

Modern Soybean Varieties' Nutrient Uptake Patterns

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Many soybean fertility recommendations are derived from research conducted during the 1930s to 1970s, and may not be adequate in supporting the nutritional needs of the greater biomass accumulation and seed yield associated with current soybean germplasm and production systems. Furthermore, no recent data exist that document the cumulative effects of improved soybean varieties, fertilizer source and placement technologies, and plant health/plant protection advancements on the rate and duration of nutrient accumulation in soybean. A more comprehensive understanding of soybean's nutritional requirements may be realized through this evaluation of the season-long nutrient uptake, partitioning and remobilization patterns in soybean.

Soybean was originally introduced to United States agriculture as a highly digestible, legume-based forage feedstock. More recently, soybean has been selected for improved seed yield potential, which has increased by four-fold since 1924 (USDA-NASS, 2014). The concentrated nutrient sink of soybean seeds, along with greater yields, creates greater demand for uptake and remobilization during reproductive development, especially compared to benchmark studies conducted during the 1930s to 1970s (Borst and Thatcher, 1931; Hammond et al., 1951; Hanway and Weber, 1971). As a result, the objective of this research was to reassess the mineral nutrition needs of soybean by quantifying season-long nutrient uptake, partitioning and remobilization in modern soybean varieties.

The study was conducted at DeKalb (2012 and 2013) and Champaign, IL (2013) using sites maintained in a corn-soybean crop rotation. A 2.8 relative maturity (RM) and 3.4 RM variety were planted at each site to achieve a final stand of approximately 145,000 plants/A. A fertility treatment included 75 lbs P₂O₅/A as MicroEssentials® SZ™ (12-40-0-10S-1Zn) (The Mosaic Company, Plymouth, MN) banded below the soil surface immediately before planting and 60 lbs K₂O/A as KCl broadcast and incorporated before planting (2013 only), collectively, and was compared to an unfertilized control. Dry matter production and accumulation of N, P, K, S, Mg, Ca, Zn, B, Mn, and Cu were determined at seven incrementally-spaced growth stages: V4 (fourth trifoliolate), V7 (seventh trifoliolate), R2 (full bloom), R4 (full pod), R5 (beginning seed), R6 (full seed), and R8 (full maturity) (Pedersen, 2009). Biomass collection crates were used to collect senesced leaf and petiole tissues. Each plant was then separated into stem (stems and petioles), leaf (individual leaves), reproductive (flowers and pods), and grain tissue components. All data are reported on a DM basis (0% moisture concentration).

Nutrient Uptake and Removal

Averaged across three site-years and corresponding treatment combinations, mean biomass and grain yield were 8,500 lbs DM/A and approximately 60 bu/A (13% grain moisture concentration), respectively. The fertility treatment resulted in an increase in total DM (+9%) and grain yield (+3%) and therefore greater nutrient accumulation. Because DM allocation and nutrient partitioning to these plant tissues were similar across fertility and varietal differences, nutrient accumulation

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cu = copper; Mn = manganese; Zn = zinc; KCl = potassium chloride; DM = dry matter (0% moisture concentration); HI = harvest index, percentage of total nutrient uptake present in the grain; RM = relative maturity.

Table 1. Nutrient accumulation associated with producing, on average, 60 bu/A of soybean grain.

Parameter	Maximum total uptake	Removal with grain	Harvest index	Nutrient removal coefficient [†]
Macronutrients		lbs/A	%	lbs/bu
N	245	179	73	2.98
P	19	15	81	0.25
P ₂ O ₅	43	35	81	0.58
K	141	57	41	0.95
K ₂ O	170	70	41	1.17
S	17	10	59	0.17
Mg	45	8	18	0.13
Ca	101	9	9	0.15
Micronutrients		oz/A	%	oz/bu
Zn	4.78	2.00	42	0.033
B	4.64	1.58	34	0.026
Mn	5.30	1.31	25	0.022
Cu	0.90	0.56	62	0.0093

[†] Multiply grain yield by nutrient removal coefficient to obtain the quantity of nutrient removal. Maximum total nutrient uptake, removal with grain, and harvest index (percentage of total nutrient uptake present in the grain) of macro- and micronutrients were averaged over treatments at DeKalb (2012 and 2013) and Champaign (2013).

was averaged across treatments in the data presented.

