Modern Corn Hybrids' Nutrient Uptake Patterns

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Biotechnology, breeding, and agronomic advancements have propelled corn yields to new highs with little guidance as to how to fertilize these modern corn hybrids to achieve their maximum yield potential. Current fertilization practices, developed decades ago, may not match uptake capabilities of modern hybrids that contain transgenic insect protection now grown at population densities higher than ever before. A re-evaluation of nutrient uptake and partitioning can provide the foundation for fine-tuning our practices as we strive to achieve corn's maximum yield potential.

As summarized by Bruulsema et al. (2012), optimizing nutrient management includes using the right source at the right rate, right time, and right place—the 4R approach. Research pertaining to primary macronutrient uptake, partitioning, and timing (Sayre, 1948; Hanway, 1962; Karlen et al., 1988), though fundamentally accurate for previous hybrids and management practices, may be unrepresentative of modern hybrids in higher yielding environments. The objective of this study was to determine how modern, transgenic insect-protected corn hybrids in high-yielding systems take up and utilize nutrients.

Nutrient contents of N, P, K, S, Zn, and B were determined at six incrementally spaced growth stages: V6 (vegetative leaf stage 6), V10, V14, R2 (blister), R4 (dough), and R6 (physiological maturity) (Hanway, 1963). Field experiments were conducted at the Northern Illinois Agronomy Research Center in DeKalb, Illinois and the Department of Crop Sciences Research and Education Center in Urbana, Illinois. A total of six hybrids ranging in relative maturity from 111 to 114 days were used with genetic resistance to feeding from Western Corn Rootworm (*Diabrotica virgifera virgifera*), European Corn Borer (*Ostrinia nubilalis*), and other species in the Lepidoptera order. In all cases, hybrids were seeded to obtain a final stand of 34,000 plants/A. Representative plants were separated, analyzed, and evaluated in four tissue fractions: 1) stalk and leaf sheaths; 2) leaf blades; 3) tassel, cob, and husk leaves; and 4) corn grain, respectively referred to as stalk, leaf, reproductive, and grain tissues. Agronomic management at planting included a soil insecticide and a broadcast application of 150 lb P_2O_5/A as MicroEssentials® SZ™ along with 180 lb N/A as urea. This was followed by 60 lb N/A as Super-U (with urease and nitrification inhibitors) side-dressed at V6 and a fungicide at VT/R1 (tasseling/silking).

Nutrient Uptake and Removal

Across the two sites in 2010, these transgenic corn rootworm resistant hybrids yielded an average of 230 bu/A (range of 190 to 255 bu/A) and we will base our discussion of nutrient needs assuming this yield level.

When developing fertilizer recommendations, two major aspects of plant nutrition are important to understand and manage in high yield corn production including: 1) the amount of a given mineral nutrient that needs to be acquired during the growing season, referred to as "total nutrient uptake," or nutrients required for production, and 2) the amount of that nutrient contained in the grain, referred to as "removed with grain" (**Table 1**). Our grain nutrient concentration values, in units of lb/bu (**Table 1**) are in agreement with those recently used by the fertilizer industry to determine replacement fertilizer rates (Bruulsema et al., 2012). In the past 50 years, however, the quantity of N, P, and K required for production and the amount of nutrients removed with the grain have nearly doubled across a variety of management systems used in the 1960s (Hanway, 1962).

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Zn = zinc; and B = boron; HI = harvest index; R1 = silking (silks visible outside the husks); R2 = blister (kernels are white and resemble a blister in shape); R4 = dough (milky inner fluid thickens to a pasty consistency); R5 = dent (nearly all kernels are denting); R6 = physiological maturity (the black abscission layer has formed); V6 = six leaves with collars visible; V10 = 10 leaves with collars visible; V14 = 14 leaves with collars visible; VT = last branch of tassel is completely visible.

Fully-filled ears of corn—an indicator of successfully matching soil nutrient supply with crop demand.

