It all started with a question. The ‘bible’ for corn growth and development for many corn agronomists trained in the last half of the 20th century was the definitive publication, *How a Corn Plant Develops*, by Richie et al. (1982). The first iteration of this classic was published by Hanway (1966) and was reprinted in 1971. A revised publication by Richie and Benson came out in 1982. The 1982 version contained a revised staging system—termed the “leaf-collar staging method”—and excellent photographs. This underwent revision in 1986. In addition to describing and illustrating the development stages, both of these versions included dry matter (DM) and NPK accumulation charts.

The accumulation charts in those 20th-century publications were the bases for the dominant thinking on seasonal nutrient accumulation and nutrient partitioning into various plant parts into the first decade of the 21st century. Were they still accurate for modern hybrids? Earn 0.5 CEUs in Crop Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/624.

**Fig. 1.** Photos reflecting the change in corn hybrids at tasseling/silking. **Left:** A double-cross hybrid from the 1960s (Hanway, 1966); **Middle:** an early 1980s “adapted mid-season hybrid in central Iowa,” likely a single-cross (Richie et al., 1986); **Right:** a 108-day, single-cross hybrid—Golden Harvest 8529 CB/LL—grown near Ames, IA in 2009 (Abendroth et al., 2011). Note the reduction in tassel size and the increase in leaf angles in the modern hybrids. Source: Iowa State University.
ent partitioning into various plant parts into the first decade of the 21st century. What we didn’t know then was upon what data the accumulation charts were based on. We asked Dr. Benson that question in late 2005 or early 2006. It turns out the charts were developed from a horizontal-leaved, double-cross hybrid—*Iowa 4570*—planted in Ames, IA in 1959! This hybrid was probably released in mid-1950s.

Corn hybrids and management have changed dramatically since 1959. U.S. national average corn yields increased from 42 bu/ac (2.6 Mg/ha) in 1955 to 177 bu/ac in 2017, and seeding rates have more than doubled since then. In terms of hybrid characteristics, a paradigm shift occurred: from horizontal-leaved, double-cross hybrids to upright-leaved, single-cross hybrids (Fig. 1).

We relied on 1959 data sources for nearly 50 years! During those five decades, few researchers have looked at macro-nutrient accumulation and concentrations, and even fewer have looked at secondary and micronutrients of modern hybrids. Determining nutrient distribution within various parts of the plant as it develops is rare.

Were the accumulation charts developed from a double-cross hybrid in 1959 still accurate for modern hybrids and management systems? This question was the genesis of a 12-year project resulting first in the Extension publication *Corn Growth and Development* by Abendroth et al. (2011a, 2011b) and then a M.S. thesis by M.J. Boyer (2013) along with several articles in *Agronomy Journal* (Woli et al., 2016, 2017, 2018, 2019). We set up a comprehensive investigation to answer this question. This article attempts to summarize this work.

Our approach

Drs. Don Duvick and Garren Benson—both now deceased—consulted, advised, and encouraged us in our efforts to update/corroborate the mid-20th century work. They helped select two popular Pioneer hybrids representative of 1960-, 1970-, 1980-, 1990-, and 2000-era decades—3206 and 3618, 3529 and SX19, 3362 and 3377, 3394 and 3489, and 33D11 and 34A15, respectively. The hybrid SX19 was Pioneer’s version of B73 × Mo17, which was never marketed, but it was a major hybrid of the 1970s and early 1980s. The hybrids were adapted to central Iowa—108- to 114-day hybrids.

Project fieldwork started in 2006 when colleagues at Pioneer developed sufficient seed for the historical hybrids. Research plot work followed at Ames, IA in 2007 and 2008. Hybrids from the different eras were seeded at rates similar to what they were historically. Seeding rates ranged from 16,000 to 34,000 seeds/ac (39,500 to 84,000 seeds/ha). The different seeding rates were required because older hybrids would not tolerate the seeding rates of modern hybrids.

We also evaluated the response to N fertilizer of a single hybrid from each era at five N rates—0 to 200 lb N/ac (0 to 224 kg N/ha)—to determine if changes in N response, agronomic optimum N rate (AONR), and nitrogen use efficiency (NUE) occurred over the 50 years of hybrid history. All other production management matched central Iowa’s standard practices in 2007 and 2008.

The research plot sizes and experimental design allowed us to not only estimate yield per unit area, but also to sample and estimate DM production as well as nutrient composition and accumulation at 10 sampling times (corresponding to development stages, Fig. 2) throughout each of the growing seasons. The plants sampled were dried to determine whole-plant DM production and N, P, K, S, Ca, Mg, and several micronutrient concentrations and accumulation. We also compared 1960- and 2000-era hybrid nutrient partitioning by dissecting plants as shown in Fig. 2.

What we found

Whole-plant DM and nutrient accumulation

- Era hybrids differed in DM and nutrient accumulation; differences in primary, secondary, and micronutrient content were mainly related to increased DM production with the more recent hybrids (Fig. 3).
- Lower nutrient concentrations moderated nutrient content in the most recent hybrids.
- Dry matter and P accumulation was linear; however, N and K accumulation slowed during the reproductive stages.
- Absolute DM production and nutrient content was greater with the most recent hybrids. However, when
we compared DM and nutrient accumulation rates based on cumulative growing degree units, the accumulation rate remained the same across era hybrids from V6 to R5 relative to the maximum DM and N, P, and K content at R5.

