

Sulfur:

An overlooked essential plant nutrient

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Sulfur is an essential macronutrient that plays a crucial role in plant growth, protein synthesis, and enzyme activity. Historically, atmospheric deposition contributed to soil sulfur levels, but stricter environmental regulations and intensive farming have led to widespread deficiencies. Sulfur depletion is especially common in sandy soils with low organic matter, where leaching is prevalent. Deficient crops exhibit symptoms like chlorosis, stunted growth, and delayed maturity, severely impacting yield and quality. Oilseeds and legumes, which have high sulfur demands, are particularly affected. Understanding sulfur dynamics in soil and adopting efficient fertilization strategies is essential for maintaining crop productivity. This article explores sulfur sources, deficiency symptoms, and sustainable management practices in agriculture.

Keywords: Sulfur, Crop, Deficiency symptoms, Nutrient management

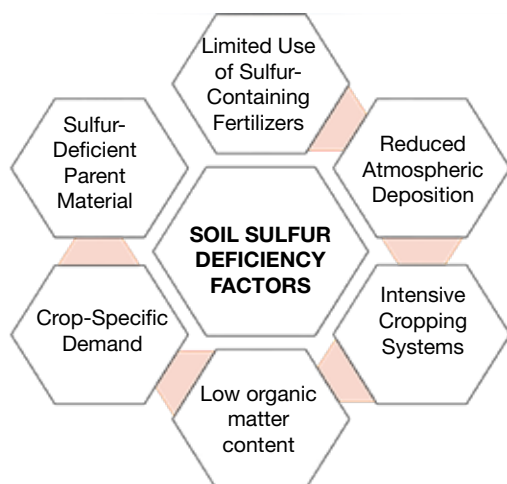
SULFUR is an often-overlooked macronutrient that plays a vital role in plant growth and development. While nitrogen (N), phosphorus (P), and potassium (K) dominate discussions around plant nutrition, sulfur is equally essential, particularly for synthesizing amino acids, proteins, and enzymes. These compounds are fundamental to various physiological processes, including photosynthesis, protein synthesis, and stress resistance, all of which are crucial for healthy plant development. Historically, sulfur was readily available in agricultural soils due to atmospheric deposition from industrial emissions. However, in recent decades, cleaner air regulations have significantly reduced this source of sulfur, leading to a noticeable decline in sulfur levels in many soils. Additionally, the widespread use of high-analysis fertilizers that do not contain sulfur, combined with intensive cropping practices, has contributed to sulfur depletion. This deficiency is particularly common in sandy soils with low

organic matter, where sulfur leaching is frequent due to rainfall or irrigation. The impact of sulfur deficiency on crops is profound. Without adequate sulfur, plants exhibit symptoms such as chlorosis (yellowing of leaves), stunted growth, and delayed maturity. These symptoms directly affect crop yield and quality, with high-sulfur-demand crops like oilseeds and legumes suffering the most. Given these challenges, understanding sulfur's role in plant physiology and implementing effective sulfur fertilization strategies are crucial for sustaining crop productivity and soil health.

Factors affecting sulfur availability to plants

Soil sulfur deficiency has become increasingly common due to a combination of natural processes and modern agricultural practices. The widespread use of high-analysis fertilizers that primarily supply nitrogen, phosphorus, and potassium has resulted in little added sulfur, leaving soil reserves unbalanced. Intensive cropping

systems, especially those growing high-yield oilseeds, legumes, and cruciferous vegetables, remove large amounts of sulfur with each harvest, further exacerbating the problem. Soils with low organic matter are particularly vulnerable because organic residues serve as a reservoir that slowly releases sulfur through microbial mineralization. Sandy soils, with their low water-holding capacity and limited nutrient retention, are prone to rapid sulfate leaching, especially under heavy rainfall or irrigation. Moreover, soil pH plays a crucial role; in alkaline soils, sulfate may form insoluble compounds that reduce availability, while in acidic soils, unfavourable conditions can hinder the microbial processes essential for sulfur release. Additionally, soils derived from sulfur-poor parent materials naturally start with lower levels of sulfur, making deficiency likely even with good management practices. These factors-including declining atmospheric inputs, limited sulfur fertilization, intensive crop removal, low organic matter, leaching in sandy