Individual nutrient HI values were calculated, which quantify the percentage of total plant uptake that is removed with the grain. Nutrients with high requirements for production (N, P, K) or that have a high HI (P, Zn, S, N) allude to key nutrients for high yield (**Table 1**). In relation to total uptake for example, nearly 80% of P is removed in corn grain compared to K and B, which are retained to a greater percentage in stover. For each nutrient, the fraction that is not removed with the grain remains in leaf, stalk, and reproductive tissues and constitutes the stover contribution that is returned to the field. Production practices that utilize all or portions of aboveground stover (i.e. cellulosic ethanol, corn grown for silage) may remove an additional 20.8 lb N, 4.0 lb P_2O_5, 23.3 lb K_2O, 1.9 lb S, 0.5 oz Zn, and 0.2 oz B per ton of dry matter.

Maximum Uptake Rates

Further improving fertility practices require matching in-season nutrient uptake with availability, a component of the right source applied at the right rate and right time. The maximum rate of nutrient uptake coincided with the greatest

Table 1. Total macronutrient and micronutrient uptake and removal in Urbana, IL and DeKalb, IL (2010).

Nutrient	Total nutrient uptake	Removed with grain	Harvest index, %	Nutrient removal coefficient, lb/bu
	------ lb/A ------			
N	256	148	58	0.64
P_2O_5	101	80	79	0.35
K_2O	180	59	33	0.26
S	23	13	57	0.06
Zn (oz)†	7.1	4.4	62	0.019
B (oz)	1.2	0.3	23	0.001

† Zn and B are expressed in oz (i.e. oz/A and oz/bu).
Each value is a mean of six hybrids at both locations (mean = 230 bu/A). Harvest index was calculated as the ratio between nutrient removed with grain and total nutrient uptake and is reported as a percent. Multiply grain yield by Nutrient Removal Coefficient to obtain the quantity of nutrient removal.

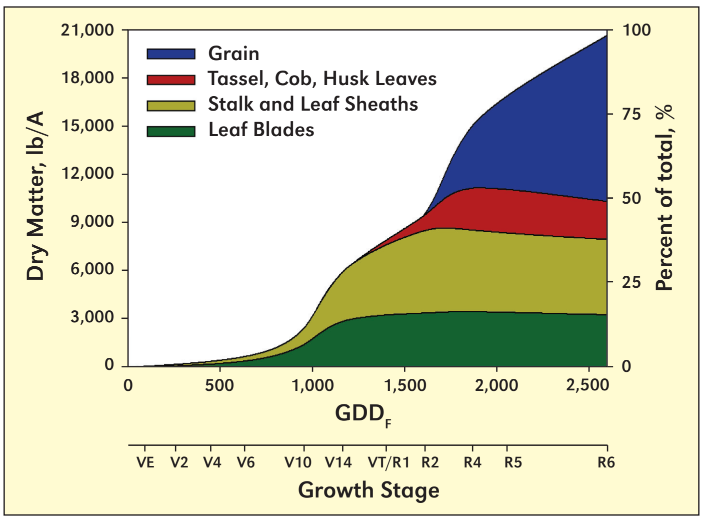

Figure 1. Total maize dry matter production and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GDD_F = growing degree days (Fahrenheit)

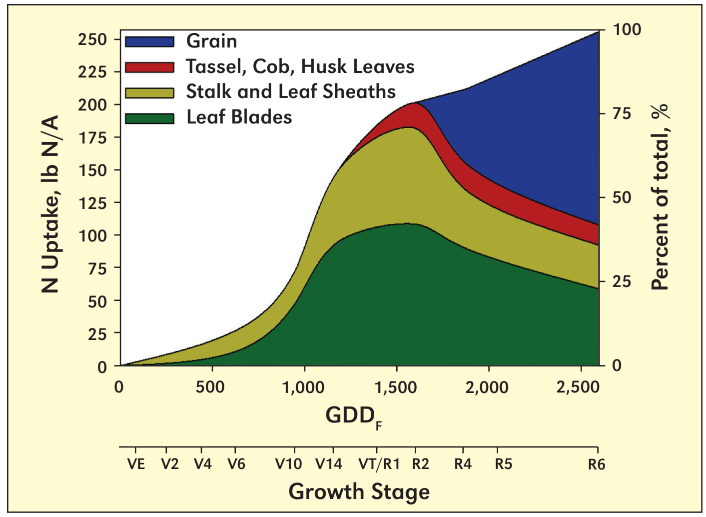

Figure 2. Total maize N uptake and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GDD_F = growing degree days (Fahrenheit)

