VARIATION IN INTERNAL N EFFICIENCY OF CORN AND IMPACT ON YIELD-GOAL BASED N RECOMMENDATIONS

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ABSTRACT

Internal N efficiency (IE) is defined as bushels per acre (GY) produced per pound of N per acre (PMN) in the plant at physiological maturity (R6). Internal N efficiency defines the required amount of plant N content at R6 in a yield-goal based N rate recommendations (currently used in 30 U.S. states) and several commercial N recommendation models. Commonly IE is assumed to be constant at an approximate value of 0.8 bu lb-N^{-1} in yield-goal based recommendations. Our research objective was to quantify the variation in IE across a wide range of environmental conditions and identify weather, soil, and crop factors contributing to the variation. Experiments were conducted in 2014 and 2015 in 8 Corn Belt states. Treatments were different rates of N (0-280 in 40 lb N ac^{-1} increments) and timing (all at planting or split between planting and V10). Nitrogen timing had little effect on IE. Internal N efficiency at the economic optimum N rate (EONR) ranged among sites from 0.83 to 1.3 bu lb-N^{-1}, averaging 1.07 bu lb-N^{-1} content. This variation in IE would result in crop N content at R6, thus N recommendations, varying ±46 lb N ac^{-1} (based on a yield goal of 200 bu ac^{-1}). Plant N content at VT and R6 of the zero N applied treatment (an indication of soil N supplying capacity) explained 41 and 15%, respectively, of the variation in IE across site-years and timing ($P \leq 0.05$). Lesser soil N capacity resulted in higher IE at the economic optimum N rate. Abundant and well-distributed rainfall (AWDR) during grain fill explained less than 10% of the variation in IE ($P \leq 0.05$). Yield at EONR, EONR, and AWDR during other growth stages did not explain variation in IE ($P > 0.05$).

INTRODUCTION

Nitrogen use efficiency (NUE) is composed of two major components (N uptake efficiency and internal N efficiency (IE)), attempts to improve NUE can be made in either one of these areas. Internal N efficiency is defined as GY produced per PMN accumulated at R6 IE= ((GY/PMN)) (Moll et al. 1982). Many researchers have noted that hybrids and genotypes differ in their ability to achieve improved NUE (Moll et al. 1982; Kamprath et al. 1982; Bänziger et al. 2007). Hybrid improvement in IE has primarily been due to a reduction in grain N concentration in the newest hybrids (Ciampitti and Vyn 2012; Woli et al. 2016). However, there was been little research to determine the effects of environment and management practices on IE.

Yield-goal based models, utilize the inverse of IE, lb N bu^{-1}, to develop N fertilizer recommendations. One issue with these models is IE is assumed to be constant at approximately 0.8 bu lb-N^{-1} (1.2 lb N bu^{-1}). It is also held constant across environments and years. Other issues are poor relationship between yield-goal based N recommendations and economic optimal N rate

(EONR), poor prediction of non-fertilizer sources, and unclear calculations of yield goals (Sawyer et al. 2006). Currently there are 30 states in the U.S. that still use yield-goal based N recommendation models.

Our main research objective was to quantify the variability in IE across a wide range of environmental conditions and identify weather, soil, and crop factors responsible for the variation in IE. The secondary objective was to note the implications on yield-goal based N recommendation models and steps that can be taken to improve N recommendations.

MATERIALS AND METHODS

Eight land-grant universities (Iowa State, Illinois, Minnesota, Missouri, North Dakota, Nebraska, Purdue, and Wisconsin), USDA-ARS, and DuPont Pioneer collaborated on conducting N rate and timing trials according to a common protocol. Each state had two fields in each of 2014 and 2015 varying in soil productivity based on historical corn yield history. The previous crop was soybean (*Glycine max* (L.) Merr.) Thirty of 32 site-years were useable to address our objective (no data for ND in 2015). Pioneer hybrids appropriate for the site and region were planted at 35,000 seeds ac^{-1}.

Nitrogen rate treatments were 0 to 280 lb N $acre^{-1}$ in 40 lb N $acre^{-1}$ increments applied as ammonium nitrate broadcast on the soil surface. Nitrogen timing treatments were; 1) all applied within 48 hours of planting or 2) 40 lb N $acre^{-1}$ at-planting and the remainder at V9. Each plot had at least one buffer row on each side and a harvest area for grain yield of 200 ft^2. Plot design was a randomized complete block with four replications.

Temperature, precipitation, and irrigation data were collected at each field site throughout the growing season. Abundant and well-distributed rainfall (AWDR; including irrigation) was calculated according to Tremblay et al. (2012). The AWDR was calculated for the entire season, two weeks before or after VT, and two weeks before and after VT.

