

LOUISIANA SOYBEAN



NUTRIENT HANDBOOK

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Soil Testing and pH Considerations

A regular soil testing regimen is paramount to a productive row cropping operation and a sound fertility program. In fact, soil testing is the only way for a crop manager to know and efficiently manage lime and fertilizer. Adequate fertility is critical in maximizing soybean production, and very few soils across the state will not require the addition of at least one nutrient to realize yield goals. The estimated uptake of phosphorus (P) and potassium (K) by a 40-, 60- and 80-bushel-per-acre (bu/A) soybean crop is presented in Table 1. Be aware that the values presented are not the amounts of nutrients that need to be applied, but rather the total uptake by the soybean crop from the soil, fertilizer and other sources.

Availability of most plant nutrients is typically greatest in soils with a pH of 5.8-7.0. Continued cultivation and the use of chemical fertilizers, especially those containing ammonium and sulfur, tend to decrease soil pH over time. This is particularly important to keep in mind when soybeans are grown in rotation with corn or other high-nitrogen-use crops. Irrigation with water high in calcium carbonate, on the other hand, tends to increase soil pH.

Soil samples should be collected and checked for the degree of acidity or alkalinity. Lime is generally recommended at pH values below 6.1. Soil texture and the buffer capacity of the soil are required for an accurate estimate of the amount of lime that is needed. If lime is needed, it is recommended to apply it during the fall to provide enough time for it to react with the soil.

The relative neutralizing material (RNV) of lime impacts the amount that is needed to be applied. The RNV of a material is based on its fineness and calcium carbonate equivalent (CCE or the amount of pure calcium carbonate to which the selected material corresponds), with finer materials reacting more quickly than coarse materials. An agricultural lime material with a CCE of 100 is "stronger" than an ag lime material with a CCE of 90. Consequently, less volume would be needed to increase the pH of a given soil.

Nitrogen

In the Plant

Nitrogen (N) accounts for the greatest concentration of all mineral elements found in plants, ranging from 1 percent to 6 percent nitrogen by weight. However, in the minds of many, nitrogen use in soybeans often takes a back seat to many of the other essential nutrients because of the presence of biological nitrogen fixation in legume crops. Producers will often check for active nodulation in young soybeans (the presence of which typically indicates an adequate supply of nitrogen) and then forget about nitrogen for the remainder of the season.

Nitrogen fixation, the act of converting atmospheric nitrogen (N₂) into the plant-usable form of ammonium (NH₄⁺), is economically essential to soybean production as soybeans utilize up to 5 pounds of nitrogen bu/A. This means that a 50 bushels-per-acre-yielding crop would require up to 250 pounds of actual nitrogen. Nitrogen fixation occurs when a bacterium (*Bradyrhizobium japonicum*) infects soybean root hairs around which the soybean will develop a nodule (Figure 1-1). Inside the nodule, the plant will supply energy in the form of sugars, carbohydrates and adenosine triphosphate (ATP) as needed for the fixation process. In return, the plant receives NH₄⁺ from the bacteria. This process can account for up to 80 percent of the nitrogen required by the plant.

Once in the plant, nitrogen is a constituent of many plant cell components, including chlorophyll and other proteins and amino acids. The presence of adequate nitrogen is necessary for optimal photosynthetic activity and vegetative growth. Excess nitrogen, however, can lead to a reduction in uptake of phosphorus, potassium and sulfur and can delay maturity in many crops.

In the Soil

Plants can utilize two forms of nitrogen from the soil, nitrate (NO₃⁻) and NH₄⁺. The presence of either of these sources depends on a variety of factors, including pH and soil moisture. However,

Table 1. Approximate amount of nutrients in a 40, 60 and 80 bu/A soybean crop.

	40 bu/A		60 bu/A		80 bu/A	
	Grain	Stover	Grain	Stover	Grain	Stover
	----- lbs. -----					
Phosphorus (P ₂ O ₅)	32	16	48	24	64	32
Potassium (K ₂ O)	56	104	84	156	112	208



Figure 1-1. Active, nitrogen fixing nodules on soybean roots. Active nodules will have a pink to red color when cut open while nonactive nodules will be green to brown. (North Dakota State University, 2014)

NO_3^- is typically found at greater concentrations in most environments. Nitrogen is ever changing in the soil, especially in the southern regions of the United States and has a high potential to be lost because of leaching of NO_3^- , fixation of NH_4^+ in clay minerals, immobilization by the decomposing of organic residues, volatilization of ammonia (NH_3) or denitrification. For these reasons, soil nitrogen is rarely included in soil tests unless specifically requested and should be assumed that supplemental nitrogen is required for most crops annually.

Although a legume crop, such as soybeans, can take up either NO_3^- or NH_4^+ , the majority of utilized nitrogen will come from nitrogen fixation in the form of NH_4^+ . The nitrogen-fixing bacteria can either be found in the soil where a history of soybean production is present or can be supplied on the seed

at planting through various commercial inoculants. Infection of the roots, nodulation and subsequent nitrogen fixation can be affected by a number of factors, including soil salinity, low pH, extreme cool or hot temperatures, and drought stress.

Deficiency Symptoms

Symptoms of nitrogen deficiency in soybeans typically begin in older leaves as the available nitrogen is remobilized in the plant to young tissues. Symptoms include the appearance of light green to yellow foliage on older growth with progressing symptoms on new growth as the deficiency worsens (Figure 1-2). Nitrogen-deficient soybeans will have markedly reduced vegetative growth with fewer leaves, ultimately resulting in reduced grain yield and quality.

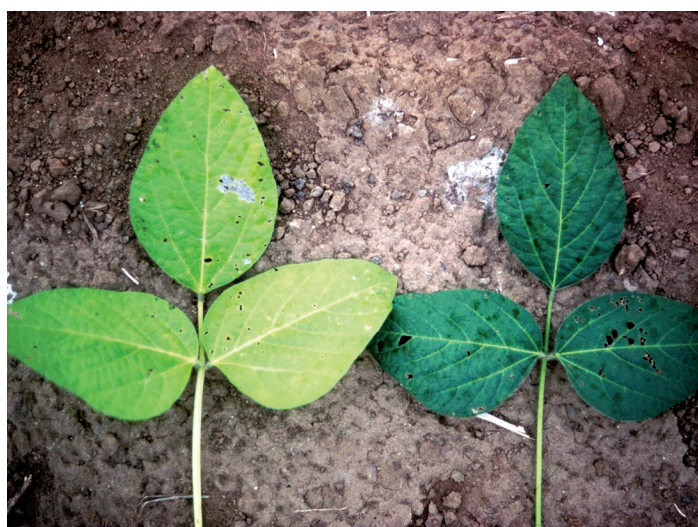


Figure 1-2. Soybean nitrogen deficiency symptoms appear as chlorosis beginning on the older leaves. (IPNI, N.R. Usherwood, 2017)

Deficiency Corrections

Because the majority of the plant's nitrogen will come from nitrogen fixation, a deficiency may not always be directly stemming from a lack of nitrogen but, in some cases, a lack of nodulation. This is often a result of poor inoculation from low pH, ineffective seed inoculation prior to planting, or poor environmental conditions at planting. Regardless of the underlying cause, supplemental nitrogen must now be provided to maintain the remaining yield potential. With the understanding that soybeans require up to 5 pounds of nitrogen per bu/A, producers must make a decision of how much nitrogen to provide based on the realistic yield potential of their individual field. If a nitrogen application is to be made because of poor nodulation, multiple applications will often be required throughout the growing season.

