SOYBEAN

UNDERSTANDING NUTRIENT REQUIREMENTS AND UTILIZATION FOR HIGH-YIELDING SOYBEANS

Characterizing soybean nutrient uptake, partitioning and removal

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OUR SOY CHECKOFF™

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INTRODUCTION:

Soybean genetics and production practices have changed significantly in the past half-century. This has resulted in consistent yield increases of 0.42 bushels per acre per year in addition to physiological changes that have undoubtedly altered nutrient utilization for the soybean plant. This publication provides an updated summary of soybean uptake and partitioning of the three macro (nitrogen [N], phosphorus [P], potassium [K]), the three secondary (sulfur [S], calcium [Ca], magnesium [Mg]) and five of the micro (zinc [Zn], manganese [Mn], copper [Cu], iron [Fe], boron [B]) nutrients for soybean growth and development. These models can be used by farmers and ag industry personnel across the country to better understand and monitor soybean nutrient utilization during the growing season, including total uptake, the uptake rate and partitioning to help guide and evaluate fertility decisions. In addition, biomass (dry matter) accumulation can provide insight into soybean growth and development.

STUDY BACKGROUND:

The aforementioned biomass and nutrient-uptake models were built from studies conducted during 2014 and 2015 at the University of Wisconsin-Madison and University of Minnesota. A yield range of 40-100 bu./A. was achieved by planting varieties within different maturity groups and at two different planting dates. This wide yield range, established across all locations, allows for much broader applicability of this data to farmers across the country.

Study details are as follows:

- **Environments:** Two years at three locations with non-limiting fertility levels. Six total environments.
- **Varieties:** Eight varieties (RM 1.0-2.5)
- **Planting Dates:** Early and late May

- **Plant Sampling:** Collected at the V4, R1, R4, R5.5, R6.5, and R8 growth stages and partitioned into the following parts:
  - Stems
  - Petioles
  - Leaves
  - Pods
  - Seeds
  - Fallen leaves/petioles
- **Nutrients Quantified:** N, P (P_2O_5), K (K_2O), S, Ca, Mg, Zn, Mn, Cu, Fe, B
- **Sample Size:** 6,672 tissue samples were analyzed to build a very robust data set.

Catch container used to collect all fallen leaves and petioles throughout the growing season from each plot.

STUDY FINDINGS:

Data from this study were used to build models that display total nutrient uptake and partitioning throughout the growing season, in addition to the daily rate of nutrient uptake. The models for dry matter (DM), N, P, K, and S were constructed at three different yield levels to provide information that is adaptable to farmers in different locations and their respective soybean yield levels. All other nutrient models were constructed at the average yield level.

High	=	82 bu./A. avg. (>75 bu./A. range) *top graph of each image*
Average	=	66 bu./A. avg. *middle graph of each image*
Low	=	54 bu./A. avg. (40 – 60 bu./A./ range) *bottom graph of each image*

P and K are displayed in fertilizer units (pounds of P_2O_5 and K_2O) for ease in relating to fertilizer recommendations and application rates.

FOR YOUR FARM

Keep in mind that as soybean yields increase, so do your soybean crop's nutrient needs. Consider your field's yield history when setting soybean yield goals to deliver an optimal return on investment for your fertilizer expenditures. Consult your state extension fertility recommendations when evaluating fertilizer decisions.

Total nutrient uptake and removal per bushel of soybean and nutrient removal per ton of harvested stover. Multiply your expected or actual soybean yield by the total uptake and removal values for each nutrient to determine total uptake and removal in lbs/acre.

