

Moving Toward A Global Approach To Nitrogen Management In Maize

Maize-N model computer simulation program recommends nitrogen rates for maize crops.

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Summary: The Maize-Nitrogen (N) model deploys a series of systematic and mechanistic analyses of climatic information, soil properties, and crop system characteristics for a given field. It is composed of three modules: 1) a maize yield module for estimating yield potential and its variation, 2) a carbon (C) and N mineralization module for estimating the indigenous soil N supply, and 3) a yield response module for estimating economically optimal N rate. Compared with conventional N rate recommendation schemes, the Maize-N model provides an analysis of biophysical and climatic parameters that govern N supply, N-use efficiency (NUE), and uptake in maize production systems. Maize-N also estimates the climate-adjusted, site-specific yield potential (Y_p) for today's modern hybrids. The Maize-N model provides a knowledge-based decision-aid that is global in scope. The link to Maize-N is: <http://www.hybridmaize.unl.edu/maizeN.shtml>



Fertilizer N rate algorithms currently used in the U.S. Corn Belt are highly empirical in nature and use varying degrees of stochastic analysis based on statistical analysis of regional N response curves. As a result, their utility is limited to the region in which they are developed and they offer little scientific insight as to the biophysical components governing the variation in actual N need. The *Maize-N* model has been designed to incorporate site-specific weather information and management data to drive estimations of both maize yield potential and indigenous N supply.

Indigenous soil N supply is estimated from daily time-step simulation of C and N mineralization of crop residues, soil organic matter, and manures. Site specific long-term average yield potential is provided by the Hybrid-Maize simulation model (www.hybridmaize.unl.edu) as a subroutine from which the upper limit of attainable yield is calculated. The user may also input site yield history in lieu of simulated yield. These components of the maize growth environment are coupled to estimates of both maize N resource use efficiency and physiological efficiency derived from

detailed analysis of a global database that defines a robust, generic relationship between maize N uptake (U) and grain yield. The *Maize-N* model structure is

“Maize-N provides a knowledge-based decision aid”

predicated on the relationship between yield response and uptake efficiency defined by Agronomic Efficiency (AE), which is the product of N recovery efficiency (RE) and Physiological Efficiency (PE) whereby: $AE = RE \times PE$, $AE = (Y - Y_0)/N$; $RE = (U - U_0)/N$; $PE = (Y - Y_0)/(U - U_0)$.

N requirement may be attained as a function of both yield potential and efficiencies of N use by the crop. The definitions of parameters are:

- $N = (Y - Y_0)/AE$
- $N = (U - U_0)/RE = (U - IN)/RE$
- Y = expected yield (kg ha^{-1})
- Y_0 = yield without N application (kg ha^{-1})
- U = total crop N uptake (kg ha^{-1})
- $U_0 = IN$ = total crop N uptake without

fertilizer addition (kg ha^{-1})

- AE = agronomic efficiency of applied N ($\text{kg yield increase/kg N applied}$)
- RE = recovery efficiency of applied N ($\text{kg N recovered in the crop/kg N applied}$).

For any N recommendation scheme to work, it must be able to estimate 1) likely maize yield for the season: Y_a = attainable yield as a function of Y_p , 2) indigenous soil N supply (IN) to the crop, 3) RE of fertilizers, and 4) economically optimal N rate (EONR) based on maize yield response to N rate, and fertilizer cost and price of maize spherical response surface within the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model. *Maize-N* uses estimates of these four components of the N demand-supply relationship in a maize system. Figure 1 displays the inputs required, process functions, and outputs of the *Maize-N* model.

Yield potential. Using long-term weather records and crop management specifications input, *Maize-N* simulates yield potential for each year in the weather data file. It then computes the mean yield potential and its coefficient of variation (CV). The yield simulation module is based on the Hybrid-Maize

crop model. It assumes optimal water supply without biotic and abiotic stresses to the maize crop. The likely yield outcome, or attainable yield (Y_a) for the current season, is assumed to a fraction (f_{gap} , default = 0.85) of Y_p . In case the user specifies the average yield of past years, the simulated Y_a will be replaced by the user-specified yield.

