K A N S A S

# Effect of Phosphorus on Economic Nitrogen Rate for Irrigated Corn – Update

By K.C. Dhuyvetter, A.J. Schlegel, and T.L. Kastens

Economic optimum rates of nitrogen (N) fertilization for irrigated corn are influenced by phosphorus (P). This article reports results of research in western Kansas.

In an article in this publication about eight years ago, it was shown that P fertilizer increased yields considerably on irrigated corn in western Kansas (Schlegel and Dhuyvetter, *Better Crops with Plant Food*, Winter 1991-92). Furthermore, that article pointed out that the benefit of applying P had increased over time compared to where no P was applied due to initial soil P levels being depleted. It was also shown that P influenced the economically optimal N rate. These results were based on a long-term research project (1961-91) at the Kansas State University Southwest Research and Extension Center – Tribune Unit. In this research, fertilizer treatments included N rates ranging from 0 to 200 lb N/A in 40 lb increments, with and without P at a rate of 40 lb $P_2O_5$/A. Because of the significant response in yield in going from 0 to 40 lb $P_2O_5$/A, a logical question of the research was, "Was P a limiting factor on yield?" As a result of this question, starting in 1992 a higher rate of P (80 lb $P_2O_5$/A) treatment was added to the study. By adding this treatment, we can determine if P was a limiting factor. Additionally, by using the same analysis procedure, but for two different time periods, we can determine if the earlier results with regards to optimal fertilizer rates are robust.

## Effect of Phosphorus Level on Yield

**Figure 1** shows the yields by year for each of the P levels (0, 40, and 80 lb $P_2O_5$/A) averaged across all N rates. Applying P increased yields by over 50 bu/A, but there was almost no difference in yields between the 40 and 80 lb/A rates. While yield levels varied from year to year (e.g., 1995 had very low yields due to an early frost), the response to P was quite stable from year to year over this

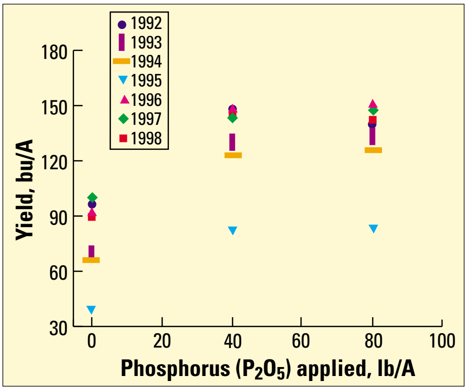


**Figure 1.** Irrigated corn yield for seven years versus applied P.

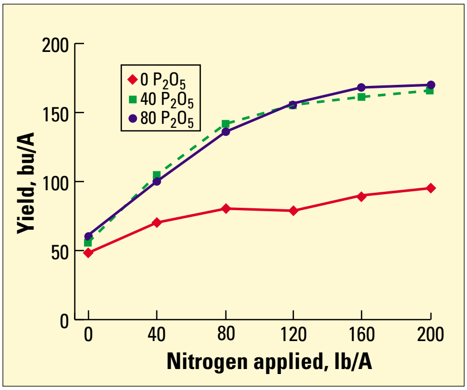


**Figure 2.** Irrigated corn yield versus N and P levels.

time period.

**Figure 2** shows the relationship between yields and N rates for each of the P levels (averaged over years). Several observations can be made from this figure. First, applying P will undoubtedly be economical. Yields when P was applied are considerably greater than when none was applied. Secondly, optimal N rates most likely are different when P is applied compared to when it isn't (i.e., the curvature of the 40 and 80 lb/A lines are different from the 0 lb/A line). Lastly, while yields respond to P, there was no additional benefit to applying 80 lb/A compared to 40 lb/A, indicating that P is not a limiting factor in this study. Based on the graphical analysis of the data (**Figures 1** and **2**), it is readily apparent that of the three rates examined, the economically optimal level of P in this study is 40 lb/A.

## Economic Optimal Level of Nitrogen

In order to estimate the optimal fertilizer N rate to apply, yield response functions are required. The yield response function used for this analysis is a quadratic. The quadratic function allows for yields to increase at a decreasing rate which is consistent with agronomic theory (i.e., decreasing marginal returns). However, a disadvantage of the quadratic is that at sufficiently high levels of fertilizer, predicted yields decrease rather than plateau. To alleviate this problem, it is often argued that a quadratic plateau is more appropriate than a simple quadratic. This analysis uses the simple quadratic function for several reasons. First, the earlier analysis (data from 1961 to 1991) was based on a quadratic; thus, for comparison purposes, the same functional form is used. Secondly, a visual appraisal of the yield-N relationship (**Figure 2**) suggests that a quadratic is probably a "reasonable fit" of the data in-sample. The yield response function estimated was the following:

**Equation 1**

$$Y = A_1 + A_2(Yr - 1998) + A_3 Yr95 + B_1 N + B_2 N^2$$

where $Y$ is observed yield (bu/A), $N$ is applied N (lb/A), $(Yr - 1998)$ is a linear trend variable,

