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Nitrogen Management Guidelines for Corn in Indiana

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MULTI-YEAR SUMMARY OF CORN RESPONSE TO NITROGEN FERTILIZER

This report summarizes corn yield response to fertilizer nitrogen (N) rate in field-scale trials conducted around the state of Indiana since 2006. These results are applicable to N management programs that use efficient methods and timings of N fertilizer application.

The **Agronomic Optimum N Rate (AONR)** represents the total amount of fertilizer N (including starter N) required to maximize yield, but not necessarily profit. The AONR in these trials varied among regions of the state from about 211 to 254 lbs N / ac, depending partly on soil organic matter and soil drainage characteristics.

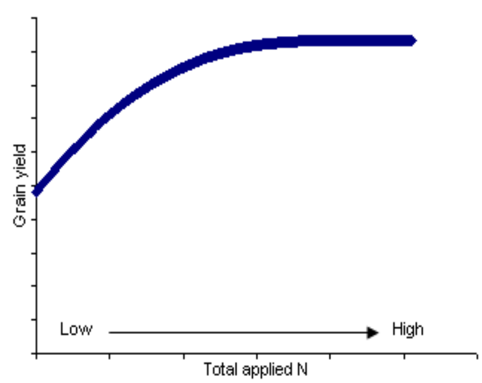
At five Purdue Ag. Centers where we conducted paired trials of corn following soybean (corn/soy) and corn following corn (corn/corn) from 2007 to 2010, the average AONR for corn/corn was 44 lbs greater than for corn/soy while average corn/corn yields were 18 bu / ac less than the corn/soy yields.

Economic Optimum N Rates (EONR) are defined as those that maximize dollar return from the nitrogen fertilizer investment. Because the yield benefits from additional N decrease as N rates approach the AONR, the EONR will almost always be less than the AONR. Region-specific EONR, calculated for various combinations of N fertilizer cost and grain price, are provided in the accompanying tables.

Nitrogen fertilizer represents a significant component of the total variable cost of production for corn in Indiana (Langemeier et al., 2021). High N fertilizer costs and the risk for negative environmental impacts dictate that growers should critically evaluate their N management program, including application rate, fertilizer material and placement, and timing.

For quite a few years, N fertilizer rate recommendations were traditionally linked to expected yield level (Camberato, 2012). For corn following soybean, the traditional rule of thumb was an N rate equal to about 1 lb of N per bushel of expected yield. For corn following either corn or wheat, the recommendation was equal to about 1.2 lbs of N per bushel.

This rule of thumb implied there was a straight-line relationship between yield and N rate; meaning that the more N you apply, the more grain you would harvest. In reality, the relationship is not a straight line. As the amount of applied fertilizer N nears the optimum rate, the magnitude of the yield response decreases to zero (see example in figure to the right). Beyond the optimum N rate, yield does not respond at all. Consequently, applying more N than is required by the crop wastes money and may harm the environment.



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Throughout the Midwest, most land-grant universities have moved away from yield-based N rate recommendations toward data-driven recommendations based on actual field trials. These recommendations are often defined in terms of Maximum Return to N (MRTN) that accounts for the relative economics of grain price and N cost (Sawyer et al., 2006; Sawyer et al., 2016).

We use the term "**Agronomic Optimum N Rate**" (**AONR)** to mean the rate of applied fertilizer N that maximizes grain yield, regardless of cost. The term "**Economic Optimum N Rate**" (**EONR)** defines the N rate that will result in the maximum dollar return to N. The EONR is usually less than the AONR, will usually decrease as N price increases, will usually increase as grain price increases, or may remain the same as long as the ratio between nitrogen cost and grain price (N:G) remains the same.

A data-driven approach requires results from numerous field trials that document corn yield responses to N fertilizer rates across a range of growing conditions. We began our current N rate trials in 2006 and to date have completed 263 field scale trials (including 2 in southern Michigan and 1 in western Ohio). About 85% of the trials were conducted on medium- and fine-textured soils, e.g., silt loams and silty clay loams. Thirty-two trials were conducted on light-textured sandier soils, 20 of which were not irrigated. Seven of the trials were conducted in muck soils. About 75% of the trials were corn grown in rotation with soybean and the rest were primarily continuous corn. About 60% of the trials were conducted on farmers' fields and the remainder were trials at Purdue agricultural research centers around the state.

