SUL4R-PLUS®, LLC: Fact Sheet

Uptake and Plant Mobility of Nutrients

Compiled by Greg Parris: APRIL 30, 2019

Nutrients important for plant growth vary in their ability to move within the soil and plant. Knowing how they move can be helpful when diagnosing deficiency problems and planning optimum fertilization strategies to achieve the full genetic potential of the crop.

Seventeen elements have been identified as vital to plant growth. Three elements, carbon, hydrogen and oxygen, are non-minerals and the other 14 (Table 2) are minerals. Carbon and oxygen enter plants through leaves as carbon dioxide. Oxygen also enters plants with hydrogen through roots as water. The other 14 (when applied to the soil) must be dissolved in soil water and enter the plant as roots take up water. Phosphate also enters the plant from a symbiotic relation with AM Fungi. Mineral elements can further be divided into primary or secondary macronutrients and micronutrients. Macronutrients are those needed in relatively large amounts while micronutrients, as their name implies, are needed in small amounts. However, a deficiency in any vital element can seriously inhibit plant development. [1]

We at SUL4R-PLUS® LLC, feel it is important to make our nutrients (Ca, SO4, Zn & B), that are immobile in the plant, available throughout the entire growing season for best yield results.

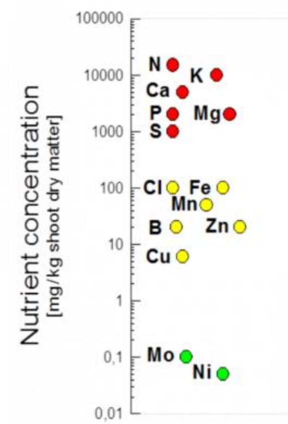

Fig 1: Example of Nutrient Concentration; Stalk dry basis [2]

What is the plant available forms for plant nutrients?

Plants need the nutrients to be available in forms that can be absorbed through the roots during transpiration. Some fertilizers require change while others are in plant available forms. The Calcium, Sulfur and Zinc supplied with SUL4R-PLUS® products are in plant available forms. The Boron is supplied as a sodium calcium borate that will dissolve into boric acid that is plant available.

Table 1. Essential Plant Nutrients

Nutrient	Ions Absorbed by Plants
Structural elements	
Carbon, C	CO_2
Hydrogen, H	H_2O
Oxygen, O	O_2
Primary nutrients	
Nitrogen, N	NO_3^-, NH_4^+
Phosphorus, P	$H_2PO_4^-$, HPO_4^{-2}
Potassium, K	K^+
Secondary nutrients	
Calcium, Ca	Ca^{+2}
Magnesium, MG	Mg^{+2}
Sulfur, S	SO_4^{-2}
Micronutrients	
Boron, B	$H_2BO_3^-$
Chlorine, Cl	Cl^-
Ccbalt, Co	Co^{+2}
Copper, Cu	Cu^{+2}
Iron, Fe	Fe^{+2}, Fe^{+3}
Manganese, Mn	Mn^{+2}
Molybdenum, MO	MoO_4^{-2}
Zinc, Zn	Zn^{+2}

Table 1: Forms for Uptake [3]

Table 2. The 14 elements essential for plant growth and their mobility and role within the plant. [1]

Macronutrients	Symbol	Mobile in plant	Role in plant
Primary			
Nitrogen	N	Yes	Formation of amino acids, vitamins and proteins; cell division
Phosphorous	P	Yes	Energy storage and transfer; cell growth; root and seed formation and growth; winter hardiness; water use
Potassium	K	Yes	Carbohydrate metabolism, breakdown and translocation; water efficiency; fruit formation; winter hardiness; disease resistance
Secondary			
Calcium	Ca	No	Cell division and formation; nitrogen metabolism; translocation; fruit set
Magnesium	Mg	Yes	Chlorophyll production; phosphorus mobility; iron utilization; fruit maturation
Sulfur	S	No	Amino acids formation; enzyme and vitamin development; seed production; chlorophyll formation
Micronutrients			
Boron	B	No	Pollen grain germination and tube growth; seed and cell wall formation; maturity promotion; sugar translocation
Chlorine	Cl	Yes	Role not well understood
Copper	Cu	No	Metabolic catalyst; functions in photosynthesis and reproduction; increases sugar; intensifies color; improves flavor
Iron	Fe	No	Chlorophyll formation; oxygen carrier; cell division and growth
Manganese	Mn	No	Involved in enzyme systems; aids chlorophyll synthesis; P and CA availability
Molybdenum	Mo	Yes	Nitrate reductase formation; converts inorganic phosphates to organic
Nickel	Ni	Yes	Nitrogen metabolism and fixation; disease tolerance
Zinc	Zn	No	Hormone and enzyme systems; chlorophyll production; carbohydrate, starch and seed formation

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What is the pH impact to nutrient uptake?

