INTERNATIONAL MOLYBDENUM ASSOCIATION
THE VOICE OF THE MOLYBDENUM INDUSTRY

Agriculture's quiet powerhouse

In today's rapidly changing agricultural landscape, efficient and sustainable crop production is more important than ever. Fertilizers are key to meeting this need by providing nutrients that help plants grow and produce more. Among these nutrients, molybdenum – only needed in minute amounts – plays an essential but often overlooked role.

Plants require a variety of essential elements to grow and reproduce healthily. This understanding was first advanced by the pioneering 19th-century chemist Justus von Liebig, whose studies revealed how plants absorb nutrients from soil and air. Nutrients needed in large quantities are known as macronutrients, while those required in smaller amounts are called micronutrients. Nitrogen is arguably the most important macronutrient for crops. However, even when nitrogen is abundant in soil and air, plants cannot effectively utilize it without sufficient molybdenum.

Molybdenum plays a particularly vital role for key global crops such as cereals, legumes, and leafy greens, which have notably high nitrogen requirements. While the essential nature of molybdenum as a micronutrient is well-established, ongoing research continues to document cases where even minimal applications of molybdate fertilizer significantly enhance crop health and productivity.

How plants use molybdenum

Plants rely on molybdenum because it enables them to synthesize nitrogen into a usable form through processes such as nitrogen fixation and nitrate assimilation. Without adequate molybdenum, these vital processes cannot occur, hindering plant growth and productivity. In legumes such as soybeans and chickpeas, molybdenum is a crucial part of the enzyme nitrogenase, which helps nitrogen-fixing bacteria convert nitrogen from the air into ammonia, a form of nitrogen plants can use. These plants form partnerships with rhizobium bacteria in their root nodules, and molybdates are necessary for these nodules to work. This process allows legumes to use nitrogen from the air for their growth. Some of the nitrogen also stays in the soil, improving fertility for future crops and reducing the need for synthetic fertilizers, which supports sustainable farming.

As part of the enzyme nitrate reductase, molybdenum also helps convert soil nitrate into nitrite, which plants can further process into ammonia and eventually into amino acids, the building blocks of proteins. Crops like cauliflower and melon, which depend on nitrate from the soil as their nitrogen source, cannot efficiently build proteins without molybdenum. Adequate molybdenum levels further support plant health by enhancing protein synthesis and chlorophyll production, which are essential for photosynthesis and growth.

Deficiency and fertilization

Although molybdenum deficiency is not a universal issue, it is a significant concern in regions with acidic, weathered or sandy soils. Such soils are commonly found in tropical, subtropical, and arid zones, including parts of South America, Africa, Southeast Asia, and Australia. When molybdenum deficiency occurs, it can significantly reduce crop yields by limiting nitrogen uptake. For example, poor soil molybdenum levels in Australian croplands have been estimated to reduce cereal yields by as much as 30%. However, addressing this deficiency can lead to remarkable improvements, as demonstrated in a study from Egypt, where treating mandarin orange trees with molybdenum increased yield by more than one third.

In some cases, molybdenum is sufficiently present in the soil but in an unavailable form. This can occur when the soil

