Review of the Role of Molybdenum in Soils and Plants

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Plants require small amounts of molybdenum for normal growth. The element is essential in nitrogen fixation by both symbiotic and free living soil organisms and is the metal constituent of nitrate reductase in higher plants. Intervenal chlorosis, leaf cupping, and leaf malformation are symptoms of molybdenum deficiency in plants. Data from several hundred soil analyses indicate an average molybdenum content of approximately 2 p.p.m. Molybdenum deficiency in crops results when available molybdenum supply is exhausted by plants or fixed in unavailable state at low soil pH, and is corrected by application of a few ounces of molybdenum salts to the acre. Crop production has been increased on many soils throughout the world by applications of small amounts of molybdenum salts. As only preliminary surveys to determine the extent of molybdenum-deficient soils have been conducted in most agricultural areas, the element will probably assume increasing importance when more thorough surveys are completed.

MOLYBDENUM occupies a unique place among the 15 chemical elements commonly accepted as essential to the normal metabolism of higher plants. It is the latest element to be added to the essential list, the one required in smallest quantity, and the heaviest of all elements needed by plants, being the only member of the fifth period of the periodic table in the group. Whether or not this latter point is of significance remains to be determined.

Ter Meulen (*29*) was among the first to investigate the molybdenum content of soils and plants. The results of his studies, reported in 1932, indicated that the element was a common constituent of both soils and plants. Fertile soils were found to contain from 0.1 to 0.3 p.p.m., while barren sands contained but 0.005 p.p.m. of the element. Plant tissues varied in content from a mere trace to 9.0 p.p.m. on a dry weight basis. Leguminous plants contained greater amounts of the element than nonlegumes. Only traces were detected in the tissues of fruit and vegetables and in the leaves and wood of trees.

In 1930, Bortels (*7*) reported that molybdenum was of biological importance in the fixation of atmospheric nitrogen by *Azotobacter chroococcum* and, 7 years later, he obtained what is believed to be the first instance of field response to applied molybdenum salts. Growth increases were reported in several leguminous crops as a result of small applications of molybdenum salts. He also noted a significant increase in the production of seed by molybdenum-treated alfalfa plants.

Neither the presence of an element in plant tissue nor growth response of plants to applied salts of the element establishes the element as being essential to plants. It must be demonstrated that the plant will not grow normally if the element in question is withheld. Because of the minute amount of molybdenum required by plants, and the difficulties involved in removing molybdenum impurities from other nutrient salts, the essential nature of the element was not established until the work of Arnon and Stout (*3*), published in 1939.

Molybdenum Requirements of Plants

There is considerable variation in the molybdenum requirements of the various species of plants. Anderson (*1*) found that clover in a grass-legume sod responded to applied molybdenum when its molybdenum content dropped to 0.3 p.p.m. The grass did not respond even though its molybdenum content was less than 0.1 p.p.m. Vanselow and Datta (*42*) reported that deficient lemon leaves contained 0.01 p.p.m. of molybdenum, while normal leaves contained 0.024 p.p.m. of the element. From these data it would appear that the molybdenum requirement of clover is 30 times that of the lemon. Other workers have reported deficiency levels for various plants falling between these two extremes.

Plants also vary with respect to their ability to extract molybdenum from the soil. Rencher (*37*) grew 33 species of plants on a Nixon sandy loam soil and found that their molybdenum contents varied from 0.3 to 4.8 p.p.m. Orchard grass contained the higher amount, while beets, onions, and spinach had the lowest levels. Legumes, cereals, and grasses had high molybdenum contents, weeds were intermediate, and vegetable crops had the lowest contents of all.

Warrington (*44*) has pointed out that the molybdenum requirement of plants is influenced by any factor that affects the rate of growth. Reducing the supply of nitrogen resulted in delaying the appearance of deficiency symptoms of lettuce grown at a deficient molybdenum level.

Role of Molybdenum in Plant Nutrition

The importance of molybdenum in the nitrogen metabolism of certain bacteria and fungi was demonstrated before the element's essentiality to higher plants was recognized. Nitrogen fixation by a group of nonsymbiotic bacteria was found to be dependent upon the presence of small amounts of molybdenum in the culture media (*7*). The molybdenum requirement of *Aspergillus niger* was significantly increased when the fungus was supplied nitrogen in the nitrate form, indicating a possible role of molybdenum in the reduction of nitrates within the plant (*39*). Later investigations confirmed these findings and extended them to higher plants.

Molybdenum is now known to be essential in the fixation of nitrogen by the symbiotic bacteria associated with leguminous plants (*14*, *24*). Nodules from alfalfa were found to contain from 5 to 15 times as much molybdenum as is present in other root tissues (*11*, *23*). It has also been demonstrated that the element is essential for the reduction of