To ensure adequate inoculation and nodulation prior to the growing season, producers should consider the following situations when deciding whether or not they need to inoculate the seed prior to planting. Molybdenum should always be added at planting to improve inoculation when pH falls below 6.2. A commercial inoculant is also recommended in fields with a pH of 6.0 or less. Growers should also include commercial inoculants in fields without a history of soybeans in the previous two to three years or in environments that are not conducive to bacterial survival. In Louisiana, a commercial inoculant should be utilized at planting when soybeans are grown in three-year rotations with sugarcane or those in flooded rotations with rice and crawfish.

There are also conflicting opinions on the use of supplemental nitrogen and its effect on soybean yield. Research from the LSU AgCenter has shown that supplemental nitrogen does not consistently provide increased yield levels. Research has also shown that high levels of soil NO_3^- can reduce nodulation and nitrogen fixation. The concern is that nitrogen fertilizer at any amount greater than the small rates used in some starter fertilizers can delay the development of active nodules beyond the amount of time in which the starter fertilizer is utilized, resulting in a reduction of plant-available nitrogen in the interim.

To check for active nodules, begin scouting when plants have two to three fully unfurled trifoliates. Plants should be dug and not pulled out of the ground because nodules will easily be knocked off the plant. To remove excess soil, rinse the plants in water. Plants should have at least five to 10 nodules at this stage and at least 15 to 20 nodules just prior to R1 (first bloom). Nodules that are actively fixing nitrogen will be pink to red when cut open, while those that are green to brown will not.

Takeaways

- Nitrogen accounts for the greatest concentration of all mineral elements found in plants and is necessary for optimal photosynthetic activity and vegetative growth.
- Nitrogen is ever-changing in the soil and has a high potential to be lost. Nitrogen fixation is necessary for adequate supplies in soybeans and can be reduced by high soil salinity, low pH, extreme cool or hot temperatures, and drought stress.
- Nitrogen deficiency symptoms include chlorosis of older foliage with progressing symptoms on new growth as the deficiency worsens.
- Correction of nitrogen deficiency due to an inoculation failure should be discussed with your local

agent to develop a season-long plan. The realistic yield goal should be determined before deciding how much nitrogen should be applied.

- In Louisiana, soybeans grown in three-year rotations with sugarcane or those in flooded rotations with rice and crawfish should always utilize a commercial inoculant.

Phosphorus

In the Plant

Phosphorus is a driver of plant growth because of its vital role in energy storage and transfer. Adenosine diphosphate (ADP) and Adenosine triphosphate (ATP) act as energy banks in plants. Energy is acquired during photosynthesis and the metabolism of carbohydrates and stored in these phosphate compounds for later use. When the phosphate (H_2PO_4^-) is split away from the ATP molecule, the energy is released. This process of providing energy for plant functions through the splitting of H_2PO_4^- from an ATP molecule is known as phosphorylation. When the ATP molecule is split, it reverts back to ADP. The addition or removal of H_2PO_4^- and conversion between ADP and ATP occur readily in environments with sufficient P.

Phosphorus is also essential in the formation of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). This genetic code is required for the production of proteins and compounds needed to develop both vegetative and reproductive structures. Phosphorus is also often associated with the root proliferation necessary for exploiting the maximum root zone available in our soils.

In the Soil

Dependent upon pH, plants will take up either H_2PO_4^- or HPO_4^{2-} (orthophosphates). H_2PO_4^- , most commonly utilized in plants, is encountered by plants in the soil solution in pH ranges of 3-7.2, while HPO_4^{2-} is most often encountered in soils with pH greater than 7.2.

Soil pH management, as it pertains to available P, is important for several reasons, the first being that HPO_4^{2-} (most prevalent at pH greater than 7.2) is taken up by plants at a much slower rate than H_2PO_4^- (most prevalent at pH less than 7.2). The second reason that managing soil pH is important for phosphorus availability is due to the fixation of phosphorus that occurs both at low and high pHs (Figure 2-1). In soils with low pH, phosphorus precipitates or is adsorbed with iron and aluminum minerals. At a high pH,

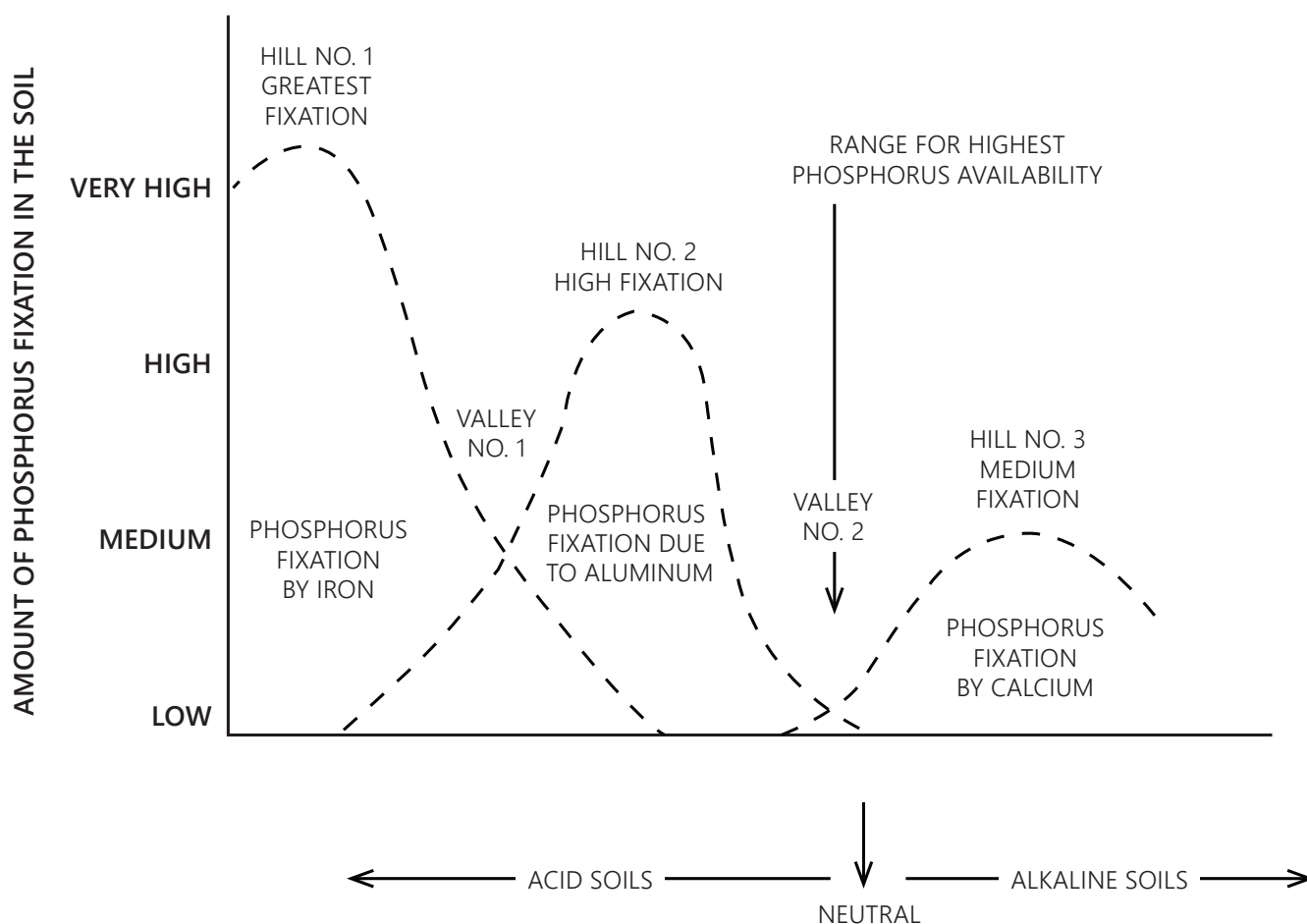


Figure 2-1. The hills and valleys of phosphorus fixation give an idea of how pH affects the availability of phosphorus. (Adapted from M. Stewart, NRCS)

phosphorus will precipitate or adsorb with calcium or magnesium minerals. Both instances can severely reduce plant-available P.

