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Nutrient Uptake Illustrated for Modern, High-Yielding Soybean

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Soybean has grown to be the major crop both in terms of land use and grain production in Brazil. In turn, soybean leads all crops in nutrient consumption. Fields growing high-yielding cultivars are capable of supporting grain yields that are twice the country's average, leading to questions about how these yields impact crop nutrient demand.

Uptake patterns find N and K in highest demand, with K having the fastest acquisition rate (63% of total K uptake occurs before pod filling). Remobilization from leaves, stems, and petioles provides a significant contribution to the total grain content of N, P, K, S, Cu, and Zn, while Mg, B, and Fe only remobilize from leaves.

KEYWORDS:
recommendations; high yields; accumulation; partitioning; removal

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc.

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Originally introduced to Brazil in 1882, soybean first became a significant grain crop in Rio Grande do Sul, Brazil's most southern state, during the first decade of the 1900s. Today, soybean dominates the country's agricultural landscape. The five-year average yield for soybean in Brazil is 3.0 t/ha, but farmers using modern varieties and best management practices are achieving 4.5 to 6.0 t/ha without irrigation. Genetic development and new technologies have created these popular, high-yielding soybean varieties with an indeterminate growth habit (i.e., vegetative growth continues through flowering). However, fertilizer recommendations are still traditionally based on older varieties with a determinate growth habit (i.e., vegetative growth ceases at flowering), which has led to a knowledge gap. In the study described below, researchers worked to quantify nutrient uptake, partitioning, and remobilization during the soybean growing season in order to collect the

Table 1. Nutrient accumulation associated with producing, on average, 6.6 t grain/ha with a modern soybean variety in the state of Paraná, Brazil.

Parameter	Total accumulation	Accumulation in grain	Harvest index[1]	Removal coefficient	Maximum accumulation rate[2]	Non-linear sigmoidal regression parameters			Growth stage at max accumulation rate
	----- kg/ha -----		%	kg/t	kg/ha/d	a	X_0	b	
Biomass (DM[3])	12,554	5,841	47	-	162	13,391	75.1	21.4	R5.2
N	429	330	77	57	5.4	482	74.9	22.2	R5.2
P	34	29	84	4.9	0.49	37.6	75.0	19.1	R5.2
K	177	112	63	19	1.89	176	52.7	23.4	R1
Ca	100	19	19	3.3	1.36	109	67.7	20.1	R4
Mg	43	16	36	2.7	0.50	47.4	70.4	23.9	R5.2
S	19	12	65	2.1	0.27	20.2	65.3	18.5	R4
	----- g/ha -----		%	g/t	g/ha/d				
B	250	89	36	15	3.3	268	62.0	20.1	R3
Cu	100	62	63	11	1.4	102	61.1	18.7	R3
Fe	1,695	703	42	120	17	1,914	73.0	28.6	R5.2
Mn	793	140	18	24	11	836	72.7	19.2	R5.2
Zn	344	211	61	36	4.8	377	69.1	19.8	R5.2

[1] Harvest index: percentage of total nutrient accumulation that is present in the grain.
[2] Maximum accumulation rate was obtained using a non-linear sigmoidal regression: $y = \frac{a}{1+e^{-\frac{(X-Xo)}{b}}}$, where y is maximum accumulation rate, a and b are coefficients, and Xo is the date after planting with maximum accumulation rate.
[3] DM = dry matter.

data critical to assessing modern soybean crop requirements (amounts and timings) for nutrient application.

The field study was conducted at the ABC Foundation Experimental Station in Ponta Grossa, Paraná, Brazil, on a typical Oxisol clay soil cultivated for 30 years under a no-till soybean-oat-maize-wheat rotation system. Soil at the site (0 to 20 cm) had pH($CaCl_2$) 5.1, $P_{(resin)}$ 47 mg/dm^3, $K_{(resin)}$ 97 mg/dm^3, base saturation 61%, and organic matter (OM) 3.6%. A modern, high-yielding soybean variety (NA 5909RG; 6.9 relative maturity) was planted with a 40-cm row spacing to achieve a final stand of approximately 350,000 plants/ha. Agronomic management at planting included seed inoculation and a N-P_2O_5-K_2O blend of 0-20-20 applied at 300 kg/ha. Dry matter production and accumulation of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn were determined at nine growth stages: V4 (fourth trifoliate), V7 (seventh trifoliate), R1 (beginning flowering), R4 (full pod), R5.2 (early seed filling), R5.4 (late seed filling), R6 (full seed), R7 (beginning maturity), and R8 (full maturity) (Ciampitti, 2017). Representative plants were separated into stem (stems and petioles), leaf (individual leaves), reproductive (flowers and pods), and grain tissue components.

