SULFUR FERTILIZATION FOR SOYBEANS

Sulfur [S] nutrition for plants has become a hot topic because of the 1) reduction in atmospheric S deposition resulting from reduced S emissions from factories and power plants, 2) increased crop removal of S because of higher yields, and 3) long-term decreases in soil organic matter [SOM]. Click here for a summary of S fertility for soybeans. Pertinent points to consider for S nutrition in soybeans follow.

- Sulfur is a component of the amino acids methionine and cysteine, and these two essential amino acids are often insufficient in protein derived from soybeans.
- Sulfur is essential for protein synthesis as well as for nodulation and nitrogen [N] fixation in soybeans.
- Soybean grain removes about 1.7 lb of S per 10 bushels of seed, or about 12 lb/acre for a 70 bu/acre yield.
- The sulfate ion [SO_4] is the form primarily absorbed by plants. Sulfate-S is mobile in most soils; thus, it is subject to leaching, especially from sandy soils. However, once S is incorporated into plants, it has low mobility.
- SOM is the main source of S in most soils. Thus, if fertilizer S in not applied to the soil, the main source of S will be the mineralization of SOM by soil microbes. Coarse-textured and low-organic matter soils are those most likely to be S-deficient.
- S levels in soil are generally considered low at 0-5 ppm, moderate at 6-8 ppm, and sufficient at >10 ppm.
- Traditional soil testing is not a good predictor of S deficiency because of the transient nature of S availability, its mobility away from the crop root zone prior to crop need, and the lack of calibration of soil tests to predict S deficiency in plants. Also, commonly-used soil tests likely will identify fields that have sufficient S, but are not very good at identifying those fields that will benefit from added S.
- Since the plant-available form of S from the soil is SO_4, apply a SO_4-containing fertilizer for an immediate crop response. These products should be applied close to peak crop demand to reduce loss by leaching. If a fertilizer containing elemental S is used, it must be applied well in advance of the crop's need.
- Ammonium sulfate [21-0-0-24S], ammonium thiosulfate [12-0-0-26S], and calcium sulfate [$CsSO_4$] or gypsum [0-0-0-17S–see June 2025 update below] are the most commonly used sulfate fertilizers. Potassium sulfate [0-0-50-18S] is a fertilizer that contains both potassium [K] and S.
- Tissue testing of the appropriate plant part at the appropriate time [~R3] is recommended to definitively identify an S deficiency. For soybeans that are < 12 in. tall, sample the whole plant; for larger plants, sample the most recently matured trifoliate. Click here for S sufficiency level in soybeans.
- Preliminary data indicate that a 1 to 1.5 bu/acre yield increase resulting from S fertilization will pay for the fertilizer amount that will normally be applied to S-deficient soils. Of course, this will depend on both the price of the selected fertilizer and the expected commodity price at harvest or sell time.
- Sulfur occurs in protein in a ratio of 1 part S to about 15 parts N. Thus, the N:S ratio of soybean plant tissue as well as the S concentration in the plant are used to identify an S deficiency–i.e. the lower the S concentration and the higher the N:S ratio, the more likely there is an S deficiency in the soybean plant.

Research conducted in West Tenn. in 2015-2016 provides information about S fertility for soybeans grown in the Midsouth. Details of and results from that research are reported in an article titled "Corn and soybean response to sulfur fertilizer in West Tennessee". A summary of the activity associated with that research follows.