Agronomic production practices and soil conditions with a capacity to supply nutrients at the listed quantities in **Table 1** would be expected to meet soybean nutritional needs for an average yield level of approximately 60 bu/A. The potential for nutrient accumulation in soybean has increased by two- to three-fold during the past 80 years as a result of increased DM production and grain yield (Borst and Thatcher, 1931). Mean grain yield values presented in this study are approximately 30 to 40% greater than the current United States average (USDA-NASS, 2014) and the presented nutrient accumulation information may serve as a resource for anticipated improvements in soybean yield.

Grain nutrient HI values are relative indicators of nutrient partitioning to soybean grain tissues, quantified as the ratio of grain nutrient removal to total nutrient accumulation. Nutrients with high requirements for production (e.g., N, K, Ca) or those that have a high HI value (e.g., N, P, S, Cu) may indicate key nutrients for high yield (**Table 1**). On average, over 80% of accumulated P was removed with harvested soybean grain tissues. Similarly, N, S, and Cu each resulted in nutrient harvest indices greater than 50%. Harvest index values for N, P, and S are similar to previously published values; however, K HI has

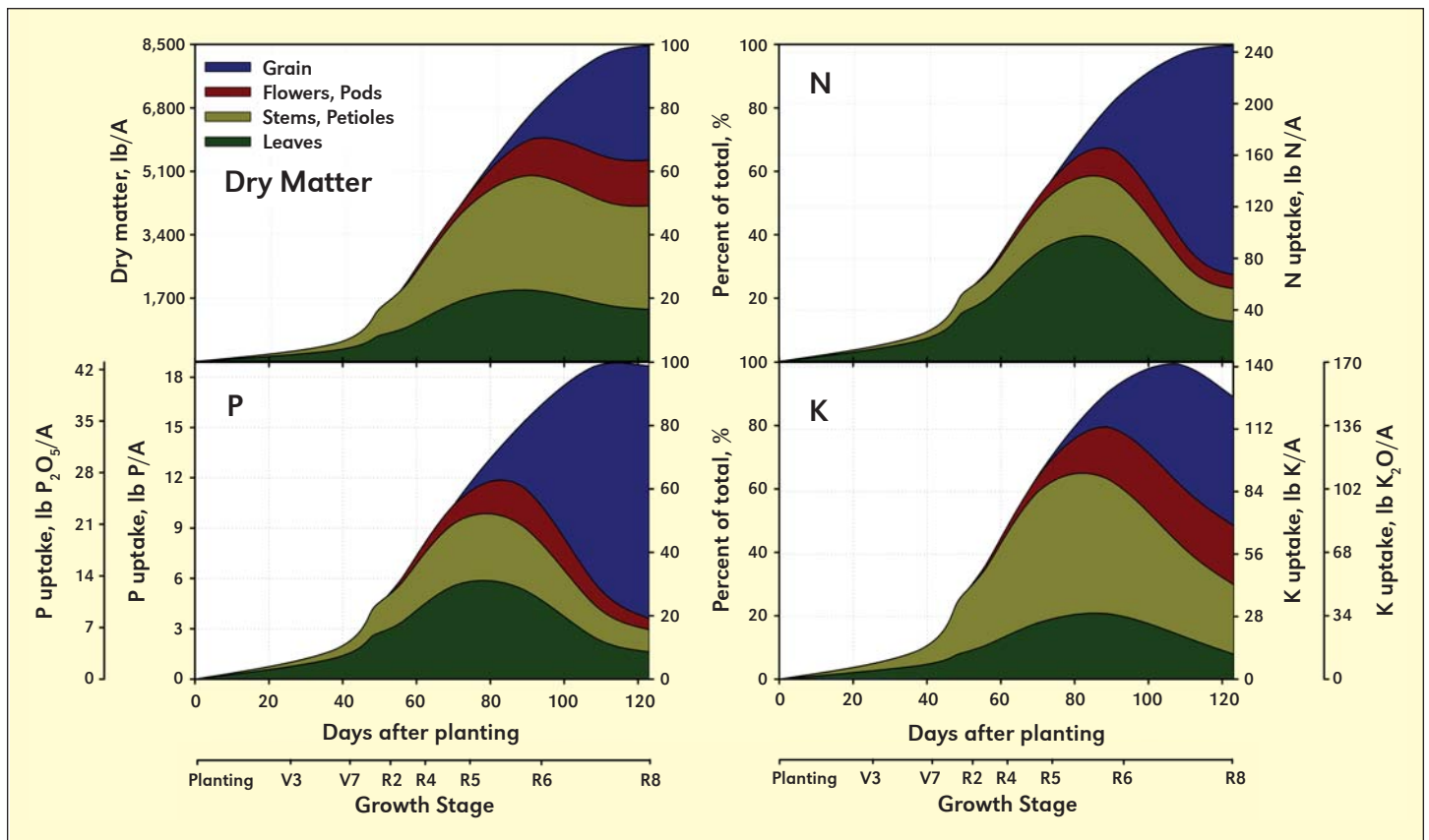


Figure 1. The seasonal accumulation and partitioning of dry matter, nitrogen (N), phosphorus (P, P_2O_5), and potassium (K, K_2O) for an average yield level of 60 bu/A as measured across three site-years during 2012 and 2013.

decreased from nearly 70% (Hammond et al., 1951) to 41% in the current study (Table 1). Agronomic production practices that harvest non-grain plant tissues for animal bedding or feed sources, commonplace in key cattle producing regions, may remove, compared to grain harvest, up to an additional 66 lb N, 4 lb P (8 lb P_2O_5), 84 lb K (100 lb K_2O), 7 lb S, 37 lb Mg, 92 lb Ca, 2.78 oz Zn (16 oz = 1 lb), 3.06 oz B, 3.99 oz Mn, and 0.34 oz Cu per acre (Table 1).

