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Nitrogen Management Guidelines for Corn in Indiana

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13-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.

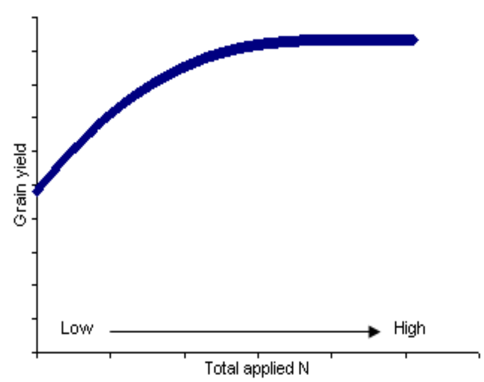
The Agronomic Optimum N Rate (AONR) represents the total amount of fertilizer N (including starter N) required to maximize yield, but not necessarily profit. The AONR varied among regions of the state from about 210 to 263 lbs N / ac, depending partly on soil organic matter and soil drainage characteristics.

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. The EONR in our trials varied throughout the state from about 170 to about 210 lbs N / ac. Region-specific EONR, calculated for various combinations of N fertilizer cost and grain price, are listed in the accompanying tables.

Nitrogen fertilizer represents a significant component of the total variable cost of production for corn in Indiana. Applying “more than enough N” is no longer cheap “insurance” as it was once considered many years ago. Applying “more than enough N” is also not environmentally friendly. High N fertilizer costs and environmental impacts dictate that growers should critically evaluate their N management program, including application rate, fertilizer material, and timing.

For quite a few years, nitrogen 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 figure to the right). Beyond the optimum N rate, yield does not respond at all. Consequently, applying more N than the crop requires 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 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).

For the purposes of this summary, the term "**Agronomic Optimum N Rate**" or **AONR** defines the rate of applied fertilizer N that maximizes grain yield, regardless of cost. The term "**Economic Optimum N Rate**" or **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 265 field scale trials around the state. About 75% of the trials are corn grown in rotation with soybean and the rest are 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), but not necessarily from early pre-plant AA, early pre-plant liquid UAN, or fall-applied AA because of the higher risk of N loss with those timings. Most of the trials were conducted on medium- and fine-textured soils, e.g., silt loams and silty clay loams. Almost all of the trials have been 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 the aid of calibrated GPS-enabled yield monitors.

Regional and Soil Differences for Optimum N Rate

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 better drainage generally provide more N to the crop and retain more fertilizer N than lower organic matter, more poorly drained soils. Because of the large number of trials in our database, we are able to identify regional differences for optimum N rates that make sense with respect to the soils in those regions. It is important to note that most of our trials used efficient fertilizer application methods and timings. Less efficient N management typically require higher fertilizer N rates in response to the greater risk of N loss.

For now, the N fertilizer results are grouped according to USDA-NASS Indiana Crop Reporting Districts (Fig. 1). The average AONR for 56 trials conducted on medium- and fine-textured soils in northcentral, southwest, and westcentral Indiana was 210 lbs N / ac. The average AONR for 35 trials conducted on medium- and fine-textured soils in northwest, southeast, and southcentral Indiana was also 210 lbs N / ac, but the EONR varied slightly. The average AONR for 37 trials conducted on medium- and fine-textured soils in northeast and eastcentral Indiana was 254 lbs N / ac. The average AONR for 23 trials conducted on medium- and fine-textured soils in central Indiana was 232 lbs N / ac. The average AONR for 16 trials conducted on non-irrigated sandy soils was 202 lbs N / ac.

The EONR is based on the relative cost of N and value of grain and consequently is lower than the AONR. Economically optimum N rates (aka Maximum Return to N or MRTN) are provided in the accompanying tables and online at the multi-state Corn Nitrogen Rate Calculator Web site (http://cnrc.agron.iastate.edu).

More field research is needed in southcentral Indiana in general, on sandy soils (irrigated and non-irrigated), and on muck fields to develop more reliable guidelines for those regions or situations. Please consider collaborating with us in conducting on-farm research N rate trials (see below for more information).