Nutrient Uptake and Removal

Average grain yield at the site was 6.6 t/ha (13% moisture content), two times higher than Brazil's average yield. Crop nutrient uptake and removal, harvest index (HI), and maximum accumulation rate and growth stage of occurrence are provided in **Table 1**.

As described by Bender et al. (2015), grain nutrient HI values are relative indicators of nutrient partitioning to the grain. In this study, six nutrients had HI values above 50%: P (84), N (77), S (65), K (63), Cu (63), and Zn (61) (**Table 1**). These results are similar to previous research with the exception of K and Zn, which were notably higher in this study. High HI values should represent a concern for high-yielding fields where large removal of key nutrients may impact the sustainability of soybean production unless adequate fertilizer input is provided.

Timing and Rate of Nutrient Uptake

Nutrients with the most rapid time of acquisition were K, Cu, and B with 63%, 58%, and 57% of total uptake, respectively, occurring before the onset of the seed filling growth stage (R4) (**Figures 1 and 2**). The uptake of other nutrients was more evenly distributed during vegetative and seed-filling growth stages. Phosphorus, N, and Zn uptake was the slowest with 39%, 43%, and 43% of total uptake acquired at R4, respectively. Maximum accumulation rates occurred as follows: K at R1 (beginning flowering), B and Cu at R3 (beginning pod), Ca and S at R4 (full pod), and N, P, Mg, Fe, Mn, and Zn at R5.2 (early seed filling) (**Table 1**). As mentioned by Bender et al. (2015), the proportion of total nutrient accumulation acquired during seed filling in