**TABLE 1.** Results of estimating **Equation 1**.

| | Parameter estimate | Standard error | *t*-value |
|---|---|---|---|
| *Intercept* ($A_1$) | 73.006 | 2.371 | 30.80 |
| ($Yr$ - 1998) ($A_2$) | 1.729 | 0.437 | 3.95 |
| *Yr95* ($A_3$) | -57.500 | 2.543 | -23.00 |
| *N* ($B_1$) | 1.237 | 0.046 | 27.10 |
| *N2* ($B_2$) | -0.0034 | 0.0002 | -15.72 |
| $R^2$ 0.864 | | | |
| *RMSE* 17.818 | | | |

**TABLE 2.** Economic optimal N rate and model predicted 1998 yields.

| | Scenario #1 | Scenario #2 | Scenario #3 |
|---|---|---|---|
| Corn price, $/bu | 1.75 | 2.25 | 2.75 |
| Nitrogen price, $/lb | 0.22 | 0.17 | 0.12 |
| Optimal N rate, lb/A | 161.4 | 168.6 | 173.3 |
| 1998 predicted yield at optimal N | 183.0 | 183.7 | 184.0 |

*Yr95* is a binary variable to account for the early frost in 1995, and the As and Bs are parameters to estimate. The results from estimating **Equation 1** are reported in **Table 1**. In-sample measures of goodness of fit ($R^2$ and *RMSE*) indicate that the quadratic functional form does reasonably well at explaining yield variability over years and N level. The linear trend variable indicates that yields increased 1.7 bushels per year, on average, over these seven years. On average, yields in 1995 were 57.5 bushels less than the other years.

Once the response function has been estimated, it is possible to determine the economically optimal N level given corn and

**Optimal fertilization** rates are needed for irrigated corn.

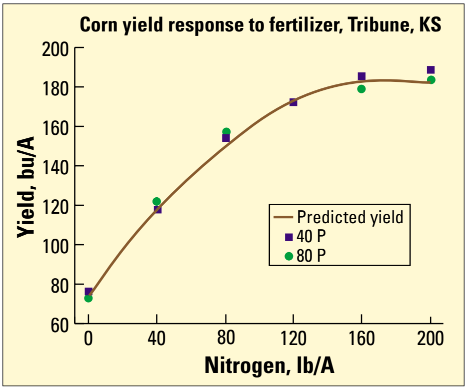


**Figure 3.** Model predicted yield response to N.

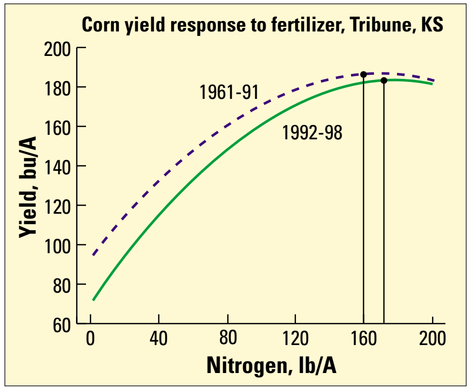


**Figure 4.** Model predicted yield response to N: 1961-91 vs. 1992-98.

N prices (remember that we have "declared" 40 lb of $P_2O_5$ to be optimal based simply on a visual appraisal of the data). Determining optimal fertilizer levels is based on setting the derivative of the equation ($dY/dN$) equal to the input-output price ratio and solving for N. For example, $dY/dN = P_N/P_C$, where $P_N$ is the price of N ($/lb) and $P_C$ is the price of corn ($/bu), gives the economic optimal level of N to apply.

**Table 2** shows the optimal fertilizer levels at three different corn-fertilizer price scenarios. The first price-cost scenario represents low corn prices and high fertilizer prices – a scenario that might result in "low" levels of fertilizer. Scenario 3 represents the opposite case (i.e., high corn prices and low fertilizer prices) where "high" fertilizer levels would be recommended. Scenario 2 represents average prices and costs. Optimal fertilizer rates are insensitive to corn and fertilizer prices, as the optimal N rate varied only 12 lb over the extreme price scenarios considered. The model-predicted yield is similar for all three scenarios because the quadratic functional form is relatively "flat" in the 160 to 180 lb range of N (**Figure 3**).

**Figure 4** compares the trend-adjusted predicted yields for the 1961-91 and 1992-98 response functions. The curvature of the lines differs somewhat, indicating the yield-N relationship may have changed slightly. However, the economically optimal N rates are roughly comparable. Based on $2.50/bu corn and $0.15/lb N, the economically optimal N rate was 160 lb/A and 171 lb/A for the 1961-91 and 1992-98 response functions, respectively.

## Summary

Optimal levels of N are dependent on P levels. Thus, when identifying optimal N rates, it is important that P is not a limiting factor. Based on 30 years of data, prior research indicated the optimal level of N on irrigated corn in western Kansas was approximately 160 lb/A. However, it was unclear whether P was a limiting factor in that study. Based on seven years of data with an additional rate of P, this analysis concludes that P was not a limiting factor in that earlier work and that economically optimal N rates have changed little over time. BC

*Dr. Dhuyvetter and Dr. Kastens are associate and assistant professors, respectively, in the Agricultural Economics Department, and Dr. Schlegel is Professor at the Southwest Research-Extension Center, all with Kansas State University.*