The N rate treatments within individual trials ranged from as little as 25 lbs N / ac to as much as 286 lbs N / ac of total applied N. Most of the trials were conducted with sidedress N application timings, primarily using liquid UAN. Similar results would be expected from late pre-plant or sidedress anhydrous ammonia (AA). Less efficient N application timings (e.g., early pre-plant AA, early pre-plant liquid UAN, or fall-applied AA) typically result in higher optimum fertilizer N rates due to their greater risk of N loss (denitrification or leaching of soil nitrate) prior to the time the crop uses the N.

Almost all the trials were field scale in scope; meaning that the individual N rate "plots" were usually field length by some multiple of the combine header width. Most of the trials were harvested with commercial combines equipped with GPS-enabled yield monitors that were calibrated to the conditions of each trial.

Fertilizer N Rate Guidelines Based on the Results of our Field Research

Nitrogen available to the corn crop originates from soil organic matter and crop residues as well as from applied fertilizer. Some soils provide as little as 25% of the crop N requirement with the remainder coming from fertilizer N. Other soils provide in excess of 50% of the crop N demand. The N supply and N loss potential of soils are related to soil properties which naturally vary around the state. Soils with higher organic matter and/or better drainage generally provide more N to the crop and retain more fertilizer N than lower organic matter and/or more poorly-drained soils.

The results from the large number of field-scale trials we conducted around the state allowed us to develop guidelines for N rate decisions that we believe are sound and reliable for most growing seasons. We have identified some regional differences for optimum N rates (Fig. 2) that make sense with respect to the soils and soil drainage in central, northeast, and eastcentral Indiana. However, the optimum N rates throughout the remainder of the state are surprisingly similar. Where we have been able to evaluate yield responses to N rates between soil types or "zones" in fields, no differences for optimum N rates have been detected.

The optimum N rates displayed in Fig. 2 represent both the AONR (maximum yield) and EONR (maximum dollar return). The EONR was calculated based on $5.00 grain price and two different possible N costs ($0.75 and $1.00 per lb N). The figure illustrates the higher N rates required to maximize yield or dollar return in northeast, eastcentral, and central Indiana compared to the rest of the state, including sandy non-irrigated areas. The higher optimum N rates are related to the generally heavier and more poorly drained soils in those areas of Indiana.

Estimates of EONR are influenced by both the grain price you expect to receive at harvest and the cost of the N fertilizer you apply to the field. Consequently, EONR often varies year to year with fluctuations in grain prices and N costs. Tables 2 – 4 provide an expanded set of EONR estimates (based on our field trial data) for a wide range of likely grain prices and N costs. Consult the table whose region of the state (Fig. 1) is applicable to your area of Indiana. Consult Table 1 to quickly determine N cost per lb for different N fertilizer sources and prices.

Muck soils have tremendous potential to supply N to the crop via the breakdown of organic matter and release of N. The amount released is dependent on temperature and moisture, as does the amount released from organic matter in mineral soils. The difference is muck soils contain 20% organic matter or more, compared to less than 5% organic matter or less in mineral soils. Each % organic matter contains about 1,000 pounds of N per acre. If as little as 1% of that organic matter broke down during the growing season then 200 pounds of N per acre would be released, which could supply most of the N needed for the corn crop.

Results from 6 of 7 N rate response trials we conducted on muck soils suggest that organic matter does satisfy a high percentage of the N needed by the corn crop. In three of 6 trials the lowest N rate treatment was 63 pounds of N per acre and higher N rates did not increase yield. In another 3 trials, 123 pounds of N per acre was the lowest N rate treatment and higher N rates did not increase yield. In a 7th trial the corn crop responded more strongly to N rate, with 223 pounds of N per acre giving the highest yield. Three trials conducted in a single muck field in Ohio in 2015-2017, with no starter N applied, showed essentially no yield response beyond 100 lbs of sidedress N (Badertscher, 2019). The only university we have found that makes an N recommendation for corn grown on muck soils is Cornell (New York) and they simply state that "*The N requirement of corn grown on muck soils is 95 pounds [of N] per acre*" but provide no data to support that recommendation (Ristow et al., 2007). Based on these limited data, it is likely the optimum N rate for muck soils in most situations is 100 pounds of N per acre or less.

