A Comparison of Two Nitrogen Credit Methods: Traditional vs. Difference

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ABSTRACT

Cereals and other nonlegumes typically require less fertilizer N when grown following a legume. Nitrogen credits for a previous legume crop often are used to reduce fertilizer N recommendations in combination with other site-specific information. Researchers continue to use two methods of determining N credits, the traditional and difference techniques, which often produce unequal estimates. Our objective was to clarify when each method provides accurate N credit estimates. The traditional method compares yield of a nonfertilized nonlegume crop grown in rotation to the fertilizer N response curve of the continuously cropped nonlegume. This approach assumes that fertilizer N compensates for all benefits of rotation. The difference method compares the economic N rate of the nonlegume crop grown in rotation with that of the continuously cropped nonlegume. We use examples from the literature to demonstrate that when non-N rotation effects are present, N credit estimates from the two methods will differ. The difference method is more accurate and should be used unless it has been demonstrated that non-N rotation effects are not present.

A NITROGEN CREDIT is the fertilizer N replacement value obtained in a crop sequence compared with a continuously grown crop, and usually refers to the legume component of crop rotations. In many states, N credits remain the most widely used approach of adjusting fertilizer N recommendations for corn (Zea mays L.) grown in rotation, and are used in combination with soil test results and other information about the site and crop management practices. Alternative approaches based solely on soil tests are not, as yet, superior to the N credit approach. The presidedress soil nitrate test has shown promise in separating N-responsive and nonresponsive sites in corn following alfalfa (Medicago sativa L.) in Iowa and Wisconsin (El-Hout and Blackmer, 1990; Bundy and An-

draski, 1993) or following legume cover crops in Maryland (Meisinger et al., 1992), but does not predict fertilizer N needs. Indicators of mineralizable soil N are correlated with N availability after legume crops within experiments, but have limited predictive capability (Thicke et al., 1993). Computer-based models that predict fertilizer N requirements for crop rotations are lacking for farmers.

Recent surveys consistently show that farmers overapply fertilizer N to corn following alfalfa (Legg et al., 1989; El-Hout and Blackmer, 1990), an indication that they are not fully implementing the N credit system. The resulting overapplication of fertilizer N increases the negative environmental impact of agriculture and reduces profit for the producer.

Many factors impede the adoption of a production technique such as N credit recommendations (Nowak, 1992). However, the N credit system appears to meet many of the criteria necessary for successful adoption by farmers. Use of the N credit system requires no investment of resources and does not conflict with other production goals on the farm, information on N credits is available at low cost from extension and agribusiness publications, implementation is relatively straightforward, and adoption is supported by traditional beliefs that legumes improve the soil. Possible impediments to adoption of N credits are (i) concerns about increased risk of negative outcomes (reduced yield or profit); (ii) conflicting or changing information about N credit estimates (i.e., a sense that N credit estimates are not accurate); and (iii) a lack of knowledge of N credits. Researchers can address the first two impediments only if the methodology used to determine N credits provides accurate and relevant information.

Documented rotation effects from legumes include: contribution of legume N (Groya and Sheaffer, 1985; Bruursema and Christie, 1987; Harris and Hesterman, 1990); recycling of mineralized soil N (Stickler et al., 1959); interruption of pest cycles (Cook, 1988); positive soil moisture effects (Barber, 1972; Roder et al., 1989); negative soil moisture effects (Brown, 1964); negative allelopathic effects (Raimbault et al., 1990); and improved soil physical properties (Barber, 1959; McVay et al., 1989; Raimbault and Vyn, 1992). Rotation effects that can be compensated for


with an application of fertilizer N are designated *N rotation effects* (Pierce and Rice, 1988). Rotation effects for which an application of fertilizer N is unable to compensate are termed *non-N rotation effects*. The objective of N credit research is to accurately estimate fertilizer N needs for crops in rotation by quantifying the N rotation effect.