Nutrient	Total Uptake	Removal in Grain†	Removal in Stover‡
	lbs/bu	lbs/bu	lbs/ton DM
N	3.75 ± *0.12*	3.30 ± *0.08*	19.0
P (P_2O_5)*	0.90 ± *0.04*	0.74 ± *0.02*	5.2
K (K_2O)	2.30 ± *0.14*	1.17 ± *0.02*	39.0
S	0.21 ± *0.01*	0.16 ± *0.01*	2.2
Mg	0.51 ± *0.04*	0.16 ± *0.003*	9.3
Ca	0.96 ± *0.1*	0.12 ± *0.01*	27.5
Zn	0.003#	0.002	0.03
Mn	0.004	0.002	0.14
Cu	0.001	0.001	0.01
Fe	0.006	0.002	0.17
B	0.002	0.001	0.05

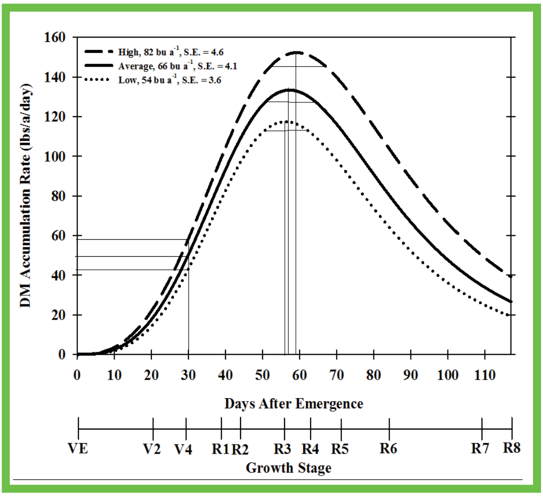
† Removal in the grain was calculated at 13% grain moisture.
‡ Stover nutrient content can vary considerably due to the year and yield level. For more exact estimate of nutrient removal with harvested stover, growers should submit samples for nutrient analysis.
* P and K are displayed in terms of their fertilizer equivalents, P_2O_5 and K_2O.
# The range in micronutrient uptake and removal per bushel was less than ±0.001 lbs/bu.

For any soybean yield goal, calculate nutrient uptake and removal estimates for your farm at *www.BadgerBean.com*.

DRY MATTER

UPTAKE:

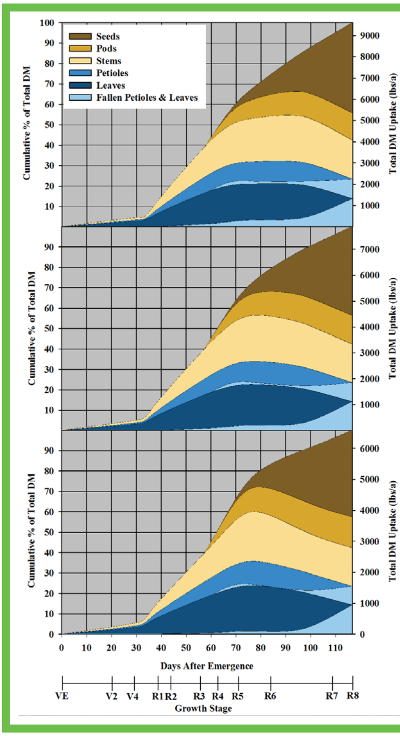
- Total DM accumulation prior to R1 (beginning flowering) was less than 15 percent of the total for all yield levels.
  - Early season DM accumulation rates were greatest for the high yield level (60 lbs./A./day).
- Only 50 percent of total DM was accumulated by R4 (full pod).
  - Just prior to R4, peak accumulation rates were reached and were greater than 100 lbs./A./day for all yield levels.
- From R5.5 to R8 (maturity), DM accumulation was greater for the high yield level (31.5 percent), compared to the average (26.7 percent) and low (22.3 percent) yield levels.
  - This was due to the greater daily accumulation rate through R8 associated with higher yields.



PARTITIONING:

- Early season DM accumulation was largely partitioned into leaf tissue until the initiation of reproductive growth, when an increasing amount was allocated to the stems and petioles and eventually into pods at R3 (beginning pod) and seeds by R4.5.
- Pooled across all yield levels at R5.5, most DM was partitioned into the stems (31 percent) followed by leaves (27 percent), pods (15 percent), petioles (14 percent), and seeds (9 percent), with the remainder as fallen leaves and petioles (4 percent).

