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Nitrogen Fertilizer Replacement Value of Soybean for Corn

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Abstract

Soybean (*Glycine max.* (L) Merrill) is often grown in rotation with corn (*Zea mays* L.) and, in response to increasing N fertilizer prices, growers ask about possible N fertilizer savings for first year corn after soybean. A literature review was conducted to evaluate potential causes for site and year differences in soybean N fertilizer replacement values (NFRVs) and predictability of N fertilizer rate adjustments for corn after soybeans. Two types of rotation effects were identified, those that can be compensated for with fertilizer N application (N rotation effects), and ones for which fertilizer N application does not compensate (non-N rotation effects). The latter included interruption of pest cycles, improved soil physical properties, moisture availability, and changes in mycorrhizal fungi communities. Soybean NFRVs reported in the literature ranged from 0 to 188 lb of N per acre. Soybean yield was not a reliable predictor of NFRV and adjustments in N rates should only be applied for one year after soybeans. We conclude a NFRV of 20 to 30 lb of N per acre can be applied for first year corn after soybean with minimal risk of a negative impact on yield. Additional research is needed to quantify impacts of management and environment (rotation, tillage, soil type, weather) on NFRV of soybean for corn.

Introduction

Soybean acreage in New York has increased from 100,000 acres in 1998 to 210,000 acres in 2007, which has resulted in more first-year corn following soybean. In response to increasing N fertilizer prices, growers with soybean-corn rotations ask about possible N fertilizer savings for corn following soybean.

Most but not all land grant universities in the northeastern and Mid-Atlantic states include some adjustment in N guidelines for corn after soybean (Table 1). Research in the Midwest showed optimum economic N rates are generally lower for corn after soybean than for corn after corn (1,3,6,18,38,49,58,66,67), but potential N fertilizer savings range widely (Table 2). Studies conducted in New York showed a 60 lb/acre N savings for corn after soybean in 3 of 5 years. In this study, however, N rate was confounded with high and low chemical input, only two N rates were used, and there was no 0-lb/acre control, making it impossible to determine the optimum economic N rate for each cropping system (28). In another New York study, results indicated a savings of 20 to 40 lb of N per acre (11) while work in Ontario (17,37,52,55) and Quebec (56) suggested N needs for corn after soybean could be reduced by 4 to 134 lb/acre.

Table 1. Nitrogen fertilizer replacement values of soybean for corn in a soybean-corn rotation as recommended by Land Grant Universities in the Northeast and Mid-Atlantic United States and Ontario, Canada.

Location		Nitrogen fertilizer replacement values[x] (lb of N per acre)	Reference
Northeast	CT	No soybean production	T. Morris (*personal communication*, 2007)
	ME	0	B. Hoskins (*personal communication*, 2007)
	MA	0	S. Herbert, X. Liu (*personal communication*, 2007)
	NH	30	T. Buob (*personal communication*, 2007)
	NJ	15	Heckman (23)
	NY	0	Ketterings et al. (29)
	VT	30	Jokela et al. (27)
Mid-Atlantic	DE	0.5 lb of N per acre soybean yield	Sims and Gartley (59)
	MD	15-40	Univ. of Maryland Cooperative Extension (64)
	PA	1 lb of N per acre soybean yield	Crop Management Extension Group (14)
	VA	0.5 lb of N per acre soybean yield[y]	Virginia Dept. of Conserv. and Rec. (68)
	WV	0.5 lb of N per acre soybean yield[y]	Virginia Dept. of Conserv. and Rec. (68)
Canada	ONT	27	OMFRA Staff (43)

[x] Nitrogen fertilizer replacement values assume soybean is harvested for grain. In New Jersey, an adjustment of 40 lb/acre is suggested for soybean grown as cover crop.

[y] If yields are unknown, a N fertilizer replacement value of 20 lb/acre is recommended.

Table 2. Nitrogen fertilizer replacement values (NFRV) of soybean for corn in a soybean-corn rotation.