Yield response. The response of maize yield to N uptake is founded on a large database of nutrient uptake by irrigated and favorable rain-fed maize grown in well-managed on-farm and on-station experiments in sub-tropical and tropical climates in southeast Asia (North Vietnam and Indonesia) as well as temperate climates (multiple sites in Nebraska, Figure 2). It covers a wide yield range from about 1 to nearly 20 Mg ha⁻¹. The QUEFTS model employs two linear boundaries that describe the range from maximum accumulation (“excess”) to maximum dilution (“deficiency”) of N, P, and K in maize. These boundaries envelop an optimized yield response curved to N uptake, which follows a spherical response curve that plateaus at the maximum upper limit for yield potential. Note that the upper limit is greater in the temperate systems of Nebraska compared to tropical and subtropical systems in southeast Asia. The relationship in Figure 2 is thus used to calculate the necessary N uptake requirement from Hybrid-Maize-determined Y_p or Y_a , or user-defined yield input.

Indigenous N. Soil Indigenous N--including N from last season carryover, mineralization of SOM, crop residues (roots and stalks), any applied manure, and irrigation water--constitutes an important part of overall N supply to the maize crop. *Maize-N* simulates daily mineralization from SOM, crop residues, and manure based on temperature and soil moisture. The starting time of C and N mineralization differs for SOM, crop roots, stalks, and manures. For SOM, mineralization starts two weeks before the last crop matures, and ends two weeks before the current maize crop matures. For stalks of the last crop, mineralization starts during tillage (plow- or reduced-till). For no-till, mineralization starts on the day of planting because the planting operation likely leads to good contact of part of crop residues with the soil. For manures,

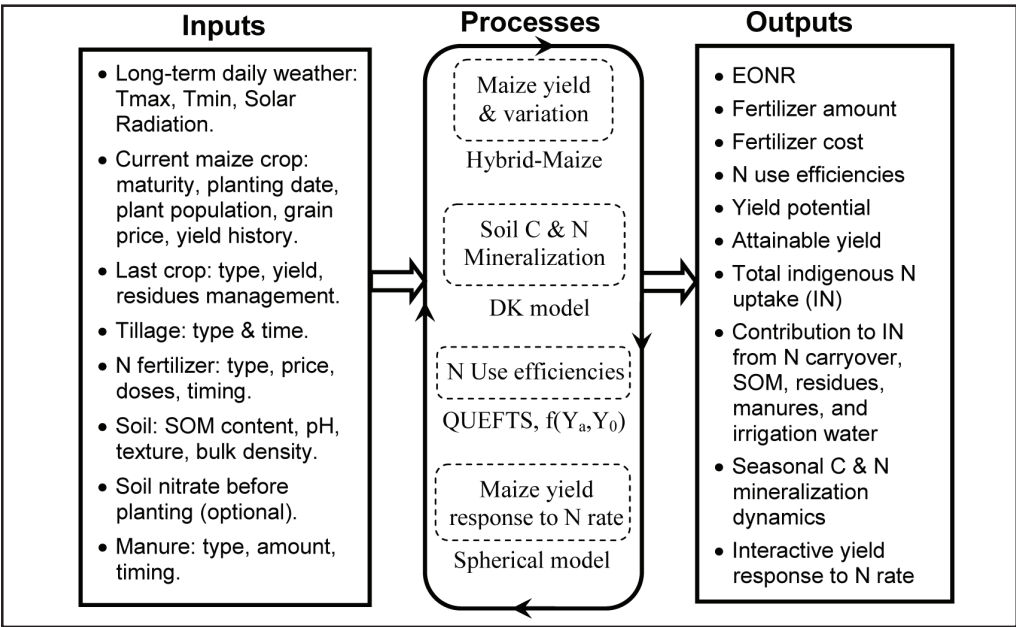


Figure 1. Generalized inputs, outputs, and process models incorporated in the Maize N model.