More Discussion on N Management

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 is N 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. Nitrification inhibitors can be used with anhydrous, urea, or liquid N to delay the conversion of ammonium to nitrate. 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 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) 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.

We Are Looking for On-Farm Trial Cooperators

Our long-term objective is to develop soil-specific N rate guidelines. Conducting N rate trials on farmer's fields is the best way for us to expand our efforts and increase the size and scope of the database for making regional recommendations. The general protocol for such trials is to sidedress-apply field-length strips of five or six N rates (for example: 70, 110, 150, 190, and 230 lbs N per acre), replicated at least three times across a field. Size of individual plots (a single N rate strip) is typically twice the width of the combine header. If you use a variable rate controller that accepts prescription N rate files, we can create and provide a prescription file that essentially eliminates the logistics of implementing the replicated N rate treatments. Use of calibrated combine yield monitors greatly reduces the harvesting logistics of field scale trials.

The general protocol for our N rate trials can be downloaded at http://www.agry.purdue.edu/ext/ofr/protocols/PurdueNTrialProtocol.pdf.

If you are interested in conducting on-farm N rate trials, contact Jim Camberato (765-496-9338 or jcambera@purdue.edu) or Bob Nielsen (765-494-4802 or rnielsen@purdue.edu). We will work with you to come up with the best compromise between our desires for statistical soundness and your desire for logistical simplicity.

Acknowledgements

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Don't forget, this and other timely information about corn can be viewed at the Chat 'n Chew Café on the Web at http://www.kingcorn.org/cafe.

Figures & tables on following pages...

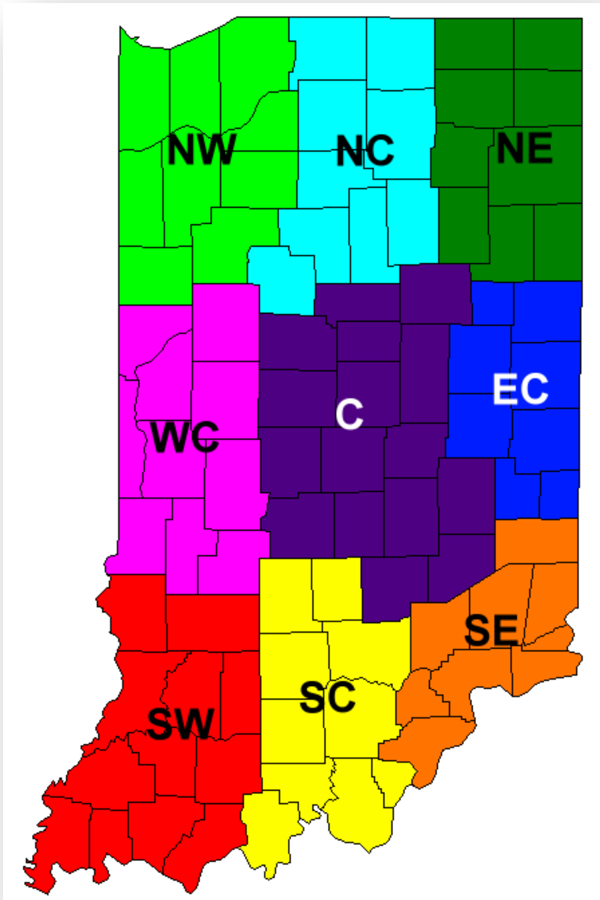

Fig. 1. Indiana crop reporting districts as identified by USDA-NASS.

Table 1. Comparative costs per lb. of actual N for varying 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
$450	$0.27	$175	$0.31	$175	$0.27	$350	$0.38
$500	$0.30	$200	$0.36	$200	$0.31	$400	$0.43
$550	$0.34	$225	$0.40	$225	$0.35	$450	$0.49
$600	$0.37	$250	$0.45	$250	$0.39	$500	$0.54
$650	$0.40	$275	$0.49	$275	$0.43	$550	$0.60
$700	$0.43	$300	$0.54	$300	$0.47	$600	$0.65
$750	$0.46	$325	$0.58	$325	$0.51	$650	$0.71
$800	$0.49	$350	$0.63	$350	$0.55	$700	$0.76
$850	$0.52	$375	$0.67	$375	$0.59	$750	$0.82
$900	$0.55	$400	$0.71	$400	$0.63	$800	$0.87
$950	$0.58	$425	$0.76	$425	$0.66	$850	$0.92
$1,000	$0.61	$450	$0.80	$450	$0.70	$900	$0.98