Location	**N fertilizer replacement value [avg.]** (lb of N per acre)	**Method**[x]	**Research reference**
Illinois	63-86	Traditional	Bergerou et al. (3)
Iowa	84	Traditional	Shrader et al. (58)
Kansas	100-157 [129]	Traditional	Omay et al. (44)
	88-188 [138]	Traditional	Omay et al. (44)
Missouri, Chisel-disk	0-70 [48]	Difference	Stecker et al. (63)
Missouri, No-Till	0-57 [21]	Difference	Stecker et al. (63)
Nebraska	14-41	Traditional	Ennin and Clegg (18)
	59	Traditional	Varvel and Wilhelm (67)
Ontario	37-53	Difference	Ding et al. (17)
	~71	Traditional	Ding et al. (17)
	37-107 [61]	Traditional	Ma et al. (37)
	39	Unknown	Ravuri (54)
	4-88 [40]	Unknown	Beauchamp et al. (2)
Quebec	<0	Traditional	Paré et al. (45,46,47)
	36-134	Traditional	Rembon and MacKenzie (56)
Wisconsin	80	Traditional	Maloney et al. (38)
	0-23 [12]	Traditional	Bundy et al. (5)[y]
	29-83 [77]	Traditional	Bundy et al. (5)[y]
	55	Traditional	Bundy et al. (5)[y]
	-20 to 13	Difference	Bundy et al. (5)[y]
	-11 to 188	Difference	Bundy et al. (5)[y]
	0-80	Difference	Bundy et al. (5)[y]
	67	Traditional	Vanotti and Bundy (66)
	59	Difference	Baldock et al. (1)

[x] In the traditional method, the NFRV of soybean preceding corn is calculated as the N application needed for corn after corn to obtain a yield equal to that of corn after soybean with no N fertilizer. The difference method compares the difference in N rates for either maximum or optimum economic yield for corn after legumes versus corn after corn and requires multiple N rates for both corn after soybean and corn after corn.

[y] Three sites, calculated with both methods.

Not all studies indicate potential N savings for corn after soybeans. Little or no differences in optimum N rates were found in some sites and years in studies by Bundy et al. (6), Stecker et al. (63), and one of two Quebec sites (45). For the second site, Paré et al. (45) reported a lower yield for corn after soybean than for corn after corn with no additional N applied, suggesting a possible negative impact of soybean on N needs for corn in the following year. An additional 18 lb of N per acre was needed to overcome this yield decline (45). Actual N savings, based on a comparison of optimum economic N rates at this site, could not be conducted as yield increased linearly for the corn after corn plots.

These seemingly contradictory findings and the wide ranges in N savings for first year corn after soybeans, raise questions about causes and predictability of N savings for corn after soybean. In this review, we summarize scientific literature on this topic.

Clarification of Terms

Fertilizer N needs are lower for corn after grass or legume sods than for corn after corn (5,20,33). This reduction in N needs is commonly referred to as "sod N credit" and taken into account in N recommendations [e.g., 29)]. Similarly, the term "soybean N credit" has been applied to the estimated N savings when corn follows soybean as compared with continuous corn (3,32). As it is generally recognized that N savings for corn after legumes are not necessarily due to N release of the previous crop only, we will use the more general term "N fertilizer replacement value" (NFRV) when discussing differences in N needs while retaining the term "soybean N credits" for direct references to N release from the soybean crop preceding corn.

Methods Used to Determine N Fertilizer Replacement Value

Most methods commonly used for determining the NFRV of soybean are variations of two main approaches: (i) the "traditional method," and (ii) the "difference method." A brief description of each is given here; they are compared in more detail by Lory et al. (35).

Traditional method. In the traditional method, the NFRV of soybean preceding corn is calculated as N application needed for corn after corn to obtain a yield equal to that of corn after soybean, given no additional N is applied to corn after soybean. This approach initially evolved because increases in yield of corn in rotation with a legume were attributed solely to the N fixing properties of the legume, largely based on the results of long-term rotation studies in Iowa and Wisconsin (57,58). The response curves for corn after corn sites were used to determine the NFRV of the legume (1,58). Assumptions in the traditional method have been questioned in the literature: (i) Can yield increases observed in soybean-corn rotations be attributed solely to the N contribution from soybean (6,62)? (ii) Are fertilizer N and residue N equally available to the corn crop (6)? (iii) Is the NFRV determined for non-fertilized corn identical to the NFRV at the optimum economic N rate for corn after soybeans? In addition, corn yields in the soybean-corn rotation without added N can exceed maximum yield obtained with applied N in a continuous corn system (1,6), something not accounted for in the traditional NFRV approach.

Difference method. The "difference method" compares the difference in N rates for either maximum or optimum economic yield for corn after legumes versus corn after corn (34,35,62). This method requires multiple N rates for both corn after soybean and corn after corn. Although an improvement over the traditional method, this method also fails to separate the effects of N release from soybeans from other rotation related yield effects.

As discussed above, corn yields after soybean are often greater than for corn following corn due to non-N rotation effects and corn after corn is usually responsive to extra N. Therefore it is not a surprise that (i) direct comparisons of both methods show differences in soybean NFRV estimates (6,35), and (ii) the difference method is usually more accurate in determining the NFRV of soybean for corn (35).

