WITH HIGH FERTILIZER PRICES IS IT BUSINESS AS USUAL OR SHOULD FERTILIZATION PRACTICES CHANGE?

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After the spike in natural gas price in the winter of 2000-2001 the price of natural gas and N fertilizers have fluctuated, but remained above previous historic levels. Seasonal trends have also resulted in both N product availability and high cost issues, including this fall. Recently, similar problems have hit phosphate and potash fertilizers where world demand and production problems (hurricanes affecting phosphate production in Florida) have negatively affected product price and supply in the United States. With these trends, are there fertilizer use practices that should change, or does crop response to fertilization pay no matter the cost?

Crop nutrient applications should be determined by evaluating expected return from each input. If allocation is required due to limited product availability, product price, or available financial resources, then decisions about fertilizer use should also be judged against other crop production needs, enterprise requirements, and overall farm business goals. Considering all potential inputs for producing crops, the focus should be on garnering optimum positive return. Following is information to help guide fertilization decisions when prices are high or product availability is short.

Nitrogen Fertilization

Corn is quite responsive to N supply and thus management is critical for profitable production. Of importance is setting an economical application rate and adjusting total N inputs by accounting for N available from all sources -- rotation following alfalfa and soybean, manure, byproducts, and secondary fertilizers like weed-and-feed, starter, and ammoniated phosphates. These sources can supply significant amounts of crop available N, and if properly accounted for and managed, will greatly lower overall primary fertilizer N application and cost.

Timing of application is important to help assure that applied N remains in the soil for crop use. Also, risk of N loss and thus potential for reduced yield becomes more important when refining to optimal or perhaps less than optimal rates. Therefore, practices should be avoided that enhance buildup of soil nitrate at times when losses are most probable. In Iowa, most nitrate leaching occurs in the early spring period and denitrification in the later spring. Spring preplant application close to planting or sidedress typically provides the least risk from loss – although if weather and soil conditions are favorable, late fall application can be comparable but risk and probability of loss increases because of the increased time applied N is exposed to the environment. An example of the specific environmental effect on N loss was demonstrated in work by Baker et al. (1995) where they applied N from fall to late sidedress (Table 1). In a dry year, corn yield with fall application was not different from early spring and both were better than with late spring. In a wet year, mid-May to late spring application had higher yield. If primary N fertilizer applications must be made in the fall, they should be targeted to soils and geographic areas with lowest loss potential, they should be limited to anhydrous ammonia (no fall urea or UAN solution), and application should not occur until soils have cooled sufficiently to slow nitrification (temperature at the 4-inch soil depth 50°F and expectation is for continued cooling, which on average occurs during early-to-mid November across Iowa).

Crop rotations have a large impact on corn N fertilization requirements. One example of the rotation benefit is corn following alfalfa. Research by Morris et al. (1993) in Iowa found virtually no N fertilization need for first-year corn after alfalfa (three of 29 sites had positive net return from application of 50 lb N/acre, the rest did not respond to applied N). Table 2 shows the low number of responsive sites and low optimum N for first year corn after forage legume measured in studies from several states. Response to N is greater and more variable for second-year corn after alfalfa, but less than for continuous corn. Another example of the rotation benefit is the increase in corn yield and lower N requirement when corn is grown after soybean compared to corn following corn. Figure 1 demonstrates this for several recent site-years across Iowa. Table 3 lists the apparent N contribution from soybean to corn measured in several studies across the corn belt. Current suggestions are to account for up to 50 lb N/acre less N fertilization need for corn following soybean than for continuous corn, which is supported by data from Iowa and other states.

Choice of N rate can impact both economic return and residual inorganic-N remaining in the soil. Application at rates greater than corn requirement, along with increased application frequency in rotations such as continuous corn, are main reasons for excess nitrate found in corn cropping systems. Although optimal fertilization rates do vary between years, using the highest-ever produced yield to set N rates will result in over-application and lower economic return most years. It is more appropriate to set rates based on N rate response data rather than the high-yielding year(s). For example, in crop rotation studies conducted at Iowa State University Research Farms located at Ames and Lewis (Figure 2), the variation in yearly optimum N rate did not coincide with annual yield. Also, the highest yielding years did not require the highest N rates. It is common for yearly yield to not be related to optimum N. Choosing a rate based on multiple-year N response data will not limit production in the high yielding years because soil processing typically supplies more plant-available-N in those years and corn is more efficient in exploring the rooting zone and utilizing fertilizer N. The combination of good growing weather, and improved N supply and uptake, results in higher yield without the requirement for higher N application.