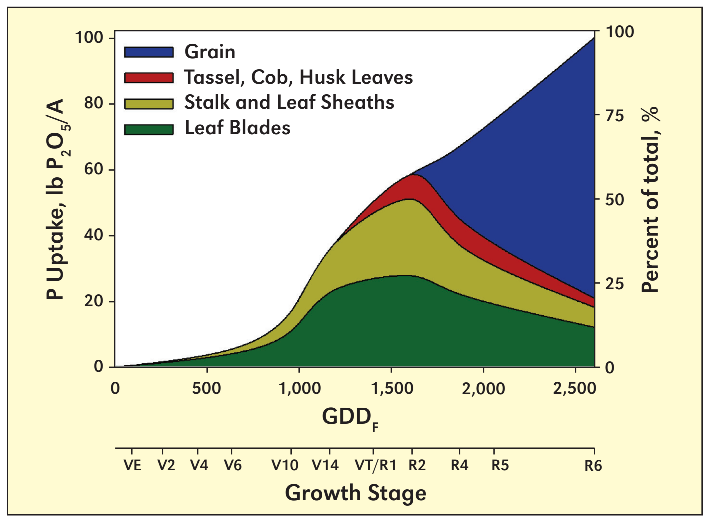

Figure 3. Total maize P uptake and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GDD_F = growing degree days (Fahrenheit)

period of dry matter accumulation during vegetative growth (**Figure 1**) for all observed nutrients (**Figures 2** to **7**). Between V10 and V14, greater than one-third of total B uptake occurred, compared to the other nutrients which ranged from 20 to 30%. During the V10 to V14 growth stages, corn required the availability of 7.8 lb N/day, 2.1 lb P_2O_5/day, 5.4 lb K_2O/day, 0.56 lb S/day, 0.21 oz Zn/day, and 0.05 oz B/day. Fertilizer sources that supply nutrients at the rate and time that match corn nutritional needs are critical for optimizing nutrient use and yield.

Timing of Nutrient Uptake

Effectively minimizing nutrient stress requires matching nutrient supply with plant needs, especially in high-yielding conditions. Sulfur and N, for example, are susceptible to similar environmental challenges in the overall goal of improving nutrient availability and uptake. However, the timing of N uptake (**Figure 2**) in comparison to S (**Figure 5**) is surprisingly different, suggesting practices that are effective for one may not improve uptake of the other. Nitrogen uptake, unlike S, followed a more traditional sigmoidal (S-shaped) uptake pattern with two-thirds of the total plant uptake acquired by VT/R1. In contrast, S accumulation was greater during grain-filling stages with more than one-half of S uptake occurring after VT/R1 (**Figure 5**). Potassium, like N, accumulated two-thirds of total uptake by VT/R1 (**Figure 4**). Interestingly, greater than one-half of total P uptake occurred after VT/R1 as well (**Figure 3**). These figures suggest that season-long supply of P and S is critical for corn nutrition while the majority of K and N uptake occurs during vegetative growth.

Unlike N, P, K, and S, which have a sigmoidal or relatively constant rate of uptake, micronutrients exhibited more

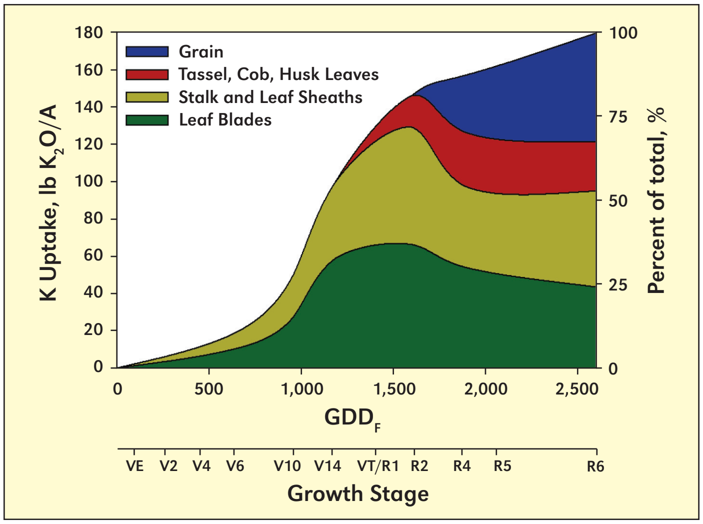

Figure 4. Total maize K uptake and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GGD_F = growing degree days (Fahrenheit)