Two methods currently are in use for determining N credits. The first approach, the traditional method, was the principal method for determining N credits into the mid 1980s. In the traditional approach, a fertilizer response curve y vs. x (yield vs. fertilizer N application rate) is developed for the continuously cropped nonlegume. The N credit is obtained by solving for x in this equation when y is equal to the yield of the nonfertilized crop grown in rotation (Shrader et al., 1966). The N credit must be reduced if fertilizer N was applied to the nonlegume in rotation, as in starter fertilizer (N credit = calculated x-value − fertilizer N applied). This approach still is identified with most definitions of the term N credit (e.g., Hesterman, 1988) and continues to be the basis for many N credit estimates (Fox and Piekielek, 1988; Sarrantonio and Scott, 1988; McVay et al., 1989; Blevins et al., 1990; Oyer and Touchton, 1990; Smyth et al., 1991; Pare et al., 1993).

The second approach, the difference method, was suggested by Smith et al. (1987). This N credit estimate is the difference between the economic N rates of the conventionally fertilized nonlegume and of the nonlegume grown in rotation. The economic N rate of the nonlegume grown in rotation is determined directly from a fertilizer response curve of the nonfertilized crop grown in rotation. The N credit is obtained by solving for x in this equation when y is equal to the yield of the nonfertilized crop grown in rotation. The N credit estimate based on the traditional approach still is identified with most definitions of the term N credit (e.g., Hesterman, 1988) and continues to be the basis for many N credit estimates (Fox and Piekielek, 1988; Sarrantonio and Scott, 1988; McVay et al., 1989; Blevins et al., 1990; Oyer and Touchton, 1990; Smyth et al., 1991; Pare et al., 1993).

The difference method may change with prices of fertilizer and the harvested product. This dependence on economic criteria in the definition can be eliminated by replacing economic N rate with the minimum N rate required to obtain maximum yield, but this approach may inadvertently imply fertilizer N recommendations that are higher than those based on marginal rate of return. Variants of the difference method have been used in recent years as limitations of the traditional method became more widely understood (e.g., Bundy et al., 1993; Mason and Rowland, 1990; Utomo et al., 1990; Zebarth and Sheard, 1992).

The assumption in the traditional method is that the sole effect of a legume on yield of the subsequent nonlegume is an N rotation effect (Shrader et al., 1966). In other words, the traditional method assumes that continuously grown and rotationally grown nonlegume crops respond similarly to available N and that both curves approach the same maximum yield. In contrast, the difference method makes no assumptions about the effects of rotation on fertilizer N response; fertilizer N response is determined independently in each crop sequence. Consequently, the difference approach consistently allows effects due to N to be separated from other rotation effects and must be considered the standard by which we judge the traditional method.

There are two challenges in N credit research: (i) accurately determining N credits, and (ii) estimating the ability of an N credit estimate to predict fertilizer N need of a future crop. Our research objective was to evaluate the accuracy of the traditional methodology by contrasting N credit estimates from the traditional and difference methods using data from the literature.

**METHODS AND MATERIALS**

Two data sets from the literature were selected that compared fertilizer N response of continuously cropped corn with the fertilizer N response of corn grown in rotation or after a winter cover crop (Randall, 1980; Oyer and Touchton, 1990). Quadratic response curves were fit to the data using linear regression within each cropping system (SAS, 1987), with slopes and intercepts being calculated separately when statistical tests were significant (Weisberg, 1985). Economic N rate was defined as the point at which marginal fertilizer cost equaled marginal return from increased grain yield, calculated by using the first derivative of the N response curve. Corn grain was assumed to have a value of $116.50 Mg⁻¹ dry matter ($2.50 bushel⁻¹ at 155 g kg⁻¹ moisture) and fertilizer N a value of $0.33 kg⁻¹ ($0.15 pound⁻¹). Difference N credit estimates were based on the difference in economic N rate between continuously cropped corn and corn grown in rotation. Traditional N credit estimates were based on grain yield of nonfertilized corn grown in rotation.

