Molybdenum Content of Corn Plants Exhibiting Varying Degrees of Potassium Deficiency

Abstract. *Leaves from corn plants exhibiting symptoms of potassium deficiency contain considerable concentrations of molybdenum. Applications of potassium fertilizer corrected the deficiency, and a significant reduction in the molybdenum content of the leaves occurred. This inverse relation between potassium and molybdenum has not been reported previously.*

Hybrid corn plants growing in the field and showing symptoms of moderate to severe potassium deficiency have been found to contain larger concentrations of molybdenum in their leaves than plants with no visible symptoms of a potassium deficiency (Table 1). Spectrographic analysis (*1*) revealed about a fourfold increase in molybdenum content in leaves from plants with deficiency symptoms as compared to leaves from normal plants. When grown on a potassium-deficient soil (Hardin silt loam), the molybdenum content of corn leaves decreased as the severity of potassium deficiency decreased (Table 2). A change in molybdenum content with a change in potassium content did not appear to occur in leaves that did not exhibit symptoms of potassium deficiency.

In an extensive review of the literature (*2*) the effect of potassium deficiency or potassium fertilization on molybdenum content of plants was not reported.

Potassium deficiency did result in a slight stunting of the corn plants, and this could account for a portion of the increased concentration of molybdenum. Also, the calcium and magnesium content of corn leaves generally increases as the potassium content decreases (see Fig. 1).

Rossiter (*3*) reported that calcium is probably needed to transport molybdenum from the roots to the tops of plants. Since the amount of calcium in potassium-deficient plants is usually higher than in normal plants, Rossiter's hypothesis may account for the greater amount of molybdenum in the potassium-deficient corn plants.

Although these observations find some support in Rossiter's hypothesis, additional investigations will be needed to determine the exact cause of high molybdenum content in potassium-deficient corn plants.

Table 1. Molybdenum content of corn leaves from potassium-deficient plants and normal plants (*1*). A fully developed leaf below the whorl was used for analysis in each instance.

Potassium-deficient plants		Normal plants	
Potassium (%)	Molybdenum (ppm)*	Potassium (%)	Molybdenum (ppm)*
Plants from Cortland, Ohio, sampled on 19 June 1963			
0.97	2.0	2.70	0.5
Plants from Carpenter, Ohio, sampled on 18 June 1963			
.56	4.0	2.49	.9
Plants from Wooster, Ohio, sampled on 3 June 1963			
.52	2.8	1.73	.7

* Molybdenum contents (in parts per million) of deficient and normal plants were significantly different at the 0.01-percent level.

Table 2. Molybdenum and potassium content of corn leaves as affected by the rate of application of potassium fertilizer along the seed at planting. The potassium was applied as fertilizer-grade KCl (60 percent K_2O). Fully developed leaves from below the whorl were taken for analysis (*1*) when the plants were about 3 feet 6 inches (1 meter) high, on 18 June 1963. The plants were grown at Carpenter, Ohio.

Amount of potassium applied (lb/acre)	Degree of potassium deficiency	Composition of leaves	
		Potassium (%)	Molybdenum (ppm)†
0	Severe	0.57	4.0
33*	Slight	1.79	1.2
66	None	2.28	0.9
100	None	2.49	0.9

* 33 lb/acre is equivalent to 36 kg/hectare.
† Duncan multiple-range test.

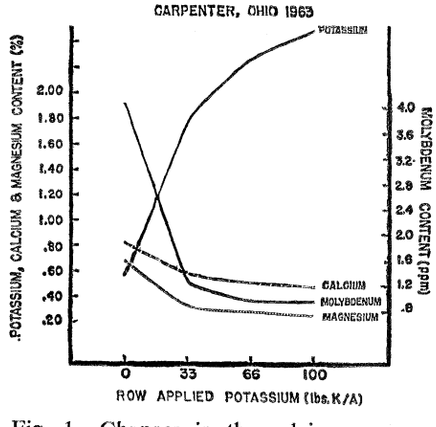

Fig. 1. Changes in the calcium, magnesium, molybdenum, and potassium content of corn leaves after fertilization of the plants with different amounts of potassium (expressed as pounds of potassium per acre; 1 lb/acre is equivalent to 1.12 kg/hectare).