Factors affecting sulfur availability

essential macronutrient, its shortage has far-reaching consequences that extend from cellular processes to whole-plant physiology, ultimately impacting yield and quality. One of the most immediately observable effects of sulfur deficiency is chlorosis, or the yellowing of leaves. Chlorophyll, the vital pigment responsible for photosynthesis, relies on sulfur for its synthesis. When sulfur is scarce, chlorophyll production is compromised, leading to pale or yellowish leaves-most notably in

growth, delayed development, and, in severe cases, abnormal tissue differentiation. Furthermore, sulfur plays a pivotal role in a plant's defense mechanisms, viz. deter pests, resist pathogenic attacks, and mitigate the impacts of abiotic stresses like drought or salinity. In addition to affecting growth and defense, sulfur is involved in the formation of various volatile compounds that contribute to the flavour and aroma profiles of food crops. For instance, the characteristic pungency of onions and garlic arises from sulfur-containing molecules. When sulfur is deficient, production of these compounds diminishes, leading to lower nutritional value and a decline in the desirable taste and aroma of these and other crops.

Moreover, the interplay between sulfur and other nutrients is critical. Sulfur and nitrogen, for example, work synergistically in the synthesis of proteins. In the absence of adequate sulfur, even if nitrogen is abundant, plants cannot efficiently synthesize proteins, leading to an imbalance in nutrient utilization. This not only affects plant health but also has economic implications, as reduced protein content and yield in major crops like wheat, maize, and soybean directly translate into lower market value.

soils, and suboptimal pH underscore the pressing need for targeted sulfur management. Implementing regular soil testing, applying sulfur-enriched amendments, and adjusting soil pH through appropriate liming or acidifying agents are vital strategies to restore and maintain sufficient sulfur levels, ultimately supporting healthier plant growth and improved crop productivity.

Effect of sulfur deficiency on crop health

Sulfur deficiency in crops is emerging as a critical challenge that adversely affects plant growth, metabolism, and overall productivity. As sulfur is an

young, actively growing tissues where the demand for chlorophyll turnover is highest and curtails overall photosynthetic efficiency, thereby stunting growth. Beyond its role in photosynthesis, sulfur is indispensable for the synthesis of key amino acids, particularly cysteine and methionine. These amino acids serve as the building blocks for proteins, including enzymes that catalyze essential biochemical reactions. A deficiency in sulfur disrupts protein synthesis, impairing the formation of structural proteins and enzymes crucial for various metabolic pathways. Consequently, plants exhibit stunted

