Nitrogen Use Efficiency for Old versus Modern Corn Hybrids

By Ignacio A. Ciampitti and Tony J. Vyn

An analysis of all known research (100 studies from around the world) that reported corn yields, N rates, plant densities, and whole-plant N uptake was performed to compare "Old" (1940 to 1990) versus "New" (1991 to 2011) corn hybrids for their yield relationship to whole-plant N uptake, and their associated N use efficiency (NUE). This summary confirmed that NUE gains in "New" hybrids were primarily achieved by increased grain yields per unit of N stored in the plant at maturity. The accompanying reduction in grain N concentrations over time suggests that future NUE progress in corn should not overlook nutritional quality of the resulting grains.

Corn grain yields have climbed progressively over the last century due to collective changes in genetics and management practices. Annual crop yield information is robust in most corn-producing countries, but there is virtually no documentation available on the progression in nutrient use efficiency over the last six decades of corn improvement. The primary objective of this investigation was to summarize previously published scientific information to advance the understanding of the relationship of corn yield to whole-plant N uptake and associated NUE changes apparent in "Old Era" (1940 to 1990) versus "New Era" (1991 to 2011) corn hybrids.

Our data were collected from studies conducted (a) from 1940 until 2011 to assure a wide range of genotypes from different eras, (b) in all continents capable of corn production, and (c) across wide-ranging N rates (from 0 to 500 lb fertilizer N/A) and plant densities (from 4,500 to 44,000 plants/A). Only "experimental treatment means" were used. In addition, the term "N uptake" utilized in this paper is limited to above-ground whole-plant N uptake, so N accumulated in the root system is not included. Other corn traits included were NUE and its components. The following equation was used for the NUE (sometimes called agronomic efficiency for N) calculation:

$$\text{NUE} = \Delta\text{Yield}/\Delta\text{N applied} \quad (1)$$

where ΔYield is the yield (bu/A) of a treatment receiving N minus the yield (bu/A) of the 0N treatment, and ΔN applied (lb N/A) is the fertilizer N applied. A component of the NUE term is the N internal efficiency (NIE), defined as:

$$\text{NIE} = \text{Yield/Plant N uptake} \quad (2)$$

where NIE is calculated on a per unit area basis (bu/lb N uptake).

Another N efficiency parameter evaluated was the N fertilizer recovery efficiency (NRE):

$$\text{NRE} = \Delta\text{Plant N uptake}/\Delta\text{N applied} \quad (3)$$

where ΔPlant N uptake is the change in whole-plant N uptake due to N fertilization (lb N/A). Maximum and minimum boundaries were established to constrain possible NRE values ($0 < \text{NRE} < 1$), so that the NRE calculation is more biologically meaningful (Ciampitti et al., 2012).

Grain Yield and Plant N Uptake: New vs. Old Corn Genotypes

Superior grain yield and whole-plant N uptake were documented for the New compared to the Old Era corn hybrids

Abbreviations and notes: N = nitrogen.

Table 1. Summary of variables compared for old and new era corn hybrids.

Variable	Old Era	New Era
Mean N rate, lb N/A	126	125
Plant density, plants/A	22,800	28,800
Plant N uptake, lb N/A	136	143
Grain yield, bu/A	115	144
N use efficiency (NUE), bu increase/lb N	0.58	0.66
N internal efficiency (NIE), bu/lb N uptake	0.89	1.00
Grain harvest Index[1] (HI), %	48	50
N harvest Index[2] (NHI), %	63	64
Grain N, %	1.33	1.20
Stover N, %	0.77	0.69
% of total plant N coming from new N uptake after R1	31%	36%
% of grain N that came from new N uptake after R1	52%	56%

[1]Grain harvest index is the percent of the total above-ground dry matter that is in the grain.
[2]N harvest index is the percent of total above-ground N accumulation that is in the grain.
Source: Ciampitti and Vyn, 2012