Phosphorus moves through the soil at a very slow rate. The majority of the movement occurs through diffusion (movement from an area of high concentration to an area of low concentration), which is often slowed during cool, wet conditions that can be encountered early in the growing season. It is not uncommon for deficiency symptoms to appear in cool, saturated soils during the seedling stage. This is often not related to a lack of available phosphorus and is often corrected with increasing soil temperatures and drainage.

Deficiency Symptoms

Unfortunately for diagnostic purposes, phosphorus deficiency symptoms are not as striking as many of the other nutrients and can therefore be difficult to notice.

Stunted plants, distorted leaf shape, and dark green to purple coloring of plant tissue are all visual symptoms of phosphorus deficiency (Figure 2-2). Leaves will often appear cupped or rounder than the typical leaf shape. Being mobile in the plant, similar to nitrogen and potassium, the older leaves will develop visual symptoms first. Phosphorus deficiencies can often delay bloom appearance and maturity.

Deficiency Corrections

Because of the lack of mobility in the soil, phosphorus deficiencies are very difficult to correct during the growing season. Therefore, the best correction for phosphorus deficiency symptoms is to develop and utilize an annual soil testing regimen prior to soybean planting as nonincorporated applications only improve phosphorus soil test levels in the top 1 inch. Phosphorus applications should either be banded near the top of the row or incorporated to improve the distribution.



Figure 2-2. Soybean phosphorus deficiency often appears as stunted plants with dark green older leaves. (IPNI, L.A. Zanao, Jr., 2012)

Takeaways

- Phosphorus is essential as the source of energy storage and transfer in the plant as well as a component of DNA and RNA.
- Phosphorus is greatly affected by pH and is most available to plants at a pH range of 6.0-7.2.
- Phosphorus symptoms appear as stunted plants with distorted and dark green to purple colored leaves.
- Correction of phosphorus deficiency symptoms are difficult during the growing season because of the immobility of phosphorus in the soil. Phosphorus applications should be made prior to the growing season based on soil test recommendations by either banding or incorporating the product.

Potassium

In the Plant

At approximately 1 to 2 percent concentration of plant dry matter, potassium (K) is the second most-common nutrient in the plant obtained from the soil. Potassium plays many roles in the plant but, unlike most other nutrients, is not a component of any biochemical compounds. Potassium occurs only in solution or is bound to negatively charged surfaces of plant tissues, which explains its high mobility in plants. Because of its presence as a cation (positively charged molecule), potassium is involved in regulating water

and solute movement, charge balance, and osmotic and turgor pressures in cells. In other words, potassium helps to move and keep water and solutes where they are supposed to be based the relative concentration of potassium in cells.

One extremely important role potassium plays in plants is the opening of stomata, which are microscopic pores in the leaf epidermis which are surrounded by a pair of guard cells. In the morning, an influx of potassium ions into the stomatal guard cells occurs, causing stomata to open. This is important because this is the pathway in which CO₂ enters the plant. With a reduction in the availability of K, stomata do not function efficiently and the rate of photosynthesis and water use efficiency both decline.

Potassium deficiencies can also affect other aspects of crop management. Because of the reduced efficiency of stomata, plants will become much less drought tolerant. Water can be lost through open stomata when turgor pressure is not maintained. Plants will also become less tolerant to diseases. Leaves and pods will become sensitive to disease infestation, and pods and seeds can become shriveled with reduced yields.

In the Soil

Unlike phosphorus and many other plant nutrients, pH has little effect on the availability of soil K. Being a cation, potassium is found both in soil solution and as exchangeable potassium at negatively charged soil particles bound by electrostatic attraction.



Figure 3-1. Soybean potassium deficiency symptoms appear as chlorosis or necrosis on the leaf margins beginning with the older growth in the lower canopy. (LSU AgCenter, 2018)

This exchangeable potassium allows for the buffering, or replenishing, of potassium as it is removed from the soil solution through leaching or removal by the plant.

The majority of potassium movement in the soil occurs via mass flow, or the movement of a nutrient with flow of water in the soil. Once near the root system, diffusion (movement from an area of high concentration to an area of low concentration) is the main mechanism of potassium movement towards the roots. For this reason, soil moisture plays a large role in the availability of K. As soil moisture decreases, the water around soil particles becomes discontinuous and increases the tortuosity of the path by which potassium moves toward the roots.

High levels of additional exchangeable cations, such as calcium (Ca) or magnesium (Mg), can influence the amount of exchangeable potassium found in the soil and can potentially reduce potassium availability. This is mainly due to the increase in presence by these cations bound on the negatively charged soil particles. The basic cation

saturation ratio (BCSR) was developed in the 1940s to show that an ideal soil should have a certain ratio of Ca:Mg:K. Regardless of the ratio, however, soil testing is the proper way to determine the adequacy of potassium availability in soils. Available potassium can be present at either adequate or deficient amounts in the soil regardless of whether the BCSR is satisfied or not. Research has shown no response to potassium fertilization when soil test potassium is adequate, regardless of the BCSR.



Figure 3-2. Soybean potassium deficiency symptoms appear as chlorosis or necrosis on the leaf margins. (IPNI, J. Coder, 2017)

Deficiency Symptoms

Potassium, being mobile in the plant, will often show visual deficiency symptoms in the older leaves in the lower part of the plant canopy. The most prominent symptoms will appear as chlorosis of the leaf margins (Figure 3-1 and Figure 3-2). As the deficiency progresses, chlorosis of the margins will develop into necrosis as the leaves begin to die back. As symptoms progress deeper into the leaf, interveinal chlorosis, or yellowing of the leaves between the leaf veins, will occur. The margins of the leaves will remain completely yellow with no green veins.

These visual symptoms will often be present during the reproductive stages of plant growth as potassium is being utilized in the development of pod and seed fill. Before visual symptoms are present, however, deficient plants will be stunted and stems can be thin and weak. Potassium deficient soybeans are at increased risk of lodging later during the growing season.

Deficiency symptoms may also appear late during reproductive growth (R5-R6) as potassium is mobilized from existing vegetative tissue to developing pod and seed. It is not uncommon for these symptoms to appear on young vegetation as this mobilization will occur from the nearest source to the pod in question. These late season symptoms do not always suggest a deficiency but rather a remobilization as leaves begin to senesce.

Deficiency Corrections

The best correction for potassium deficiency symptoms is by developing and utilizing an annual soil testing regimen prior to soybean planting. The majority of potassium utilized by the plant will be taken up during vegetative development even though the majority of the utilization may occur during reproductive growth. It is often the case that any steps taken to correct potassium deficiency during reproductive growth will not improve yield. If a deficiency is apparent prior to reproductive development because of a misapplication or nonapplication prior to the growing season, muriate of potash (0-0-60) can be applied at soil test recommended rates. Be aware, rainfall or irrigation will be required to move potassium into the root zone.

Takeaways

- Potassium is essential to several functions in the plant, including regulation of stomatal openings and movement and regulation of water and solute translocation to various parts of the plant, including pod and seed.
- Potassium availability is affected by soil moisture, and uptake is greatly reduced in dry environments.
- Potassium symptoms appear as chlorosis and necrosis of the leaf margins and interveinal chlorosis of the inner leaf. Symptoms will appear first on older growth.
- Correction of potassium deficiency symptoms are difficult during the growing season, especially during reproductive growth. Potassium applications should be made prior to the growing season based on soil test recommendations.