- After R5.5 further DM accumulation was directed toward seeds and pods in conjunction with apparent remobilization of DM from vegetative tissue (senescence). In comparison, the continued partitioning of DM to stems and pods until R6.5 at the high yield level led to more vegetative DM that possibly supported greater pods m^{-2}, which is considered to be an important yield component.
  - In addition, leaves and petioles maintained constant DM levels through R6.5 for the high yield level, which could theoretically support greater photosynthesis.
- Dry matter partitioning by R8 resulted in harvest indexes of 45.2, 44.2, and 42.8 percent for the high, average and low yield levels, respectively.
  - Harvest index is defined as the ratio of harvested grain to the total above-ground dry matter.



FOR YOUR FARM

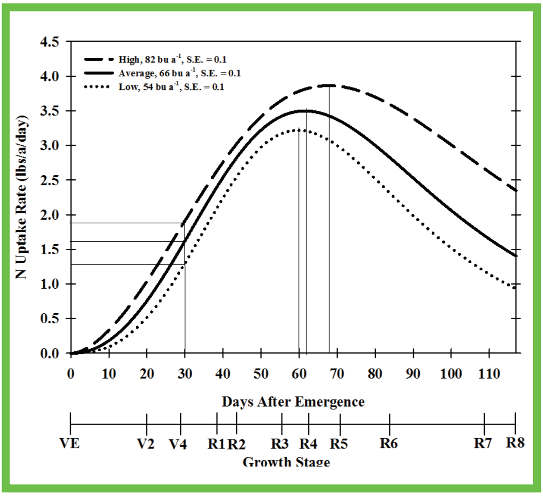
Most dry matter/biomass accumulation in the soybean plant occurs during the reproductive (R) growth stages with the greatest amount of accumulation beginning just before the start of seed production (R4) through seed maturity (R8).

As can be predicted, the dry matter/biomass accumulated during vegetative (V) growth stages mostly accumulates in the leaves, while dry matter/biomass accumulation after R1 (beginning flowering) begins to be heavily allocated to stems and petioles, followed by pods and seeds after R5 (beginning seed).

NITROGEN

UPTAKE:

- Total N uptake prior to R1 was minimal due to a lag in the early season N uptake rate.
  - However, the high yield level did have a greater early season uptake rate of 1.9 lbs. N/A./day at V4 (fourth trifoliolate).
- Peak N uptake rates occurred between R4 – R5, with the high yield level showing a later peak uptake period and greatest uptake rate (4.0 lbs. N/A./day).
  - This demonstrates greater reliance on late season N uptake for higher yields.
  - This is confirmed by the late season uptake rate for the high yield level which was 63 percent of its peak rate compared to only 38 and 28 percent for the average and low yield levels, respectively.



- Like DM, 50 percent of N uptake was reached between R4–4.5, and the amount of total N taken up after R5.5 differed between the high (40.1 percent), average (34.7 percent) and low (29.7 percent) yield levels.

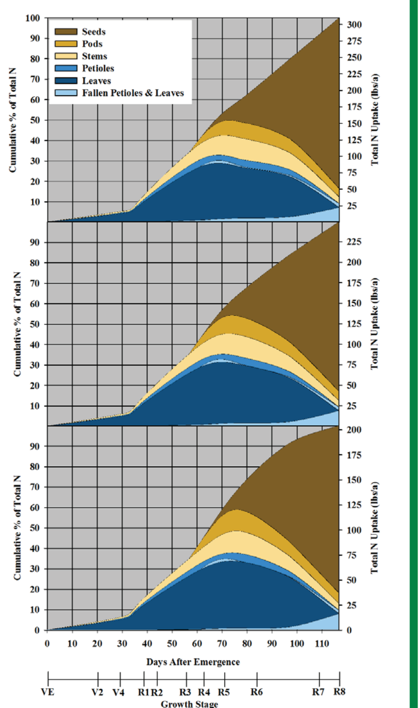
PARTITIONING:

- Prior to R5.5 nearly 50 percent of the acquired N was stored in leaf tissue.
- After R5.5 further N uptake was directed toward the seed, while N in vegetative tissue began rapid remobilization to the seed. Roughly 68 percent of vegetative N was remobilized to the seed.
- Seed N accrued after R5 from continued uptake was greatest for the high yield level (61.1 percent) compared to the average (55.9 percent) and low (50.4 percent) yield levels.
  - While vegetative N remobilization is important in meeting seed N demand, greater reliance on continued

uptake (61.1 percent) as an alternative to vegetative N remobilization (38.9 percent) after R5 was associated with higher yields.