Underlying Causes of Differences in Soybean NFRVs

Possible causes of changes in N needs due to the inclusion of legumes in the corn rotation cited by Baldock et al. (1) and Lory et al. (35) included: (i) contribution of legume N; (ii) recycling of mineralized soil N; (iii) interruption of pest cycles; (iv) improved soil physical properties; (v) soil moisture effects; and (vi) growth promoting substances introduced by legumes. Additionally, changes in the abundance and composition of vesicular-arbuscular mycorrhizal fungi populations might cause a rotation effect (26). Lory et al. (35) concluded their list by identifying two types of rotation effects, those that can be compensated for with fertilizer N application (N rotation effects) and ones for which a fertilizer N application does not compensate (non-N rotation effects). Each will be discussed briefly.

N rotation effects: N fixation. Values for seasonal dinitrogen (N_2) fixation by inoculated soybean reported in the literature range widely, from 1 to 190 lb of N per acre (7,18,19,48,54). The amount of N_2 fixed by soybean is impacted by soil nitrate level (8,19,24), harvest maturity of soybean cultivar (19,48,54), rhyzobial strain used as inoculant (53,54), rate of inoculation (24), soybean plant population (18), and seasonal effects on soil water availability (54).

The N_2-fixing characteristic of soybean may not be a major factor in the overall N savings effect that might occur when corn follows soybean. In central Ontario, Canada, Ravuri and Hume (54) noted that most of the N fixed by the soybeans was partitioned to the seed (85 to 94% of N), which raises questions related to the total amount of N returned to the soil with soybean residue. In addition, nodulated and non-nodulated soybean similarly enhanced grain and silage yields of the subsequent corn crop, suggesting that the response is due to a combination of N and non-N rotation effects (3,38). Research in Minnesota and Nebraska showed corn grain yields after fallow that were the same as or higher than corn yields after soybean (12,18,25), also suggesting N fixation was not the only contributor to the rotation effect.

N rotation effects: Residue driven immobilization and mineralization. Differences in carbon to nitrogen ratios and total biomass of corn and soybean residues could affect N availability to the next year's corn crop by altering rates of soil mineralization or immobilization (3). Rembon and MacKenzie (56) reported 26 to 75 lb more soil NO_3-N to a 40-inch depth in the spring after soybean than after corn (no N applied). Soil organic N studies to a 6-inch depth in Iowa showed an average decrease of 328 lb of N per acre between early spring and fall harvest of a corn crop while soybean production resulted in a 286 lb of N per acre enrichment the following season, suggesting that soil N is supplemented during soybean growth (39).

In a study by Gentry et al. (21) of soil N mineralization rates for corn after corn and corn after soybean, mineralization rates peaked higher and earlier (0.86 lb of N per acre, on 7 June) for corn after soybean than for corn after corn (0.59 lb of N per acre, on 12 July). The cumulative net soil N mineralization was 36 lb/acre greater for corn after soybean (21). Research by Green and Blackmer (22) supports the earlier N peak and attributed it to a more rapid N immobilization and subsequent N mineralization after soybean residue decomposition.

Non-N rotation effects. A commonly mentioned non-N rotation effect is soybean induced interruption of pest cycles. Meese (40) and Maloney et al. (38) found a greater incidence of rootworm damage, borer damage, root pruning, and barren stalks in continuous corn than for corn after soybean.

In addition, soybean in the rotation could have a positive impact on corn root functioning (9). Knowles and Ries (31) observed that triacontanol increased growth of corn seedlings in laboratory studies, but Crookston et al. (12) found no impact of triacontanol on corn yield in field studies. Additional work is needed to understand the role of soybean root exudates in changes in optimum N rates for corn. The type of soybean inoculum could impact the NFRV value of the soybean as well. For example, Dean et al. (15) saw a yield increase of 48% when barley followed soybean inoculated with rhizobia that released hydrogen into the surrounding rhizosphere as compared with barley after soybean inoculated with a non-hydrogen releasing strain. The literature on the topic of root exudates is scarce and further research is needed.

Changes in mycorrhizal fungi communities have also been mentioned as a potential contributor to a positive rotation effect. Johnson et al. (26) proposed a conceptual model in which continuous cropping selects for the most rapid growing and sporulating VAM fungal species that provide for their growth at the expense of their plant symbionts. They hypothesized that interruption of a monoculture reduces the relative abundance of detrimental fungi and increases the abundance of beneficial ones (26).