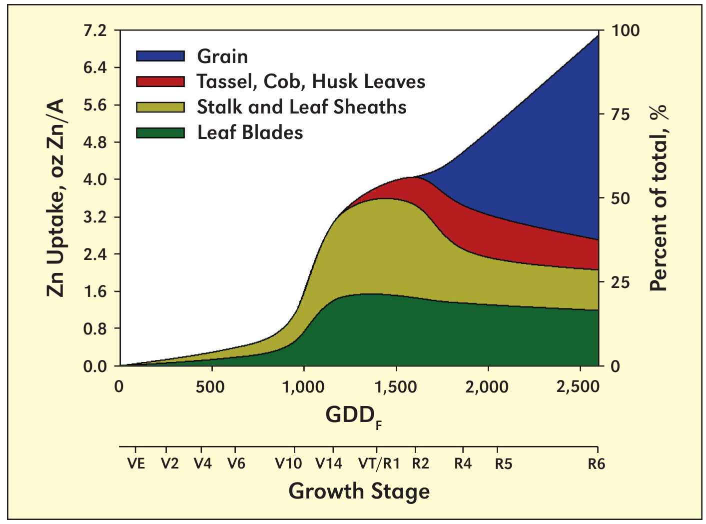

Figure 6. Total maize Zn uptake and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GGD_F = growing degree days (Fahrenheit)

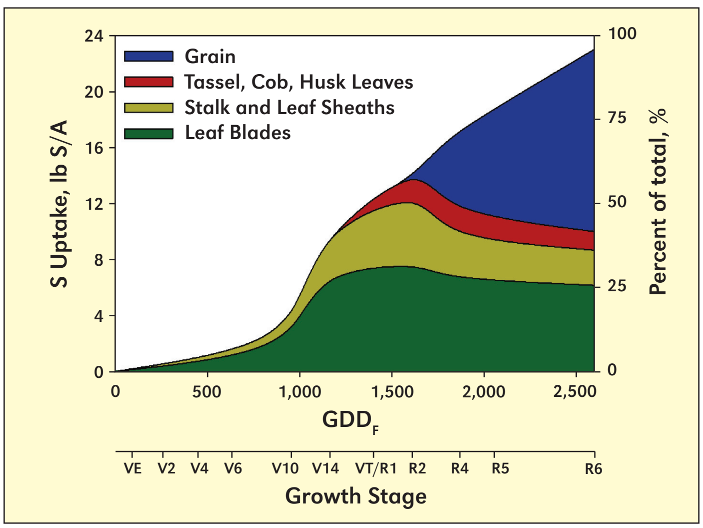

Figure 5. Total maize S uptake and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GGD_F = growing degree days (Fahrenheit)

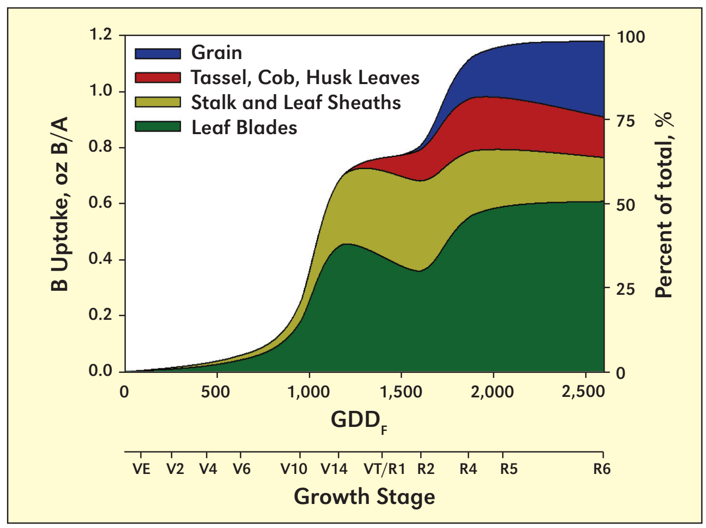

Figure 7. Total maize B uptake and partitioning across four plant stover fractions: leaf, stalk, reproductive, and grain tissues. Each value is a mean of six hybrids across two site-years at Urbana, IL (2010) and DeKalb, IL (2010). GGD_F = growing degree days (Fahrenheit)