Sulfur

In the Plant

Sulfur (S) is found in legume plants, such as soybeans, at about 0.25 to 0.3 percent dry matter. Similar to nitrogen (N), sulfur is essential for the makeup of three amino acids needed for protein production in plants. These two nutrients are so intertwined, in fact, that a reduction in sulfur will often reduce N-use efficiency in most plants. The function of sulfur in proteins is the formation of disulfide bonds that help hold proteins together. Sulfur is also essential for the synthesis of several coenzymes and vitamins needed for plant metabolism, as well as chlorophyll synthesis, although it is not a direct constituent.

Sulfur is taken into the plant mainly as sulfate (SO_4^{-2}), although the roots can also absorb thiosulfate ($\text{S}_2\text{O}_3^{-2}$). Similar to the reactions required for the reduction of nitrates, the reduction of SO_4^{-2} to a plant-usable form is one of the most energy-intensive reactions that occurs in plants.

In the Soil

Sulfate reaches the roots mainly through mass flow, the movement of nutrients with the soil solution because of transpirational water uptake by the plant. Therefore, reduced transpiration in the plant due to drought or reduced plant function can reduce sulfur movement to the roots. Waterlogged soils will also reduce sulfur uptake as roots remove have little capacity for nutrient uptake in anaerobic conditions. It is important to remember that just like N, SO_4^{-2} can leach from soils and the potential for leaching losses increase with increasing quantities of water moving through the soil (i.e., more rain or irrigation).

In acid soils, adsorbed SO_4^{-2} is also an important fraction of total S, especially in areas of high Al/Fe oxides. Adsorbed amounts of SO_4^{-2} are typically greater in acid subsoils as SO_4^{-2} is leached from surface soils. On the other end of the spectrum, SO_4^{-2} availability decreases in calcareous soils, with increasing pH due to its coprecipitation with calcium compounds, though this is fairly uncommon in Louisiana soils.

Elemental, or inorganic, sulfur is often used as a fertilizer source, but it must be oxidized before becoming plant-available. This oxidation process can be slow depending on the environmental conditions and must be considered when determining what fertilizer source will best fit a producer's program. Factors affecting the rate of sulfur oxidation include soil microbial activity, sulfur source characteristics, and soil conditions such as temperature, moisture, and pH.

Deficiency Symptoms

Because both sulfur and nitrogen are both constituents of amino acids and proteins, the deficiency symptoms are strikingly similar. Sulfur deficiency symptoms include pronounced stunting and yellowing, or chlorosis, of leaves (Figure 4-1). The main difference between the symptoms of sulfur and nitrogen are the location with which the yellowing of leaves will begin in the canopy. Sulfur, being fairly immobile in the plant, will typically begin showing deficiency symptoms in young, new leaves. Plants deficient in sulfur can also look spindly with thin stems.



Figure 4-1. Soybean sulfur deficiency symptoms appear as a general stunting and chlorosis of the leaves beginning with young, new growth. (IPNI, V. Casarin, 2018)

Deficiency Corrections

Sulfur deficiencies can be corrected during the growing season but only with SO_4^{2-} containing fertilizer sources. Common sources of immediately available sulfur include ammonium or potassium sulfates. Elemental sulfur should not be used during the season to correct a deficiency except for early season applications with which 20-25 percent of the applied sulfur must be in the readily available SO_4^{2-} form.

If low sulfur is discovered in a soil test prior to the growing season, then producers can broadcast and incorporate elemental sulfur alone in the fall or spring if 20 to 25 percent of the total sulfur applied is in the readily available SO_4^{2-} form. When utilizing elemental S, broadcasting and incorporating the product will increase the rate and amount of oxidation compared to banded or nonincorporated applications. Uniform incorporation of elemental sulfur can also help to minimize the acidifying effects of the oxidation process.

Oxidation rates of elemental sulfur will depend on the characteristics of the product, particularly the size of the individual particles. With decreasing particle size, oxidation rates are increased because of an increase in particle surface area for oxidation to occur. Regardless of elemental sulfur fertilizer source or application, the farther ahead of planting that elemental sulfur is applied, the greater the SO_4^{2-} availability will be for the crop.

Takeaways

- Sulfur (S) is a secondary plant nutrient essential in the development of three amino acids and subsequent protein development.
- Sulfur deficiency symptoms include chlorosis of young foliage along with a pronounced stunting of all new tissues.
- Sulfate, although immediately available for plant uptake, is highly mobile in the soil solution and has an increased leaching potential similar to nitrates. Conversely, elemental sulfur must be oxidized to be plant available and should not be used to correct in-season deficiencies.

Calcium

In the Plant

Calcium (Ca) is essential in the formation of new cell walls, specifically the middle lamella that separates plant cells. It is required for normal plant membrane functions and permeability. Low calcium results in increased permeability of cell membranes, reduction of nutrient uptake, potential loss of cellular contents and the reduction of cell division. Because of its function in the makeup of cell walls, calcium is also essential for the translocation of many photosynthetic products and nutrients in the plant. As the carbohydrates build up in leaves under a calcium deficiency due to a lack of adequate translocation, root function will decline, and nutrient uptake is severely reduced.

Calcium is immobile in the plant. When calcium is taken into the plant through the roots, it is moved through the xylem with transpirational water. Once in the leaves, minimal amounts of calcium are moved through the phloem to other parts of the plant. Because of this, it is important that plants have a continuous supply of calcium for adequate root and shoot development. Conditions that will limit root growth will hinder access to calcium and can potentially induce a calcium deficiency.

In the Soil

Calcium, a cation in the soil (Ca^{+2}), occupies the negatively charged sites found on the surface of clay particles that make up a soil's cation exchange capacity (CEC). In many Louisiana soils with a neutral or alkaline pH, calcium often dominates these exchangeable sites. As with any cations that occupy these sites, soil calcium will exist in equilibrium between solution and exchangeable Ca. As calcium is removed from the solution because of plant uptake or leaching, exchangeable calcium will desorb from these sites into the soil solution to maintain this equilibrium. Plant roots often encounter calcium through mass flow or through root interception as the growing roots come into contact with the calcium in the solution.

Deficiency Symptoms

Because of the immobile nature of calcium in plants and the function of calcium with newly developing cells, deficiency symptoms are primarily found in meristematic regions, or regions of rapid cell division, such as terminals and apical growing points of roots. Newly developing leaves and root tips will become necrotic as cells attempting to divide die. Because cell walls do not form, the contents of dividing cells are



Figure 5-1. Soybean calcium deficiency cause a dieback of meristematic regions and unfurling leaf tissues will often stick together as newly dividing cells lack adequate cell wall formation. (IPNI, T.L. Roberts, 2018)

lost and often cause the developing leaflets to stick together as the trifoliates unfold (Figure 5-1).

In the soil, calcium deficiencies can lead to poor nodulation, while the nodules that do form are white to green when sliced open instead of the characteristic pink color of active nodules. Root development will be reduced, and root tips will also have a dark color as the roots also begin to die back.

Deficiency Corrections

Calcium deficiencies in Louisiana are very uncommon as many of our soils contain large amounts of plant-available Ca. Soils with the potential for low plant-available calcium levels will often have a low pH. To correct both low soil pH levels and the potential for calcium deficiencies in soybean, soils should be limed with either CaCO_3 (calcitic lime or ag-lime) or $\text{CaMg}(\text{CO}_3)_2$ (dolomitic lime). If calcium is needed to correct low soil calcium without the need to increase soil pH, then $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (gypsum) should be applied.

Takeaways

- Calcium (Ca) is a secondary plant nutrient essential in the development and function of plant cell walls, including the translocation of many carbohydrates and nutrients found in plant tissues.
- Calcium occurs as a cation in the soil (Ca^{+2}), both in solution and adsorbed to the negatively charged exchangeable sites on clay particles that make up the majority of a soil's CEC. Low pH soils typically have reduced plant-available calcium and require greater concentrations of calcium to maintain root growth than do soils with a higher pH.

