Nutrient Uptake and Partitioning in High-Yielding Soybean

Crop Physiology

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Introduction:

- Nutrient uptake capabilities of soybean varieties with management practices in the 1920's through 1970's are well documented (Table 1).
- Refined agronomic production practices (e.g., improved fertilizer placement and source technologies, narrower row spacing, herbicide tolerance, etc.) with modern soybean germplasm may have changed the potential for season-long nutrient accumulation and utilization (Table 1).
- Current fertilizer recommendations based on older nutrient uptake data with lower yield levels may not be adequate in supporting modern varieties and management practices.

Research approach:

- The field experiment was conducted in 2012 at DeKalb, Illinois on a Drummer-Elburn silty clay loam. Plots were planted in DeKalb on June 12th achieving a final stand of approx. 366,000 plants ha^{-1} (148,000 plants ac^{-1}).
- Immediately before planting, 84 kg P_2O_5 ha^{-1} was applied as MicroEssentials® SZ™ (12-40-0-10S-1Zn) in a subsurface band placed 10 – 15 cm below the row. The rate was designed to target the P needs at a 5.0 Mg ha^{-1} yield level (i.e., 85 bu ac^{-1} @ 13.0% moisture).
- Soybean varieties possessed herbicide tolerance, were treated with their respective commercial seed treatments, and represented an appropriate relative maturity (RM) range for the region:
  - 92Y80 RM = 2.8
  - AG3432 RM = 3.4
- Ten plants per plot were sampled at each of seven growth stages (V4, V7, R2, R4, R5.5, R6.5, R8) for dry weight and nutrient analysis. Dropped leaves and petioles were collected using constructed bio-crates (Figure 1). Grain and stover samples were analyzed for N, P, K, Ca, Mg, S, Zn, B, Mn, Fe, and Cu concentration by A&L Great Lakes Laboratories (Fort Wayne, IN). Only N, P, K, and S are presented here.
- All values are expressed on a dry weight (0% moisture) basis. Figures were prepared in SigmaPlot using the simple spline option with smoothed data points.

Figure 1. Bio-crates designed to retain fallen leaves and petioles senesced during soybean reproductive growth and pod maturation.

Nutrient uptake - A look back:

Table 1. Agronomic management practices and measured total nutrient uptake in soybean, compiled from select nutrient accumulation studies during the past 80 years. All units are expressed on a dry weight (0% moisture) basis.

	Borst and Thatcher, 1931[α]	Hammond et al., 1951[β]	Hanway and Weber, 1971a/1971b[γ]
Agronomic parameters			
Row spacing, cm	20	97	102
Plant density, 1000's plants ha^{-1}	667-890	445	388
Productivity, Mg ha^{-1}			
Grain yield	1.2	2.0	2.7
Biomass yield	4.7	6.2	8.6
Nutrient uptake, kg ha^{-1}			
N	125	164	265
P_2O_5	34	31	52
K_2O	46	61	104
Ca	45	96	-
Mg	33	47	-

[α] Borst and Thatcher, 1931: Ohio Agr. Exp. Sta. Bul. 494:51-96.
[β] Hammond et al., 1951: Iowa Agr. Exp. Sta. Bul. 384:463-512; Productivity and nutrient uptake data were averaged across two soil types.
[γ] Hanway and Weber, 1971a: Agron J. 63:406-408 and 1971b: Agron J.63:227-230; Productivity data was estimated from Hanway and Weber (1971b) and nutrient uptake data from Hanway and Weber (1971a).

- Previous literature demonstrates the range in nutrient uptake capabilities of varieties and agronomic practices common in the 1930's through the 1970's (Table 1).
- Although the biology of soybean nutrient uptake and partitioning has likely not changed from earlier studies, increased grain yields and biomass production may be associated with greater total plant uptake and increased removal.
- These studies provided background on macronutrient accumulation but no information on seasonal accumulation of micronutrients.