- Interestingly, the 1980- and 1990-era hybrids had the same grain yield (GY), total plant biomass, NUE, plant nitrogen uptake (PNU), response to N, and AONR.

**Nutrient partitioning—1960 and 2000 era hybrids**

- Plant component primary, secondary, and micronutrient contents (lb/bu; kg/ha) were greatest for 2000-era hybrids.
- Primary, secondary, and micronutrient concentrations in plant vegetative components and grain were typically lower for 2000- than 1960-era hybrids.

- The greater modern hybrid nutrient content of most plant components was mainly due to greater DM.

**Era hybrid responses to N**

- Nitrogen use efficiency (NUE) generally increased with more recent hybrids.
- Grain yield increased 65% and total plant biomass increased 43% from 1960 to 2000.
- Total PNU increased only 19% and across N rates was only higher for the 2000-era hybrid.
- At the AONR, we found a linear GY increase of 2 bu/ac/yr (0.13 Mg/ha/yr) and a GY N response of 1.4 bu/ac/yr (0.091 Mg/ha/yr), indicating considerable genetic gain over the years. There was no trend in AONR across eras.
- SPAD readings—a measure of plant N status—decreased and canopy index values increased with more recent era hybrids. All NUE measures indicated improvement in NUE. The apparent nitrogen recovery efficiency was greatest at N rates near the AONR.
of each era; however, it was not highest for the most recent eras.

- Harvest index, grain nitrogen harvest index, and fraction of total PNU accumulated by R1 were the same among eras. However, we observed a trend of more PNU in reproductive stages with our 1990- and 2000-era hybrids compared with older hybrids, which is similar to findings of other researchers with modern hybrids.
- Grain nitrogen concentration was 24% lower for the 2000 compared with the 1960 era.
- Corn hybrid development across the 50-year period improved productivity and NUE, but AONR was quite similar.

Take these findings to the field

Were the accumulation charts developed from a double-cross hybrid in 1959 still accurate for modern hybrids and management systems? No! The main change was DM accumulation and yields. Let’s summarize our findings:

Corn hybrids have indeed changed significantly since 1960. In our study, GY increased 65% and plant DM 45%. It is apparent that higher primary, secondary, and micronutrient content in newer hybrids was driven mainly by increases in DM and associated nutrient uptake rates. This occurred as yield potentials increased.

Although nutrient concentrations in plant vegetative components and grain were lower in modern hybrids, nutrient accumulation patterns were similar across the eras. Grain N in our modern hybrids was 24% less than those of the 1960s.

Yield potential and not genetic development for nutrient use timing has driven nutrient use over the decades included in this study. We expect these trends to continue unless breeding efforts concentrate more on nutrient concentrations along with yield. Thus, accurate values for crop nutrient removal in vegetation and grain will continue to be important components of nutrient management planning.

Corn hybrid development across the 50-year period improved both productivity and NUE. No significant change in yield-maximizing N rate occurred.

As overall DM production and yield potential increases in the future, we must closely watch corn primary, secondary, and micronutrient concentration and uptake of new hybrids. It is important to continue to monitor new hybrids for nutrient uptake patterns and removal, especially in view of water quality concerns and as we consider harvesting vegetative material as well as grain.

Access to newer hybrid plant component macronutrient concentrations like those we’ve provided in these publications will also help us estimate global corn nutrient use. In addition, agronomists will be better able to determine the effects on nutrient cycling and stover nutrient return to soil, nutrient uptake and recycling relationships with water quality, and soil nutrient budget estimations.

On-farm research [continued from p. 33]

due to random variation. Statistical analysis is conducted to estimate the probability that the observed differences were caused by the applied treatments. The differences between treatments are commonly determined using the Least Significant Difference (LSD)–a parameter designed to minimize the risk of making an incorrect conclusion about treatment differences. If two treatment means (averages) differ by more than the LSD value, the difference is due to treatment effects, and similar results can be expected if the experiment is repeated. On the other hand, if two treatment means differ by less than the LSD value, it is likely that the difference is due to random variation or error, and the same results are not likely to be observed in the future. Typically, a 95% confidence level is used, which means that there is a 95% chance that measured differences are due to the treatments rather than random variation or error.

Requesting assistance from those who do research for a living is not a bad idea. A poorly planned and designed on-farm research project has a high risk of not being successful. University researchers, Extension specialists and educators, industry researchers, and crop consultants are available to assist growers. For data analysis and interpretation of their results, growers are encouraged to work closely with university researchers who have access to statistical specialists and resources.

Growers may be able to access funding to help them conduct on-farm research, e.g., through USDA’s Western SARE (www.westernsare.org/) or NRCS in Idaho (https://www.nrcs.usda.gov/wps/portal/nrcs/main/id/programs/financial/). These funds are awarded through a statewide competitive process.
Updating an old paradigm
[continued from p. 37]

References

OATs [continued from p. 41]

References