play a role in mediating or modifying some of the changes observed after irradiation, it seemed of interest to determine whether hypophysectomy would prevent the adrenal response to X radiation and to note whether survival and some of the typical changes in organ weights would be altered under these conditions.

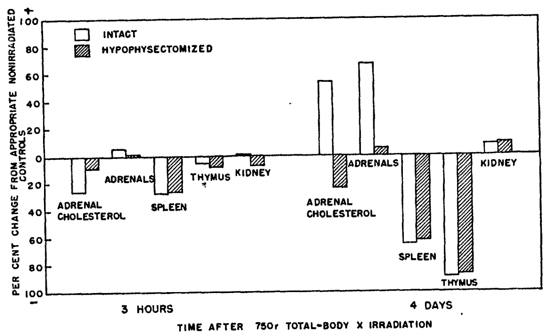

FIG. 1. Per cent change in adrenal cholesterol and organ weights in intact and hypophysectomized rats after 750 r. (Cholesterol and organ weights expressed as per cent of body weight in calculating per cent change. Minimum of 10 rats in each group.)

TABLE 1

ADRENAL CHOLESTEROL AND ORGAN WEIGHTS IN INTACT AND HYPOPHYSECTOMIZED RATS AFTER 750 r

Group	Sacrifice time: After hypophysectomy	Sacrifice time: After X-ray	No. of rats	Body wt. (gm)	Adrenal cholesterol (mg/100 mg of adrenal)	Adrenal cholesterol (mg/100 gm of body wt.)	Adrenal wt. (mg/100 gm of body wt.)	Spleen wt. (mg/100 gm of body wt.)	Thymus wt. (mg/100 gm of body wt.)	Kidney wt. (mg/100 gm of body wt.)
Intact										
Nonirradiated	....	......	14	278.5	1.90 ± 0.18*	0.25 ± 0.03	12.8 ± 0.4	301 ± 11	184 ± 6	346 ± 6
Irradiated	....	3 hrs	10	268.9	1.37 ± 0.12	0.18 ± 0.02	13.5 ± 0.5	221 ± 8	174 ± 10	351 ± 5
"	....	4 days	10	220.0	1.77 ± 0.24	0.38 ± 0.04	21.4 ± 0.9	104 ± 8	20 ± 1	374 ± 9
Hypophysectomized										
Nonirradiated	7 days	......	10	194.3	4.11 ± 0.41	0.41 ± 0.05	9.8 ± 0.8	267 ± 10	190 ± 12	310 ± 7
Irradiated	7	3 hrs	10	204.4	3.74 ± 0.19	0.37 ± 0.08	9.9 ± 0.5	198 ± 9	174 ± 9	289 ± 9
Nonirradiated	11	......	10	188.8	3.18 ± 0.36	0.30 ± 0.03	9.4 ± 0.3	215 ± 8	179 ± 9	290 ± 7
Irradiated	11	4 days	12	168.4	2.39 ± 0.28	0.23 ± 0.03	9.8 ± 0.4	81 ± 4	24 ± 1	317 ± 9
Nonirradiated	14	......	5	199.9	2.36 ± 0.76	0.20 ± 0.07	8.4 ± 0.6	217 ± 8	168 ± 14	273 ± 7

* Indicates mean and standard error.

Sixty white male rats (Sprague-Dawley) weighing 200–300 gm each received total-body X radiation in a single exposure (750 r; 200 kv; dose rate, 18 r/min). Thirty of the rats were hypophysectomized one week prior to irradiation. The animals were exposed in groups of 10, each exposure group containing equal numbers of intact and hypophysectomized rats. All rats including the normal and hypophysectomized nonirradiated controls were fed bread and milk, Fox Checkers, and water *ad libitum*. Animals were sacrificed with Nembutal (IP) 3 hrs and 4 days after irradiation, and the adrenals, spleen, thymus,