- The objectives of the study were to 1) identify optimal at-planting S for corn and soybean yield, and 2) evaluate the effect of S rate on crop growth and yield, leaf nutrient level, and seed S content. Soil pH at the site averaged 6.7 and SOM averaged 1.8%.
- No-till experiments were conducted without irrigation in 2015 and 2016 on a site with silt loam

soil. Each year, a corn crop was preceded by soybean, and a soybean crop was preceded by corn. The site used in the study was chosen because it had a history of visual S deficiency in corn.
- Ammonium sulfate was broadcast-applied at 0, 10, 20, and 30 lb S/acre at planting.
- Soybean canopy color did not differ among S rates at R1, but the S fertility treatments did result in a visibly greener canopy later in the season at the R5 stage. However, soybean leaf S concentrations did not differ among S treatments at early bloom.
- Soybean seed weight did not differ among S fertility treatments.
- Soybean seed S levels increased from 0.23% for the no-S fertilizer treatment to 0.27%, 0.29%, and 0.29% for the three treatments that had added S fertility. Thus, S fertility resulted in a significant seed S increase.
- Soybean yield in the four S fertility treatments ranged from 51 to 54 bu/acre in 2015 and from 62 to 64 bu/acre in 2016. The differences among the S treatments were not significant in either year.

From their results, the authors concluded the following. 1) An S application to soybean grown on a site with characteristics similar to those in this study is not warranted from a yield increase standpoint, but may be considered if increased seed S is desired. 2) Plant tissue analysis did not indicate an S deficiency in soybean, even where visual S-deficiency symptoms were observed. 3) Tissue sampling at R1 may be too early and not useful for predicting later-season S deficiency or sufficiency in soybean.

An article in the European Journal of Agronomy titled "Sulfur fertilization in soybean: A meta-analysis on yield and seed composition" by numerous authors provides the following points.
- The objectives of the analysis were to 1) quantify the effect of S application at different growth stages on soybean yield and seed S content, and 2) identify the main environmental factors that affect soybean response to S fertilization.
- Field experiments were conducted in 2017-2019 at 18 locations in 8 U.S. states [including Ark.] for a total of 44 unique site-years.
- Soybean is the leading crop in the world for protein production. However, soybean meal is known for having low concentrations of sulfur-containing amino acids [SAA] relative to other amino acids.
- The developmental stage of soybean at which S deficiency occurs affects the expression of quality traits in soybean seed.
- The soil's S supply is dependent on the mineralization of SOM.
- Sulfur mobilization from vegetative to reproductive soybean tissues is less efficient than N mobilization. Even if soybean accumulates high amounts of S in its leaves, this S is unavailable to meet needs of the plant during reproductive development.
- The above two points suggest that S management for improving soybean seed quality must assure sufficient S late into plant development.
- Application of S at planting resulted in a 1) 1.7% yield increase, 2) 0.4% increase in seed protein, 3) 0.3% increase in essential non-SAA, and 4) 1.0% increase in SAA.
- Seed SAA level increased regardless of the S fertilization timing.
- Air temperature, SOM, drought stress, and soil S concentration were significant contributors to the variation in yield and seed quality responses to S fertilization.
- The high variation in response to S fertilization across the environments in this analysis should be considered as a limiting factor in developing specific conclusions and/or recommendations for S fertilization of soybean to improve yield and seed quality.
- The finding that seed protein concentration was increased only by S application at planting may be related to the added S improving biological N fixation.

The information in the preceding narrative supports the following guidelines for S fertilization of soybean in the Midsouth. 1) Consider S fertilizer application to coarse-textured soils with low SOM since this is likely where an S deficiency in soybean will occur. 2) Both traditional soil testing and visual difference in greenness of the soybean canopy are poor indicators of potential or actual S deficiency in soybean that is associated with seed yield. Rather, use tissue testing during critical growth stages [likely R3-R5] to determine S deficiency or sufficiency in appropriate soybean plant tissues. 3) Sulfur fertilization of soybeans may be warranted on S-sufficient soils if an increase in seed S [especially SAA] is the goal. 4) Apply an SO_4-containing fertilizer as close to the crop need as possible for an immediate crop response. 5) A positive response of soybean to S fertilization is highly dependent on weather variables, absence of drought stress, and SOM content.