Year to Year Variability in Available Soil N and AONR

Although we report a single AONR for a region, specific AONR values often vary from field to field and from year to year for a single field. For example, the 10-year average AONR for corn grown in rotation with soybean at our research site near West Lafayette was 197 lbs N / ac, but the AONR for individual years (2006 - 2015) ranged from 130 to 262 lbs N / ac. The year to year variation in optimum N rate is not surprising given the annual variability in soil N supply, fertilizer N loss, and weather. Weather influences both soil N supply and fertilizer N efficiency. Crop health, N uptake, and N use efficiency are also influenced by soil characteristics and weather variability.

Soil or fertilizer N lost to leaching, denitrification, or volatilization represents N that is no longer available to the plant (Nielsen, 2006). The most efficient N application method and timing for minimizing N loss is to inject N prior to the beginning of rapid crop N uptake at roughly growth stage V6 (six leaves with visible leaf collars, approximately 18 inches tall). If making fall or early-spring applications, anhydrous ammonia is the least risky of the N sources relative to N loss because it is the slowest to convert to the nitrate form that is susceptible to leaching or denitrification losses. Urea-containing fertilizers should be incorporated to eliminate volatilization losses, or a urease inhibitor used for surface applications to delay the initial conversion of urea to ammonia, reducing the risk of volatilization loss (Camberato, 2017). Nitrification inhibitors can be used with anhydrous, urea, or liquid N to delay the conversion of ammonium to nitrate. More information on urease and nitrification inhibitors can be found at Franzen and NCERA-103 Committee (2017). In most situations proper placement and timing of N fertilizer applications are more effective than inhibitors in preventing N loss. **NOTE: Practices such as fall-applied or early-spring applied N or surface-applied urea typically result in the greatest N loss and therefore typically require higher N rates than we report to achieve optimum yield.**

Even if you take steps to minimize the risk of N loss, predicting the optimum N rate for a particular field in a particular year remains a challenge. Several tools exist that may improve N management. These include: the Pre-Sidedress Nitrate Test (Brouder & Mengel, 2003b; Camberato & Nielsen, 2017) which can be used to estimate soil N supply in manured fields or soils with very high organic matter content, a chlorophyll meter (Brouder & Mengel, 2003a) or active optical sensors in conjunction with a high-N reference strip that can be used during the growing season to evaluate crop N status, and the end-of-season stalk nitrate test (Brouder, 2003; Camberato & Nielsen, 2014) which serves as a "report card" to determine whether N was over-applied.

Remember that N use in corn is part of a complex biological system that interacts with everything under the sun and is difficult to model with computer programs. We cannot accurately predict the weather. We cannot accurately predict soil N supply or availability throughout the year. Yet, we cannot afford, financially or environmentally, to simply apply "more than enough" N. We can minimize the risk of fertilizer N loss by understanding the processes and matching N source with placement and timing. We can develop average N rate recommendations that will work to optimize profit over several years. We can attempt to fine-tune those recommendations with tests, models, optical sensors, or simply educated guesses.

Acknowledgements

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Figures & tables on following pages...