The average corn yield response to applied fertilizer N for corn following soybean across many years in Iowa (data from studies conducted in 1979-2003) is shown in Figure 3. Based on this average response, the economic optimum N rate is 125 lb N/acre (at a 0.10 N ($/lb):corn ($/bu) price ratio), which interestingly is the middle of the currently suggest range of 100 to 150 lb N/acre for corn following soybean (ISU Extension publication PM-1714, Blackmer et al., 1997), and which was the N rate range suggested 20 years ago by Voss and Schrader (1984) in the ISU Extension publication PM-905 "Crop Rotations-Effect of Yields and Response to Nitrogen."

Crop and N prices both influence economic optimal N rates, with higher optimal rates when N price is low and crop price is high, and conversely, lower rates when N price is high and crop price is low. Within a corn price range from $3.00 to $1.50/bu, reduction in optimum N rate is not large unless N prices are high (Table 4). One should carefully consider the prices used in these evaluations – the price now may not be what it is in the future or at harvest.

Using the approach outlined in Nafziger et al. (2004) for analyzing economic optimum return to N from many individual site-years of data, the highest return to N for Iowa response data occurs at 120 lb N/acre for corn following soybean (Figure 4). Return to N does not change appreciably around the highest return, with a range that is approximately 20 to 30 lb N/acre above and below the highest return or from 100 to 150 lb N/acre (assuming within approximately $1.00/acre of the maximum return, and using a 0.10 N:corn price ratio, which has been a common price ratio over the years). This N rate range coincides with the suggested range in Voss and Schrader (1984) and Blackmer et al. (1997) for corn following soybean. Figure 4 also indicates that N applied at the top end of this range would supply optimal N at 90% predicted sufficiency, while N applied at the low end of this range would supply optimal N at 45% sufficiency. This analysis also indicates there is little to be gained from applying N above 150 lb N/acre when corn follows soybean. Decreasing or increasing the price ratio affects the return level, the range of greatest return to N, and the range for N sufficiency (Figure 4). At a N:corn price ratio of 0.05, highest return shifts to 150 lb N/acre and at a N:corn price ratio of 0.15 highest return shifts to 100 lb N/acre. This data analysis should help producer decisions regarding N applications as their expectation for corn pricing and N cost fluctuates, and should help with risk management and understanding financial benefit or penalty if applied N is not optimal in a given season.
As mentioned earlier, the price ratio has held fairly constant over time, and changes in N rates should be weighed carefully in regard to corn prices for grain sold or expected sales. There are three main impacts of changing price ratios: one, the economic penalty for over-application increases significantly when N price becomes relatively high (this penalty is almost non-existent at low relative N price); two, the range of greatest economic return to N becomes smaller and the rate sufficiency moves to lower N rates when N price becomes relatively high; and three, the range in greatest return to N and rate sufficiency move to higher N rates when corn price is high relative to N. Currently, N prices are getting high, but this must be weighed relatively to the price received for corn grain. This type of response data analysis data can also be used to help judge use of differently priced N products.

For continuous corn, return to N is greater compared to corn following soybean due to larger yield increase from N application and the highest return to N occurs at 170 lb N/acre, which is 50 lb N/acre higher. Also, a constant range in highest return to N rate occurs from approximately 150 to 200 lb N/acre (Figure 5), which coincides with the suggested N rate range of 150 to 200 lb N/acre in Voss and Shrader (1984) and Blackmer et al. (1997) for continuous corn. At a N:corn price ratio of 0.05, highest return shifts to 200 lb N/acre and at a N:corn price ratio of 0.15 highest return shifts to 140 lb N/acre.

Manure is an excellent source of crop available N. Multiple studies in Iowa show both high corn yield and high nutrient availability from manure application. In some instances corn yields with applied manure are higher than with fertilizer alone. Appropriately utilizing manure N is another opportunity to lower fertilizer N use.

Soil Testing

Decisions regarding P and K fertilization are based on information derived from soil test results.

Without this information it is not possible to make informed decisions regarding nutrient applications. With high product prices, utilizing soil tests is the best approach to ensure successful use of dollars spent on P and K fertilizers. Methods for collecting soil samples are outlined in Sawyer et al. (2003).