J. BENTON JONES, JR.
Agronomy Department,
Ohio Agricultural Experiment Station,
Wooster 44691

References and Notes

1. Molybdenum and potassium contents were determined by means of a Jarrell-Ash 1.5-meter direct-reading emission spectrograph, the 4044-Å line being used for potassium and the 2816.2-Å line in the second order for molybdenum.
2. M. W. Borys and N. F. Childers, *The Role of Molybdenum in Plants and Soils* (Horticulture Department, Rutgers Univ., New Brunswiek, N.J., 1960).
3. R. C. Rossiter, *Australian J. Agr. Res.* **3**, 244. (1952).

18 January 1965

Electron Spin Resonance Characteristics of Some Normal Tissues: Effect of Microwave Power

Abstract. *Electron spin resonance measurements of normal tissue at 77°K indicate the presence of two types of resonances which can be identified by varying the incident microwave power: (i) an intense, easily saturable, organic free-radical component and (ii) a weak but relatively nonsaturating component probably due to paramagnetic trace elements.*

Studies on electron spin resonance (ESR) signals in normal tissue do not always appear to yield the same result. Commoner and Ternberg (*1*) and Kerkut *et al.* (*2*) find that most tissues have a relatively simple ESR spectrum consisting of a symmetrical resonance centered at $g = 2$ (g is proportional to energy/magnetic field) occurring both at physiological (273°K to 323°K) (*1*) and at low temperatures (77°K) (*1*, *2*). Nebert and Mason (*3*), on the other hand, find a much more complex ESR spectrum in normal liver and cardiac muscle at low temperatures (110°K), including prominent peaks some distance from $g = 2$. Our examinations of normal tissue at 77°K indicate that both types of observations are correct and that the apparent conflict is due to variance in the modes of operation of the electron spin resonance spectrometers.

The ESR spectra of normal tissue (Fig. 1) were obtained from a mongrel dog by laparotomy; the tissue was placed into glass tubes, frozen quickly in liquid nitrogen, and then removed from the tubes in the form of frozen

cylinders. The frozen cylinders of tissue were then kept at 77°K and observed in our Varian ESR spectrometer at that temperature. Figure 1*a* is a representative spectrum of liver observed under high microwave power. This spectrum consists of several prominent peaks located at points well away from the $g = 2$ area as well as a definite signal in the $g = 2$ area. This fairly complex spectrum agrees in most details with that published by Nebert and Mason for normal liver.

Figure 1*b* shows the same liver specimen observed under identical conditions except that the microwave power has now been attenuated about 20 decibels. One now observes a relatively simple spectrum with the only prominent peak occurring at the $g = 2$ area ($g = 2.004 \pm 1$). This spectrum agrees quite closely with those obtained at room temperature (*1*) and at low temperature (*1, 2*). Figures 1*h* and 1*i*, the spectra of another specimen of liver at intermediate and low microwave power, respectively, show the gradual transition from a spectrum with several peaks and several values of g to a spectrum with a single peak at $g = 2$. Figure 1, *c–e*, shows the same phenomena in heart, with high, intermediate, and low power spectra. Again we note a more complex spectrum at high power than at low power. At high power the two main peaks appear to be almost identical in intensity and shape, but as the microwave power is progressively diminished the second peak drops out while the peak at the $g = 2$ area remains prominent. The fact that the $g = 2$ peak does not decrease as power is reduced indicates that this signal was partially saturated at the high power. Figures 1*f* (high power) and 1*g* (low power) show the same phenomenon in lung tissue. Similar results were found in all tissues investigated.

Thus it becomes obvious that the apparent variance in experimental findings was due to the mode of observation of the tissues and not to intrinsic differences in the tissues themselves. Commoner (*4*) explicitly states that his instrument, designed primarily for observing aqueous solutions, is a low microwave power instrument. Nebert and Mason (*5*) used a relatively high microwave power (with a Varian V-4500 ESR spectrometer), which is roughly equivalent to our "normal" power.