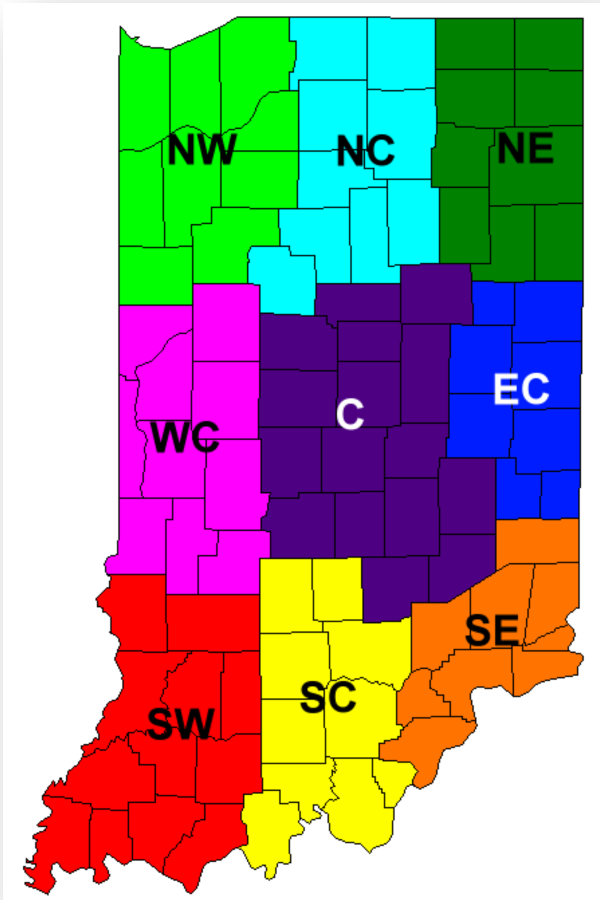

Fig. 1. Indiana crop reporting districts as identified by USDA-NASS.

Table 1. Comparative costs per lb. of actual N for a range of costs per ton of product for four fertilizer sources of N commonly used in Indiana.

Anhydrous	N cost/lb	28% UAN	N cost/lb	32% UAN	N cost/lb	Urea	N cost/lb
$1,200	$0.73	$500	$0.89	$725	$1.13	$825	$0.90
$1,250	$0.76	$525	$0.94	$750	$1.17	$850	$0.92
$1,300	$0.79	$550	$0.98	$775	$1.21	$875	$0.95
$1,350	$0.82	$575	$1.03	$800	$1.25	$900	$0.98
$1,400	$0.85	$600	$1.07	$825	$1.29	$925	$1.01
$1,450	$0.88	$625	$1.12	$850	$1.33	$950	$1.03
$1,500	$0.91	$650	$1.16	$875	$1.37	$975	$1.06
$1,550	$0.95	$675	$1.21	$900	$1.41	$1,000	$1.09
$1,600	$0.98	$700	$1.25	$925	$1.45	$1,025	$1.11
$1,650	$1.01	$725	$1.29	$950	$1.48	$1,050	$1.14
$1,700	$1.04	$750	$1.34	$975	$1.52	$1,075	$1.17
$1,750	$1.07	$775	$1.38	$1,000	$1.56	$1,100	$1.20