Six whole plants were sampled in non-yield rows at tasseling (VT) and physiological maturity (R6). Biomass samples were dried at 140ºF until they reach a constant weight. Stover was ground to pass a 0.04 inch screen in preparation for N analysis. Grain was shelled from the ears, dried and ground for N analysis. Cobs were weighed and their N content estimated. Nitrogen was determined with combustion analysis at Agvise Laboratories (Northwood, ND).

Statistical analysis was performed with SAS v. 9.2 and 2013 Microsoft Excel. A quadratic-plateau equation was chosen to explain the grain yield response to N rate. Data was fitted to the quadratic-plateau equation using proc NLIN in SAS 9.2. The economic optimum N rate was calculated based on \$4.00 bu^{-1} corn grain and \$0.40 lb^{-1} fertilizer N. The EONR was set not to exceed the maximum N rate (280 lb N ac^{-1}). A linear equation best fit the response of IE to N rate and the IE at EONR (IE@EONR) was calculated. Linear regression was used to determine the amount of variation in IE@EONR explained by several variables. on IE@EONR VT and R6 plant N content at 0 N rate, growing season AWDR, EONR, yield and yield at EONR to determine the amount of variations contributed to IE. Level of significations was determined by using a t-test table to a P-value ≤ 0.05.

Internal N efficiency was calculated by taking the GY from each plot and dividing it by PMN. Economic optimum N rate was calculated based on a N price to corn price ration of 0.40 cent to \$4.00. A quadratic-plateau function was used to calculate EONR. Economic optimum N rate at IE was calculated by fitting EONR to a regression equation formulated from IE negative linear relationship with N rate.

RESULTS AND DISCUSSION

Internal N efficiency decreased linearly with increased N rate at 27 of 30 site-years. For example, in Indiana 2014 on both soil series IE decreased from ~1.4 to ~0.9 bu lb-N^{-1} with N increasing from 0 to 280 lb N ac^{-1} (Fig. 1). In 2015 at the same sites, IE decreased from ~1.4 to ~ 0.7 bu lb-N^{-1} (data not shown). There was no effect of application timing in either year in Indiana or for 13 site-years overall (data not shown).

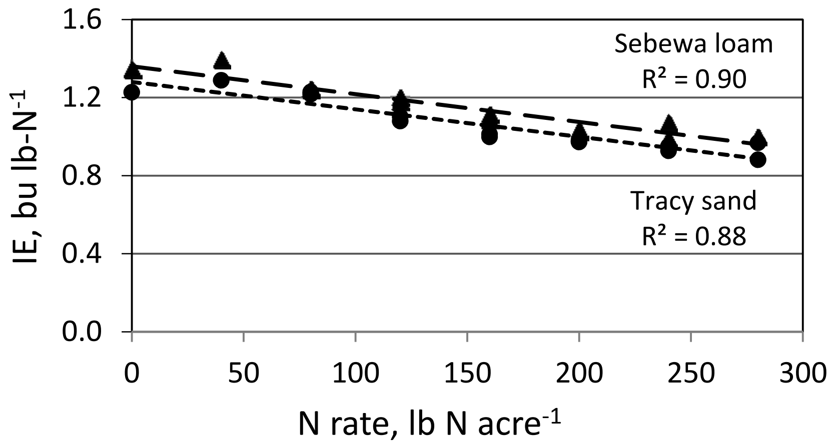

Figure 1. Increased N rate decreased internal N efficiency (IE) on 2 Indiana soil series in 2014. Each point represents the mean of four replications. Similar effects occurred at 27 of 30 site-years.

The EONR ranged from 9 to 280 lb N ac^{-1} across the 30 sites. Grain yield at the EONR ranged from 97 to 259 bu ac^{-1}. Across all sites the IE@EONR ranged from 0.83 to 1.3 bu lb-N^{-1} and averaged 1.07 bu lb-N^{-1}. This level of variation in IE would result in crop N at harvest varying ±46 lb N ac^{-1} (based on a yield goal of 200 bu ac^{-1}; Table 1).

Table 1. The range and average of internal N efficiency among 30 site-years and the impact on yield goal-based N fertilizer recommendations.

Statistic	IE, bushel per pound N	1/IE, pounds N per bushel	Yield goal, bushels per acre	Plant N at harvest, pounds per acre
Minimum	0.83	1.19	200	239
Maximum	1.30	0.75	200	150
Average	1.07	0.93	200	143

There was a linear decrease in IE@EONR with increased plant N content at VT (Y= -0.002x + 1.230, R^2 = 0.41, P ≤ 0.05) and R6 (Y = -0.001x + 1.172, R^2 = 0.15, P ≤ 0.05) across the 30 site-years (Fig. 2 and 3). Plant N content ranged from 31 to 160 lb N ac^{-1} at VT and 32 to 216 lb N ac^{-1} at R6.