If soil testing is an on-going component of overall crop management then soil test histories, soil test trends, and past nutrient applications will be available to assist in application decisions. If current soil tests are not available then some money should be spent determining this information – it is the only way to understand the potential need for fertilization. For fields with sub-field or intense soil test information, then directing P and K applications only to deficient testing areas can aid in reducing overall input costs. Also, documented records and information on the productivity of soils, fields, or field areas help derive nutrient recommendations that fit reasonable expectations of crop yield. Having soil test and nutrient application records are also important components for meeting future requirements of farm programs, like the Conservation Security Program (CSP), and manure application planning that includes the Iowa P-Index.

Phosphorus and Potassium Fertilization

Potential crop yield increase to P and K application is reflected by soil test levels. The percentage of P and K applications expected to result in a yield increase within soil test categories are: Very Low 80%, Low 65%, Optimum 25%, High 5%, Very High <1%. Highest priority for P and K applications should be to fields or field areas with soil tests in the Very Low and Low categories – soil tests below the Optimum category where yield increase will provide greatest return to the fertilizer investment (Mallarino et al., 1991; Webb et al., 1992; Sawyer et al., 2002). If adequate fertilizer cannot be applied in these situations, then reduced yield and profitability will occur. These expected responses are reflected in suggested P and K application rates for different soil test levels (Tables 5 and 6). If manure is available, then application should be targeted to these fields. With the advent of intense soil sampling on grids or in management zones, and the ability to selectively apply fertilizers and manure within fields, there is opportunity to make applications only to the deficient testing areas, and avoiding those that do not need additional nutrients.

It would be desirable to apply P and K to soils testing Optimum as some yield increase is expected at those soil test levels and over time it is economical to maintain soil tests in the Optimum category. However, yield increase and return to the fertilizer cost is not as frequent or as large as with lower soil tests. This is especially the case with increased price for P and K fertilizers. For the long-term it may be profitable to maintain soil tests in the Optimum range, but in times of high product prices or tight finances, those applications could be reduced or withheld for the current year. However, they should not be eliminated unless necessary and not for an extended number of years.

On the short term, P and K can be withheld on soils testing slightly above Optimum, however realizing that with crop harvest and resultant removal of nutrients soil tests will decline and increased fertilization will eventually be required. Application at this test level is not needed when application is for one crop year, and partial crop removal is optional for multi-year application in row crops (Sawyer et al., 2002). If recommended rates of P and K are applied to deficient testing soils over the years, then soil test levels will increase to the Optimum range. Once that occurs, fertilizer application can be withheld during tight financial times with no detrimental impact on crop production (which is one goal of having soils built to Optimum). Soils testing Very High have little probability of yield increase from nutrient application, and could have P and K withheld for several years before fertilization would be required. Application is not needed, and considering environmental P issues, P application should be avoided on Very High testing soils. Soils should be tested to monitor changes in test levels if fertilization is withheld.

The number of years fertilizer is withheld until a yield decline is observed is dependent upon the beginning soil test level. When soil tests are already deficient, yield loss will occur in the first year, but when soil tests are High to Very High, there will be several years before soil tests decrease to responsive levels and a yield loss would be observed. Examples from long-term studies are shown in Tables 7 and 8. Data from recent years at these sites show similar trends in crop and soil response. The soil test K shown in Table 8 was determined on field moist samples, which will be lower than for dried soil samples as currently used in Iowa. The length of the time period to when yield response begins increases with higher initial soil test levels. For instance as shown in Table 7, at a soil P test of 17 ppm three crops were grown before the fourth crop showed a response to applied P. But at a soil P test of 43 ppm, nine crops were grown before the tenth crop showed a response to applied P. Similar results would be expected for K (Table 8). Also, as the soil test becomes more deficient, the yield increase from P or K application grows larger, or conversely, if P or K is withheld the yield loss becomes larger.