Time and Rate of Nutrient Uptake

The rate and time of acquisition varied among nutrients and were associated with specific vegetative or reproductive growth periods. Nearly 75% of K uptake occurred before the onset of seed filling (Figure 1) compared to the uptake of N, P, S, Mg, Ca, Zn, B, Mn, and Cu, which were more evenly distributed during vegetative and seed-filling growth phases (Figures 1, 2 and 3). With the exception of K, maximum rates of nutrient uptake were consistent across macro- and micronutrients and tended to occur during a brief period that bracketed R4. Unlike the rapid uptake of mineral nutrients before tassel emergence in maize (Bender et al., 2013a), nutrient uptake in soybean more closely coincided with DM accumulation, producing a steady, season-long pattern of nutrient assimilation. Soybean nutrient uptake patterns closely resemble those published during the last 80 years (Borst and Thatcher, 1931; Hammond et al., 1951; Hanway and Weber, 1971), although in modern cultivars, the proportion of total nutrient accumulation acquired during seed-filling has increased over time. The differences are especially apparent for N, P, Mg, and Ca, which have increased by as much as 18% during this part of

the reproductive period. Collectively, these findings suggest that the improved yield of soybean has concomitantly increased the potential for nutrient accumulation.

Nutrient Use

Grain acquired nutrients from a combination of 1) direct partitioning to developing grain tissues, and 2) nutrient remobilization from leaf, stem, or flower and pod tissues. Nutrients with relatively high (greater than 50%) HI values included P, N, Cu, and S (Table 1). Nutrient remobilization from other tissues complemented nutrient acquisition during seed filling to meet grain nutrient demands.