While we will not get into detail here with respect to pH, it is important to always know the soil pH and impact for nutrient deficiency. 6.5 pH average seems to be the best if you wish to use SUL4R-PLUS® products.

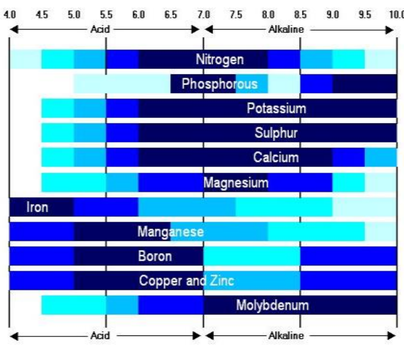

Fig 2: Nutrient response to Soil pH [10]

What is the plant mobility and uptake of supplied Nutrients in SUL4R-PLUS® products?

Nutrient must be in proper form for plants to absorb them. Table 1 gives a list of the most common ion forms. Let's review each nutrient:

Calcium Sulfate Dihydrate: This is the salt form of calcium and sulfate that is supplied with SUL4R-PLUS® products. The salt is slightly soluble as compared with highly reactive salts (NaCl) and provides a very low salt index (SI) of 8. This make calcium and sulfate available for the entire growing season when other products are gone in 2 to 3 weeks. Each time the plant respiration occurs then soluble Ca^{2+} and SO_4^{2-} is drawn into the plant root system along with other soluble nutrients. As the water moisture in the soil is absorbed the calcium sulfate salt precipitates near the root and is ready for the next respiration cycle.

Due to low solubility index the calcium sulfate dihydrate relies on micronized particulate size for enhanced release rate characteristics. Experimental data show that SUL4R-PLUS® products have a 30% to 100% increased release rate over larger particle products.

Calcium: Uptake form Ca^{2+}:
Plant Function: Cell division and formation; nitrogen metabolism; translocation; fruit set.

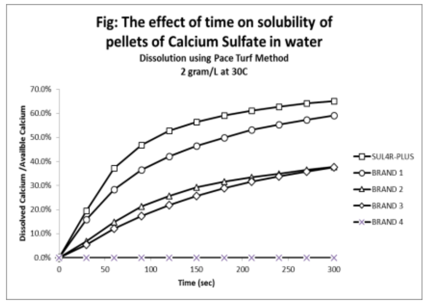

Fig 3: Dilution Studies of Pelletized Calcium Sulfate products

Once fixed, calcium is not mobile in the plant. If the plant runs out of a supply of calcium, it cannot remobilize calcium from older tissues. Deficiency: The calcium supply to growing tissues will rapidly become inadequate if soluble calcium is not available through transpiration. Additional calcium cannot help if plants are water stressed. Proper water irrigation should be considered. [5]

Sulfur: Uptake form SO_4^{2-} (Sulfate):
Plant Function: Amino acids formation; enzyme and vitamin development; seed production; chlorophyll formation.

Sulfates taken up by the roots are the major sulfur source for growth, though it has to be reduced to sulfide before it is further metabolized. Root plastids contain all sulfate reduction enzymes, but the reduction of sulfate to sulfide and its subsequent incorporation into cysteine predominantly takes place in the shoot, in the chloroplasts.

Cysteine is the precursor or reduced sulfur donor of most other organic sulfur compounds in plants. The predominant proportion of the organic sulfur is present in the protein fraction (up to 70% of total sulfur), as cysteine (Cys) and methionine (Met), two amino acids, residues." [11]

Deficiency: Once sulfate is converted to organic compounds, they are exported through the phloem to the sites of active protein synthesis (esp. root and shoot tips, fruits and grains) and then become largely immobile within the plant. The symptoms of S deficiency occur first in the younger tissues and are seen as leaves and veins turning pale green to yellow. These chlorosis symptoms look similar to those that occur with N deficiency, but because of its higher internal mobility a low N supply becomes first visible in the older leaves. When S deficiencies are first observed, some crops may not entirely recover the lost growth following S fertilization. [12]

Boron: Uptake form H_2BO^{3-}:
Plant Function: Pollen grain germination and tube growth; seed and cell wall formation; maturity promotion; sugar translocation.