The rate of soil test decrease when P or K fertilizer is withheld appears to depend upon the beginning soil test level (examples from long-term studies in Tables 7 and 8), prior rate and time period of nutrient application, and yield (crop removal rate). For instance, at a beginning soil test level of 17 ppm, after four crop years soil test P had declined to 9 ppm, a decrease of 8 ppm. After another four crop years soil test P declined further to 6 ppm (a change of 3 ppm). And for another four crop years soil test P did not decline further, it remained at 6 ppm. From these studies it appears that the higher the soil test level, the greater the decline – especially in situations where soil tests were increased by a large nutrient application (likely from a combination of soil processing and crop removal). When tests have moderated for a few years after the initial fertilizer application, the rate of decrease is smaller and tests are more stable. If soil tests have been maintained at a high level for a number of years, the rate of decrease would likely not be as rapid as found shortly after a one-time large P or K application. Also, as soil tests approach very low levels equilibrium occurs between crop removal, re-cycling of P and K from crop residues, and soil chemical reactions that supply available P and K – thus soil tests only slowly decline or reach roughly a stable test level. For P, soil fixation of applied P appeared to be only a small factor in regard to recovering applied fertilizer P in these studies. In the long-term P study (Table 7), with a one-time application of 300 lb P_2O_5, the soil test P returned to the original 17 ppm level after crop removal of roughly the same amount as initially applied (seven years of soybean and corn crop removal at the yields measured in the study). The same occurred for the higher 600 lb rate, the only difference being it took 13 years of crop removal at the yields measured in the study to reach the original soil test P level. Soil test K was more variable and more influenced by soil interactions that with soil test P.

Starter should be applied for corn if soil or environmental conditions frequently result in response to that application. If reduction in recommended broadcast P and K rates is necessary, then consider banding which will enhance efficiency and lower fertilizer costs. Several studies across the corn belt have shown good yield increase in no-till corn to high N (20 to 30 lb N/are) in 2 by 2 starter (2 inches beside and 2 inches below the seed) placement. When using a sidedress application for primary N, use of a high N rate at planting will help ensure adequate N until the sidedress application, which is especially important in wet springs.

Also, account for P and K in manure applications. Most manure contains significant amounts of crop available P and K, and application to meet crop N fertilization often supplies P and K needs of more than one crop.

Ways to Maintain and Even Improve Crop Yields While Refining Nutrient Costs

- Rotate crops to achieve higher yields and reduce N applications
- Account for rotation N benefits when planting corn after soybean, alfalfa, or other legumes
- Don't apply N rates greater than 150 lb N/acre for corn following soybean and 200 lb N/acre for continuous corn
- Time N fertilizer and manure application appropriately for most efficient crop use
- Account for all intended fertilizer N applications – weed and feed, starter, and ammoniated phosphates – before making the primary N fertilizer or manure application
- Investigate use of N diagnostic tools in corn such as soil nitrate testing, in-season plant N stress sensing (leaf chlorophyll reading, canopy sensing, aerial imaging), and fall cornstalk nitrate to help assess corn N fertilization requirements
- Soil test
- Don't apply P and K to soils testing above Optimum
- Use and account for manure nutrient sources
- Accurately apply fertilizer and manure
- Manage crop production practices such as plant populations, hybrid/varieties, and pest management to ensure high yields but be realistic when setting yield expectations

Summary

High fertilizer prices, uncertain product supply, and limited financial resources add to the challenge of achieving most profitable crop production. This is especially difficult for management of nutrient inputs because their cost can be a substantial part of all needed production inputs and returns may accrue over multiple years. With careful attention to the nutrient areas affording greatest potential return, applications can be targeted to priority situations critical for producing a crop and optimizing economic return. Also remember the decisions made now when considering future nutrient applications, and use soil testing to confirm impacts of high crop yields or reduced applications.

Acknowledgements

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Figure 1. Difference in average optimum N rate and yield between continuous corn and corn following soybean at five sites in Iowa from 2000-2003.

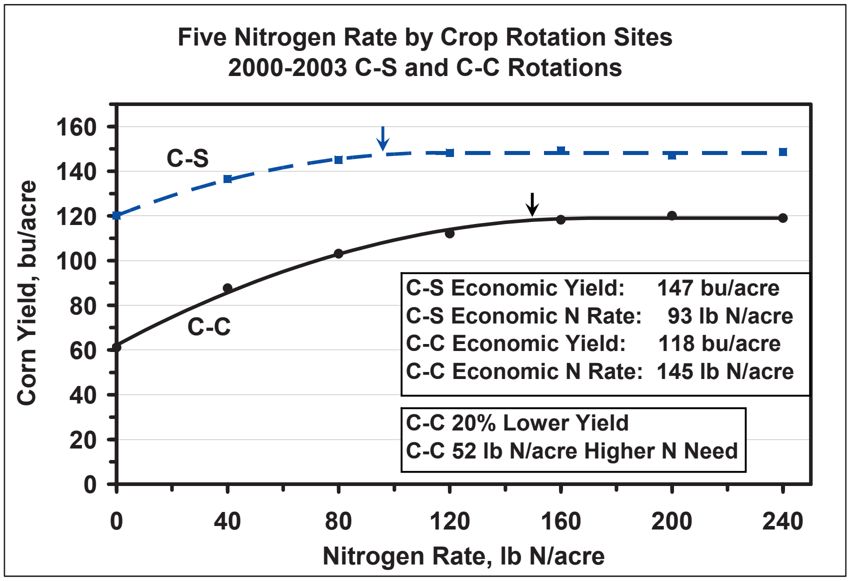


Figure 2. Change in economic optimum N rate and corn yield across years at Ames and Lewis, Iowa for continuous corn and corn following soybean from 1999-2004.