Consistent with earlier studies, the amount of grain N and P obtained from remobilization was as much as 4-fold greater from leaf versus stem tissues. The opposite was discovered with K where approximately twice the amount of K was remobilized from stem compared to leaf tissues. Although the magnitude of K remobilization from existing stem tissues had not been previously documented, these data reinforce the importance of season-long nutrient availability and the utility of existing plant tissues as reservoirs to accommodate intra-seasonal periods of elevated nutrient demand.

Implications for Soybean Production

Intensified agronomic production practices and improved varieties have contributed to greater soybean yields than ever before and provide the driving force for greater nutrient accumulation. From a historical perspective, routine fertilizer applications of K were potentially used to maximize total biomass, especially during the introduction and populariza-

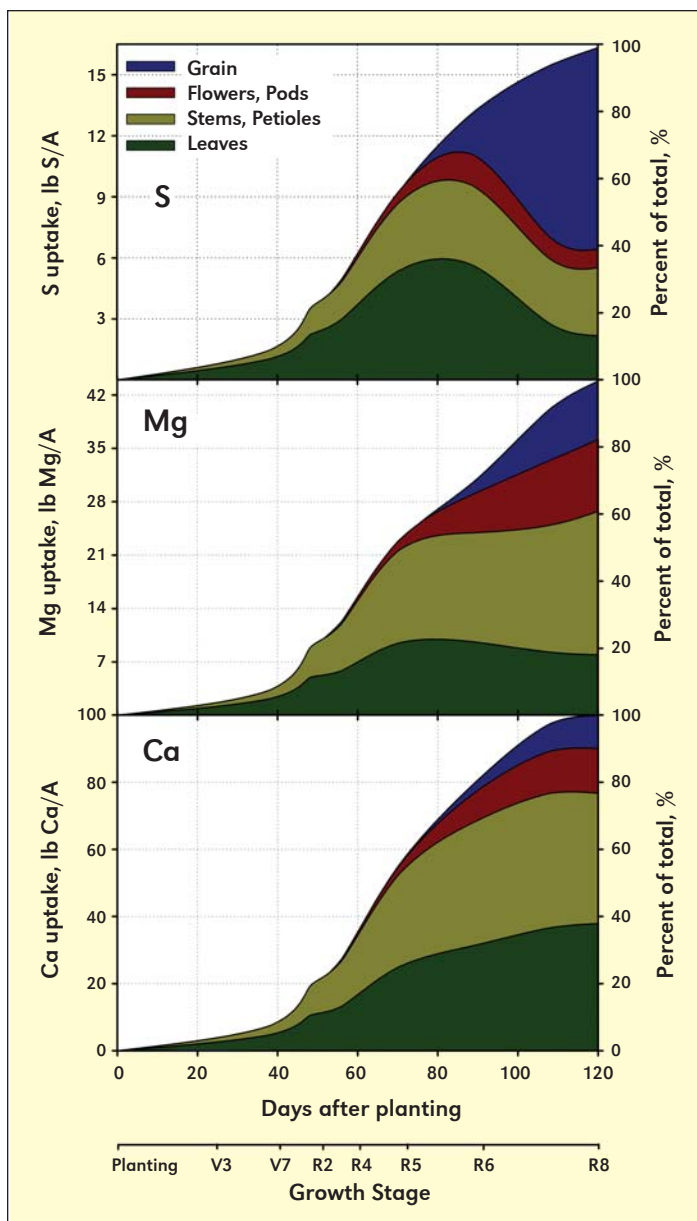


Figure 2. The seasonal accumulation and partitioning of sulfur (S), magnesium (Mg), and calcium (Ca) for an average yield level of 60 bu/A as measured across three site-years during 2012 and 2013.

tion of soybean as a forage legume in the United States. After comparing current data to initial soybean nutrient uptake research (Borst and Thatcher, 1931), newer soybean varieties selected for high seed yield have increased HI values for DM (+11%) and P (+13%) with a simultaneous reduction in K HI (-17%). Altered DM and nutrient harvest indices with substantial increases in the percentage of total nutrient accumulation during seed-fill necessitate precise nutrient management for current production systems. Although total P accumulation measured approximately half that of a maize crop yielding 230 bu/A (Bender et al., 2013a and 2013b), similar P HI values of nearly 80% suggest that P removal in corn/soybean systems is significant and needs to be monitored closely to ensure adequate nutrient replacement rates. The partitioning of K in soybean has different agronomic implications. The low K HI places emphasis on the cycling of K from various depths in the soil to the plant and eventually to the soil surface as K leaches

from plant tissues, beginning after R6 (**Figure 1**). This process may promote the stratification of K in soil, particularly under reduced tillage systems.