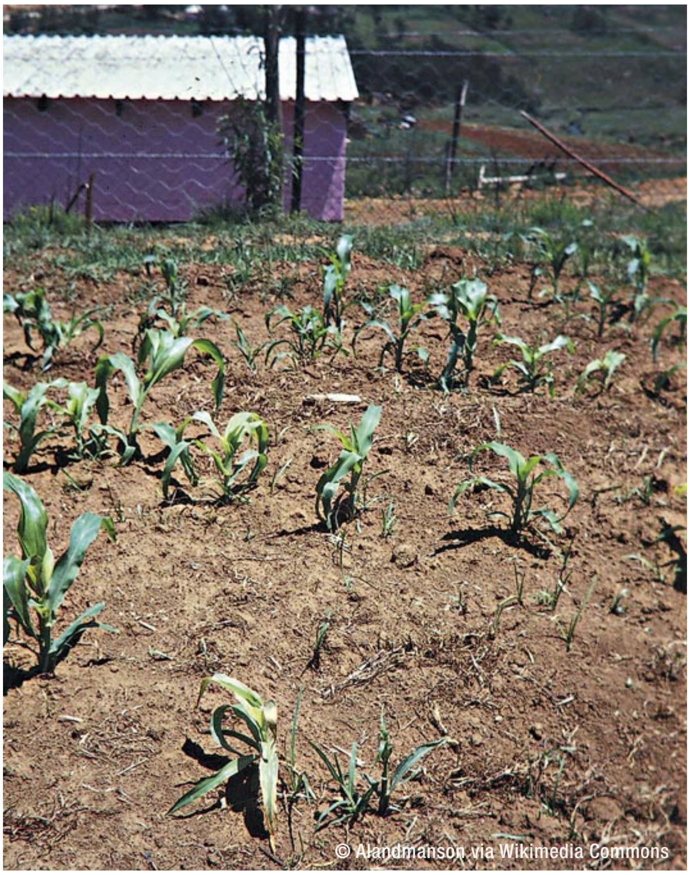
Essential plant nutrients

Primary macronutrients:
nitrogen (N), phosphorus (P), potassium (K)

Secondary macronutrients:
calcium (Ca), magnesium (Mg), sulfur (S)

Micronutrients:
iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni)

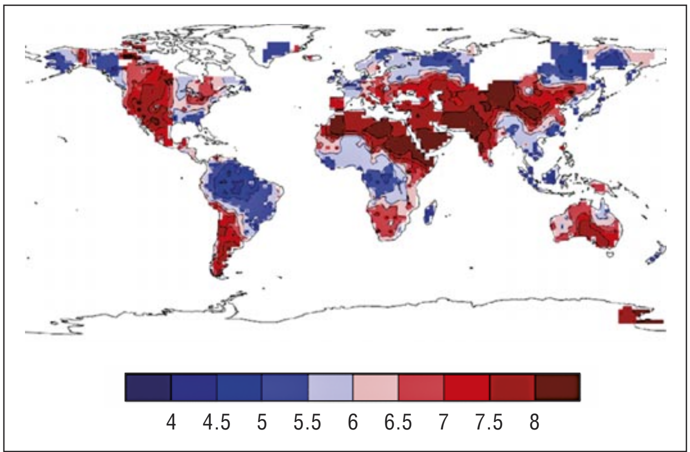
› Molybdenum deficiency symptoms include delayed flowering, stunted growth, yellowing leaves, and low seed production.



Justus von Liebig: the father of chemical fertilizers

Our current understanding of molybdenum's significance in agriculture is built on the work of Justus von Liebig, a pioneering 19th-century chemist. Born in 1803 in Germany, Liebig was among the first to advocate for the artificial supplementation of nutrients to improve soil fertility and boost crop yields. He challenged the dominant theories of his time by demonstrating that plants need mineral nutrients from the soil for healthy growth. His identification of essential nutrients, such as nitrogen, phosphorus, and potassium, laid the foundation for modern fertilizer practices.

One of Liebig's most influential contributions is the "Law of the Minimum," also known as "Liebig's Law," which states that plant growth is limited not by the total amount of resources available, but by the scarcest nutrient.



Global distribution of soil pH. © Meng et. al via ResearchGate

is acidic (<5.5 pH). In most cases, adding lime or dolomite will correct the problem slowly over several months, but this usually isn't fast enough to be viable. Unless the lime amendment provides secondary benefits, adding a molybdate fertilizer is often quicker and less expensive.

Molybdates are added to fertilizers primarily as sodium molybdate (Na_2MoO_4) and ammonium molybdate ($(NH_4)_2MoO_4$). These compounds are highly soluble in water, making them easily available for plant uptake. Molybdates can be applied through various methods, including:

- soil application that incorporates molybdates into the soil, where plant roots can absorb them
- foliar spraying that delivers molybdenum directly to plant leaves, providing a quick remedy for deficiencies
- seed treatments that involve coating seeds with molybdates before planting, ensuring that young plants have immediate access to molybdenum as they germinate and grow.

Sodium molybdate or ammonium molybdate are typically effective in small amounts. Monitoring soil molybdenum levels and understanding the specific needs of different crops is crucial for avoiding over-fertilization.