Other non-N rotation effects discussed in the literature are the impacts of soybean on soil physical properties and moisture availability, which may also affect corn root functioning and growth (9). Raimbault and Vyn (51) showed that two years of soybean cropping resulted in a seedbed with a higher proportion of fine aggregates than continuous corn. Copeland et al. (10) and Ennin and Clegg (18) suggested the enhanced yield of corn after soybeans in their studies may have been due to greater water availability after soybean than after corn (growing corn resulted in greater and deeper water depletion than growing soybean). Singer and Cox (60) reported that corn after soybean versus continuous corn had lower soil water potential values at 12- and 24-inch depth in June and early July, presumably because of more root activity. On the other hand, Bullock (4) concluded that short rotations (2 to 3 years) such as corn-soybean do not necessarily remediate and may even have a negative effect on soil structure in terms of soil aggregation, bulk density, water infiltration, or water holding capacity. He did find supportive evidence for rotation with soybean providing beneficial effects on control of populations of deleterious soil microorganisms and promotion of beneficial ones, and reduction of weed, insect, disease, and nematode pests.

Management Factors that Affect Soybean NFRV

Field selection (soil type and properties). For a silt loam and a loam, Omay et al. (44) determined 2-year average N fertilizer savings of 129 and 138 lb of N per acre, respectively (traditional method). They attributed the higher N savings on the loam to its coarser texture and lower organic matter content. On the other hand, in a study with forage corn in Quebec, Paré et al. (45) did not find any difference in yield for corn after soybean versus corn after corn at 0 N in trials on a silty loam, but a lower yield for corn after soybean at 0 N on a sandy loam, indicating a possible negative impact of soybean in the rotation on available soil N at that site. Similarly, in a study conducted on an irrigated sandy soil, Bundy et al. (6) concluded that N credits could not be assigned because soybean history did not impact N needs consistently over the years, possibly due to the loss of soybean-released N by leaching before it could be used by the following year's corn crop. These studies suggest it may not be advisable to recommend N savings for coarse textured soil types in humid climates or irrigation-based management systems.

Stecker et al. (63) reported no difference in optimum economic N rates for corn after soybean versus corn after corn on poorly drained claypan soils with sprinkler irrigation in Missouri, suggesting N savings might be minimal for heavy textured soils as well.

Though confounded by other factors, a comparison of studies from different states suggests organic matter may also have an effect on NFRVs. Omay et al. (44) found the N benefit from the soybean year to be much greater in soils with lower organic matter. Addition of manure or fertilizer N and/or high levels of available N in the soil limit N fixation by legumes (4,8,24,30,32) and if crop N removal exceeds N additions through fertilizer and/or manure, a soybean crop could deplete soil mineralizable N. If soil organic matter levels are already high and soil N mineralization supplies all corn N needs, a large yield gain for corn after soybean would only be expected if non-N rotation effects significantly increase yields. Organic matter level cannot explain higher optimum economic yields for corn after soybean without additional N as compared to a continuous corn system with N applied (1,6), but it is clear that N savings may need to be adjusted downward for soils with high organic matter content.

Soybean population density. Ennin and Clegg (18) hypothesized that soybean N fixation increased with population density due to greater intra-plant competition for soil N and that increased N_2 fixation would more than offset increased N removal in higher yields at the higher plant populations. This would leave more soil N for corn and a greater amount of soybean residue. In their study, high amounts of N removed in the harvest resulted in low or negative net N balance values (-43 to +15 lb of N per acre) and N savings due to the soybean year were variable. The highest N savings were associated with the fallow treatment (49 lb of N per acre) and the lowest soybean population of about 7000 plants/acre (41 lb of N per acre). Due to the partitioning of greater amounts of N into the harvested soybean seeds, soybean contributed ≤15 lb/acre residual N and may have depleted soil N, especially at the lowest soybean populations. Ennin and Clegg (18) concluded that although soybean population density impacts N fixation, it is not a reliable predictor for soybean NFRVs.

Tillage system. As farmers in New York and other states change to conservation tillage systems, there is a need for information on the effects of minimum or no-till systems on N needs of corn after soybean as compared with continuous corn. Grain yields for continuous corn are often lower under no-till than conventional tillage, depending on soil drainage and texture – in particular, on silt loams and finer textures and more poorly drained soils (41,51,63,69).