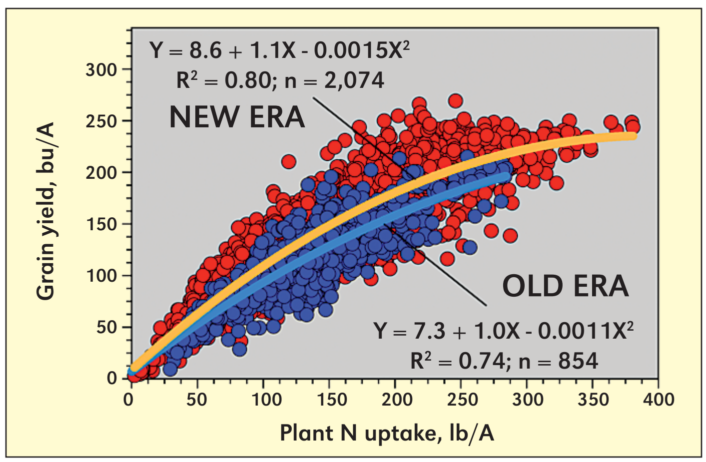

Figure 1. Corn grain yield versus plant N uptake at maturity in studies conducted from 1940 to 2011. Blue circles correspond to Old Era observations from 1940 to 1990 (n = 854), and the red circles refer to the New Era from 1991 to 2011 (n = 2074).

(**Table 1**). Nitrogen internal efficiency followed a quadratic model (**Figure 1**), and higher average yield-levels were evident for newer (240 bu/A) vs. older (200 bu/A) hybrids as plant N uptake increased.

Following adjustments for plant density in each trial (**Table 1**), it was clear that NIE was greater for newer versus older

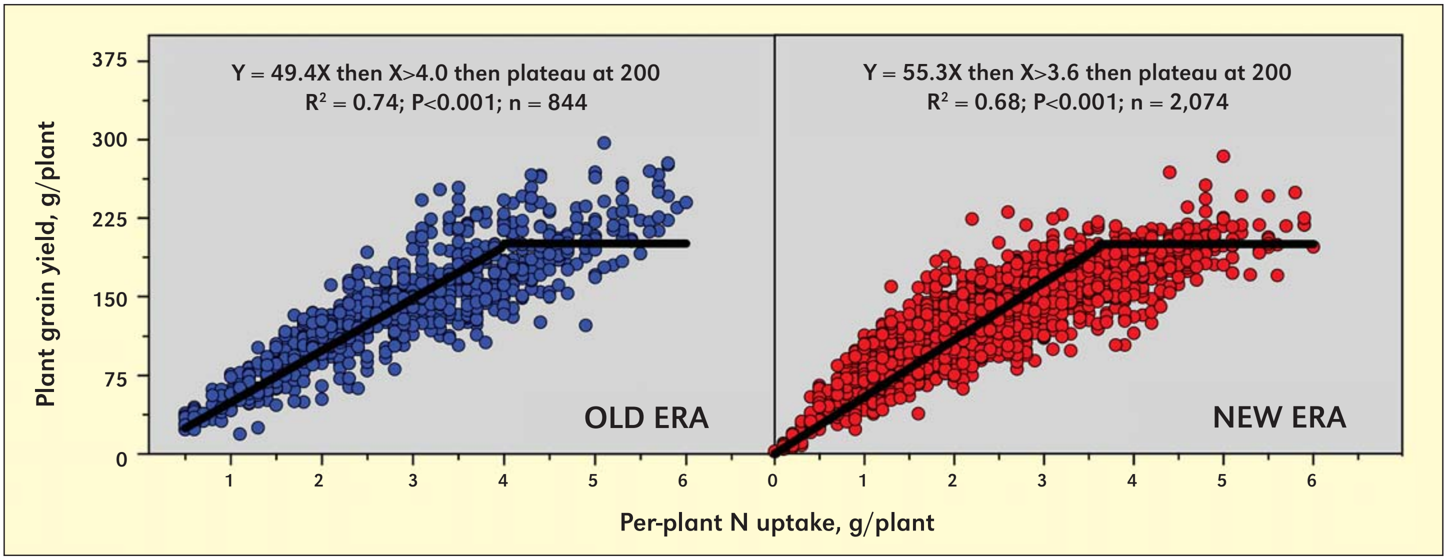

Figure 2. Relationships between grain yield and whole-plant N content at the per-plant-scale for older (Old Era, blue color: observations from 1940 to 1990) versus newer corn genotypes (New Era, red color: research carried out between 1991 and 2011).