Additional points that should be considered regarding S fertility follow.
- Elemental S must be oxidized by soil microorganisms before it is available to plants. Most elemental S oxidation is catalyzed by a diverse population of soil microbes.
- Elemental S oxidation occurs on the surface of the S particles. Thus, the rate of oxidation depends on the surface area rather than the quantity of elemental S that may be applied as fertilizer.
- Generally, S particles must be less than about 20 µm in diameter and effectively dispersed in the soil for them to significantly contribute to satisfying early-season crop S requirements.
- Elemental S oxidation is suppressed when S particles are close to each other. Therefore, broadcast vs. banded application of elemental S fertilizer should be more effective.

MAY 2023 UPDATE

Results from research conducted in Ohio and reported in an article titled "Ohio grain crop response to sulfur fertilization" by L. Fleuridor et al. support research results cited above. Pertinent points from the Ohio research follow.
- 34 soybean field trials were conducted in 16 counties on 16 different soil series from 2013 to 2021.
- At least two treatments [S fertilized and unfertilized] were used at each location.
- Across all trials, S fertilization did not affect grain yield of soybean; it increased soybean seed yield in only 3 of the 34 trials.
- Across all trials, both leaf S and seed S concentration were significantly increased by S fertilization.
- Relative to soybean seed yield, both leaf and seed S concentrations were more directionally positive in response to S fertilization.
- Overall results showed that 1) soybean seed yield responses to S fertilization were rare across locations and soil textures that ranged from loam to clay, 2) tissue and seed S concentrations were more frequently affected by S fertilization than was seed yield, and 3) common soil tests and leaf and seed diagnostic tests for S deficiency are poor predictors of soybean seed yield response to S fertilization.
- These results led the authors to conclude that S fertilization is not now needed to optimize soybean production in Ohio.

MARCH 2024 UPDATE

Articles titled "Can sulfur slow down SDS in soybeans?" and "Consider sulfur for early-planted soybeans" by Tom Bechman, plus a 2023 presentation of results from S research conducted by Dr. Shaun Casteel at Purdue Univ., provide the following information about applying S fertilizer to soybeans.
- In cases where sudden death syndrome [SDS] is known to occur or occurs, S fertilizer application is associated with a lower incidence of the disease. [At this time, SDS is not a problem in the Midsouth, but soybean producers should be aware of this finding from the research conducted in Indiana].
- Midsouth soybean producers may see a significant yield increase when applying S fertilizer prior to **early** planting–i.e. early- to mid-April in the Midsouth. This is likely because ample S must be available to soybeans when they emerge, and this is not likely the case because less S is mineralized in the spring when soils are cooler.
- S fertilizer addition will not likely affect the yield of later plantings.
- Soils low in OM are not likely to have enough S to mineralize from the OM to provide the amount of S needed to sustain a high yield potential–e.g. 75 bu/acre or more.
- Tissue testing for leaf S level at R3-R5 will likely determine S sufficiency/deficiency in soybeans. Results from this test can be used to remedy S deficiency in subsequent soybean crops.

- To benefit from S fertilization of soybeans, a soluble S fertilizer should be applied no more than 6 weeks prior to planting.

The above-cited results from research with S fertilization of soybeans lead to the following conclusions.

- Most soils do not now need S fertilization to optimize soybean seed yield. This may change with continually high and/or increasing seed yields, reduced sulfur compounds in the atmosphere, low or declining SOM at sites used for soybean production, and a major move to earlier soybean planting in all U.S. regions.
- Definitive soil and plant diagnostic tests for S deficiency that may be related to soybean yield are lacking.
- Tissue testing of the appropriate plant part at the appropriate time [~R3-R5] during the growing season is recommended to definitively identify an S deficiency. However, the results from such tests can only be considered for S fertilizer additions to a future soybean crop.
- Consider S fertilizer application to soils with low OM since this is likely where an S deficiency in soybean will occur, especially where soybean is planted early in soils that are cooler than with later planting.
- Sulfur fertilization of soybeans may be warranted if an increase in seed S [especially SAA] is the goal.
- A positive response of soybean to S fertilization is highly dependent on SOM content since much of the S in soil is contained in both OM and residue from a previous crop.
- Sulfur fertilization of soybean may be related to improved performance and/or control of SDS where that disease occurs.
- Sulfur fertilization of early-planted soybeans has the potential to increase seed yield because S availability may be limited by environmental conditions early in the growing season.