A consideration of the signals observed in tissue here and elsewhere indicates separation of the "natural" ESR signals of tissue into two classes. One class of signals is relatively weak (being observed only at relatively high power), has a complex structure, and at least part of it is located away from the $g = 2$ area. The other class of signals is relatively intense (being still observable at low power), is simple in structure, readily exhibits power saturation, and is located near $g = 2$. The signal at $g = 2$ most likely is attributable to organic radicals.

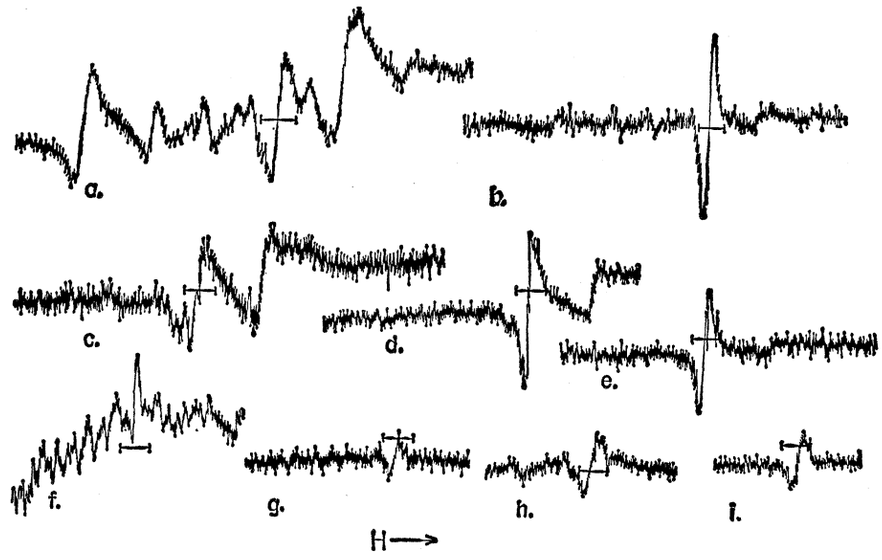

Fig. 1. Electron spin resonance spectra of normal tissue at 77°K. Markers indicate the position and width of the diphenylpicrylhydrazyl resonance (54 gauss). The arrow indicates the direction of the linearly increasing magnetic field. *a*, Liver at normal power; *b*, liver at 20 decibels (db) attenuation from normal power; *c*, heart at normal power; *d*, heart at 10 db attenuation; *e*, heart at 20 db attenuation; *f*, lung at normal power; *g*, lung at 20 db attenuation; *h*, liver at 10 db attenuation; *i*, liver at 20 db attenuation.

The evidence for this conclusion includes (i) the usual location of organic radicals at $g = 2$ (*6*), (ii) the typical power saturation properties of organic radicals in other experiments (*7*), and (iii) the close relation of the signal at $g = 2$ both in frozen tissue (*2*) and at room temperature (*1*) to cellular metabolism.

The other class of signals probably is inorganic in nature and represents either trace metals normally present in tissue or contaminants common to all of the described experiments. The occurrence of resonances due to trace elements in biological materials has been amply documented in studies of DNA and other biological molecules (*8*).

Because of the similarity in position and shape of free radical ESR resonances in various biological materials, an understanding of the various ESR parameters such as microwave power saturation enables us to obtain more information. For example, Smaller and Avery (*7*) were able to differentiate, by the respective saturation properties, the radicals induced by the irradiation of yeast cells from those in intracellular or extracellular water; an observation of the "direct" and "indirect" components of radiation effects in the same sample. On the other hand, failure to realize the saturability of organic free radicals will invalidate quantitative findings on different samples.

HAROLD M. SWARTZ
ROBERT P. MOLENDA
Division of Nuclear Medicine, Walter Reed Army Institute of Research, Washington, D.C. 20012

References and Notes

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9. The principles of laboratory animal care as promulgated by the National Society for Medical Research were observed.

4 February 1965