Table 1. Sulfur deficiency symptoms in plants

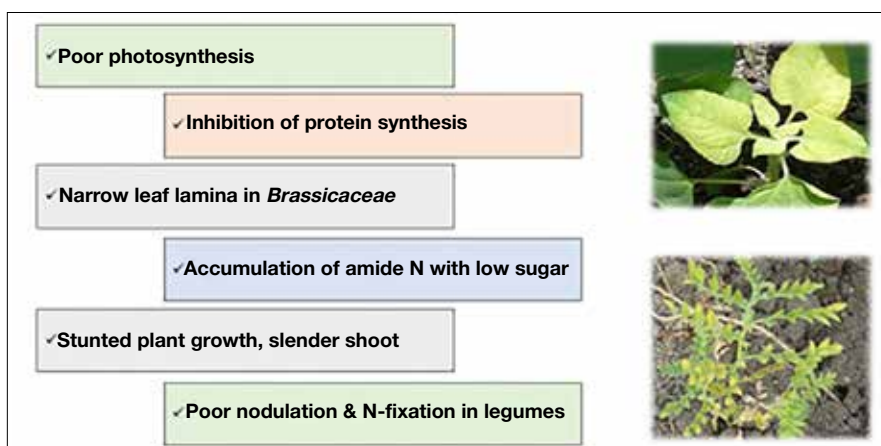
Crop	Symptoms
Banana	Young leaves show chlorosis, young leaves become yellowish-white, chlorosis is clearer and pale stripes visible, growth retarded, small fruits.
Blackgram	Chlorosis from tips of young leaves, young leaves severely chlorotic, stems thin and woody, bushy appearance.
Chickpea	Plants appear erect, premature drying and withering of young leaves, entire foliage turns chlorotic, restricted nodulation and seed setting.
Coconut	Yellowish-green or yellowish-orange leaflets, leaves droop, reduced leaf number and size, weak stem, premature nut fall, rubbery kernel.
Coffee	Yellow discolouration on youngest leaves, general chlorosis of mature leaves, newer leaves smaller and more chlorotic, mottled appearance.
Cotton	Persistent yellowing of new leaves, reddening of petiole, older leaves may be affected first.
Cowpea	Stunted growth, short internodes, pale young leaves, delayed flowering, chlorotic new leaves, low pods and seed yield.
French bean	Short internodes, fewer and smaller leaves, pale green foliage, poor growth, low yield.
Greengram	Stunted, poor branching, bushy appearance, reduced flowers, shrunken seeds in pods.
Groundnut	Smaller young plants, pale, erect trifoliolate leaves, while older leaves remain green, restricted nodulation and pod formation, delayed seed maturity.
Horsegram	Pale entire leaf, interveinal chlorosis of young leaves, severe deficiency spreads to middle leaves.
Linseed	Yellowing, curling, premature drying of young leaves, spreading chlorosis, slender stem, poor branching, reduced floral buds.
Maize	Yellowing between veins in young leaves, later reddening at base of stem and leaf margins.

Crop	Symptoms
Oilpalm	Small pale-green to white fronds in seedlings, necrotic spots in older leaves, terminal necrosis.
Pea	Pale young leaves, interveinal chlorosis spreads from young to older leaves, reduced root nodulation, flowering, and yield.
Pigeonpea	Yellow young and middle leaves, suppressed branching, leaf size, flowering, early flower shed, retarded pod and seed development.
Pineapple	Yellowish-green leaves, later pinkish red margins, spreads to all leaves, no flowers or fruits.
Potato	Inward curling of youngest leaves, yellowing stems, general yellowing of the plant.
Rapeseed Mustard	Cupped leaves, reddening of underside of leaves and stem, premature flower abortion, reduced oil content in seeds.
Rice	Yellowish leaf sheath and blade, whole plant chlorotic at tillering stage, reduced plant height and tillers, fewer panicles and spikelets.
Rubber	Yellowish-green entire leaf, reduced size, brown necrotic spots at tip or all over, young shoots first affected.
Sesame	Retarded growth, smaller leaves, pale then golden yellow leaves, reduced flowers and pods, lower yield.
Sorghum	Shorter, more erect young leaves, pale green, older leaves may remain green, severe deficiency turns older leaves pale green.
Soybean	Pale-yellowish green new leaves, reduced leaf size and internodes, chlorosis from leaf margins inward, premature leaf fall, reduced flowering and fruiting.
Sugarcane	Yellowish-green younger leaves, faint purplish tinge in younger and older leaves, thinner stems taper towards tip.
Sunflower	Pale leaves and flowers, smaller plants with shorter internodes, smaller leaves.
Tea	Yellow leaves, reduced size, short internodes, shrunken appearance, severe deficiency causes curled leaves with brown edges and tips, dwarf yellow leaves.
Tobacco	Pale yellow-green new leaves, condition extends to whole plant, smaller leaves, shorter internodes.
Tomato	Smaller, lighter green plants, yellowing in various parts, severe deficiency causes reddening of petioles and stems.
Wheat	General yellowing of plant, more prominent between veins, older leaves remain green.