- Calcium deficiency symptoms include the dieback of terminal meristems in shoots and apical meristems in roots. Leaflets of a soybean trifoliate will often remain stuck together as they unfurl because of the lack of cell wall separation in newly dividing cells.

- To correct both low soil pH levels and the potential for calcium deficiencies in soybean, soils should be limed with either CaCO_3 (calcitic lime or agricultural lime) or $\text{CaMg}(\text{CO}_3)_2$ (dolomitic lime). If producers need to correct low soil calcium without the need to increase soil pH, then $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (gypsum) should be applied.

Magnesium

In the Plant

Although magnesium (Mg) is considered a secondary nutrient, the roles it plays in plant structure and metabolism are anything but. Fifteen to 20 percent of the magnesium in plants can be found in chlorophyll as a vital, structural component of the chlorophyll molecule, without which photosynthesis would not occur. Magnesium is also needed for the energy transfer reactions of phosphate transfer from ATP, which was previously discussed with phosphorus. These reactions are required to supply the energy for many plant processes, including photosynthesis, respiration and many other metabolic processes in the plant.

In the Soil

Similar to calcium (Ca) in our soils, magnesium occurs as a cation (Mg^{+2}) in the soil and in the plant and occupies the negatively charged sites found on the surface of clay particles that make up a soil's cation exchange capacity (CEC). In many Louisiana soils with a neutral or alkaline pH, magnesium can be very high and occupy a lot of these exchangeable sites. As with any cations that occupy these sites, soil magnesium will exist in equilibrium between solution and exchangeable Mg. As magnesium is removed from the solution because of plant uptake or leaching, exchangeable magnesium will desorb from these sites into the soil solution to maintain this equilibrium. Plant roots often encounter magnesium through the mass flow or diffusion of solution Mg. There is the rare potential, in the presence of very high Ca, for magnesium deficiencies to be induced because of a high Ca:Mg ratio of 10:1 to 15:1. Magnesium uptake can also be reduced by high levels of aluminum (Al^{+3}), ammonium (NH_4^+), or potassium, although all three cases will be rare in Louisiana.



Figure 6-1. Soybean magnesium deficiency appears as interveinal chlorosis. (IPNI, E.A.B. Fransisco, 2018)



Figure 6-2. Soybean magnesium deficiency appears first on the older growth of the lower part of the canopy. (IPNI, L.Prochnow, 2018)

Deficiency Symptoms

Though very rare in Louisiana, magnesium deficiency symptoms are similar to both iron and manganese symptomology, including interveinal chlorosis, or the yellowing of leaves between the veins of the leaf (Figure 6-1). Because of the mobility of magnesium in the plant, however, symptoms will begin to occur in older leaves in the lower part of the canopy instead of new growth like iron and manganese (Figure 6-2). Under severe deficiencies, the symptomology will progress to a uniform chlorosis and necrosis of the leaves.

Deficiency Corrections

Magnesium fertility should only be necessary in some of our coarser soils with low inherent fertility. Magnesium fertility in soils with accompanying acid pH levels can be treated with $\text{CaMg}(\text{CO}_3)_2$ (dolomitic lime) to correct both low magnesium levels and low pH. In soils with a more neutral pH, $\text{K}_2\text{SO}_4\cdot\text{MgSO}_4$ (K-mag) can be utilized. Magnesium levels are reported in most routine soil test results and any deficient levels should be corrected prior to the growing season.

Takeaways

- Magnesium (Mg) is a secondary plant nutrient that is an essential structural component of chlorophyll and is necessary for the energy transfer reactions that occur during photosynthesis, respiration and many other metabolic processes.
- Magnesium occurs as a cation in the soil (Mg^{+2}) both in solution and adsorbed to the negatively charged exchangeable sites on clay particles that make up the majority of a soil's CEC. Although calcium will often take up the majority of these exchangeable sites in our soils, magnesium will occupy a significant portion.
- Magnesium deficiency symptoms include the interveinal chlorosis of older leaves in the lower part of the canopy. Progressing deficiency symptoms will appear as a total chlorosis or necrosis of older leaves.
- To correct both low soil pH levels and the potential for magnesium deficiencies in soybean, soils should be limed with $\text{CaMg}(\text{CO}_3)_2$ (dolomitic lime). If producers need to correct low soil magnesium without the need to increase soil pH, then $\text{K}_2\text{SO}_4\cdot\text{MgSO}_4$ (K-mag) can be applied.



Figure 7-1. Soybean iron deficiency appears as interveinal chlorosis. (LSU AgCenter)

Iron

In the Plant

Iron (Fe) is taken up and found in the plant as either Fe^{+2} or Fe^{+3} . Iron readily exists in both forms in the plant and, because of this, has the ability to either donate or accept an electron dependent upon its current state. This attribute allows iron to be utilized as a component of enzymes required for the transfer of electrons in photosynthesis and respiration. Iron is also utilized in a similar role during the synthesis of chlorophyll, which is thus reduced in Fe-deficient environments.

Iron is also critical in soybeans because of its role as a constituent of both nitrogenase and leghemoglobin, both required for nitrogen fixation. Nitrogenase is an enzyme that catalyzes the high-energy reactions necessary for fixation. Leghemoglobin is responsible for transporting oxygen to the respiring, N-fixing bacteria, similar to how hemoglobin in humans transports oxygen to respiring our cells. Leghemoglobin is responsible for the pink color associated with healthy, active nodules on the plant roots.



Figure 7-2. Soybean iron deficiency symptoms can appear scattered as soil conditions affecting iron availability vary throughout the field. (LSU AgCenter)

In the Soil

Iron cation (Fe^{+2} or Fe^{+3}) concentrations are very low in soil solution compared to other cations, such as potassium (K^{+}), calcium (Ca^{2+}) or magnesium (Mg^{2+}). Because of this lack of solubility, iron often requires organic compounds in the soil to chelate the iron to increase the solubility and supply to plant roots. Chelated iron will then diffuse toward the plant roots where the concentration is lower. The iron will then dissociate from the chelate due to interactions with the cell walls of the plant roots. The chelating compound will then diffuse away back into the bulk solution, again with the concentration gradient, where the cycle will continue.

Iron solubility in soils is extremely dependent on soil pH. For every unit increase in soil pH, iron concentration in solution will decrease a thousandfold. This high pH environment is common in many parts of Louisiana, and iron deficiency symptoms are seen annually on

many of these soils. Because of the inherent insolubility of iron coupled with the high pH soils we often find in our state, it is of additional importance that soybeans, along with many other plants, have the ability to modify the rhizosphere to enhance iron solubility to increase uptake by the roots. Soybean roots will exude protons (H^{+}) to acidify the rhizosphere. This, along with additional enzymes in the roots, will increase iron solubility and allow for increased uptake. This activity will increase in Fe-deficient environments.

Deficiency Symptoms

Iron deficiency chlorosis (IDC), as it is often termed, will first appear in young growth in the upper parts of the canopy. Symptoms will begin as interveinal chlorosis, a yellowing of the leaf tissues between the veins of the leaves (Figure 7-1). The veins will remain bright green in the early stages of deficiency symptoms. As the deficiency progresses, the veins will also become chlorotic and the leaf can appear bleached. The

chlorosis stems from the requirement of iron for the synthesis of chlorophyll. Eventually, leaves will become necrotic and begin to die back with increasing severity.

Symptoms will often appear scattered as soil conditions will vary throughout the field (Figure 7-2). Soil conditions, including soil moisture, compaction, and pH, can influence the availability of Fe.