Soybean assimilates a substantial amount of N during its growth due to the high protein concentration of the grain. Although the current study did not distinguish between N acquired from the soil versus N acquired through symbiotic N_2 fixation, past literature suggests that, on average, the soybean plant obtains approximately 50% of its N from N_2 fixation when supplied 22.5 lb N/A as in this study (Salvagiotti et al., 2008). Also, roots and nodules comprise approximately 4.8% of the total plant N (Schweiger et al., 2014), so would contribute 12 lb N/A to the total. Given the total accumulation of 245 lb N/A (grain + vegetative) and 12 lb N/A in the roots, we can assume that approximately half, or 129 lb N/A, was obtained from N_2 fixation. Harvesting the soybean grain removed 179 lb N/A and would thus result in soil depletion and a negative N balance of nearly 50 lb N/A.

Conclusions

The primary objective of this research was to quantify nutrient uptake, partitioning and remobilization using current soybean varieties in modern soybean production systems. Biomass production, grain yield, and, for some nutrients, harvest indices have risen during the last 80 years, resulting in concurrent increases in nutrient accumulation. Patterns of biomass production and nutrient accumulation are presented for an average yield of approximately 60 bu/A and are most suitable for producers targeting this yield level. Although nutrient acquisition was most rapid between R3 to R4 for measured nutrients, patterns of nutrient accumulation revealed intra-seasonal differences in the timing of nutrient acquisition. Uptake of K primarily occurred during late vegetative and early reproductive growth in contrast to uptake patterns of N, P, S, Mg, Ca, Zn, B, Mn, and Cu, which were more evenly distributed throughout the entire growing season. Consequently, soil conditions and agronomic practices that also ensure nutrient availability through late-season reproductive growth would be expected to meet soybean fertility needs for these nutrients.

During seed-filling, grain tissues acquired nutrients through remobilization and season-long nutrient accumulation. Four nutrients had HI values greater than 50%: P (81%), N (73%), Cu (62%), and S (59%), reinforcing the need for adequate nutrient availability during reproductive growth.

The findings in this study provide insight into the dynamics of nutrient accumulation in modern varieties of soybean and are expected to contribute to improvements in agronomic recommendations. In particular, this study indicates that proper soybean nutrition requires adequate nutrient availability throughout the growing season, including late-season reproductive growth. [DC](#)

