SOYBEAN NITROGEN CONTRIBUTIONS AND ROTATION EFFECTS[1]

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Corn-soybean rotations are widely used in Midwestern grain production. These rotations usually produce higher corn yields and require less supplemental nitrogen (N) than corn grown following corn. The yield benefits are usually attributed to rotation effects, although the precise mechanisms responsible for the yield enhancement are often not well defined. Nitrogen contributions from soybean in rotations are also not well understood because nitrogen budgets for soybean show that soybean harvested for grain removes more N from the system than is added by symbiotic nitrogen fixation (Heichel and Barnes, 1984; LaRue and Patterson, 1981). Thus, the apparent nitrogen contribution from soybean in rotations probably results from different processes than those involved in the N contributions from forage legumes. With forage legumes, crop residues returned to the soil decompose with a net release of plant-available N. Because soybean is a grain legume, most of the N accumulated by the crop is removed in the harvested grain. The increasing importance of soybean corn rotations emphasizes the need to recognize the yield and N effects of this cropping sequence. The purpose of this paper is to review current information on the extent of rotation effects and N contributions in crop rotations that include soybean.

Rotation Effects in Soybean-Corn Crop Sequences

Yields of corn following soybean usually are at least 10 to 15% higher than in continuous corn. Results from several experiments conducted in the Midwest (Table 1) show a yield benefit ranging from 10 to 33%. The higher yields where corn follows soybean are attributed to a rotation effect that may include both nitrogen contributions from the previous crop and rotation benefits not associated with nitrogen Baldock et al., 1981; Welch, 1985). Rotation effects due to nitrogen contributions are those that can be offset by addition of fertilizer N, while the non-N rotation effects cannot be overcome by addition of N and may be caused by factors such as improved soil physical properties, addition of growth promoting or phytotoxic substances associated with residues, and reduced pest damage. Definitive information on the causes of non-N rotation effects is limited; however, several studies in soybean-corn rotations have been conducted to investigate these influences (Crookston and Kurle, 1989; Nickel et al., 1995).

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Table 1. Yield benefits of soybean-corn rotations compared to continuous corn in selected experiments.

Location	Yield benefit[1]	Reference
	------- % ------	
Illinois	16	Welch (1976)
Iowa	11	Meese (1993)
Minnesota	10	Crookston et al. (1991)
Minnesota	33	Hesterman et al. (1986)
Nebraska	27	Kessavalou & Walters (1997)
Wisconsin	10	Lund et al. (1993)
Wisconsin	15	Meese et al. (1991)

[1]Yield benefit = % increase in yield in soybean-corn sequence compared to continuous corn.

In most N rate studies involving soybean-corn rotations, addition of fertilizer N can compensate for a large part of the yield difference between rotation and monoculture (Welch, 1985). This suggests that increased N availability is a major cause of the yield enhancements associated with soybean in rotations. Many experiments have been done to estimate the N contribution or "credit" by soybean to subsequent cereal crops in rotations. Most of these studies indicate that soybean can supply an average of 40 to 60 lb N/ acre to a following corn crop (Shrader, 1973; Baldock et al., 1981; Voss and Shrader, 1984; Schepers and Mosier, 1991).

Nitrogen Contributions from Soybean in Rotations

Several approaches have been used to estimate the amounts of N provided to subsequent crops by soybean in rotations. Perhaps the most widely used of these is the fertilizer replacement value (FRV) approach (Hesterman, 1988). In this method, the FRV is defined as the amount of fertilizer N required in a corn-corn sequence to produce yields equal to those in a legume-corn sequence without fertilizer N. The disadvantage of this approach is that it assumes that fertilizer N can compensate for all of the rotation benefit (Lory et al., 1995). This disadvantage has been recognized in several more recent experiments where the N contribution from soybean in rotations was estimated by comparing the N rates needed to maximize or optimize yields in a corn-corn sequence with those needed where corn followed soybean (Bundy et al., 1993; Stecker et al., 1995; Blackmer, 1996). The difference between the N rates needed to optimize yields in the two rotations is considered to be the legume N contribution or "credit".