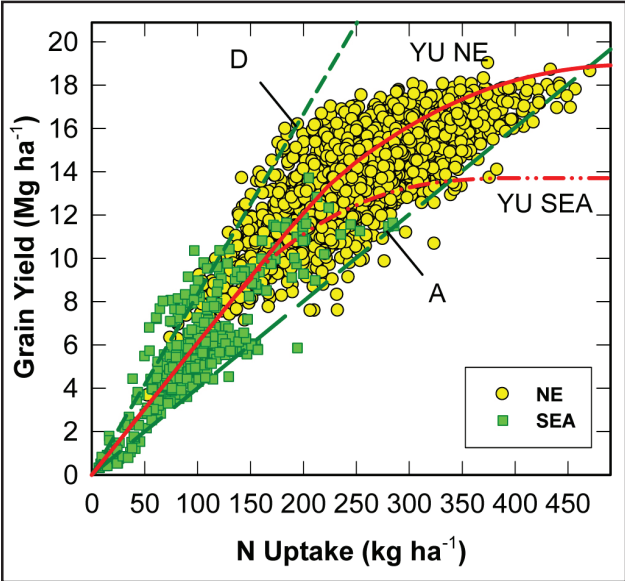


Figure 2. Maize yield response to N uptake in Nebraska and southeast Asian sites (North Vietnam and Indonesia). “D” = boundary of maximum N dilution and “A” boundary of maximum N accumulation.

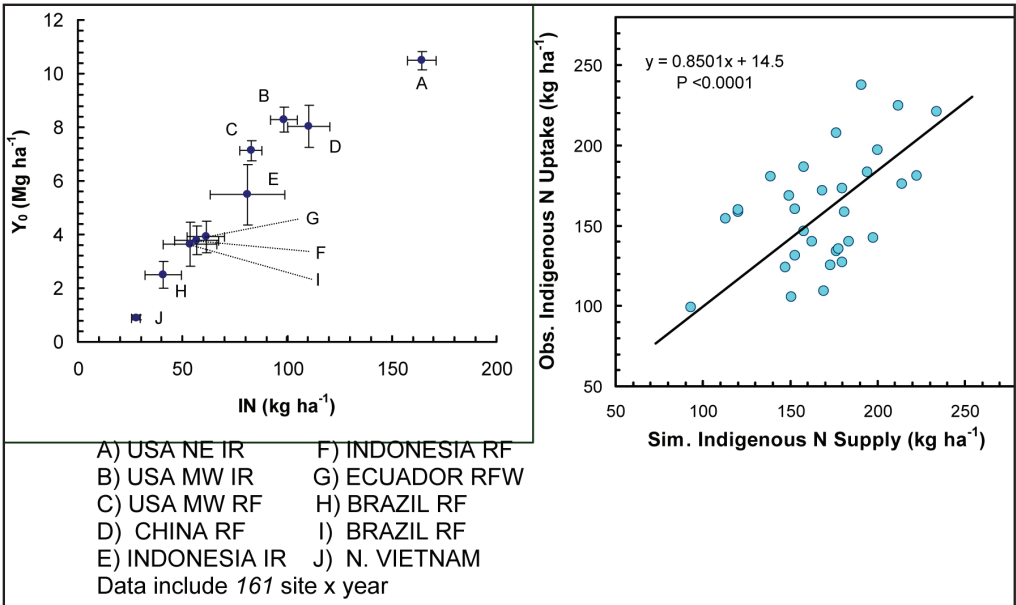


Figure 3. Relationship between observed unfertilized yield (Y_0) and Indigenous N uptake for a large database (left) and simulated Indigenous N supply from DK-C&N model against observed Indigenous N uptake Y_0 in Nebraska (right).