The storehouse for most on the boron solids is the soil organic matter. As a result, most of the available boron is in the plow layer, where organic matter is highest. Soils low in organic matter are deficient in boron more often than soils with high organic matter content. When the soil surfaces dry out, plants are unable to feed in the zone where most of the available boron is present. This can lead to boron deficiency. When water moistens the soil, the plants can again feed from the surface soil and the boron deficiency often disappears. [14]

Note: Calcium sulfate dehydrate will help retain moisture and eliminate surface cracking thus improving the boron continuous feed and uptake by the plant. Further SUL4R-PLUS® products contain about 8% Humic that provide organic matter for the boron to complex with.

Boron is not readily held by soil particles and will leach below the root zones of many plants. Sandy soils are more boron deficient than silty loam/clay soils. Soils above pH of 7 are more likely to be boron deficient and for that reason liming is not recommended for soils > 6.8 pH. [14]

Between pH 5 and 9, H_3BO_3 (Boric Acid) is the dominant form of B in the soil solution. The sorption capacity for B in composed organic matter is about 4 times greater than for soil or clay. Adsorption is believed to be thru ligand exchange and is facilitated with the use of ALS. B uptake is a possible combination of active transport as esters with cis diols and passive diffusion as undissociated boric acid.

But the exact nature of boric acid transport across cell membrane is still not totally resolved. Boric Acid more properly expressed in the aqueous solution:

$$B(OH)_3 + 2H_2O <=> B(OH)_4^- + H_3O^+$$

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The Boron used in SUL4R-PLUS® products is Ulexite, hydrated sodium calcium borate hydroxide. Different size Ulexite minerals have different release characteristics. Most Boron's used for dry blends are 2 to 4 mm in size. The Boron used in SUL4R-PLUS® products are ground for improved release rates. Ground material are usually not used due to poor bendability but the boron in SUL4R-PLUS® products is added to each pellet so that the boron is equally spread over all acres.

Ulexite formula: N**$aCaB_5O_6(OH)6\text{-}5H_2O$**

Here are two release rate curves for boron material that include a ground Ulexite. Release rate of nutrients are directly tied to surface and surface area dramatically increase with particle size reduction.

Ulexite is shown to release consistently 12 mg/g over 40 weeks where Boric Acid and DOT product will release at 100 to 200 mg/g applied over 10 weeks.

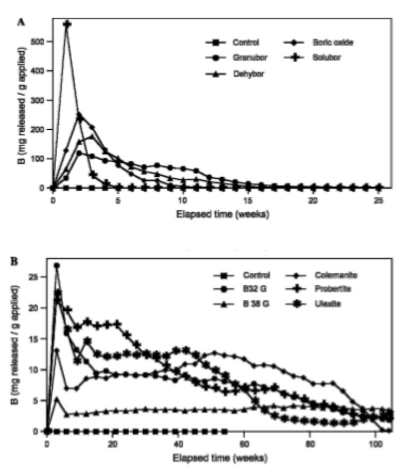

Fig. 1. Weekly release of boron (B) from soluble and controlled-release B fertilizers. (A) Release of B from soluble and short-term controlled-release products. (B) Release of B from longlasting products. Data are means from three replicate columns ± SE. Granubor, Solubor, and Dehybor are manufactured by U.S. Borax, Inc., Valencia, CA. B 32 G and B 38 G are manufactured by Frit Industries, Walnut Ridge, AR (1 mg·g⁻¹ = 0.1%).

HortTechnology · July–September 2008 18(3)

Fig 4 & 5: 2008 Boron release study [9]

Studies show that adequate B nutrition improves root uptake of phosphorus (P) and potassium (K) by maintaining proper function (through ATPase activity) and structure of root cell membranes. Boron has an important role in colonization of roots with mycorrhizal fungi, which contributes to root uptake of P. In short-term experiments with corn plants, reduced root uptake of P and K under low B supply was restored within one hour after B was added to the growth medium. Experimental evidence also suggests that adequate B supply is needed for mitigation of aluminum toxicity in plants grown in low-pH soils. [6]

<u>Deficiency:</u> It is known that certain crops are susceptible to boron deficiency. The high susceptible crops are Alfalfa and Cotton while Maize is only moderately susceptible to being deficient.