**RESULTS AND DISCUSSION**

The presence of non-N rotation effects can introduce substantial error into N credits determined by the traditional method. The sensitivity of traditional N credits to non-N rotation effects is best illustrated by considering these two examples from the literature (Randall, 1980; Oyer and Touchton, 1990). In the first example (Fig. 1), there was a positive N rotation effect and a positive non-N rotation effect associated with corn following wheat (*Trifolium aestivum* L.) or corn following wheat + alfalfa. That is, for corn grown in rotation, the economic N rate was smaller and maximum yield was greater than for continuous corn (Randall, 1980; Fig. 1). The N credit estimate based on the traditional method was 75 kg N ha⁻¹, whereas the N credit estimate based on the difference method was 32 kg N ha⁻¹. The positive non-N rotation effect caused the traditional N credit method to overestimate the actual N credit by over 40 kg N ha⁻¹.

In the second example (Fig. 2), there was also a positive N rotation effect and a positive non-N rotation effect when crimson clover (*Trifolium incarnatum* L.) was grown as a winter crop in a continuous corn system (Oyer and Touchton, 1990). The N credit estimate based on the traditional method was 45 kg N ha⁻¹, whereas the N credit estimate based on the difference method was 19 kg N ha⁻¹. Adding soybean (*Glycine max* L. Merr.) to the cropping system had no effect on the N rotation effect (both rotations with crimson clover had the same economic N rate), but further increased the non-N rotation effect (the rotation including soybean attained a higher maximum yield). The traditional N credit method erroneously suggested that including soybean increased the N credit from 45 to 79 kg N ha⁻¹ when there was no additional N benefit from soybean to corn. These examples demonstrate that the limitations of the traditional method can produce inaccurate estimates of the N credit.
The majority of quantified non-N rotation effects increase yield over the continuous nonlegume system. One implication of this is that many N credit estimates made with the traditional method may be too high because positive non-N rotation effects inflate the traditional N credit estimate. Some recent users of the traditional method continue to ignore the impact of these effects on their N credit estimates (e.g., McVay et al., 1989; Oyer and Touchton, 1990; Smyth et al., 1991; Pare et al., 1993).

A second possible effect of non-N rotation effects is to interact with yield response to the total N supply (as opposed to fertilizer N). Total N supply is the sum of all plant-available N sources, including mineralized N from soil organic matter, added organic sources, and crop residues, residual NO$_3^-$ in the soil, N contained in precipitation and irrigation water, and fertilizer N. The interaction of yield with non-N rotation effects has been documented in comparisons of alfalfa–corn rotations with continuous corn crop sequences (Lory et al., 1995). Three other reports have observed no interaction effect when comparing the same crop sequences (Shrader et al., 1966; Baldock and Musgrave, 1980; Baldock et al., 1981). The impact of interaction effects on traditional N credit estimates is unknown in most cropping systems, because there is limited information on the prevalence and nature of this effect. However, accuracy of N credits is not compromised by interaction effects when the difference method is used.

A disadvantage of the difference approach to estimating N credits is the doubling of required experimental treatments compared with the traditional N credit method. When fully implemented, the difference approach demands at least four (and preferably more) fertilizer N rates for the continuously cropped nonlegume and each crop rotation. An rigorous experimental protocol is required when the objectives are to accurately estimate N rotation effects and to quantify other rotation effects.

**CONCLUSION**

Farmers will more readily adopt N credit recommendations if they believe that the credits are accurate, reliable, and relevant to their farm. Researchers can ensure the accuracy of N credit measurements and evaluate their reliability only if the appropriate methodology is used.
We recommend that the difference method be used to determine N credits whenever possible. This method consistently gives an accurate, unambiguous estimate of the N credit, because it is not confounded by non-N rotation effects. If the traditional method is used, researchers should demonstrate that non-N rotation effects have not invalidated their N credit estimate.

REFERENCES