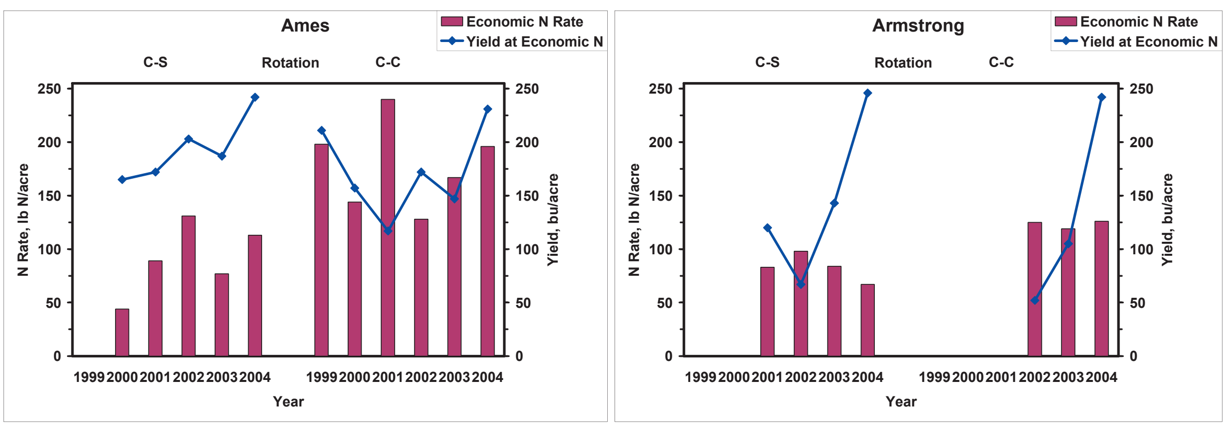


Figure 3. Corn yield response to fertilizer N rate and optimum N averaged from 1979 to 2003 for corn following soybean.

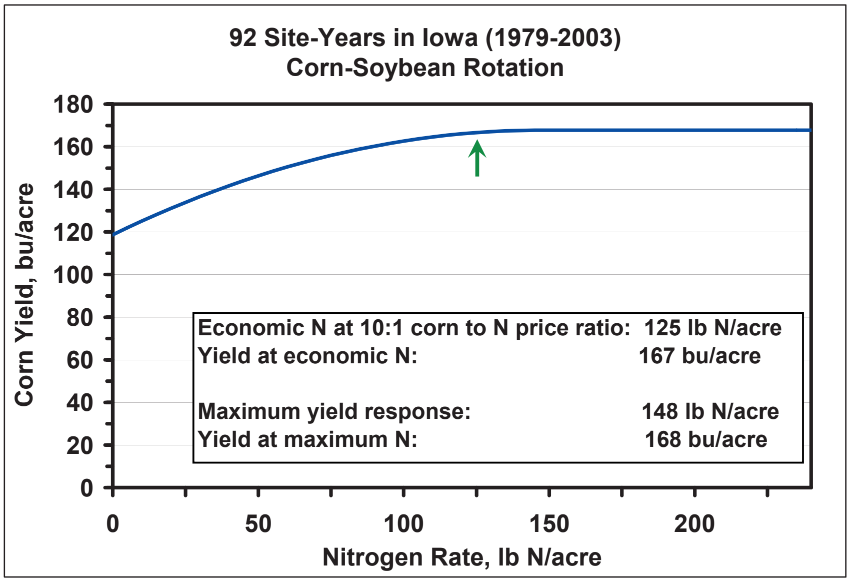


Figure 4. Average economic return to N and N rate optima for 93 site-years (1992-2003) in Iowa for corn following soybean. Nitrogen to corn price ratios are 0.05, N at $0.11 and corn at $2.20; 0.10, N at $0.22 and corn at $2.20; and 0.15, N at $0.33 and corn at $2.20.