Deficiency Corrections

When IDC is observed in Louisiana, it is commonly related to the current environmental conditions rather than a true deficiency. Environmental conditions limiting iron uptake include both waterlogged soils and extremely dry soils. Waterlogged soils, often with low oxygen and high carbon dioxide concentrations, reduce iron availability often because of an increase in bicarbonates in the soil. Dry soils reduce iron availability because of an increase in the tortuosity of the soil and a reduction of diffusion of chelated iron to the roots. In either case, symptoms will typically improve with the drying or wetting of the soil, respectively. In cases of IDC not related to environmental conditions, iron can be applied foliar to soybean with chelated materials at typical rates of 0.1-0.2 of a pound per acre to correct most deficiencies.

Takeaways

- Iron is essential for the synthesis of chlorophyll and many reactions occurring during photosynthesis and respiration. Iron is also necessary for nitrogen fixation in soybeans.
- Iron availability is affected by varying soil conditions and is greatly reduced in high pH soils.
- Iron deficiency chlorosis (IDC) symptoms appear as interveinal chlorosis with prominent green veins. Symptoms will appear first on new, young leaves.
- Most IDC observations in Louisiana will be caused by environmental conditions associated with either waterlogged or dry soils and will correct themselves as conditions improve. If necessary, applications of 0.1 to 0.2 of a pound per acre of actual iron are required to correct IDC using a chelated iron product.

Zinc

In the Plant

Zinc (Zn) is taken into the plant as the cation Zn^{2+} . Zinc is required for many enzymatic activities and the metabolism of protein, carbohydrates and lipids in the plant. It is also required for the synthesis of chlorophyll

and has been shown to contribute to plant resistance against diseases and drought stress. Zinc is also vital in the synthesis of tryptophan. Tryptophan, an amino acid, is subsequently required for the production of plant hormones, such as indoleacetic acid, that regulate the development of new tissues.

In the Soil

Zinc availability is highly influenced by soil pH and will decrease in availability to plants as pH increases. Zinc deficiencies can occur in high pH, calcareous soils as zinc is adsorbed strongly to calcium complexes in the soil and can become unavailable to plants. Similar to iron, zinc is often chelated in soils and thus moves towards the plant roots in soil solution through diffusion from high to low concentrations. Therefore, drought environments can also reduce the movement of zinc to the plant, reducing availability.

Deficiency Symptoms

Being less sensitive to zinc deficiencies than corn and other small grains, zinc deficiencies are fairly uncommon in Louisiana soybean. When deficiency symptoms are observed, they will begin in the older growth because of the mobile nature of zinc in the plant. Symptoms will appear as an interveinal mottling, light green and yellow spotting between leaf veins. As symptoms progress in the older leaves, a more typical interveinal chlorosis will be observed before leaf tissues begin to show signs of bronzing and necrosis and will eventually fall from the plant (Figure 8-1). Because of the role zinc plays in the synthesis of plant hormones, internodes will be shortened, and newly emerging leaves will often be small and distorted. Few flowers and pods will be set and those that are will develop abnormally and eventually abort.



Figure 8-1. Soybean zinc deficiency causes interveinal mottling leading to necrosis of older leaves, shortened internodes, and malformed development of new tissues. (IPNI, D. Whitney, 2018)

Deficiency Corrections

Producers should soil test on a regular basis to monitor zinc levels in soils. Prevention of low soil levels is the best method of maintaining proper plant nutrition. If necessary, 0.5 pound of an elemental zinc product per acre or 1 pound of a zinc sulfide or zinc oxide product can be applied foliar to correct deficiencies.

Takeaways

- Zinc is essential for the synthesis of chlorophyll and plant growth hormones as well as the metabolism of proteins, carbohydrates, and lipids.
- Zinc availability is affected by varying soil conditions and is greatly reduced in high pH soils.
- Beginning in older leaves, zinc deficiency symptoms begin as interveinal mottling progressing to chlorosis and necrosis. Shortened internodes and small, distorted new tissues are also signs of inadequate zinc levels.
- Preventative measures should be taken through regular soil testing regimens. If necessary, foliapplications of 0.5 a pound per acre of elemental zinc or 1 pound per acre of zinc sulfide or zinc oxide are required to correct deficiencies.

Copper

In the Plant

The micronutrient copper (Cu) is taken into the plant as Cu^{+2} . Copper is used throughout the plant for electron transport in both photosynthesis and respiration because of the ease with which it can both accept and donate electrons. Plastocyanin, a protein involved in energy transfer during photosynthesis, contains about 50 percent of the copper found in plant cells or chloroplast. Additionally, several copper containing enzymes are needed for the synthesis of lignin, the constituent of plant cell walls that gives strength to plant tissues. The reduction of lignin development because of a copper deficiency can also increase disease susceptibility. Copper also plays roles in the metabolism of carbohydrates (sugars, starches, celluloses) and nitrogen.

In the Soil

Very little Cu^{+2} is found in the soil solution. It is often encountered by the roots in the form of organic complexes and the diffusion of these copper chelates

through the soil solution. Copper is more strongly bound to organic matter than most nutrients and can also be adsorbed onto clay minerals in the soil. Coarse, highly leached soils, soils high in organic matter, and those with high pH are at the greatest risk of copper deficiencies. High levels of zinc, iron and phosphorus can also reduce copper absorption by the roots.

Deficiency Symptoms

Copper deficiencies are rare, and symptoms can vary, but deficiencies most often result in the stunting of plants and chlorosis of leaves as nitrogen fixation is reduced. Flowering and maturity are often delayed, and pollen can be sterile, resulting in blank pods. Deficiencies will often begin in new leaves as copper is fairly immobile in the plant.

Deficiency Corrections

Routine soil testing as part of an overall fertility management plan will alert a producer to any potential issues related to low Cu. Copper sulfate (CuSO_4), at 2 to 4 pounds per acre, will provide adequate copper for several years when soil test levels are low.

Takeaways

- Copper is essential in small amounts to aid in electron transport during photosynthesis and respiration, for the synthesis of lignin in cell walls, and for the metabolism of carbohydrates and nitrogen.
- Only small concentrations of copper are found in solution as most is strongly bound to the organic fractions of the soil. Soils at a greater risk for copper deficiencies include coarse sands, soils high in organic matter or soils with high pH.
- Copper deficiencies appear as a general stunting of the plant and chlorosis of young leaves because of its role in photosynthesis and the reduction of nitrogen fixation. Flowering and maturity are often delayed, and pollination efficiency reduced.

Manganese

In the Plant

As do all 16 essential plant nutrients, manganese (Mn) plays a vital role in plant growth and development. One of the major functions of manganese in the plant is the oxidation of two water molecules into one molecule of oxygen and four hydrogen ions. This splitting of the water molecules

helps power the photosynthesis process by supplying electrons that are needed throughout. This Mn-requiring, photosynthetic complex is also the source of almost all of Earth's atmospheric oxygen and is the only known biochemical system to perform this reaction. Manganese also has a role in several metabolic reactions including respiration and the reduction of N-nitrate to a form of nitrogen readily utilized by the plant.

In the Soil

Manganese availability is tied to soil pH variations. As the pH increases by one unit, manganese availability in the soil solution decreases a hundredfold. Reduced availability of solution manganese can occur at soil pH as low as 6.5. With many of the soils in Louisiana having neutral or greater pH, it is not uncommon for manganese deficiency symptoms to appear based on a lack of available manganese even if total soil manganese is adequate or even high. As the soil pH decreases, manganese will become increasingly soluble, leading to potentially toxic levels (pH < 5.5).