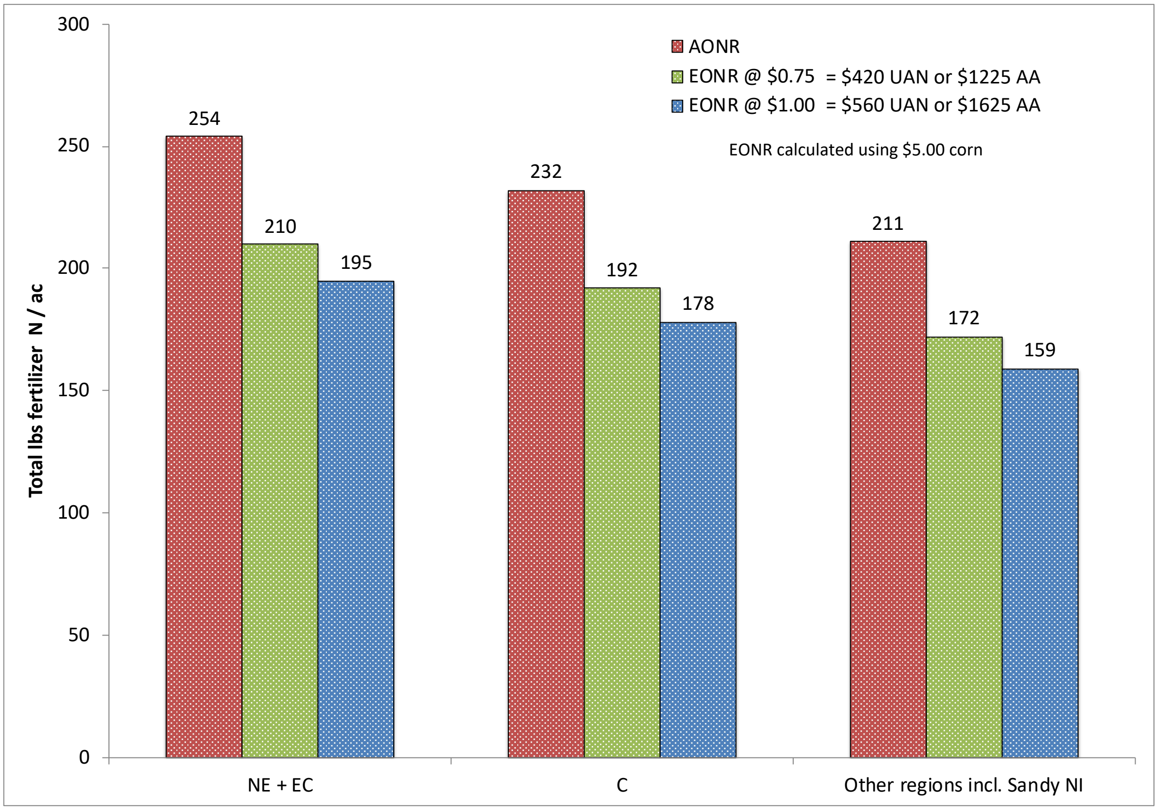

Fig. 2. Average agronomic optimum N rates (AONR) and economic optimum N rates (EONR) for corn following soybean in selected geographic regions in Indiana (see Fig. 1), based on 166 trials conducted from 2006 to date. The EONR were calculated using $5.00 corn and nitrogen fertilizer prices of either $0.75 or $1.00 per lb of N. These N prices equate to UAN (28-0-0) costs of $420 and $560 per ton or AA (82-0-0) costs of $1225 and $1625 per ton. See Tables 2 – 4 for EONR calculated using other corn prices and N costs.

Table 2. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for **corn following soybean** in **central Indiana on medium- and fine-textured soils** as influenced by nitrogen cost per lb N (Table 1) and grain price per bushel. The underlying yield response data are from 23 field scale trials conducted from 2006 to date. The average agronomic optimum N rate for this region of Indiana is approximately 232 lbs N / ac. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Central Indiana

	Grain price						
N cost	**$4.50**	**$5.00**	**$5.50**	**$6.00**	**$6.50**	**$7.00**	**$7.50**
$0.60	196	200	203	205	207	209	211
$0.75	187	192	195	198	201	203	205
$0.90	178	184	188	192	195	197	200
$1.05	169	175	181	185	189	192	194
$1.20	160	167	173	178	182	186	189
$1.35	151	159	166	171	176	180	184
$1.50	142	151	158	165	170	174	178
$1.65	133	143	151	158	164	168	173

Table 3. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for **corn following soybean** in **northeast and eastcentral Indiana on medium- and fine-textured soils** as influenced by nitrogen cost per lb N (Table 1) and grain price per bushel. The underlying yield response data are from 37 field scale trials conducted from 2006 to date. The average agronomic optimum N rate for these regions of Indiana is approximately 254 lbs N / ac. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Northeast & Eastcentral Indiana

	Grain price						
N cost	**$4.50**	**$5.00**	**$5.50**	**$6.00**	**$6.50**	**$7.00**	**$7.50**
$0.60	215	219	222	225	227	229	231
$0.75	205	210	214	217	220	223	225
$0.90	195	201	206	210	213	216	219
$1.05	185	192	198	203	207	210	213
$1.20	176	184	190	195	200	204	207
$1.35	166	175	182	188	193	197	201
$1.50	156	166	174	181	186	191	195
$1.65	146	157	166	173	179	185	189

Table 4. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for **corn following soybean** in **northcentral, northwest, southcentral, southeast, southwest, and westcentral Indiana primarily on medium- and fine-textured soils, plus sandy non-irrigated areas throughout the state** as influenced by nitrogen cost per lb N (Table 1) and grain price per bushel. The underlying yield response data are from 106 field scale trials conducted from 2006 to date. The average agronomic optimum N rate for these regions of Indiana is approximately 211 lbs N / ac. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Northcentral, Northwest, Southcentral, Southeast, Southwest, Westcentral + Sandy Non-irrigated areas of Indiana

	Grain price						
N cost	**$4.50**	**$5.00**	**$5.50**	**$6.00**	**$6.50**	**$7.00**	**$7.50**
$0.60	176	180	182	185	187	188	190
$0.75	167	172	175	178	181	183	185
$0.90	159	164	168	172	175	177	180
$1.05	150	156	161	165	169	172	174
$1.20	141	148	154	159	163	166	169
$1.35	132	140	147	152	157	160	164
$1.50	124	132	139	145	150	155	159
$1.65	115	124	132	139	144	149	153

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