mineralization starts on the day of application. The amount of roots and stalks is estimated based on the grain yield in the previous crop and generic coefficients for harvest index and shoot-root ratio. The amount of N mineralization from stalks also depends on tillage method. By default, 100 percent of stalks will enter the mineralized pool when plowed, 75 percent in reduced-till, and 50 percent in no-till. Note that these values can be modified by the user, depending on expert information about these proportions. Results of soil C and N mineralization are attained for each substrate for each day. If soil nitrate before or at planting is measured, the simulated N mineralization is corrected by subtracting from values of daily total soil nitrate the difference between measured soil nitrate and simulated value on the day of soil sampling. If soil nitrate is not measured, a default amount of N carryover from last season is used (=50 kg/ha, modifiable). Indigenous soil N simulated by the DK-C and N model is used to set Y_0 using the cubic-solver for N uptake vs. yield. The magnitude of the yield response to applied N, called the delta yield ($Y_a - Y_0$) is used to estimate AE calculated for estimation of a yield-potential-based N requirement. The efficiency of Indigenous N uptake is set at 0.85 (Figure 3).

Empirical estimation. RE of N is defined as the ratio of N uptake by crop (U) to N supply from indigenous sources and fertilizers. Nitrogen from different sources likely has different RE. Nitrogen from mineralization of SOM and other organic sources becomes available to the crop in a gradual manner, which results in a high RE (Figure 3), while N carryover from the previous season would have a relatively lower RE because a large part of it may be present deep in the soil and is at risk of leaching. By default, an RE value of 0.85 is assigned to N from mineralization of SOM based upon the observed relationship between U_0 and simulated Indigenous N supply, crop residues and manures, as well as N in irrigation water. RE of fertilizer N is estimated based on fertilizer type, number of doses, timing of application, and soil properties. For each type of fertilizer, there is a default RE value that occurs when the best fertilizer management practices are used (i.e., one preplant application and two in-season side dresses) in an optimal soil

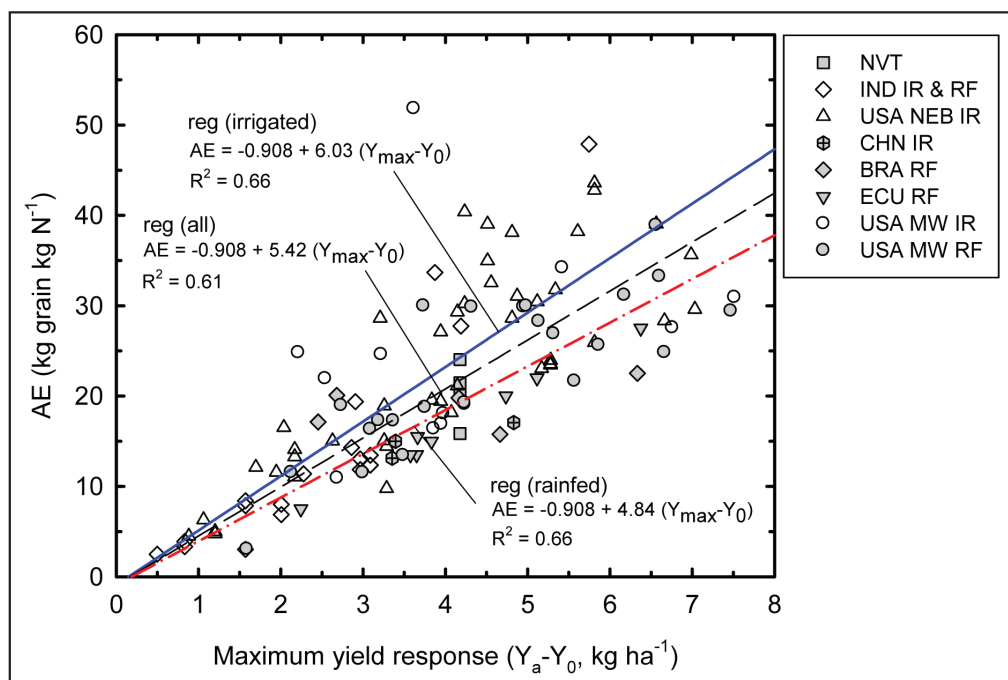


Figure 4. Observed relationship between delta yield ($Y_a - Y_0$) and agronomic efficiency (AE).