The apparent N contributions from soybean estimated by different methods in several experiments are shown in Table 2. The average N contributions identified in these studies are not greatly different from the 40 to 60 lb N/acre reported in earlier work. However, the important result from the work summarized in Table 2 is the large year and site variation in the apparent N contributions in each of the experiments. This finding indicates that, use of average N contribution values to adjust N recommendations for corn following soybean will seldom accurately predict actual soybean N contributions or corn N needs at individual sites. These results emphasize the need for diagnostic tool to predict N needs for corn following soybean on a site-specific basis. Several states have modified their approach for determining corn N recommendations following soybean to include use of soil nitrate tests (see discussion below) or to consider corn following soybean as a separate cropping system with its own unique N recommendations.

Table 2. Apparent nitrogen contributions from soybean to a subsequent corn crop.

Location	Apparent N contribution			Reference
	FRV[1]	DNM[2]	Avg.[3]	
	----------- lb N/acre -----------			
Iowa	--	-219-204	60	Blackmer (1996); Meese (1993)
Missouri	--	0-142	48	Stecker et al. (1995)
Quebec	36-134	--	90	Rembon & MacKenzie (1997)
Wisconsin	0-83	-20-188	47	Bundy et al. (1993)

[1]FRV = fertilizer replacement value.
[2]DNM = Difference in N rates needed to produce maximum or optimal yields in corn-corn and soybean-corn sequences.
[3]Average N contribution across sites and years.

Factors Affecting Apparent Soybean Nitrogen Contributions

Attempts to develop methods for more accurate estimation of corn N needs following soybean and to better understand the mechanisms involved in the apparent soybean N contribution have examined several potential factors affecting N availability following soybean production. Since soybean production causes a net removal of N from the system, the source of the apparent N contribution is not well understood. One possibility is that net N mineralization from soil organic matter is greater following soybean than following corn. In a laboratory study, Green and Blackmer (1995) confirmed that net N mineralization is higher following soybean than following corn, and that the difference is approximately equal to the average "credit" commonly recommended for corn following soybean. This work showed that the difference in net N mineralization was due to greater immobilization of available N by corn residues compared to soybean residues. Generally similar results were obtained in a recent laboratory incubation study using soils (without residue addition) from continuous corn and corn following soybean treatments in a long-term crop rotation study at Lancaster, Wisconsin (VanSchaik ,1998, unpublished M.S. thesis) showed that the soil from the corn following soybean treatment mineralized about 40% more N than the continuous corn treatment in a 10-week aerobic incubation. If this data is converted to field scale, net N mineralization in the corn following soybean treatment would be about 38 lb N/acre higher than in continuous corn.

Vanotti and Bundy (1995) also obtained evidence that N availability is enhanced following soybean compared to following corn using 15-year data from the long-term crop rotation experiment at Lancaster, Wisconsin. This work identified a 67 lb N/acre fertilizer replacement value for the corn following soybean treatment, suggesting a substantial increase in N mineralization compared to where corn was the previous crop. This work also indicated that N availability to cereal crops in the second year following soybean was reduced by 32 lb N/acre compared to a corn-corn sequence. This result suggests that part of the N contribution to the first-year corn following soybean is realized at the expense of reduced N availability to corn in the second year following soybean. Interestingly, Crookston et al. (1991) observed a reduction in corn yields in the second year following soybean in field experiments that would be consistent with the lower second-year N availability reported by Vanotti and Bundy (1995). However, in similar experiments, Meese et al. (1991) and Lund et al. (1993) did not detect significant yield reductions in the second year following soybean.

Since net mineralization of N from residues returned to the soil following soybean could impact available N supplies for subsequent crops, the amounts and fate of N in soybean residues has been studied. Dry matter residue yields and N contents found in several experiments are summarized in Table 3. These data indicate that the total amounts of N in soybean residues are relatively low compared to the apparent N contributions observed for corn following soybean. Even if all of the N in these residues mineralized, the N released would not account for the entire soybean N contribution. This lends support to the idea that factors other than release of N during decomposition of soybean residues contribute to the soybean N effect in rotations.