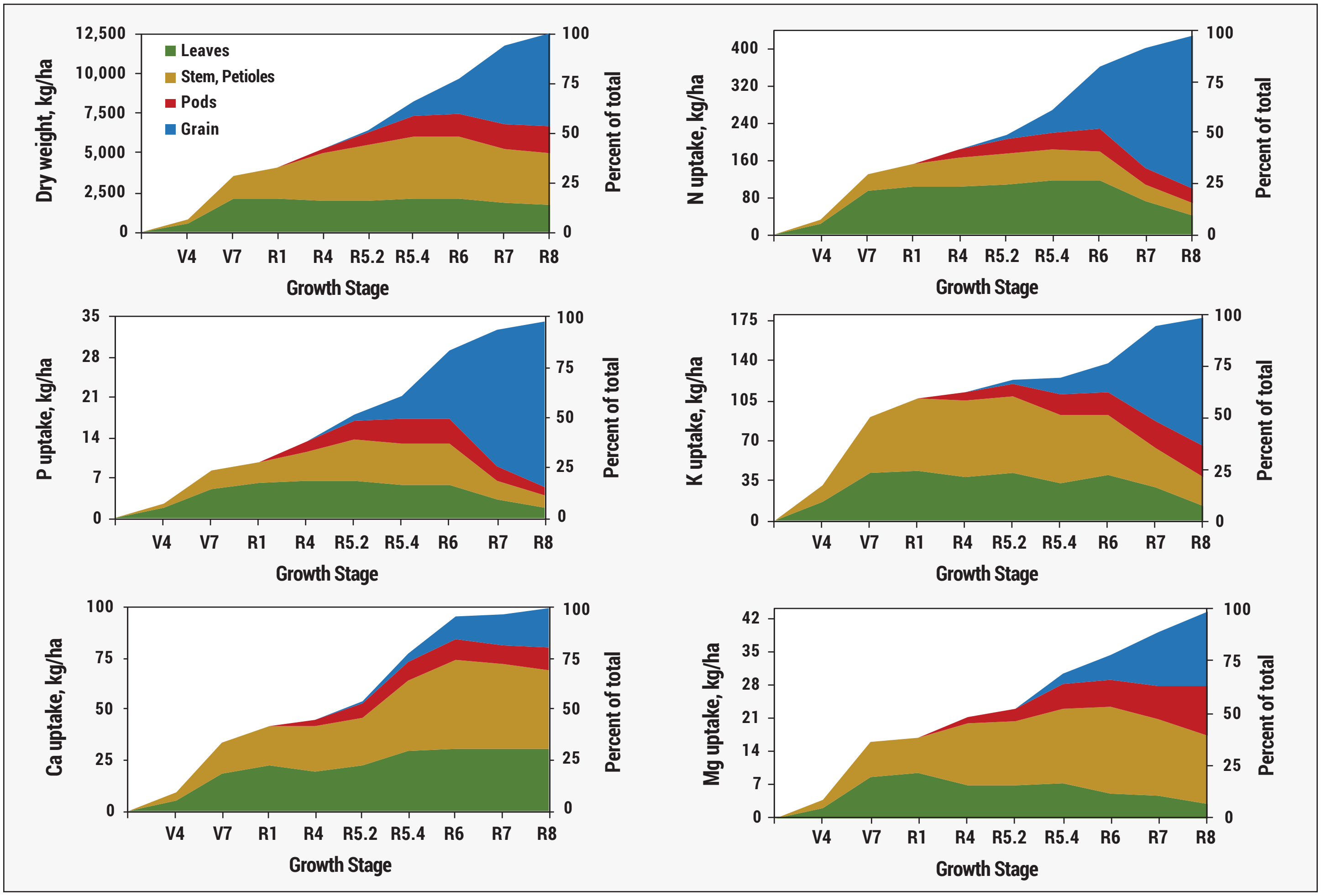

Figure 1. The seasonal accumulation and partitioning of dry matter, N, P, K, Ca, and Mg for an average yield level of 6.6 t grain/ha with a modern soybean cultivar.

modern cultivars has increased over time (**Table 2**), especially for N, P, Ca, and Mg, which have increased by an average of 42% compared to data from the 1970's. This means that higher-yielding cultivars have the potential to accumulate more nutrients.

Grain nutrients are acquired from direct uptake, partitioning, or remobilization from others parts. In the current study, remobilization from leaves, stem, and petioles was responsible for 33% of total grain content of N, P, S, and Cu, while K and Zn showed 61% and 17%, respectively. Some nutrients remobilized only from leaves Mg, B, and Fe. Calcium and Mn accumulated in all parts showed no remobilization.

Implications for Soybean Production

The high N demand in this study (over 400 kg per ha) was mostly met by biological N_2 fixation (BNF) since no mineral N was applied and high soil N supply is not expected from soil with less than 3.6% OM content. Therefore, seed inoculation with Bradyrhizobium is very important to obtain high yields in tropical soils. However,

Table 2. Percentage of total nutrient accumulation after the completion of R4, as compared to other nutrient accumulation studies. Days after planting (DAP) was used to estimate the length of time spent during specific phase of crop growth across studies.

Parameter	Hammond et al., 1951*	Hanway and Weber, 1971*	Bender et al., 2015	Current study
	------------- Growth season information -------------			
DAP to R4	80 d	75 d	70 d	68 d
DAP to R8	135 d	126 d	123 d	130 d
Approximate days during seed filling	55 d	51 d	53 d	62 d
	Percentage of total nutrient accumulation after the completion of R4			
Biomass	34	42	51	58
N	37	40	46	57
P	35	43	45	61
K	29	42	28	37
Ca	36	-	45	55
Mg	31	-	49	51
S	-	-	-	47
B	-	-	-	42
Cu	-	-	-	43
Fe	-	-	-	45
Mn	-	-	-	54
Zn	-	-	-	57