  - Thus, farmers should focus on production practices that maximize N_2 fixation and soil N mineralization throughout the whole growing season.

- At the high yield level, vegetative N remobilization (~100 lbs. N) combined with continued uptake to the seed after R5 (~160 lbs. N) resulted in an N harvest index near 84 percent.
  - The N harvest index increased in parallel with yield.



FOR YOUR FARM

Most nitrogen uptake occurs during reproductive (R) growth stages, peaking between R3 and R5. High-yielding soybeans have greater nitrogen uptake rates across the whole growing season, and significantly higher rates during seed development (R5 and later) than average and lower-yielding soybeans.

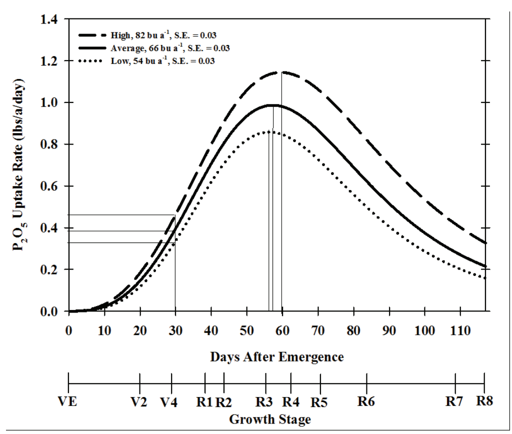
For all soybean yield levels, large amounts of nitrogen are stored in leaf tissue until the R5.5 growth stage, when nearly 70 percent of all stored nitrogen is redirected to the seed. Furthermore, all additional nitrogen uptake after R5.5 is sent directly to the seed.

Higher-yielding soybeans demand more nitrogen throughout the whole growing season, especially during seed fill. Therefore, growers should focus on maximizing N-fixation and soil N mineralization throughout the whole growing season rather than a single nitrogen application. For high-yielding soybeans, 84 percent or more of the nitrogen taken up during the growing season is removed in the seed during harvest and does not return to the soil for the next crop, demonstrating the plant's extraordinary nitrogen use efficiency.

PHOSPHORUS

UPTAKE:

- Phosphorus uptake followed similar patterns as N uptake.
  - Total P uptake prior to R1 was minimal (~13 percent) due to a lag in the early season P uptake rate.
  - The high yield level did have a greater early season uptake rate of 0.5 lbs. P_2O_5/A./day at V4.
  - Peak uptake rates occurred between R3-R4 with a peak rate of 1.2 lbs. P_2O_5/A./day for the high yield level.
  - 50 percent of total P uptake occurred by R4, and the amount of P taken up after R5.5 differed between the high (32.2 percent), average (27.2 percent) and low (22.8 percent) yield levels.
- Unlike N uptake, P uptake rates after R4 decreased at identical rates between yield levels.



PARTITIONING:

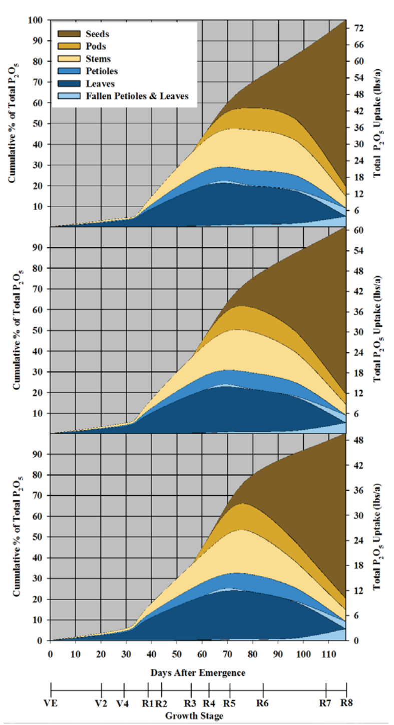
- Phosphorus accumulated prior to R1 was mainly partitioned into leaf tissue (64 percent) and thereafter, an increasing amount was allocated to the stems. At R4, 75 percent of acquired P was held in stem and leaf tissue.
- Compared to N, a relatively similar amount of vegetative P was remobilized to the seed (69 percent) after R5.5.
- Seed P demands were met equally (50/50) between vegetative P remobilization and continued P uptake past R5.
  - These two seed supply mechanisms resulted in a P harvest index near 81 percent, which is again, almost identical to the N harvest index.

FOR YOUR FARM

Phosphorus uptake and partitioning follows a similar pattern of nitrogen uptake and partitioning. Most phosphorus uptake occurs during reproductive (R) growth stages, peaking between R3 and R4. High-yielding soybeans have higher phosphorus uptake rates throughout the whole growing season.

For all soybean yield categories, most phosphorus is stored in leaf tissue until the R5.5 growth stage, when nearly 70 percent of all stored phosphorus is remobilized to the seed. All additional phosphorus uptake after R5.5 is sent directly to the seed.

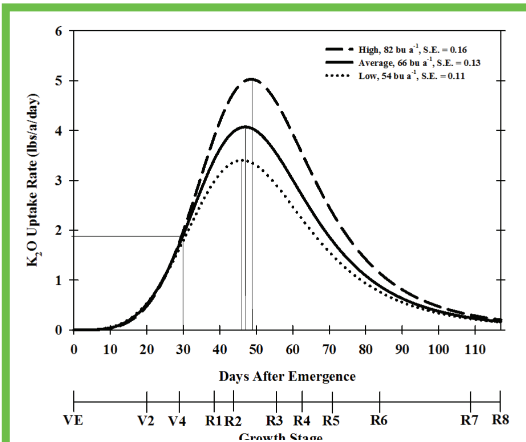
Approximately 50 percent of phosphorus used by the plant is acquired from the soil after the R5 growth stage. More than 80 percent of the phosphorus used by the plant will be removed from the field with the grain during harvest. It is important to maintain adequate phosphorus levels in the soil for a soybean rotation for proper seed development and to replenish the phosphorus for the next crop rotation. Test your soils regularly to know where your soil phosphorus levels are and what you may need to apply to maintain optimal soil levels to achieve desired crop yields.



POTASSIUM

UPTAKE:

- Total K uptake prior to R1 was substantial (18–26 percent) depending upon the yield level.
  - While the relative amount of uptake by R1 varied between yield level, the quantity was similar (38 lbs. K_2O/A.). This is due to the identical early season uptake rates between the three yield levels.
- After R1 the uptake rates for each yield level separated and reached peak uptake rates shortly after R2, ranging between 3.5 – 5.2 lbs. K_2O /A./day.
- Unlike N and P, total K uptake neared completion at R5.5.
  - 91, 97 and 100 percent of the total K uptake was reached by R5.5 at the high, average and low yield level, respectively.



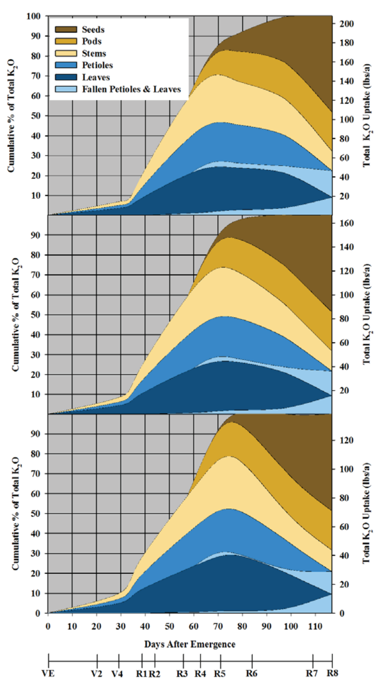
PARTITIONING:

- Potassium was partitioned nearly the same between stem, petiole, leaf and pod tissue.
- After R5.5, seed K accumulation relied on vegetative K remobilization (63–90 percent) more so than continued K uptake.
- However, the large demand from the seed for vegetative K remobilization only represented 37–46 percent of total vegetative K because total K uptake prior to R5.5 was so great (>90 percent).
  - Therefore, the K harvest index was much smaller for all yield levels (~49 percent) compared to that of N and P.
  - The large amount of total K uptake (138 – 208 lbs. K_2O/A.) and relatively low K harvest index, makes stover removal a major pathway for K removal and soil K depletion if not replaced with fertilizer.

FOR YOUR FARM

Nearly one-quarter of potassium uptake occurs before the R1 growth stage, with similar quantities across the different yield levels. Potassium uptake peaks following R2 and, unlike nitrogen and phosphorus, is nearly complete by R5.5, depending on actual yield levels.

Potassium is stored in the leaves, stem, petioles and pod tissue in fairly equal proportions unlike nitrogen and phosphorus. Since little to no potassium uptake occurs after the soybean plant begins seed fill, the potassium needed after R5.5 for seed development is mainly remobilized from the vegetative tissue reserves and only slightly from continued soil uptake. Nearly half of total potassium uptake stays in the vegetative structures and remains in the field after harvest as stover. Unless stover is removed from the field (intentionally or by wind or water flow), potassium from the stover will return to the soil and will be available for future crops.



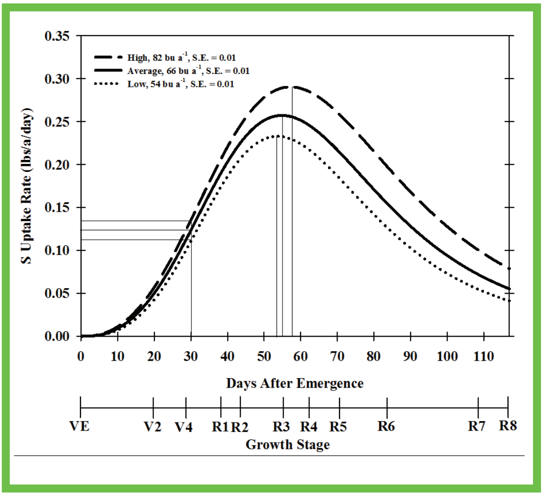
Soybeans are large users of potassium. For example, a 60 bu./A. soybean crop removes 75 lbs. of K_2O per acre compared to only 50 lbs. K_2O per acre removed for a 200 bu./A. corn crop. Therefore, farmers should ensure that soil potassium levels are adequate prior to planting their soybean crop as late season applications of potassium are not helpful because the soybean plant acquires a majority of its potassium prior to R5.5.

SULFUR

SULFUR

UPTAKE:

- Total S uptake prior to R1 was less than 2 lbs. S/A. for all three yield levels.
- Early season uptake accelerated after V2 to peak uptake rates shortly after R3 of approximately 0.3 lbs. S/A./day depending upon the yield level.
- Like that of N, the amount of total S taken up after R5.5 differed between the high (32 percent), average (29 percent) and low (25 percent) yield levels, showing the importance of season-long soil S supply as yield increases.



PARTITIONING:

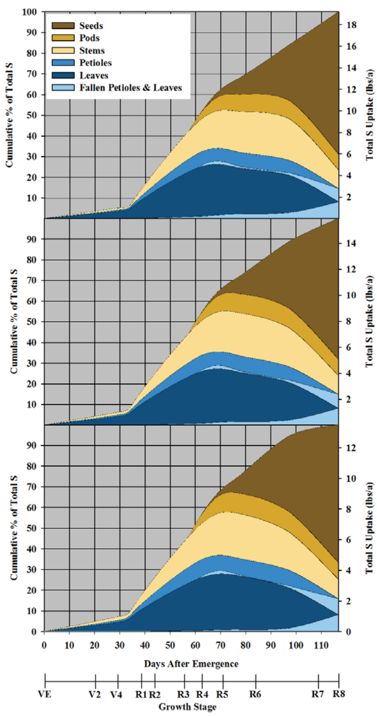
- Leaf and stem tissue were major storage organs of S for subsequent remobilization to the seed after R5.5 for the low and average yield levels, and R6.5 for the high yield level.
  - Only 50 percent of vegetative S was remobilized to the seed, regardless of the yield level resulting in S harvest indexes near 69 percent for all yield levels.
- Seed S accrual relied heavily on both vegetative remobilization and continued S uptake after R5, however greater reliance was placed on continued uptake at the high yield level (58 percent) compared to the low (50 percent).