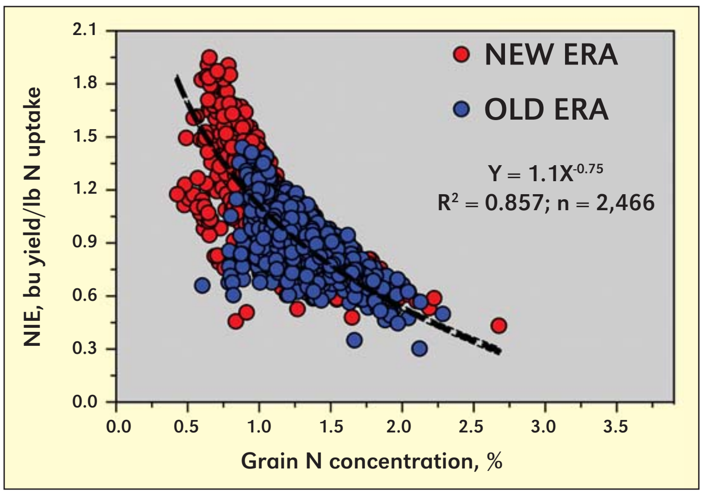

Figure 3. Relationship between nitrogen internal efficiency (NIE), calculated on a per unit area basis, and grain N concentration determined at maturity stage for Old (blue color, studies from 1940 to 1990) and New (red color, from 1991 to 2011) Eras.

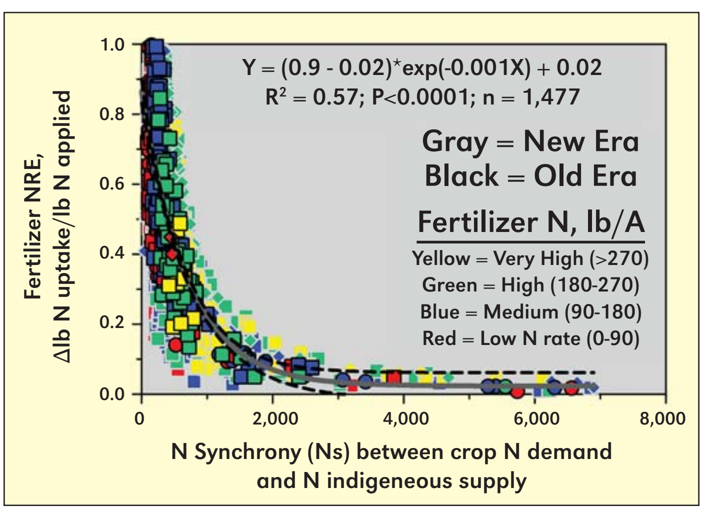

Figure 4. Relationship between N synchrony and fertilizer N recovery efficiency (NRE). New Era = experiments from 1991 to 2011; Old Era = studies from 1940 to 1990.

genotypes (**Figure 2**). In addition, maximum N uptake per plant at maturity (6 g N/plant) had not changed between Eras despite increased plant densities in newer genotypes.

Nitrogen Use Efficiency Components: NIE and NRE

The NIE change previously documented is primarily accounted for by changes in the grain N concentration (%N; **Figure 3**). Grain %N declined about 10% from older to newer genotypes (with similar reductions in whole-plant %N). Both Duvick (1997) and Scott et al. (2006) documented a similar diminishing pattern in grain protein for corn hybrids representing different eras.

Both older and newer corn genotypes had similar NRE with an overall average of 0.46. The synchrony between soil N supply and crop N demand (hereinafter termed "N synchrony") is the key component determining the fertilizer NRE term (Cassman et al., 2002):

$$\text{N Synchrony } (N_S) = \text{N applied} / (1 - \text{N uptake at 0N / N uptake with N applied})$$

Smaller values of N_S indicate greater synchrony.

The association between the N_S and the NRE showed that greater N synchrony can be obtained in a NRE range from 0.4 to 1.0, corresponding primarily to low and medium N rate levels from 0 to 180 lb/A (**Figure 4**). When fertilizer N was applied in excess (>270 lb/A; yellow points), the mean NRE was dramatically reduced (usually between 0.3 to 0.1). Reduction in NRE increases both environmental risk of N loss and lower farmer profitability.

Yield and N Uptake Responses to Fertilizer N Rates: New vs. Old Era Hybrids

For an integrated evaluation of the yield and plant N uptake responses at diverse fertilizer N rate levels, data from studies were arbitrarily divided into seven N fertilizer rate ranges based on successive 45 lb/A N-rate increments (starting from 45 lb/A).

A summary analysis presented in **Figure 5** highlights that i) when no N was applied, the grain yield advantage of newer versus older corn genotypes (ΔGY_{0N}) was ~ 13 bu/A; ii) the yield gap enlarged as the fertilizer N rate increased; iii) with highest N rates (>215 lb/A), the yield advantage (ΔGY_N) increased to 32 bu/A; and iv) at the plant-scale, N uptake was very similar for both Eras under (at) the full range of N fertilizer rates. This analysis permitted us to conclude that per-plant N uptake has not changed since 1940; nonetheless, per unit area, greater stress tolerance to N deficiency and N responsiveness to fertilizer N rate was observed in modern corn hybrids.