* Data adapted by Bender et al., 2015

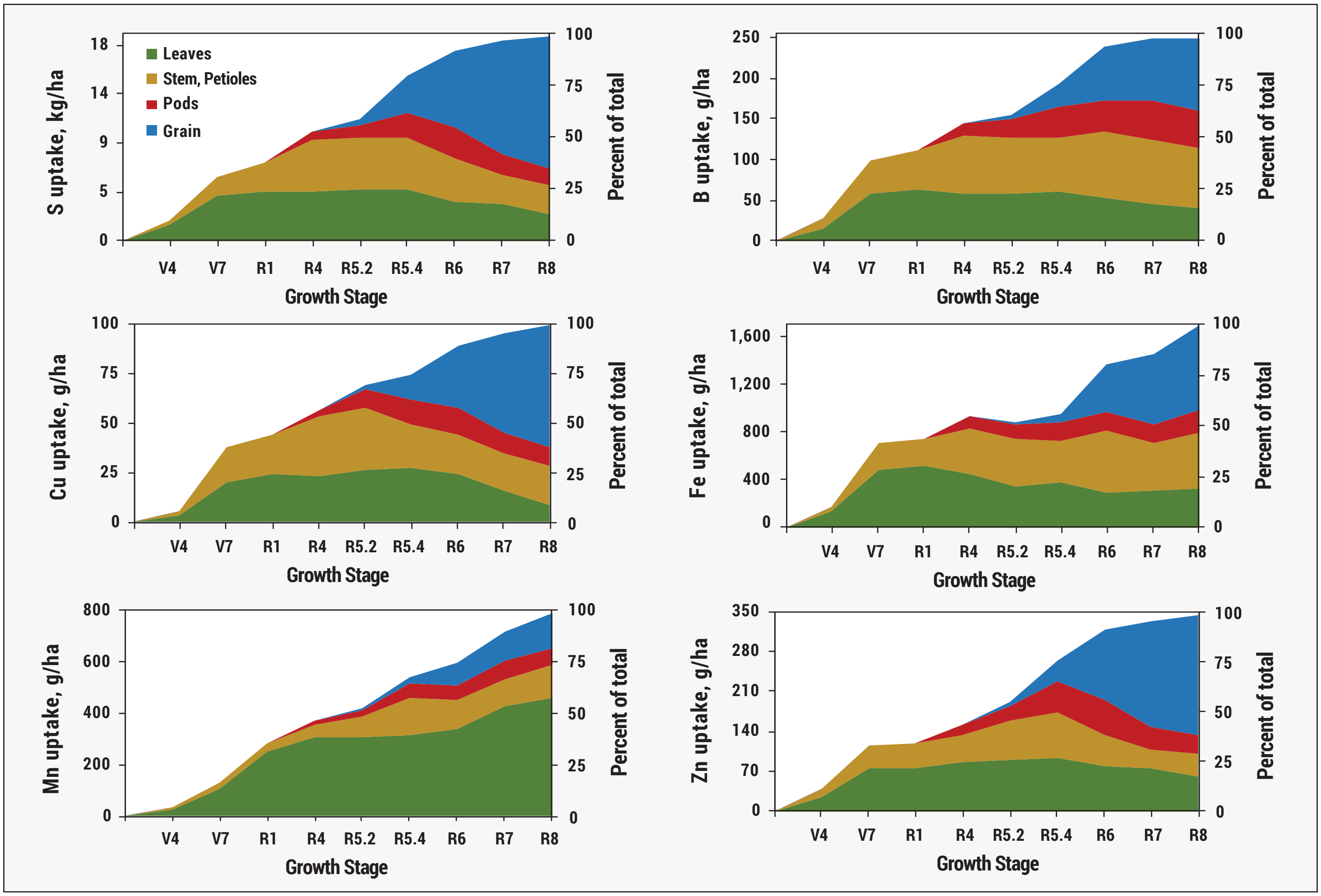

Figure 2. The seasonal accumulation and partitioning of S, B, Cu, Fe, Mn, and Zn for an average yield level of 6.6 t grain/ha with a modern soybean cultivar.

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BNF efficiency is suppressed by soil conditions such as high acidity, poor aeration/compaction, and high temperature—all of which can be managed. Potassium uptake was noticeably high and rapid, which requires good soil K availability in the first half of the growing season. Potassium applications should occur near planting and rates recommended by soil testing. A split application of K further along in the season may be strategic to overcome any leaching losses in sandy soils. The high percentage of nutrient accumulation after the full pod stage indicates that good nutrient supply during seed filling stages are crucial to sustain high yields. In Brazil, soybean fields are heavily attacked by Asian rust and worms and bugs that can cause significant damage to parts of the plant. Maintaining good control over these diseases and pests is key to avoiding the loss of leaves and stems that are the source of remobilized nutrients.

Conclusions

The objective of this study was to quantify nutrient uptake, partitioning, and remobilization of a high yield soybean crop. The highest uptake by high-yielding soybean varieties is N, K, and Ca, and attention for the amount and timing of uptake involves N and K. In the current study, six nutrients presented HI values higher than 50%: P (84), N (77), S (65), K (63), Cu (63), and Zn (61). Therefore, soil management and agronomic practices must be adequate to ensure nutrient availability through early and late season growth stages to meet soybean needs for these nutrients. Current findings on high-yielding soybean nutrient uptake and partitioning may contribute to existing agronomic recommendations and help best management practices to be performed providing nutrient availability all season-long. **BC**

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References

Bender, R.R. et al. 2015. Agron. J. 107:563-573.

Ciampitti, I.A. 2017. Soybean Growth and Development. Kansas State Research and Extension, February 2017, MF3339.