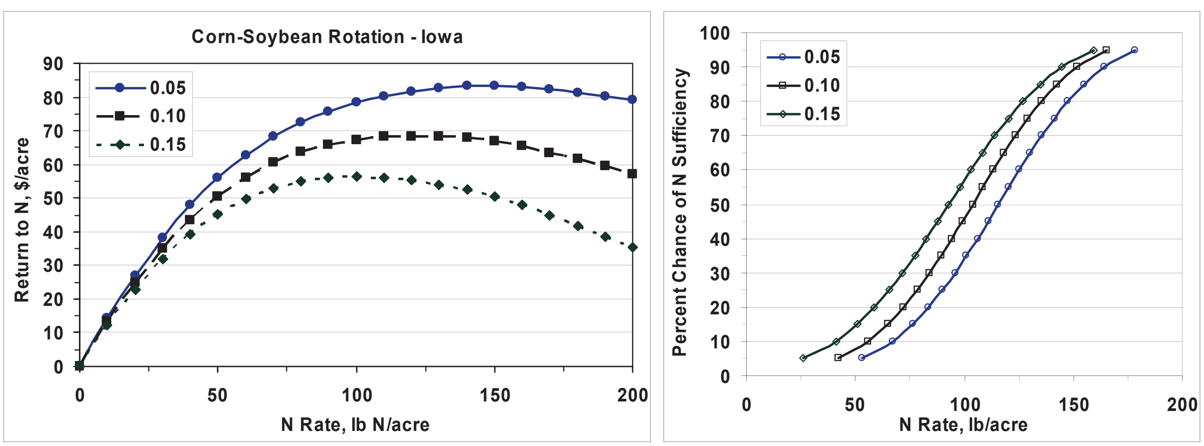
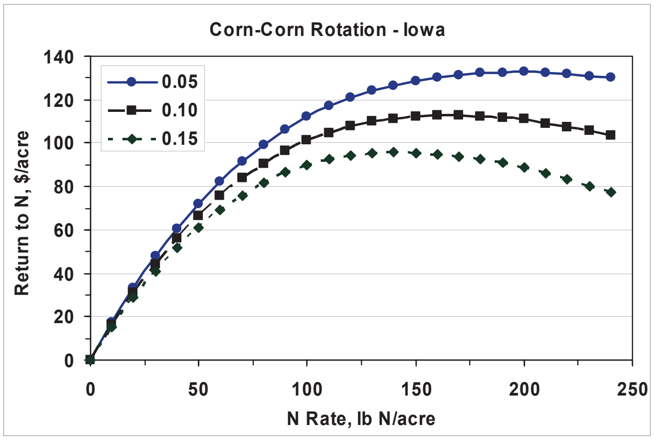


Figure 5. Average economic return to N and N rate optima for 28 site-years (1992-2003) in Iowa for continuous corn. Nitrogen to corn price ratios are 0.05, N at $0.11 and corn at $2.20; 0.10, N at $0.22 and corn at $2.20; and 0.15, N at $0.33 and corn at $2.20.



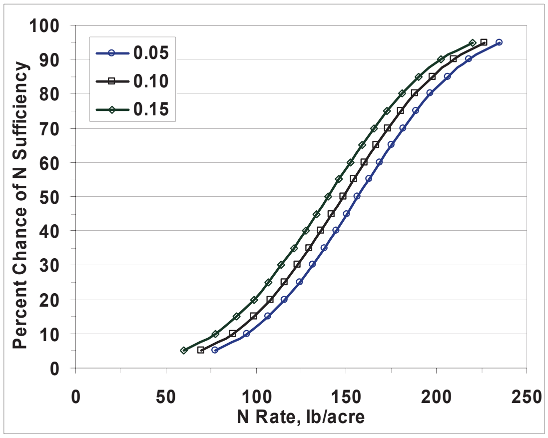


Table 1. Effect of N application timing on corn grain yield in a wet and dry year. Adapted from Baker et al. (1995).

Year	Fall	4/1	4/15	5/1	5/15	6/1	6/15	7/1	Split E.	Split L.	CK
	---------------------- bu/acre ----------------------										
1989 (Dry)	151	144	149	151	151	138	131	128	143	142	59
1990 (Wet)	114	126	128	128	140	145	143	137	130	136	68

N applied at 112 lb N/acre as liquid fertilizer. Split early was at first cultivation, split late was at second cultivation (half – half rate split). Continuous corn. Baker et al., 1995, Ames, IA.