Conclusion

Improvements in NUE in past decades were primarily achieved by increasing NIE at the expense of lower grain N concentrations. Future NUE improvements should attempt to achieve simultaneous gains in NRE and grain yields without further sacrifices in grain N concentrations. From the management perspective, further optimization of best management practices (the "4 Rights": Source, Rate, Timing, and Placement) need additional research to improve global food security while minimizing N "footprints" in corn production systems around the world. BC

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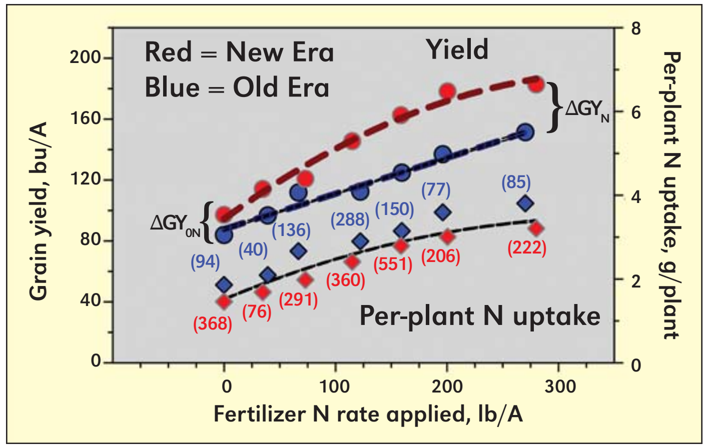

Figure 5. Corn yield and per plant N uptake (at maturity) versus overall fertilizer N rate applied. Red and Blue symbols refer to New and Old Era, respectively. Diamond symbols refer to plant N uptake and the circles refer to grain yield. Values refer to the total number of data points for each N rate and Era combination. GY_{0N} denotes the difference in grain yield between Old and New Era hybrids when no N was applied. Similarly, ΔGY_N indicates differences in N-fertilized yield.

References

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Research Notes

Agriculture: Sustainable Crop and Animal Production to Help Mitigate Nitrous Oxide Emissions

Nitrous oxide (N_2O), a potent greenhouse gas, is emitted from many natural and human activities; including from the soil following nitrogen (N) application. This article discusses several options to reduce N_2O emissions from agricultural fertilizer N use at the field scale.

Improved Efficiency Reduces N_2O Losses

Improving the crop recovery of N fertilizer helps reduce residual soil N that is susceptible to conversion to N_2O or losses through nitrate leaching. Research has confirmed that proper fertilizer management practices can provide reduced N_2O losses, which are generally small until the optimum fertilizer N rate is significantly exceeded.

Enhanced Efficiency Fertilizers

Several coated N fertilizers may significantly reduce N_2O emissions, while some N fertilizer treated with additives (e.g., nitrification inhibitors) have more consistently reduced N_2O emissions when compared with standard N fertilizers, in a variety of soil conditions.

Crop Sensors

Use of optical crop N sensors allows farmers to better match fertilization with crop N needs, and often results in improved fertilizer N efficiency and farmer profitability. One recent study on corn reported that sensor use could save farmers 10 to 50 kg of N/ha. A citrus fertilization study showed that optical sensors resulted in 40% less fertilizer N use, >60% less nitrate leaching, and improved profitability compared with traditional N practices.

Winter Cover Crops

Winter cover crops help protect soil from erosion, build soil organic matter, and capture residual soil nitrate. In some soils, cover crops stimulate N_2O emissions, due to the release of soluble carbon and N from decaying cover crop residues. In other situations, cover crops prevent N losses and lower N_2O emissions. There are many specific site factors that determine the effectiveness of cover cropping practices.

Summary

The quandary of producing 50% more food by 2050 while protecting environmental quality and minimizing N_2O emissions rests with both demand-side measures (such as dietary choices and reducing food waste), and implementing improved farmer 4R fertilizer practices. These important goals can be met through proper education, research, and supportive policies. BC

Adapted from: Snyder, C.S., E.A. Davidson, P. Smith, and R.T. Venterea. 2014. Agriculture: sustainable crop and animal production to help mitigate nitrous oxide emissions. Curr. Opin. Environ. Sustain. 9–10:46–54. (OPEN ACCESS) http://dx.doi.org/10.1016/j.cosust.2014.07.005