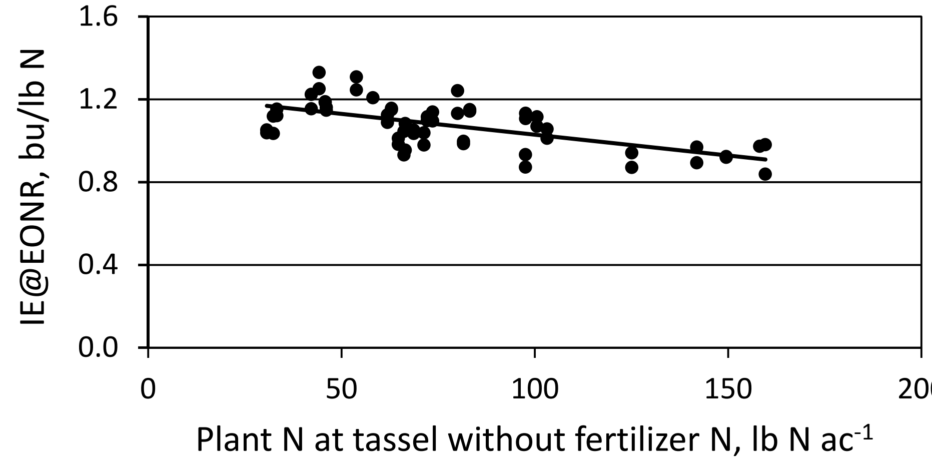

Figure 2. Increased plant N content at tassel without fertilizer N was associated with decreased internal N efficiency at the economic optimum N rate (IE@EONR). Each point represents a single site-year.

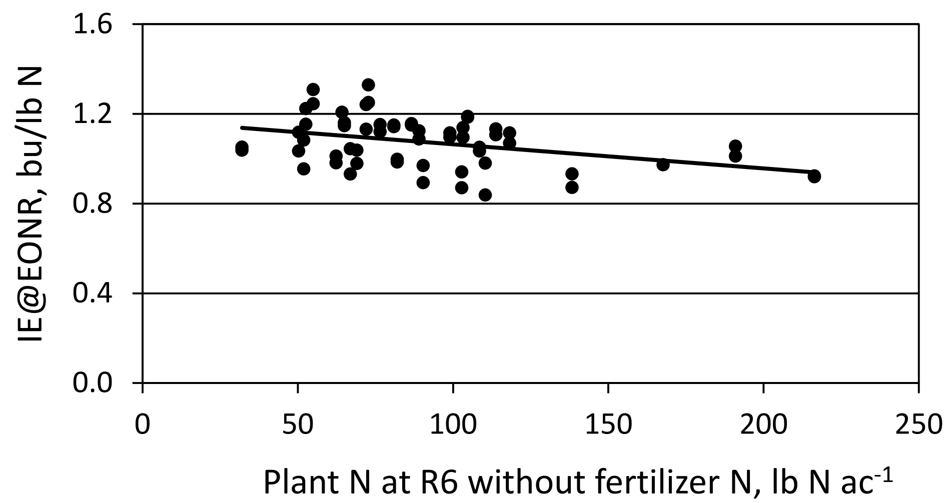

Figure 3. Increased plant N content at physiological maturity (R6) without fertilizer N was associated with decreased internal N efficiency at the economic optimum N rate (IE@EONR). Each point represents a single site-year.

The amount and distribution of rain is known to affect yield and N accessibility during the growing season and therefore may affect IE. Across site-years the AWDR during grain fill accounted for <10% of the variation in IE. The AWDR ranged from 1.2 to 9.6 inches (Fig. 4) ($Y = 0.017x + 1.005$, $R^2 = 0.10$, $P \leq 0.05$). Internal efficiency increase with great distribution of water availability throughout the grain fill period. This is due to decrease plant stress and better translocation of N to the ear.

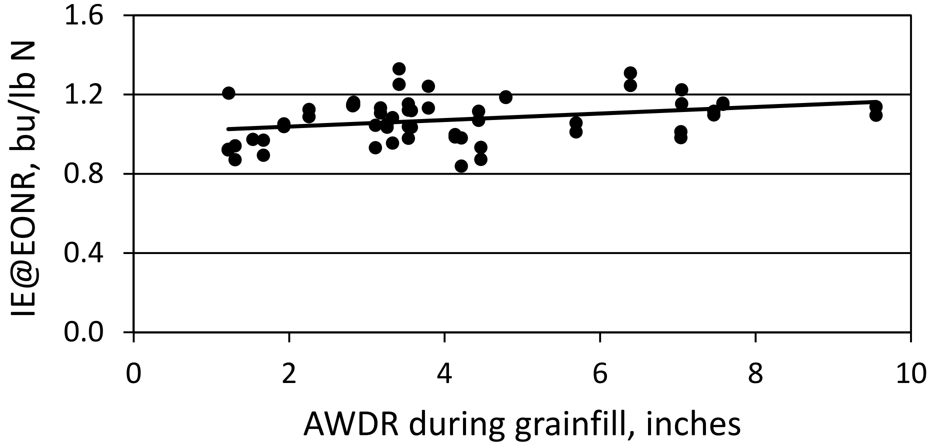

Figure 4. Increased adequate and well-distributed rainfall (AWDR) during grainfill was associated with increased internal N efficiency at the economic optimum N rate (IE@EONR). Each point represents a single site-year.