FOR YOUR FARM

Most sulfur uptake occurs after R1 and peak uptake rates occur around R3. Total sulfur uptake after R5.5 depends on actual yield levels, with more uptake for higher yields and slightly less uptake for lower yields.

Like previously described nutrients, sulfur is stored in vegetative structures until seed development begins. About half of the stored sulfur is moved to the seed while more sulfur is simultaneously taken up from the soil directly into the seed.

It is important for seed development that sulfur is available through the entire growing season. Consult your soil fertility records and local agronomist to determine if a sulfur application before a soybean rotation is warranted.



MAGNESIUM AND CALCIUM

UPTAKE:

- Early season Ca and Mg uptake lagged until R1 where they then accelerated reaching peak uptake rates of 0.6 and 1.8 lbs./A./day, respectively, near R3.
  - Due to the larger Ca uptake rate and reduced late season uptake, 91 percent of the total Ca was acquired by R5.5 compared to only 77 percent of total Mg

PARTITIONING:

- The large amount of Ca acquired by R5.5 was mainly held in stem, petiole, leaf and pod tissue and only 7 percent of this vegetative Ca was remobilized to the seed.
  - Due to the extremely small amount of remobilized Ca, the Ca harvest index was only 13 percent.
- Mg also saw very little vegetative remobilization to the seed (12 percent). However, greater amounts of total Mg were accumulated after R5 and partitioned directly to the seed, which accounted for 85 percent of the seed Mg content. Thus, the Mg harvest index (25 percent) was double that of Ca.
- Soybean grain production typically does not require annual fertilizer application of Ca or Mg due to the small (Mg) and very small (Ca) nutrient harvest indexes and ample native soil supply of Ca and Mg.

FOR YOUR FARM

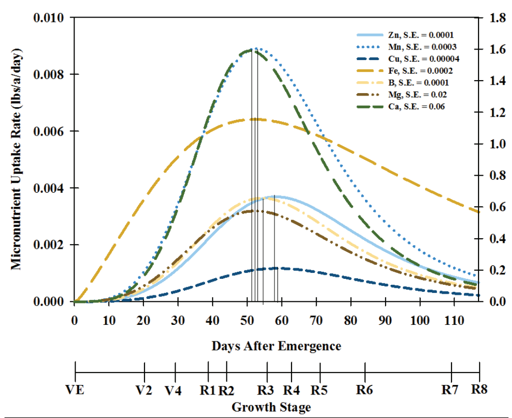
Most calcium and magnesium uptake occurs after reproductive (R) growth stages begin. The calcium uptake rate peaks around R3, and about 90 percent of the total calcium uptake occurs before R5.5. The magnesium uptake rate also peaks around R3, but only about 75 percent of the total magnesium uptake occurs before R5.5.

Only 13 percent of calcium taken up ends up in the seed, meaning that most of the calcium remains in vegetative structures, returning to the field after harvest. More magnesium is taken up to the seed during seed development, but still only 25 percent of total magnesium uptake ends up in the seed and is removed at harvest. Because of these low uptake and removal rates, calcium and magnesium needs are generally met by existing soil reserves and are usually not a necessary fertilizer component.