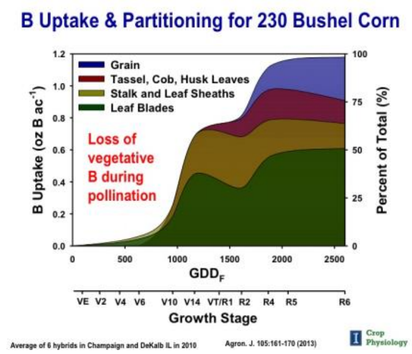

Fig 6: Shows the loss of vegetative B during pollination maize. [4]

Zinc: Uptake form Zn^{2+}:

<u>Plant Function</u>: Hormone and enzyme systems; chlorophyll production; carbohydrate, starch and seed formation

While zinc is only needed by plants in small quantities, it is crucial to plant development, as it plays a significant part in a wide range of processes. Zinc activates enzymes that are responsible for the synthesis of certain proteins. It is used in the formation of chlorophyll and some carbohydrates, conversion of starches to sugars and its presence in plant tissue helps the plant to withstand cold temperatures. Zinc is essential in the formation of auxins, which help with growth regulation and stem elongation. [7]

<u>Deficiency:</u> Like most micronutrients, zinc is immobile, meaning the deficiency symptoms occur in the new leaves. Symptoms vary depending on the crop. Typically, they are expressed as some varying pattern of chlorosis of the new leaves (often interveinal) and necrotic spots may form on the margins or leaf tips. These new leaves are smaller in size and often cupped upward or distorted. The internodes shorten, giving the plant a rosette appearance and bud development is poor resulting in reduced flowering and branching. [7]

Figure 7 shows over 50% Zn uptake during grain fill and limited vegetative remobilization.

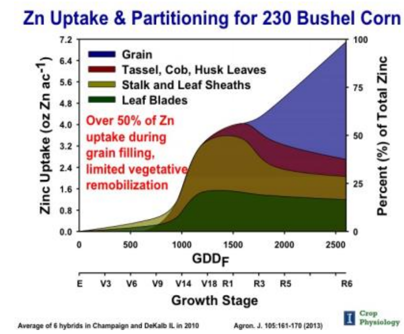

Fig 7: Zn Uptake Curve [4]

Nitrogen: Uptake forms NO_3^- and NH_4^+: While Nitrogen is not listed on the label, SUL4R-PLUS® products contain ~0.5% NH_4^+ complexed on the ALS additive. It is worth noting that N uptake efficiency will be enhanced by the availability of S, 14:1 ratio N:S. Such that, if the plant is short on S then the nitrogen will not be metabolized. It would be fair to state that there is a balance in that as more N is taken in then more S, P and K are taken in/required as well.

Phosphorus (P): Uptake $H_2PO_4^-$, HPO_4^{2-}: Experimental evidence suggests that Boron has an important role in colonization of roots with mycorrhizal fungi, which contributes to root uptake of P. Both Boron an ALS are known positive colonization factors for AM fungi.

Potassium (K): Uptake form K^+:

K uptake increases with root temperature which in turn results in depressed Ca uptake. Plant species differences in the proportion of K vs Ca uptake are often related to root cation exchange capacity. The cations K^+, Mg^{2+}, Na^+, NH_4^+, and H^+ directly and indirectly depress Ca^{2+} uptake and distribution.

The availability of K is largely dependent on the relationship between Ca, Mg and K with Ca and Mg being antagonistic to K under normal soils. In sodic soils the Ca and Mg are in small abundance and will not act antagonistic to K.

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However, when Ca is added to the soil and Na is release the clays will flocculate. This flocculation releases K and becomes plant available. This is also true for S and both K and S enjoy a synergistic relationship as seen in figure 8.

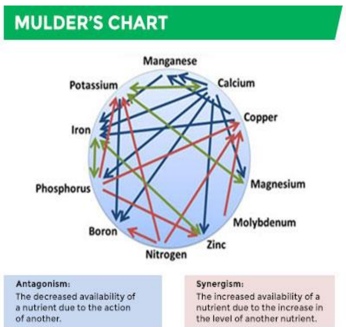

Fig 8: Mulders Chart [13]

Experimental field studies have shown increased K uptake from standard practice.

Let's look at one such trial field trial in 2008 on wheat, 100 lb/A of K-Mag vs 100 lb/A of SUL4R-PLUS® B+Z product. SUL4R-PLUS® B+Z product showed increases in N, K, Ca and S in tissue test at Feekes 9. See Figure 8.

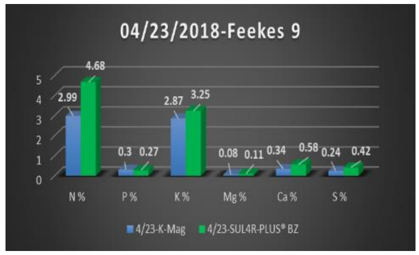

Fig 8: SUL4R-PLUS® B+Z Wheat Trial Henderson, Ky 2018

Ammonium Lignosulfonate (ALS): The additive in SUL4R-PLUS® products, is a low molecular weight Humate, Fulvic Acid. Fulvic acids are know for their ability to dilate roots for nutrient absorption and complexing of nutrient (SO_4^{2-}, H_2BO^{3-} and Zn^{2+}) for improved plant availability.