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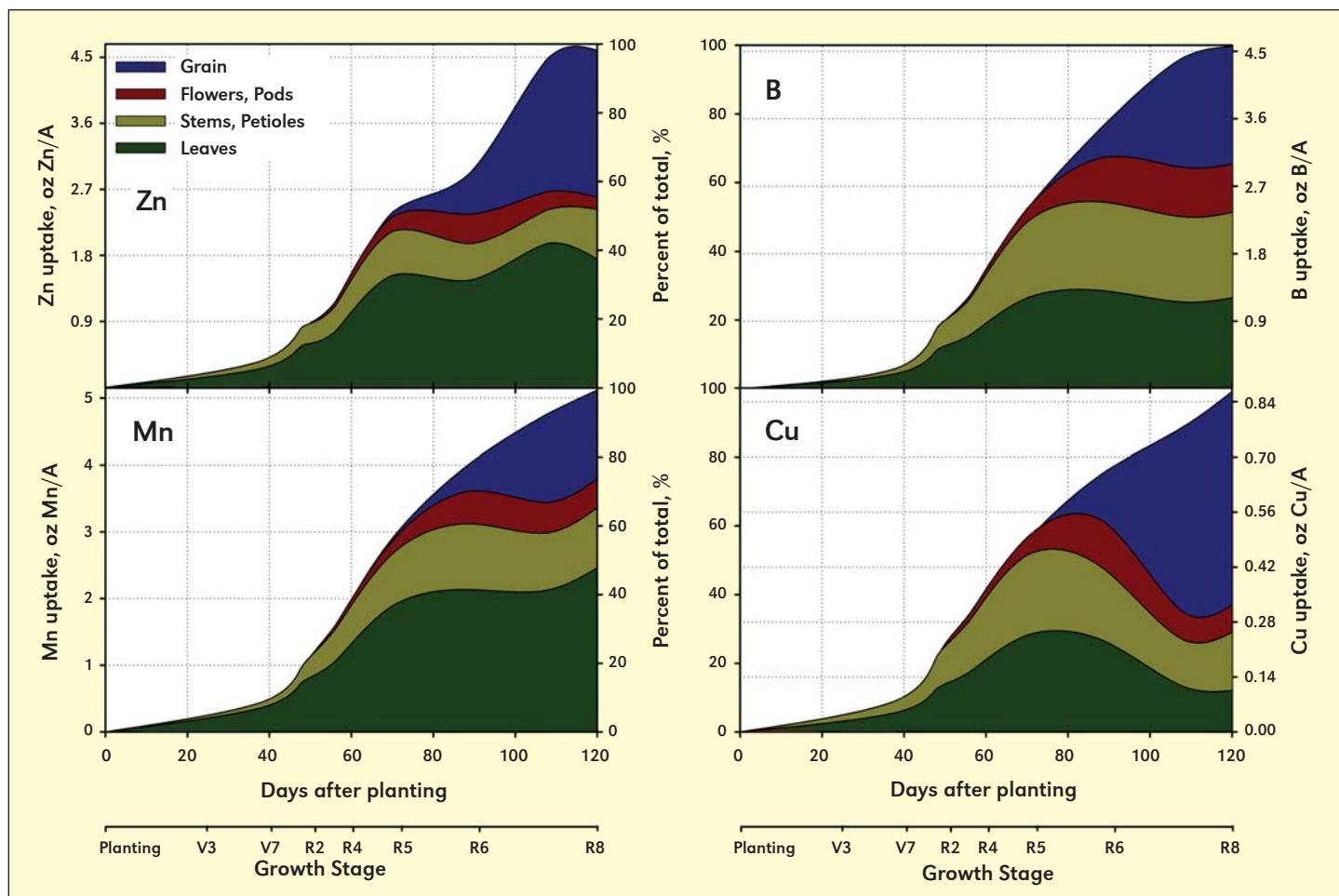


Figure 3. The seasonal accumulation and partitioning of zinc (Zn), boron (B), manganese (Mn), and copper (Cu) for an average yield level of 60 bu/A as measured across three site-years during 2012 and 2013.

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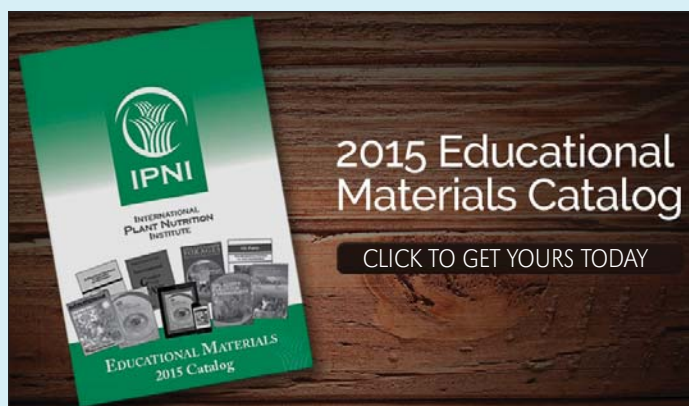
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