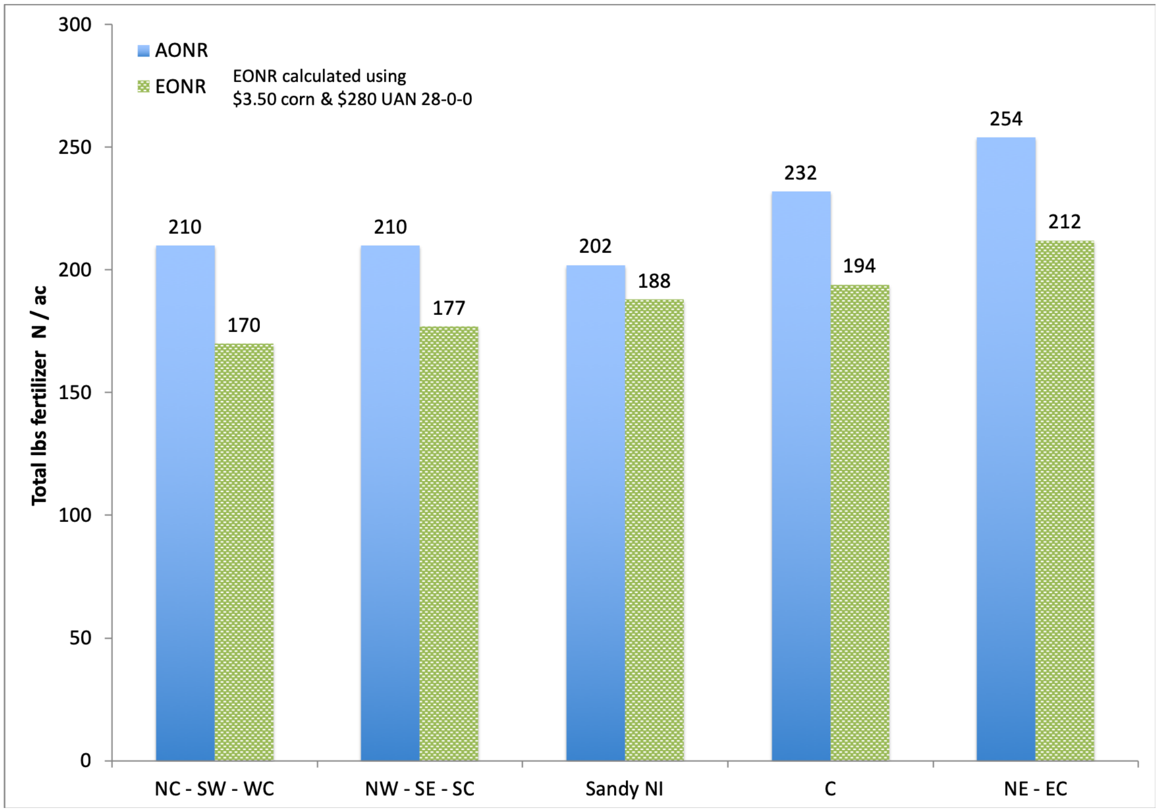

Fig. 2. Average agronomic optimum N rates (AONR) and economic optimum N rates (EONR) for corn following soybean on sandy non-irrigated (Sandy NI) soils and medium- and fine-textured soils in selected geographic regions in Indiana (see Fig. 1), based on trials conducted 2006 - 2018. The EONR were calculated using $3.50 corn and $280 UAN 28-0-0 fertilizer. See the following tables 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 as influenced by nitrogen cost per lb. N (Table 1) and grain price per bushel based on yield response data summarized over **northcentral, southwest, and westcentral Indiana on medium- and fine-textured soils**. The average agronomic optimum N rate for these regions of Indiana is approximately 210 lbs N / ac.