What are the nutrient uptake requirements for 230 bu/A corn?

Season-long supply of P, S, Zn, and Cu is imperative as we strive to maximize corn yields. Relative to total uptake, P is removed to a greater extent than any other nutrient. Agronomic practices which do not adequately replace removed P may eventually lead to a depletion in soil fertility levels.

Contrary to nutrients like N and K, nutrient accumulation of P, S, Zn, and Cu is equally distributed between vegetative growth and during reproductive growth (i.e. ear development and grain-fill). [4]

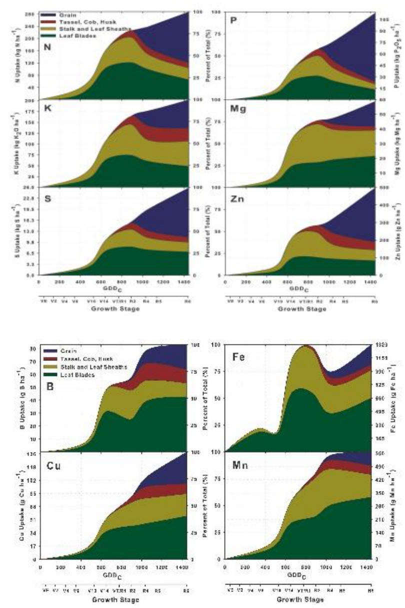

Fig 9 & 10. Total corn N, P, K, Mg, S, Zn, & B, Fe, Cu, Mn uptake and partitioning across four plant stover fractions for corn averaging 230 bushels/acre. [4]

Plants have the best opportunity to reach their full genetic potential, when given the correct nutrition, at the best times, in the proper amounts. SUL4R-PLUS® products increase the odds of you meeting your performance targets.

Estimated Nutrient Requirements (lbs) in 50 bu Soybeans									
	N	P_2O_5	K_2O	Ca	Mg	S	Cu	Mn	Zn
Uptake	277	56	148	49	19	35	0.05	0.06	0.05
Removal	188	40	74	19	10	23	0.05	0.06	0.05

Table 3: Uptake Requirements for 50 bu Soybeans

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Resources:

1) Knowing nutrient mobility is helpful in diagnosing plant nutrient deficiencies, November 14, 2013 - Author: Ron Goldy, Michigan State University Extension https://www.canr.msu.edu/news/knowing_nutrient_mobility_is_helpful_in_diagnosing_plant_nutrient_deficienc
2) http://plantsinaction.science.uq.edu.au/book/export/html/231
3) https://www.pinterest.com/trigemh/for-the-love-of-science-botany-101/
4) http://cropphysiology.cropsci.illinois.edu/research/nutrient_uptake.html Bender, Ross R, Jason W Haegele, Matias L Ruffo, and Fred E Below. 2013. "Nutrient uptake, partitioning, and remobilization in modern, transgenic insect-protected maize hybrids." Agronomy Journal 105 (1):161-170;
5) The Importance of Calcium, http://www.tetrachemicals.com/Products/Agriculture/The_Importance_of_Calcium.aqf
6) https://www.cropnutrition.com/importance-of-boron-in-plant-growth
7) https://www.pthorticulture.com/en/training-center/role-of-zinc-in-plant-culture/
8) Boron Products for Fertilizer Use, ETiMaden, ETiMINE USA INC.
9) Broschat, Timothy K., Release Rates of Soluble and Controlled-release Boron Fertilizers, HorTechnology, July–September 2008 18(3)
10) http://www.micromix.com/haa/the-effect-of-soil-ph-on-nutrient-availability/
11) https://en.wikipedia.org/wiki/Sulfur_assimilation
12) By Rob Norton, Robert Mikkelsen and Tom Jensen , Sulfur for Plant Nutrition, Better Crops/Vol. 97 (2013, No. 2) http://ipni.net/publication/bettercrops.nsf/0/A04D690D24FB9E6085257B7200552E54/$FILE/BC%202013-2%20p10.pdf
13) https://omexcanada.com/plant-nutrition/hppn/using-micronutrients-in-a-liquid-blend
14) Kelling, K.A., Soil and Applied Boron, 1999, SR-07-99-.075M-25, University of Wisconsin-Extension,
15) http://cropphysiology.cropsci.illinois.edu/soyuptake.html