MICRONUTRIENTS

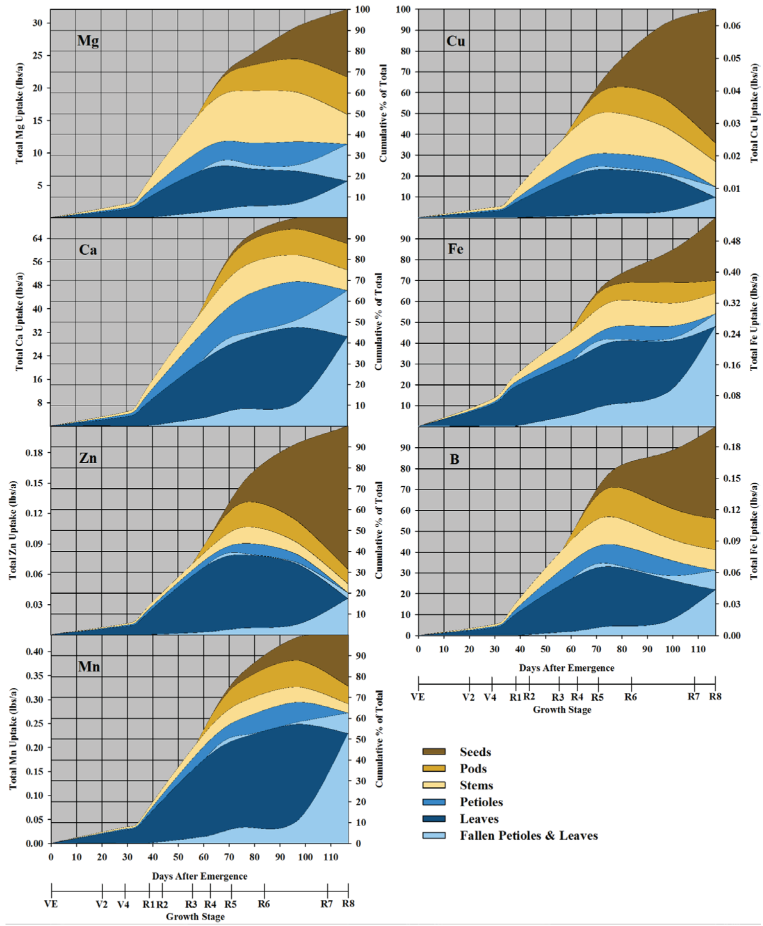
UPTAKE:

- Total uptake prior to R1 was minimal for all micronutrients except for Fe, which approached 25 percent.
- Greater than 80 percent of all Mn and B was acquired by R5.5, whereas uptake during seed fill was greater for Zn and Cu.
- Micronutrient uptake rates were hardly measurable during vegetative growth stages, and peak uptake rates near R3 were less than 0.01 lbs./A./day.



PARTITIONING:

- At R5.5, relatively large portions of total Zn (46 percent), Mn (52 percent) and B (35 percent) were held in leaf tissue while stem tissue accumulated a majority of the Cu (27 percent).
- After R5.5, vegetative Zn and Cu remobilization was greatest, while Mn and B remobilization to the seed was minimal and Fe saw no mobility to the developing seed.
- Uptake after R5 for Mn and Fe accounted for 83 and 100 percent, respectively, of the seeds' demand for these nutrients, while Zn, Cu and B still met the majority (>50 percent) of seed nutrient demand through uptake past R5, signifying the importance of season-long micronutrient availability, although in small amounts.
- Micronutrient harvest indexes ranged from 25–68 percent. However, the overwhelming fact that extremely low amounts of these nutrients are accumulated throughout the growing season suggests that annual application of these nutrients is likely not needed in most environments.



FOR YOUR FARM

While micronutrients, including boron, copper, iron, manganese and zinc, are vital to soybean production, these nutrients are needed in very limited quantities as compared to nitrogen, phosphorus or potassium. It may appear that a significant percentage of total uptake for these nutrients is removed with the seed at harvest in the partitioning models, but the actual quantity removed is extremely low when compared to other nutrients (>0.5 lbs./A.). As such, application of these nutrients is rarely necessary.

Technical editing for this guide was led by researchers from the University of Wisconsin-Madison.