Question: *What are the season-long mineral nutrition needs in modern soybean production?*

Objective: *Quantify nutrient uptake and partitioning in commercial germplasm grown under modern management practices.*

Current nutrient uptake capabilities:

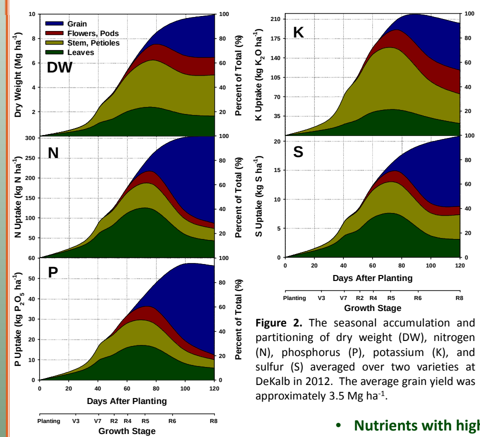

Figure 2. The seasonal accumulation and partitioning of dry weight (DW), nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) averaged over two varieties at DeKalb in 2012. The average grain yield was approximately 3.5 Mg ha^{-1}.

Table 2. Total macronutrient uptake and removal at DeKalb, IL (2012). Harvest Index (HI) was calculated as the ratio between nutrient removed with grain and total nutrient uptake and is reported as a percent.

	Total Nutrient Uptake		Nutrient Removal		Nutrient HI	
Measurement	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
	Mg ha^{-1}				%	
Dry Weight	9.9	9.7 – 10.1	3.5	3.4 – 3.6	35	34 – 36
	kg ha^{-1}				%	
N	304	303 – 305	218	209 – 227	72	69 – 75
P_2O_5	56	56 – 56	44	42 – 45	79	75 – 81
K_2O	202	195 – 210	85	79 – 89	42	38 – 46
S	21	20 – 21	12	11 – 13	57	56 – 61

- **Average grain yield and total biomass production were 3.5 and 9.9 Mg ha^{-1} respectively (Figure 2). Nutrients supplied in these quantities (Table 2) would be expected to meet soybean requirements for this yield level.**
- **Yield at maturity was significantly different among varieties (*$P<0.001$*, data not shown) and as a result, ranges of nutrient uptake are shown in Table 2. Variety did not influence total nutrient uptake (data not shown), thus uptake patterns between varieties were combined (Figure 2).**
- **Nutrients with high total uptake (e.g., N, P, K) represent a yield limitation if not supplied in sufficient quantities. Those nutrients with greater HI values (e.g., N, P, S) are removed from a cropping system to a relatively greater extent.**
- **Our data (Table 2) suggest that total nutrient uptake has increased nearly two-fold compared to values reported by Hammond et al. (1951; see Table 1) and require as much N, K, and S as a high-yielding maize crop (Bender et al., 2013: Agron J. 105:161-170).**

Nutrient uptake timing:

- **Over 40% of N, P, and S accumulation occurred during pod-filling compared to less than one-quarter for K (Table 3, Figure 2).**
- **Maximum rates of nutrient accumulation coincided with maximum rates of dry weight production, a 50-day period between V7 and R5.5 (Table 3). This period accounted for 60-70% of total uptake for all nutrients.**

Table 3. Rates of biomass and nutrient accumulation and the percent of total nutrient uptake during pod-filling (i.e., after R4) for varieties at DeKalb during 2012. Rate of accumulation represents the maximum rate of nutrient uptake during a 50-day period between late vegetative growth, V7, and mid reproductive growth, R5.5.

Measurement	Rate of accumulation	Accumulation during pod-fill
	kg ha^{-1} day^{-1}	%
Biomass	173	46
N	4.6	42
P_2O_5	0.8	44
K_2O	3.8	23
S	0.3	41

Conclusions:

1. Are there key nutrients for high yield soybean production?
   ✓ **<u>Yes</u>, nutrients with high requirements for production (N, P, K), or that have a high HI (N, P, S) allude to important nutrients for high yield.**

2. Can the agronomic management of nutrient application rate, placement, and timing in soybean production be further improved?
   ✓ **<u>Yes</u>, over 40% of N, P, and S accumulation occurred during pod-filling and as such, season-long supply of these nutrients are critical for optimal grain production. Application of fertilizers should meet plant needs during the greatest period of nutrient uptake: reproductive growth.**

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