Source: www.sulfurinstitute.org

Management of sulfur in crops

Sulfur management is crucial for optimizing crop productivity and quality, particularly in regions like India's Indo-Gangetic Plains where soils are often sulfur-deficient. Adequate sulfur improves oil content in oilseeds like mustard and groundnut, enhances protein levels in pulses, and boosts sugar yield in sugarcane. A recent research report from ICAR (2020) shows that applying 20–60 kg S/ha (and up to 80 kg/ha for sugarcane) can lead to yield increases in mustard of 12–48% under irrigation and 17–124% in rainfed systems. For effective sulfur management, basal applications of gypsum or phosphogypsum (both offering 18–19% sulfur) are often preferred due to their solubility and cost-effectiveness. In organic farming, alternatives such as press mud (1–2% S) and neem cake (1–1.5% S) provide sustainable sulfur sources while also enhancing soil organic matter. Furthermore, timing and method of application are critical; applying sulfur during pre-flowering stages and using techniques such as band placement rather than broadcasting can improve efficiency by ensuring the nutrient is readily available in the crop's root zone.



Symptoms of sulfur deficiency

Table 2. Sulfur containing fertilizers

Fertilizer Name	% Sulfur Content	Remarks
Gypsum	18–19%	Calcium sulfate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$); widely used for reclamation of alkaline soils.
Ammonium Sulfate	24%	$(\text{NH}_4)_2\text{SO}_4$; provides nitrogen (21%) and sulfur.
Single Super Phosphate (SSP)	12–14%	Contains phosphorus (16–18%) and sulfur; suitable for basal application.
Phosphogypsum	15–18%	Byproduct of phosphate fertilizer industry; cost-effective.
Elemental Sulfur	90–100%	Requires oxidation to sulfate by soil microbes; slow-release.
Potassium Sulfate	17–18%	K_2SO_4 ; preferred in sulfur-deficient and high-value crops.
Sulfur Bentonite	90%	Granular, slow-release; used in high-precision agriculture.

Source: Bouranis et al. 2018, Narayan 2022, Paulsen (Thunen Institute); Degryse et al. 2017.

Table 3. Organic manures for sulfur management

Organic Manure	% Sulfur Content	Remarks
Farmyard Manure (FYM)	0.2–0.3%	Low but consistent sulfur supply; improves soil organic matter.
Compost	0.2–0.4%	Depends on feedstock; municipal compost may have higher S.
Press Mud	1.0–2.0%	Byproduct of sugarcane processing; rich in organic S.
Poultry Manure	0.4–0.5%	Higher sulfur content compared to FYM; fast mineralization.
Neem Cake	1.0–1.5%	Oilseed waste; acts as a biofertilizer and pest repellent.
Green Manures	0.3–0.5%	Includes crops like sunnhemp; incorporated into soil to enhance fertility and sulfur content.

Source: Bouranis *et al.* 2018, Narayan 2022, Paulsen (Thunen Institute), Degryse *et al.* 2017.

SUMMARY

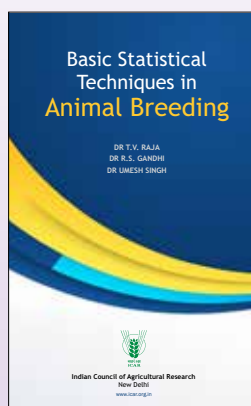
Sulfur stands as an indispensable pillar of crop nutrition, yet its silent role in agriculture has too often been overshadowed by the focus on nitrogen or phosphorus. The unintended reduction in atmospheric sulfur deposition, coupled with decades of high-intensity farming and reliance on sulfur-depleted fertilizers have quietly eroded soil sulfur reserves. This depletion manifests not only in yield stagnation but in the

subtle unraveling of crop quality: diminished oil content in mustard, faltering protein synthesis in pulses, and compromised sucrose accumulation in sugarcane. Yet the path forward is neither uncertain nor insurmountable. By adopting deliberate, site-specific strategies and judicious use of sulfate-rich amendments like gypsum, integration of organic manures such as press mud, and precision in application timing- we can recalibrate sulfur's equilibrium in

agro-ecosystems. Such stewardship does more than addressing deficiency; it rebuilds soil resilience, elevates farm productivity, and reconnects modern agriculture with the biogeochemical rhythms that sustain it. In reimagining sulfur management, we cultivate not just crops, but a legacy of resource-conscious farming for generations to come.

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