Increasing crop yields

Recent studies have found that increased use of molybdate fertilizer can improve agricultural outcomes. For example, Nakai and Maruyama-Nakashita report that spraying dry bean leaves with a molybdenum fertilizer at 40 ppm – the highest concentration tested – increased seed yield by over 80%. Similarly, Osman et al. found molybdate amendments in chickpeas significantly improved productivity. These findings highlight the critical role of molybdenum as a micronutrient in crop production.

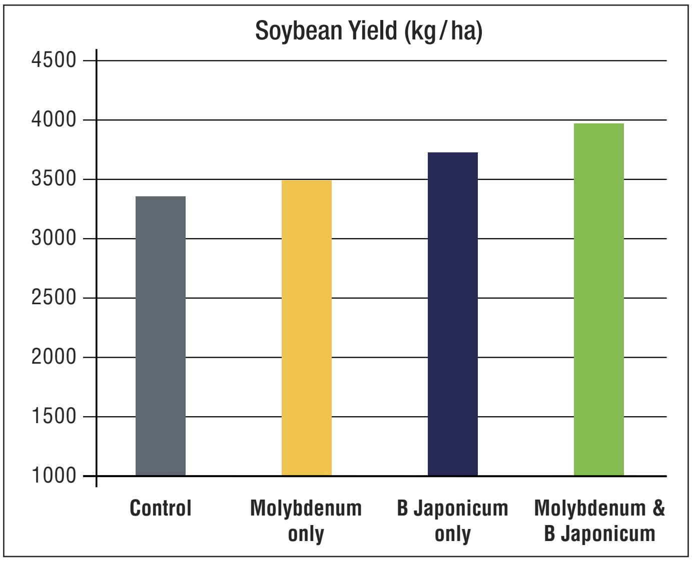
Adding tiny amounts of molybdate delivers significant economic benefits, with improved crop yields and reduced fertilizer use far outweighing their costs. By enhancing nitrogen fixation, molybdates also help minimize fertilizer waste and nutrient runoff. Whether included in synthetic fertilizers, organic amendments, or soil inoculants, molybdates play a key role in optimizing nutrient availability and supporting sustainable agriculture.

Soybean case study

Soybean is the world's most significant source of plant-based protein and oil, cultivated on 120–130 million hectares – an area roughly five times the size of the UK. The largest producers include the US, Argentina, China, and Brazil, with Brazil currently leading global production and exports. In the 2021–2022 season, Brazil harvested an impressive 124 million tonnes.

A key region for soybean cultivation in Brazil is the Cerrado, a tropical savannah. While this region benefits from low land and clearing costs and is easily mechanized, the soils are among the oldest and most leached in the world due to heavy rainfall. This nutrient depletion has rendered them some of the least fertile, requiring significant supplementation with minerals like molybdenum. Continuous farming has further worsened the problem, underscoring the importance of effective fertilization strategies.

Given the vital role of soybeans, increasing productivity without expanding cultivated land is essential. Recent studies have explored the synergy between micronutrients and beneficial microorganisms in enhancing soil fertility. In 2023, Jarecki reported that soybeans inoculated with *Bradyrhizobium japonicum* and supplemented with molybdenum showed improved growth, higher nitrogen content, and increased seed production, collectively boosting crop performance. Inoculating soybeans with *B. japonicum* enhances biological nitrogen fixation, especially in soils lacking native bacterial populations. Molybdenum further supports this process by promoting nodulation and nitrogen uptake, ultimately leading to higher yields.



Meeting evolving challenges

As agriculture confronts increasingly complex challenges, including climate change, soil degradation, and resource limitations, the role of molybdates in fertilizer innovation becomes more critical than ever. Current research seeks to uncover the mechanisms of molybdenum's interactions with plants and soil microbiota, optimize fertilizer formulations, and develop sustainable practices that leverage the full potential of molybdates. These efforts aim to advance global food security while promoting environmental stewardship. (John Thompson)

❯ **A healthy soybean plant, important not only for food but also cosmetics, cleaners, plastics, paints, and even crayons!**