Takehome Message. Midsouth soybean producers who have 1) practiced early planting for several years at sites with low SOM, and 2) used irrigation to achieve high yields over those years, should be especially aware of the S status of soybean plants and be prepared to apply the proper S fertilizer at the proper time if/when needed.

JAN. 2025 UPDATE

An article titled "Why sulfur on soybeans makes sense" by Richard Roth at Iowa State Univ. provides the following points to keep in mind.

- Because of soybeans' importance to the national agricultural sector, it is essential that nutrient management for the crop be optimized.
- Sulfur has emerged as a potential factor for achieving higher yields and better seed quality.
- Sulfur is often called the "fourth major nutrient" after N, P, and K, and is essential for optimum soybean growth and development.
- Sulfur is a critical component of several amino acids that comprise proteins and enzymes.
- Cover crops–e.g. cereal rye–used in soybean systems can effectively scavenge available S from the soil, and this can result in a depletion of soil S for a subsequent soybean crop.
- Even moderate S deficiencies can result in decreased soybean pod numbers and lower seed weight.
- Plant tissue testing is the most reliable method for identifying S deficiency in plants.
- Fertilizers such as AMS and gypsum can be applied to address S deficiency in fields where an S deficiency is expected to occur.
- Due to potential leaching of fall-applied S, it is likely more practical to apply sulfate-S in the spring.
- Effective application–e.g. even spreading of S-containing fertilizers–is crucial to ensure maximum S availability to the soybean plant.
- Optimization of S management is a key factor in ensuring adequate nutrition to the soybean plant, and this is especially so as yields continue to increase.

Mar. 2025 Update

Articles titled "Following cereal rye? Apply sulfur!" and "Should you spend money on sulfur this year?" provide information that can be used to help determine if adding S to a soybean crop is economically feasible. Points from those articles follow.

- Commonly-conducted soil tests were not good indicators of S deficiency.
- The greatest response to S fertilization has occurred on soils with less than 2% OM.
- Early-planted soybeans are the most likely to respond to S fertilization.
- A crop following a high-biomass crop such as a cereal rye cover crop will be the most likely to respond to S fertilization to overcome any potential S immobilization.
- If needed, S fertilizers such as ammonium sulfate or pelletized gypsum should be applied in early spring through planting since a benefit from added S will decrease as application is delayed.
- Since an S deficiency can lead to poor N-fixation in soybeans, applying S at the proper time should overcome this.
- For best results, a cereal rye cover crop preceding corn should be terminated 2-3 weeks prior to corn planting. Of course, this will significantly reduce the amount of biomass that can be accumulated by the rye cover crop.

All of the above underline the importance of appropriately testing the soil and plant to ensure that no nutrient element, especially one such as S that is deemed essential for optimum growth and development, is allowed to be deficient.

June 2025 Update

Gypsum is a hydrated calcium sulfate that is chemically represented by $CaSO_4 \bullet 2H_2O$, and is a common mineral. Gypsum is a good source of both Ca and S, both essential plant nutrients.

Results reported in an article titled "Impact of gypsum applications and cover crops on soybean elemental composition" by Gonzalez et al. provides the following information.

- Field experiments were conducted in Alabama, Indiana, and Ohio over 5 years [2012-2016].
- Gypsum application at 2 tons/acre improved S uptake by soybeans and increased S content in soybeans at all three sites used in this study.
- The results from this research indicate that gypsum is a potential S source for soybean producers who have determined that soils at their sites of production are S-deficient.

Most soybean production sites in the Midsouth have <1.5% SOM, so soybean producers in the region should be cognizant of potential soil S deficiencies that must be addressed by adding supplemental S-containing products such as gypsum.

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