Table 2. Influence of previous forage legume on subsequent corn N fertilization need.

First Year Corn N Need Following Forage Legume			
State	Site Years	Responsive Sites	Optimum N Rate
			lb/acre
Iowa (Voss and Shrader, 1981)	11	0	0
Iowa (Morris et al., 1993)	29	6	25
Wisconsin (Bundy and Andraski, 1993)	24	0	0
Minnesota (Schmitt and Randall, 1994)	5	1	42
Illinois (Brown and Hoeft, 1997)	4	0	0
Pennsylvania (Fox and Piekielek, 1998)	2	0	0

Table 3. Apparent N contribution from soybean to a subsequent corn crop from several studies across the corn belt.

Apparent N Contribution from Soybean		
Location	Average	Data Source
	lb N/acre	
Iowa	52	Saw yer (2003)
Iowa	60	Blackmer (1996), Meese (1993)
Missouri	48	Stecker (1995)
Wisconsin	47	Bundy (1993)
Illinois	50	Illinois NWRC (1996)
Nebraska	56	Shapiro (1998)

Table 4. Change in optimum N rate for different N fertilizer and corn grain prices. Calculations based on the average yield response for corn following soybean shown in Figure 3.

Corn	Nitrogen Price, $/lb N						
Price	$0.10	$0.15	$0.20	$0.25	$0.30	$0.35	$0.40
$/bu	- - - - - - - - - - - - - - - - Optimum N Rate, lb N/acre - - - - - - - - - - - - - - - -						
$1.50	133	125	118	111	103	96	88
$1.75	135	129	122	116	110	103	97
$2.00	137	131	125	120	114	109	103
$2.25	138	133	128	123	118	113	108
$2.50	139	134	130	125	121	117	112
$2.75	140	136	131	127	123	119	115
$3.00	140	137	133	129	125	122	118
$3.25	141	137	134	131	127	124	120

Table 5. Soil test interpretations and suggested P and K application rates for corn grain (ISU Extension Publication PM-1688, Nov. 2002). Rates in the Optimum category are based on crop removal.

	Phosphorus Soil Test (ppm)				
Soil Test Category:	**Very Low**	**Low**	**Optimum***	**High**	**Very High**
Bray P_1 and Mehlich-3 P:					
Low Subsoil P	0-8	9-15	16-20	21-30	31+
High Subsoil P	0-5	6-10	11-15	16-20	21+
Olsen P:					
Low Subsoil P	0-5	6-10	11-14	15-20	21+
High Subsoil P	0-3	4-7	8-11	12-15	16+
Mehlich-3 ICP:					
Low Subsoil P	0-15	16-25	26-35	36-45	46+
High Subsoil P	0-10	11-20	21-30	31-40	41+
	P_2O_5 to apply (lb/acre)				
	100	75	55	0	0

	Potassium Soil Test (ppm)				
Soil Test Category:	**Very Low**	**Low**	**Optimum***	**High**	**Very High**
Ammonium Acetate and Mehlich-3 Extractable K:					
Low Subsoil K	0-90	91-130	131-170	171-200	201+
High Subsoil K	0-70	71-110	111-150	151-180	181+
	K_2O to apply (lb/acre)				
Fine Textured	130	90	45	0	0
Sandy Textured	110	70	45	0	0

Table 6. Soil test interpretations and suggested P and K application rates for soybean (ISU Extension Publication PM-1688, Nov. 2002). Rates in the Optimum category are based on crop removal.

	Phosphorus Soil Test (ppm)				
Soil Test Category:	**Very Low**	**Low**	**Optimum***	**High**	**Very High**
Bray P_1 and Mehlich-3 P:					
Low Subsoil P	0-8	9-15	16-20	21-30	31+
High Subsoil P	0-5	6-10	11-15	16-20	21+
Olsen P:					
Low Subsoil P	0-5	6-10	11-14	15-20	21+
High Subsoil P	0-3	4-7	8-11	12-15	16+
Mehlich-3 ICP:					
Low Subsoil P	0-15	16-25	26-35	36-45	46+
High Subsoil P	0-10	11-20	21-30	31-40	41+
	P_2O_5 to apply (lb/acre)				
	80	60	40	0	0

	Potassium Soil Test (ppm)				
Soil Test Category:	**Very Low**	**Low**	**Optimum***	**High**	**Very High**
Ammonium Acetate and Mehlich-3 Extractable K:					
Low Subsoil K	0-90	91-130	131-170	171-200	201+
High Subsoil K	0-70	71-110	111-150	151-180	181+
	K_2O to apply (lb/acre)				
Fine Textured	120	90	75	0	0
Sandy Textured	100	85	45	0	0

Table 7. Corn yield, soybean yield, and soil test P as affected by initial and annual P fertilizer application, Kanawha, IA (Clarion-Webster Research Center).