Manganese occurs in the soil as oxide and hydroxide minerals and as Mn^{+2} in the soil solution. As a result, dry soil conditions (increased oxygen levels) can also reduce manganese availability from the formation of low-soluble Mn-O compounds. In some cases, manganese deficiency symptoms can be corrected through proper irrigation or a measurable rainfall event. As counterintuitive as it may seem, this is the reason that some fields may not show symptoms beneath tire tracks because of the reduced pore space and subsequent reduced O_2 levels found in compacted areas.



Figure 9-1. Soybean manganese deficiency symptoms appear as interveinal chlorosis with prominent green veins. (IPNI, R.J. Gehl, 2010)



Figure 9-2. Soybean manganese deficiency symptoms can appear scattered as soil conditions affecting manganese availability vary throughout the field. (IPNI, R.J. Gehl, 2010)

Deficiency Symptoms

Manganese is an immobile nutrient in the plant. This means as manganese becomes deficient in the plant, what is present cannot be moved to new or developing tissues. Therefore, the first symptoms will appear on young or newly emerged leaves. The most prominent symptoms appear as interveinal chlorosis, or yellowing of the leaves between the leaf veins (Figure 9-1).

Symptoms will often appear scattered as soil conditions will vary throughout the field (Figure 9-2). Soil conditions, including soil moisture, compaction, and pH, can influence the availability of Mn.

Manganese deficiency symptoms can be difficult to distinguish from iron deficiencies, and either deficiency can occur under some of the same environmental conditions. A knowledge of the local soils can help to narrow down the potential culprit, but a tissue sample is often necessary to distinguish between the two.

Deficiency Corrections

To correct manganese deficiencies during the season, growers have few options. A foliar application of 1 pound per acre of actual manganese at the first appearance of symptoms and can apply an additional 0.5 to 1 pound per acre if deficiency symptoms reappear. Sources can include either manganese sulfate or a chelated manganese material. Many manganese products may recommend reduced rates; however, these are often maintenance rates and a full rate as listed will be needed to correct deficiencies.



Figure 10-1. Soybean boron deficiency can cause a stacking of nodes resulting in stunted plants. (IPNI, B.R. Golden, 2018)

Manganese toxicity can occur when over applied or in soils with low pH. If there is any question as to whether the present symptoms are not manganese related, then a tissue sample is warranted.

Takeaways

- Manganese is essential to several functions in the plant, including photosynthesis and conversion of nitrates to plant-usable forms.
- Manganese availability is affected by varying soil conditions and is greatly reduced in high pH soils.
- Manganese deficiency symptoms appear as stunted plants with interveinal chlorosis with prominent green veins. Symptoms will appear first on new, young leaves.
- Foliar applications of 1 to 2 pounds per acre of actual manganese are often required to correct deficiencies using either manganese sulfate or a chelated manganese product.

Boron

In the Plant

Uptake of the micronutrient boron (B) by plants is an active process as boric acid (H_3BO_3) requires the presence of hydrogen (H^+) to be moved into plant cells. Because of the necessity for H^+ , boron uptake is reduced in alkaline soils. Boron is readily moved to the leaves through the xylem and will remain there because of its immobile nature in the plant. Much of the boron found in the plant will be present in cell walls where it is vital for cell elongation, regulation of cell calcium and H^+ , nitrogen metabolism and translocation of photosynthetic products from the leaves to the rapidly growing meristematic regions of the plant.

In the Soil

Boric acid is mobile in soils and is often transported through soil solution by both diffusion and mass flow. Because of its mobility in soils there is a potential for boron to leach through the root zone, especially in coarsely textured, low pH soils. Boron availability is reduced in high pH soils and in the fine textured soils with high pH that are common in Louisiana. In addition, calcium can impede boron availability. Boron deficiencies are also associated with dry soil conditions as moisture is needed to aid in the transport of boron through the soil to the root surface.

Deficiency Symptoms

Boron deficiency symptoms can vary but will often begin in the upper part of the canopy on young, newly developing tissues because of the immobile nature of boron in the plant. Because of boron's role in cell division and elongation, symptoms are often seen in or near regions of rapid growth, such as shoot terminals. The first visible symptoms will typically occur as a stunting of the plant because of the stacking of nodes (reduced internode lengths) (Figure 10-1). Deficient plants will be shorter than neighboring, healthy plants but may have the same number of nodes. Young leaves will be discolored and will often cup downward, similar to some auxinic-type herbicides, as symptoms progress (Figure 10-2). Severe symptoms can cause terminal dieback similar to calcium deficiencies.



Figure 10-2. Soybean boron deficiency can cause discoloration and cupping downward of leaves. (IPNI, B.R. Golden, 2018)

A major portion of the boron used by the plant is taken up during the reproductive stages of growth and a deficiency late in the growing season can reduce pod set and seed fill even though vegetative symptoms may not appear.

Deficiency Corrections

Unlike many nutrient deficiencies that can be corrected with no further sign of the offending symptoms, boron symptoms will not be eliminated even with proper correction practices. Correction practices can minimize the yield losses. However, prevention of the deficiency is a much better option. Soil test reports low in plant-available boron should be corrected through the use of a granular boron product broadcast at 0.5 to 1 pound per acre.

Although, numerous products are available to correct boron deficiencies, care should be taken in their application because of the potential of both reduced germination of seed and phytotoxicity on emerged plants. Boron fertilizers have the potential to reduce soybean germination and, therefore, should not be banded near seed. Broadcast applications should be made at least one to two weeks prior to planting to prevent reduced germination of seed. Foliar products can be used during the growing season but should not be applied at rates greater than 0.5 of a pound per acre and should not be applied to soybean under water stress.

Takeaways

- Boron (B) is a micronutrient essential in the function of plant cell walls, including the regulation of calcium and hydrogen and the translocation of many carbohydrates and nutrients found in plant tissues.
- Boron availability decreases with increasing pH and soybean uptake of boron grown in fine-textured, high pH soils can be impeded by high levels of calcium.
- Boron deficiency symptoms typically include the stacking of nodes on stunted plants and leaves will often be discolored and can be cupped downward. Severe deficiencies can cause terminal dieback.
- Late season deficiencies may reduce pod set and seed fill even without visible symptoms on vegetative structures.
- Prevention of boron deficiencies is important as visual symptoms will not be eliminated though yield losses can be minimized through foliar products.
- Fertilization of soybean with boron should be done with care to prevent reduced germination of soybean seed or phytotoxicity of emerged plants.

Chloride

In the Plant

Chloride (Cl) is absorbed and utilized in plants strictly as the anion, chloride (Cl^-). Chloride is often taken into the plant through other anion channels such as nitrate, sulfate, or phosphate. The main function of Cl^- throughout the plant is to maintain electroneutrality as cations are utilized in various plant processes. Of these processes, the two most important are the evolution of oxygen during photosynthesis and the maintenance of turgor pressure in stomatal guard cells to regulate water loss and gas exchange. In both cases, Cl^- is used by plants to balance the oxidation or transport of cations in plant cells. A reduction of Cl^- concentration in the plant will both reduce the rate of photosynthesis and increase water loss because of a reduction of stomatal regulation.

In the Soil

Chloride is very soluble in soils, and nearly all of the Cl^- in soils will occur in soil solution. Excess Cl^- can accumulate in areas without sufficient water to leach excess Cl^- , soils with poor drainage characteristics, soils with a high water table or soils with a layer of restricted drainage (i.e., tillage pan or hard pan). These can all lead to excess Cl^- availability in localized areas in which root growth is concentrated.

Deficiency and Toxicity Symptoms

Although Cl^- deficiencies are rarely observed in soybeans, two main symptoms include the chlorosis of younger leaves and wilting of the plant. These symptom descriptions make sense when we consider the role of Cl^- in both photosynthesis and stomatal regulation.