Northcentral, Southwest, Westcentral Indiana

	Grain price						
N cost	**$2.50**	**$3.00**	**$3.50**	**$4.00**	**$4.50**	**$5.00**	**$5.50**
$0.20	188	192	194	196	198	199	200
$0.30	177	182	186	189	192	194	195
$0.40	166	173	178	182	186	188	190
$0.50	154	164	170	175	179	182	185
$0.60	143	154	162	168	173	177	180
$0.70	132	145	154	161	167	171	175

Based on 56 field scale trials conducted 2006-2018. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Table 3. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for corn following soybean as influenced by nitrogen cost per lb. N (Table 1) and grain price per bushel based on yield response data summarized over **northwest, southeast, and southcentral Indiana on medium- and fine-textured soils**. The average agronomic optimum N rate for these regions of Indiana is approximately 210 lbs N / ac.

Northwest, Southeast, Southcentral Indiana

	Grain price						
N cost	**$2.50**	**$3.00**	**$3.50**	**$4.00**	**$4.50**	**$5.00**	**$5.50**
$0.20	191	194	197	198	200	201	201
$0.30	182	187	190	192	194	196	197
$0.40	173	179	183	187	189	191	193
$0.50	163	171	177	181	184	187	189
$0.60	154	163	170	175	179	182	185
$0.70	145	156	163	169	174	177	180

Based on 35 field scale trials conducted 2006-2018. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Table 4. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for corn following soybean as influenced by nitrogen cost per lb. N (Table 1) and grain price per bushel based on yield response data summarized over **throughout Indiana on sandy, non-irrigated soils**. The average agronomic optimum N rate for these soils is approximately 202 lbs N / ac.

Sandy non-irrigated soils

	Grain price						
N cost	**$2.50**	**$3.00**	**$3.50**	**$4.00**	**$4.50**	**$5.00**	**$5.50**
$0.20	194	195	196	197	198	198	198
$0.30	190	192	193	194	195	196	197
$0.40	186	189	191	192	193	194	195
$0.50	182	185	188	190	191	192	193
$0.60	178	182	185	187	189	190	191
$0.70	174	179	182	185	187	188	189

Based on 16 field scale trials conducted 2006-2018. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Table 5. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for corn following soybean as influenced by nitrogen cost per lb. N (Table 1) and grain price per bushel based on yield response data summarized over **central Indiana on medium- and fine-textured soils**. The average agronomic optimum N rate for this region of Indiana is approximately 232 lbs N / ac.

Central Indiana

	Grain price						
N cost	**$2.50**	**$3.00**	**$3.50**	**$4.00**	**$4.50**	**$5.00**	**$5.50**
$0.20	211	214	217	219	220	221	222
$0.30	200	205	209	212	214	216	217
$0.40	189	196	201	205	208	211	213
$0.50	178	187	194	198	202	205	208
$0.60	167	178	186	192	196	200	203
$0.70	156	169	178	185	190	194	198

Based on 23 field scale trials conducted 2006-2018. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

Table 6. Range of economic optimum N rate (EONR) values (lbs applied N / ac) for corn following soybean as influenced by nitrogen cost per lb. N (Table 1) and grain price per bushel based on yield response data summarized over **northeast and eastcentral Indiana on medium- and fine-textured soils**. The average agronomic optimum N rate for these regions of Indiana is approximately 254 lbs N / ac.

Northeast, Eastcentral Indiana

	Grain price						
N cost	**$2.50**	**$3.00**	**$3.50**	**$4.00**	**$4.50**	**$5.00**	**$5.50**
$0.20	231	235	237	240	241	242	244
$0.30	219	225	229	232	235	237	238
$0.40	207	215	221	225	228	231	233
$0.50	195	205	212	217	222	225	227
$0.60	184	195	204	210	215	219	222
$0.70	172	185	195	203	208	213	217

Based on 37 field scale trials conducted 2006-2018. These rates assume N management practices that minimize the risk of N loss prior to plant uptake.

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