Table 3. Soybean residue dry matter yields on nitrogen contents in several experiments.

Reference	Residue yield	N concentration	N content
	lb/acre	%	lb N/acre
Doran et al. (1984); Smith & Sharpley (1990)	1964-4820	0.84-0.93	--
Meisinger & Randall (1991)	--	0.7-1.0	
Schoessow (1996)			
Arlington, WI	4443	0.98	45
Lancaster, WI	6088	0.60	35
Platteville, WI	6167	0.78	47
Belmont, WI	8380	0.90	76

In a detailed study of the effects of soybean residue management in Wisconsin, Schoessow (1996) found that removing or returning soybean residues following grain harvest or removing soybean in a forage harvest at the R6 development stage usually had no effect on the yield or N response of a subsequent corn crop (Table 4). Where soybean residue management did have a significant effect, corn yields were lower and more N was needed to optimize corn yields in the residue returned treatment rather than where residues were removed. These results provide further evidence that the apparent soybean N contribution does not depend on mineralization of N from the soybean residue, but is related to an increase in net N mineralization from soil organic matter.

Prediction of Soybean N Contributions

The apparent N contributions from soybean shown in Table 2 vary substantially across locations and years, emphasizing the need for diagnostic tests to predict soybean N contributions on a site-specific basis. In a series of experiments with corn following soybean in Wisconsin, several N recommendation procedures were compared with the economic optimum N rates observed in field experiments to evaluate their utility for predicting N needs for corn following soybean. Results in Table 5 are representative data from this study previously presented at this conference (Schoessow et al., 1996). Comparison of the N recommendations with observed optimum N rates shows that the standard N recommendation used for corn following corn in Wisconsin consistently overestimates the N need for corn following soybean and confirms the need for some adjustment of N rates. Use of the current fixed value N credit of 40 lb N/acre for a previous soybean crop reduces the excess N applied to some extent, but still results in over application at most sites. Similarly, using a preplant soil nitrate test to adjust corn N recommendations (Bundy and Sturgul, 1994) leads to above optimum N rates in most cases. Combining the fixed value N adjustment (40 lb N/acre) with the adjustment for the preplant soil nitrate test produces N recommendations that are usually similar to the observed optimum N rates, and represents the most promising approach to predicting soybean N contributions on a site-specific basis. Recommendations based on the presidedress soil nitrate test frequently underestimated the observed optimum N rate.

Table 4. Soybean harvest management system (HMS) and N fertilizer rate on corn rain yield at two Wisconsin locations, 1994. (Schoesow, 1996)

		N fertilizer rate, lb/acre				
Location	HMS	0	40	80	120	160
		---------------- grain yield, bu/acre ----------------				
Arlington	Returned	183	207	207	207	205
	Removed	180	195	195	200	210
	Forage	191	204	194	199	202
Lancaster	Returned	123	163	195	201	217
	Removed	122	172	199	216	227
	Forage	130	156	192	213	226

Table 5. Comparison of several methods of making N recommendations for corn following soybean with observed optimum N rates. Wisconsin, 1994-1995.

Location	N Recommendation Method[1]					Observed optimum N rate
	STD	STD-NC	PP	PP-NC	PS	
	lb N/acre					
1994						
Arlington	160	120	154	114	0	40
Lancaster	160	120	160	120	100	160
Platteville	160	120	65	27	0	0
Belmont	160	120	123	83	0	80
1995						
Arlington	160	120	116	76	0	80
Lancaster	160	120	131	91	150	120
Platteville	160	120	126	86	0	40
Belmont	160	120	104	64	0	40

[1]SDT = standard N recommendation; SDT-NC = standard recommendation minus 40 lb N/acre N credit; PP = preplant soil nitrate test recommendation; PP-NT = PP recommendation minus 40 lb N/acre N credit; PS = Presidedress nitrate test recommendation.

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