One might expect that yield level, EONR, and AWDR at other growth stages would explain some of the variation in IE, with higher yielding crops needing less N being the most efficient and having the highest IE. However, yield at EONR (Fig. 5), EONR (Fig. 6), and AWDR at other growth stages (data not shown) explained none of the variation in IE among the 30 sites-years.

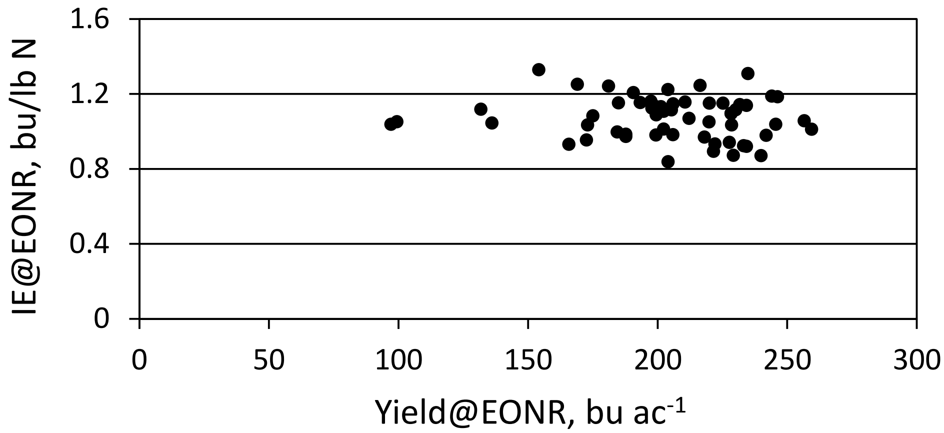

Figure 5. Yield at the economic optimum N rate (Yield@EONR) had no effect on internal N efficiency at the economic optimum N rate (IE@EONR). Each point represents a single site-year.

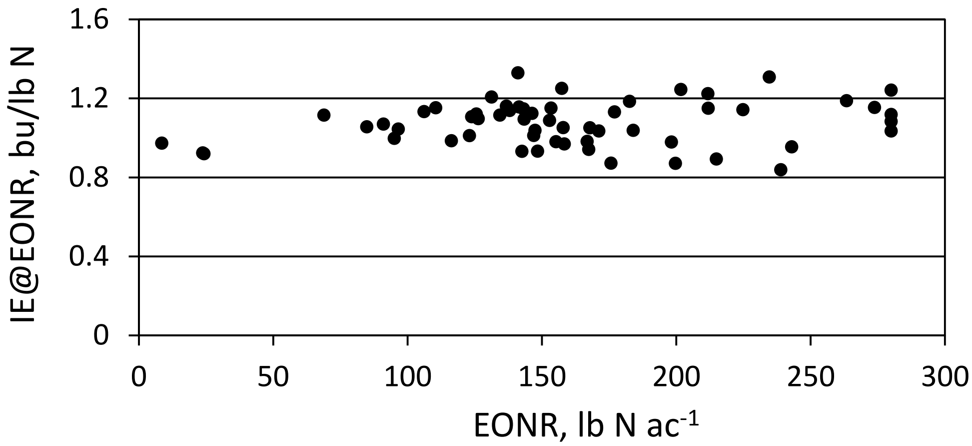

Figure 6. The economic optimum N rate (EONR) had no effect on internal N efficiency at the economic optimum N rate (IE@EONR). Each point represents a single site-year.

SUMMARY

Internal N efficiency at the economic optimum N rate (EONR) ranged from 0.83 to 1.3 bu lb-N^{-1} and averaged 1.07 bu lb-N^{-1} across 30 site-years. This range in IE would result in a crop N requirement of ±47 lb N ac^{-1} in a yield-goal N recommendation system with 200 bu ac^{-1} as the yield goal.

Higher IE occurred at low N supply, arising from either fertilizer N or soil mineralization, perhaps because limited N availability during grainfill resulted in greater remobilization of N accumulated during vegetative growth. Adequate and well-distributed rainfall during grainfill may have caused higher IE because limited water supply increase plant stress and reduced its ability to translocate N to the grain. A number of other factors we studied, including yield, optimum N rate, or AWDR for growth stages other than grainfill, did not explain any variation in IE across the 30 sites.

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