Application[b] 1975	Annual	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
lb P_2O_5/acre		Corn or Soybean, bu/acre													
0		Corn													
	0	138	134	151	161	158	163	146	120	111	145	116	130	60	123
	23	140	135	153	166[a]	167[a]	179[a]	168[a]	152[a]	140[a]	175[a]	154[a]	161[a]	90[a]	161[a]
		Soybean													
	0	39	35	44	41	39	38	38	36	32	25	33	32	28	28
	23	40	36	43	42[a]	42[a]	40[a]	43[a]	44[a]	41[a]	31[a]	41[a]	38[a]	36[a]	30[a]
Soil P, ppm[c]:		14	13	11	9	9	9	8	6	6	7	7	6	6	3
300		Corn													
	0	139	135	157	177	170	185	179	147	152	175	157	153	75	143
	23	145	136	155	172	171	187	185	153	153	180[a]	162	168[a]	93[a]	157[a]
		Soybean													
	0	40	37	43	44	44	41	41	44	38	29	36	42	33	33
	23	41	37	46	44	43	43	44	45	39	32	43[a]	47	37[a]	38[a]
Soil P, ppm[c]:		33	36	29	23	25	23	18	14	13	14	15	10	9	8
600		Corn													
	0	125	133	153	172	170	178	182	158	155	187	160	165	97	166
	23	129	136	148	174	168	182	182	154	156	182	159	166	90	175
		Soybean													
	0	39	35	44	44	40	43	41	43	38	31	40	43	38	30
	23	37	36	44	43	40	41	43	41	40	31	41	45	35	32
Soil P, ppm[c]:		68	60	43	43	42	37	32	23	26	22	22	19	18	12

[a] Significant yield increase to annual P application.
[b] Initial 1975 application a one-time application of 0, 300, or 600 lb P_2O_5/acre in the spring of 1975. Initial soil test of 17 ppm with zero P applied.
[c] Bray P_1 soil test of the zero annual P application treatment.
Data from Webb et al., J. Prod. Agric. 5:148-152 (1992).

Table 8. Corn yield, soybean yield, and soil test K as affected by initial and annual K fertilizer application, Kanawha, IA (Clarion-Webster Research Center).

Application		Corn							Soybean						
Initial[d]	Annual	1976	1978	1980	1982	1984	1986	1988	1977	1979	1981	1983	1985	1987	1989
lb K_2O/acre		bu/acre													
0	0	121	134	146	162	122	161	100	32	34	32	38	15	35	26
	Avg.[c]	131[a]	147[a]	159[a]	180[a]	155[a]	171[a]	120[a]	34[a]	38[a]	36[a]	45[a]	24[a]	43[a]	29[a]
Soil K, ppm[b]		54	58	53	50	53	51	--	65	54	66	45	58	49	56
600	0	136	153	156	182	147	161	125	36	38	35	44	16	41	30
	Avg.[c]	135	150	162	183	158[a]	171[a]	119	35	40[a]	38	46	24[a]	44[a]	29
Soil K, ppm[b]		88	86	62	64	58	52	--	103	70	91	54	68	58	64
1400	0	131	151	172	182	158	174	114	34	42	40	47	23	43	27
	Avg.[c]	131	152	171	185	159	171	113	34	41	37	46	25	46[a]	31[a]
Soil K, ppm[b]		182	133	103	89	76	69	--	189	121	130	81	87	80	74

[a] Significant yield increase to the average annual K applications.
[b] Ammonium acetate field moist soil sample K test of the zero annual K rate application treatment.
[c] Average yield for all of the annual K fertilized treatments.
[d] Initial K application totals were annual application of 60 or 240 lb K_2O/acre from 1971 to 1974 to corn, and one application of 360 or 480 lb K_2O/acre to soybean in the spring of 1975. Initial soil test of 56 ppm with zero K applied.

Data from Mallarino et al., J. Prod. Agic. 4:560-566 (1991).