intricate uptake patterns. Uptake of Zn and B, for example, began with a sigmoidal (S-shaped) uptake pattern in the early vegetative stages and plateaued at VT/R1 (**Figures 6** and **7**). Thereafter, Zn exhibited a constant uptake rate similar to that of P and S, while B uptake included a second major sigmoidal uptake phase concluding around R5 (dent). Zinc and B favored shorter periods of more intense uptake in comparison to macronutrients. During only one-third of the growing season, late vegetative and reproductive growth accounted for as much as 71% of Zn uptake (**Figure 6**). A similar trend was noted for B; as much as 65% of B uptake occurred over only one-fifth of the growing season (**Figure 7**). Matching corn micronutrient needs in high-yielding conditions clearly requires supplying nutrient sources and rates that can meet crop needs during key growth stages.

Plant Nutrient Mobility

Unlike plant dry matter, specific nutrients possess mobility characteristics allowing them to be utilized in one tissue, then later transported (remobilized) and used in another (Sayre, 1948; Hanway, 1962; Karlen et al., 1988). For many nutrients, including N, P, S, and Zn, a large percentage of total uptake is stored in corn grain at maturity (**Table 1**). Nutrients with high HI values accumulated them from a combination of assimilation during grain fill (after VT/R1) and remobilization from other plant parts. Phosphorus, for example, accumulated more than one-half of total uptake after VT/R1 and remobilized a significant portion that was originally stored in leaf and stalk tissues (**Figure 3**). Nitrogen and S achieved similar HI values although through two different mechanisms. Post-flowering S uptake was the major source of grain S (**Figure 5**) compared to N, which was largely obtained from remobilization (**Figure 2**). Plant Zn exhibited a unique mobility characteristic in which stalk tissue served as a major, but temporal Zn source. By R6, nearly 60% of stalk Zn was remobilized, presumably to corn grain. Similar to that of Karlen et al. (1988), leaf B content appeared to drop around VT/R1, indicative of its role in reproductive growth (**Figure 7**).

Optimization of Nutrient Management

Although nutrient management is a complex process, improving our understanding of uptake timing and rates, partitioning, and remobilization of nutrients by corn plants provides opportunities to optimize fertilizer rates, sources, and application timings. Unlike the other nutrients, P, S, and Zn accumulation were greater during grain-fill than vegetative growth; therefore, season-long supply is critical for balanced crop nutrition. Micronutrients demonstrated more narrow periods of nutrient uptake than macronutrients, especially Zn and B. As a percentage of total uptake, P was removed more than any other nutrient. In a corn-soybean rotation, it is commonplace in Illinois to fertilize for both crops in the corn production year. While farmers fertilize, on average, 93 lbs P_2O_5 for corn production (Fertilizer and Chemical Usage, 2011), the 80% of soybean fields receiving no applied P would have only 13 lbs P_2O_5 remaining (Fertilizer, Chemical Usage, and Biotechnology Varieties, 2010). These data suggest a looming soil fertility crisis if adequate adjustments are not made in usage rates as productivity increases. This plant nutrition knowledge is critical in understanding our current nutrient management challenges.

Summary

As a result of improved agronomic, breeding, and biotechnological advancements during the last 50 years, yields have reached levels never before achieved. However, greater yields have been accompanied by a significant drop in soil macronutrient and micronutrient levels. The latest summary on soil test levels in North America by IPNI reported that an increasing percentage of U.S. and Canadian soils have dropped to levels near or below critical P, K, S, and Zn thresholds during the last 5 years (Fixen et al., 2010). Soils with decreasing fertility levels coupled with higher yielding hybrids suggest that producers have not sufficiently matched nutrient uptake and removal with accurate maintenance fertilizer applications. Integration of new and updated findings in key crops, including corn, will better allow us to achieve the fundamental goal of nutrient management: match plant nutritional needs with the right source and right rate at the right time and right place. BC

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