While a number of studies have compared the effect of tillage systems on corn yield under continuous corn and soybean-corn rotation (16,28,36,41,42,51,60,61,69,70), few have looked at the effects on N savings. Results were inconclusive in a study by Rembon and MacKenzie (56) who reported NFRVs (traditional method) of 80 and 34 lb of N per acre in two successive years for a conventionally tilled clay soil, and NFRVs of 133 and > 161 lb of N per acre for a silty clay loam in the same two years. Under no-till, NFRVs were higher (134 and 75 lb of N per acre) for the clay soil and lower (56 and 45 lb of N per acre) for the site with a silty clay loam soil. Due to linear yield responses to added N for all treatments except corn after soybean under conventional tillage at one site, the authors were unable to clearly separate soybean N effects from non-N rotation effects and thought that some of the benefit of soybean was due to non-N factors. On poorly drained claypan soils in Missouri, soybean NFRVs (difference method with quadratic model) for no-till corn ranged from 0 to 57 lb of N per acre with an average of 21 lb of N per acre, varying considerably more over 5 site years than values for conventionally tilled (spring chisel-disk) corn, which averaged 48 lb of N per acre (63). When the quadratic-plateau model was used, the difference was even greater (85 lb of N per acre for the chisel-disk and 36 lb of N per acre for no-till). The authors concluded that at maximum yield, no-till corn after soybean required 15 lb of N per acre (8%) more N by the quadratic model and 36 lb of N per acre (35%) more N by the quadratic-plateau model than the chisel disk system. At fertilization levels that produced maximum profit, both models predicted that no-till corn after soybean would require 36 to 40 lb of N per acre more than the chisel-disked corn (63).

Corn crop use. New York State has a large dairy industry with about 50% of the corn grown for silage rather than grain (65). Only one study (38) in the current literature has evaluated N savings for silage corn as opposed to grain corn after soybeans. Maloney et al. (38) found no differences in N savings for grain versus silage in the first year of corn after soybean. Silage corn grown in rotation with either nodulating or non-nodulating soybean yielded about 2.1 tons/acre more than continuous corn and the NFRV (traditional method) was 80 lb of N per acre. Another study on the effect of soybean and faba bean (*Vicia faba* L.) in rotation with forage corn (45,46,47) showed NFRVs of 134 lb of N per acre and 29 lb of N per acre for the faba bean rotation, but it was impossible to estimate the NFRV of soybean for forage corn because without N addition, the yield for corn after soybean was lower than that of corn after corn.

Duration of N Savings

Corn yields are generally highest for the first year after soybeans (13,42,47). Findings on yields and N uptake for second year and continuous corn vary. Maloney et al. (38) observed higher yields and N uptake in the second and even third year following one or two years of soybean when compared to continuous corn, though the difference diminished with each successive year. Raimbault and Vyn (51) showed corn yields 2 year after soybean were similar to those for continuous corn. Mayer-Aurich et al. (42) found second year corn yields were lower than yields for continuous corn and similar findings were reported by Crookston et al. (13), although additional work (50) indicated no differences among second to fifth year corn after five years of soybeans. Despite contradictory findings for second year corn, it is clear that adjustments to N rates for corn after soybean apply to the first year of corn only.

Predictors for Soybean NFRV

Several states derive soybean NFRVs from the soybean yield preceding the corn, with savings ranging from 0.5 to 1 lb of N for each bu/acre of soybean yield (Table 1). However, there are varying reports in the literature about the reliability of soybean yield as a predictor for N savings for the following corn crop. Bundy et al. (6) did not find a relationship between preceding soybean yields and differences in corn response to N among sites and years. Katsvairo and Cox (28) found that, when averaged across years, soybean yields provided reasonable estimates for N savings at two N input levels, but soybean yields may overestimate the N savings in years with average or below average corn yields and underestimate the N savings when yields are above average. Thus, soybean yield might not be a reliable predictor of N savings across sites and years.

Summary and Conclusions

- Research reported in the scientific literature suggests optimum N rates for corn after soybean are often, but not always, lower than for corn after corn.
- Nitrogen savings are often attributed to non-N rotation effects including interruption of pest cycles, improved soil physical properties, changes in mycorrhizal communities, and/or presence of growth promoting substances related to soybean.
- Soybean yield was not a reliable predictor of NFRV.
- Second year corn yields are generally lower than or equal to continuous corn yields so adjustment in N recommendations should only be applied for first year corn after soybeans.
- Management (rotation selection, soil fertility management, tillage) and environmental factors impact the NFRV of soybean for corn, but current scientific literature does not allow for quantification of their impact on NRFVs.
- Based on this summary, we conclude a NFRV of 20-30 lb of N per acre can be applied for corn in the first year after soybean with minimal risk of a negative impact on yield.
- Additional research is needed to quantify impacts of management and environment (rotation, fertility management, tillage, soil type, weather) on NFRV of soybean for corn.

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