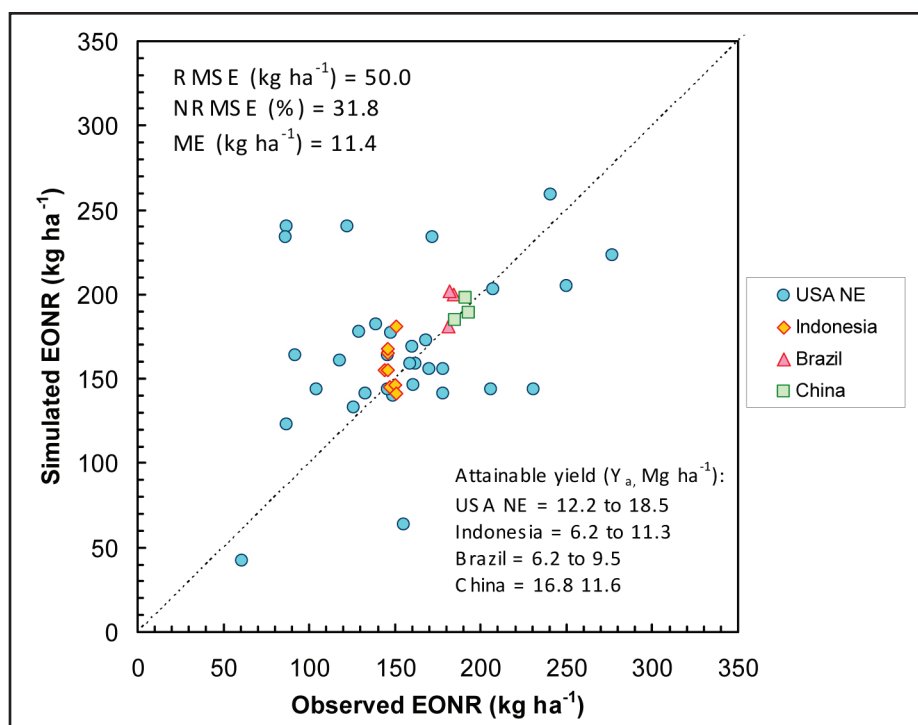


Figure 4. Maize-N simulated vs. observed economic optimum N rate (EONR) for sites in USA, Asia, and South America.

(i.e., loam texture with neutral or acid pH). When N fertilizer management and/or soil properties deviate from the optimal conditions, smaller RE values are used to account for less efficient uptake. As a default, RE can be calculated as a function of the regression in Figure 4 divided by the PE generated by QUEFTS. Carryover residual nitrate is assigned the same RE as N fertilizer.

Optimal N rate. Economically optimal N rate (EONR) within Maize-N is estimated as the rate of N application

at which marginal profit of the maize yield increase due to applied N equals the cost of N fertilizer to achieve the increase. The required amount of fertilizer (F) is estimated as: $F = \text{EONR}/N$ content. Figure 5 shows the relationship between the simulated EONR and measured EONR for U.S., southeast Asian, and Brazilian sites where sufficient data were available on residue inputs, and N application rates and methods. Within the irrigated NE sites, there were approximately four sites where

EONR was overestimated and four sites where EONR was underestimated. In the case of these sites, the N uptake and yield relationship did not fall on the standard QUEFTS spherical N uptake response function (Figure 2). In each of these simulations, the yield potential estimates were made from Hybrid-Maize simulations of Yp. Use of site-specific, user-specified Ya (an option in Maize-N) might have resulted in a more precise estimate of the (Ya-Y_p) delta yield used to calculate N need.

Citations:

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