The more prevalent issue in Louisiana, however, is Cl^- toxicity. Chloride toxicity is often observed in soybeans under continuous irrigation with water high in Cl^- . Toxicity symptoms include interveinal chlorosis and progress to scorching, or necrosis, of the leaf margins. Leaves will thicken, and eventually tissue will die and fall from the plant. Symptoms often appear shortly after irrigation water is applied.

Toxicity Prevention

Producers should have irrigation water tested regularly to determine water quality. Seasonal environment will also play a large role in whether toxicity issues are seen. If rainfall is adequate,

irrigation will be utilized less, and symptoms will be less obvious. Rainfall, and soil water in general, will also affect the appearance of Cl^- toxicity because of its mobile nature in soils. Soil tests taken from the same point in a field can vary greatly even within 24 hours as Cl^- can move into or out of the root zone readily dependent on soil water.

Therefore, the best prevention practice for producers is variety selection. Many varieties will be labeled as either Cl^- excluders or includers. This information can often be found at manufacturer websites and on variety tech sheets. Although both excluders and includers take up similar amounts of Cl^- , excluder varieties can tolerate high Cl^- levels as excess Cl^- is held in the roots and not translocated to leaves and other tissues. Includer varieties will continually transport excess Cl^- to new growth even to toxic concentrations. Regardless of the ability of excluder varieties to tolerate excess Cl^- , the yield potential of both excluders and includers will be reduced in soils with high Cl^- levels.

Takeaways

- Chloride is essential in small amounts to maintain electroneutrality in many processes in the plant, including photosynthesis and plant water regulation.
- Chloride is very mobile in the soil and is easily leached through soils with adequate amounts of rainfall or irrigation. Chloride can accumulate in soils with continuous irrigation with water high in Cl^- .
- Chloride toxicity can occur under continuous irrigation with water high in Cl^- . Toxicity symptoms appear as light chlorosis progressing to scorching, or necrosis, of leaf margins.
- Irrigation water should be tested on a regular basis to prevent against the use of poor-quality water for irrigation. The yield potential of every soybean variety will be reduced under high Cl^- concentrations and Cl^- excluder varieties should be selected to improve tolerance when necessary.

Molybdenum

In the Plant

Molybdenum (Mo) is essential to all plants because of its role associated with nitrogen metabolism in the plants. As a component of nitrogen reductase in the chloroplasts of plants, it helps in the conversion of nitrates to nitrite as it is assimilated into the plant cell. Even more so to

soybeans, and various other legumes, molybdenum is an essential structural component to nitrogenase. Nitrogenase is the enzyme responsible for converting nitrogen gas to ammonia during nitrogen fixation. Molybdenum also plays a role in iron uptake and translocation.

In the Soil

Molybdenum is taken into the plant as molybdate, which typically occurs through mass flow, the movement of nutrients through the soil towards the plant with the transpirational movement of water. Unlike most micronutrients, molybdenum availability in soils increases with increasing pH. Optimal availability of molybdenum will occur in the pH range of 6.5 to 7.

Other nutrients such as phosphorus and magnesium have been shown to increase molybdenum uptake in plants. Nitrogen has also been shown to play a role in some plant uptake of molybdenum dependent on the source. Nitrates have been shown to increase molybdenum uptake while ammonium can reduce uptake. This is most likely because of the slight increase in alkalinity in the rhizosphere commonly associated with the uptake of nitrates.

Deficiency Symptoms

Since molybdenum is required in small amounts that are typically provided by native soil concentrations, molybdenum deficiencies are rare. Symptoms of a molybdenum deficiency in most plants will appear as interveinal chlorosis like that of iron. This is most likely because of the role molybdenum plays in iron uptake and translocation.

However, because of the essential role of molybdenum in nitrogen fixation, symptoms of molybdenum deficiency in soybean often appear as a nitrogen deficiency because of the lack of nitrogen fixation in the roots. Nodulation is often reduced, and chlorosis will appear on older leaves. Most often, this occurs in low pH soils. This is often a function of both reduced availability of molybdenum and a reduction in *Rhizobium japonicum* (the bacteria responsible for nodule formation and nitrogen fixation in soybean) activity because of the low pH.

Deficiency Corrections

LSU AgCenter recommendations for molybdenum are based on soil pH. A molybdenum seed treatment should be applied to seed when soil pH is below 6.2. At pH 6.0 or less, producers should apply both a commercial inoculant and Mo. However, our recommendations are being refined to account for



*Figure 11-1. Molybdenum seed treatments (B) reduced the viability of *Rhizobium japonicum* in commercial inoculants when compared to seed treated only with commercial inoculants (A). (LSU AgCenter, A. Orgeron)*

the affect that the molybdenum salt seed treatments have on the viability of the rhizobia. Rhizobia are living organisms that can die if not kept in a proper environment. Commercial products can often remain viable even after seed treatment for up to 90 days, depending on the individual product. When mixed with a molybdenum seed treatment, however, the salt has been shown to desiccate the rhizobia, reducing the number of viable bacteria on the seed. This occurrence was observed at the Sugar Research Station in St. Gabriel, Louisiana, in 2018. A reduction in nodulation was observed after planting soybean seed that was both inoculated and treated with a molybdenum seed treatment compared to those inoculated seed without the molybdenum treatment (Figure 11-1).

Research from surrounding states have shown that seed treated with both inoculant and a molybdenum seed treatment more than a few hours before planting have reduced viable rhizobia compared to those not treated with a molybdenum seed treatment or those planted immediately after the molybdenum seed treatment was applied. Therefore, until additional research is conducted in Louisiana, producers should be cautious in applying molybdenum seed treatments to inoculated seed unless seed will be planted

immediately. In soils with a pH below 6.0, producers should always treat seed with a commercial inoculum.

Takeaways

- Molybdenum is essential to several functions in the plant, including both the assimilation of nitrogen in plant cells and the fixation of nitrogen in soybean.
- Molybdenum availability is affected by varying soil conditions and is greatly reduced in low pH soils.
- Molybdenum deficiency symptoms in soybeans typically appear as a nitrogen deficiency because of the reduction of nitrogen fixation.
- Producers should avoid applying both a commercial inoculant and a molybdenum seed treatment because of the potential reduction in viable rhizobia unless intentions are to plant immediately.

Nickel

In the Plant

In the latter part of the 20th century it was determined that nickel (Ni) was an essential component of urease, an enzyme necessary for the breakdown of urea in plant cells. Urease is the only enzyme in the plants that is able to “extract” the

available nitrogen from urea. Without the ability to breakdown urea, toxic levels can build up, resulting in leaf-tip necrosis. Producers may be familiar with these symptoms as they may also be observed after a foliar application of urea, “urea burn” (Figure 12-1).

Nickel has also been shown to be a vital component of hydrogenase, an enzyme required for the breakdown of hydrogen gas in nodules that is associated with the fixation of nitrogen. When hydrogen gas is formed in the fixation process, it essentially robs the process of vital energy. Hydrogenase allows for the breakdown of this byproduct, releasing electrons back into the fixation process. A lack of nickel availability reduces hydrogenase levels and subsequent efficiency of nitrogen fixation.

Deficiency Symptoms

Nickel is needed in such small amounts that it is rarely considered when producers think about plant nutrition. In almost all circumstances nickel is supplied in adequate amounts by native soils. Deficiency symptoms are similar to those seen if urea is applied foliar to crops. Necrosis of the leaf tips are observed due to a buildup of toxic urea levels (Figure 12-2).



Figure 12-1. Nickel deficiency symptoms in soybean mimic “urea burn” due to the buildup of urea levels associated with deficiencies. (Mississippi State University, B. Golden)



Figure 12-2. Nickel deficiency symptoms in soybean mimic “urea burn” due to the buildup of urea levels associated with deficiencies. (Mississippi State University, B. Golden)

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