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Introduction

Yearly nitrogen (N) input is typically required for optimal corn yields in the majority of Iowa crop rotations. The exception would be first-year corn following established alfalfa where none to only a small N input is typically needed. If not fertilized with N over time, corn yield will be very limited as the soils ability to supply plant-available N becomes depleted. Long-term research in Iowa shows corn yields will average only about 60 bu/acre for continuous corn and 115 bu/acre for corn following soybean when corn is not fertilized with N. Optimally fertilized corn can easily yield more than 200 bu/acre, indicating the large yield increase possible due to N application. Where does plant-available N come from if there is no N fertilization? Some originates from precipitation and ammonium can be released from clay minerals. However, the majority comes from microbial processing (net mineralization) of crop residues and soil organic matter. The amount of N release from breakdown of organic matter sources varies significantly between previous crop, previous N management, soils, and growing seasons (largely due to weather conditions); can be a large part of the total N taken up by corn; and typically (for normally fertilized fields across time) is more than N taken up directly from applied fertilizer.

There is ongoing debate about N fertilizer rate needed to maintain soil N (and soil carbon), and long-term sustainability of crop production for Iowa cropping systems. For corn and soybean, several principles are clear.

- Maintaining soil N means maintaining soil organic matter (soil carbon).
- Without N fertilization, soil N will deplete and small changes in total soil N can influence plant-available N supply.
- Without N fertilization, soil organic matter will decline and supply of plant-available N will decrease; and stabilize at a low net plant-available N level with resultant low corn yield.
- High (acceptable) corn yields require N fertilization to supplement the soil N supply.
- The goal is for optimal N rates to approximately balance the input and output of N from soil (maintain soil N) in corn production systems. In continuous corn this is possible, but in rotation with soybean the corn phase cannot overcome the soil N depleting effect of soybean.
- Nitrogen mineralization from soil organic matter supplies inorganic plant-available N; however, nitrate from soil organic matter mineralization will also leach from soils as evidenced by nitrate-N concentrations in tile flow when no N is applied.
- Nitrogen fertilization supplies needed plant-available, but increases nitrate that can leach from soils.
- Reducing N fertilization to below economic optimum rates can reduce nitrate loss, but will not eliminate it.
- Because the soil is an open system (top and bottom), N losses will occur. This makes maintenance of soil N (and organic matter) and production of optimal crop yields through N fertilization difficult while attempting to eliminate negative environmental impacts.

Nitrogen rate guidelines

Since 2005, N rate guidelines in Iowa and seven states across the Cornbelt for continuous corn and corn following soybean have been provided by the online Corn Nitrogen Rate Calculator (CNRC; http://extension.agron.iastate.edu/soilfertility/nrate.aspx). The CNRC uses the Maximum Return To Nitrogen (MRTN) approach, which provides the most economical N rate (MRTN rate) and range of most profitable N rates that are within one dollar economic return to N (RTN) of the MRTN rate. The MRTN approach is fully outlined in the Extension and Outreach publication PM 2015 (Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn). A main aspect of the approach is that optimal N rate is not related to yield level (Figure 1). Instead, the yield increase to N application generated from N rate response trials is used to determine suggested rates. This change in approach is still controversial, and perhaps slowed adoption of the MRTN approach. While the MRTN is used in seven states, the N rates provided are different for each state; that is, the approach is regional but the N rate guidelines are state specific. Since the MRTN uses recent N rate trials as the basis for rate determination, research conducted in each state provides the basis for rate guidelines. It makes sense then that rates would vary by geographic (state) region, especially when one considers the differences in climate and soils.

The MRTN uses economic return to N application as the basis for rate suggestions. Optimal rate is determined as the point where additional yield just pays for the last increment of added N (Figure 2). The MRTN rate is then determined as the N rate, across response trials for a specific rotation, which produces the greatest (maximum) net RTN and the most profitable range within $1/acre of the maximum RTN (Figure 3). The N rate that produces the MRTN varies with N and corn prices (Table 1 for Iowa).

Proposed Iowa MRTN regions

In Iowa, since the first development of the MRTN and CNRC, there has been a uniform N rate provided for the entire state (Table 1). The reason is that N rate trial data had not indicted a need to differentiate different geographic or soil differences that would warrant different rates. In other words, the many N rate trials conducted across Iowa had similar variation whether in sub-state regions or across the state. This has not been the case in some states, where different geographic or soil regions have been identified as needing different N rate guidelines (for example Illinois geographic regions, Wisconsin soil yield potentials, Indiana soil/geographic regions). Weather conditions, specifically rainfall, has increased in recent years. The normal rainfall trend across Iowa is higher rainfall in southeast Iowa to less in northwest Iowa. The high rainfall, in conjunction with poorly drained soils (slow internal drainage) in southeast Iowa, has created situations where N fertilization requirements have increased relative to the rest of the state. Therefore, it is proposed that southeast Iowa have different N rate guidelines (Table 2). The general southeast Iowa area would be soil regions 21, 22, and approximately the south half of soil region 17 (generally south of highway 92) (Figure 4). Soils for trial sites in the southeast region include poorly drained soils like Haig, Kalona, Macksburg, Mahaska, Nira, Otley, Richwod, Taintor, and other similar soils. If specific soils in the southeast region are better drained, then use of the main Iowa region would be appropriate. The rest of the state would continue as the main Iowa region. Due to the combination of higher rainfall and poorly drained soils, the southeast Iowa region has higher suggested N rates than the main area of Iowa. This delineation of a "southeastern" Iowa sub-state region is similar to that in Illinois where the southern one-third of Illinois has different rate guidelines due to similar soil/precipitation conditions as in southeast Iowa; and despite having generally lower yield potential.

Rainfall effects on nitrogen response

Periods of greater than normal rainfall and soil wetness can affect available N supply from soil, loss of applied N from fertilizer and manure, and hence total needed N application. Compared to "normal" moisture and temperature conditions, seasonal differences (lower or higher rainfall) can reduce or increase needed N application and cause variation in yearly optimal N rate. In recent years, there has been a trend of more than normal springtime rainfall. This has resulted in an increase in suggested MRTN rates for corn in Iowa (Figure 5). This trend, while not good for economics of corn production, is a positive for the MRTN approach (and rate guidelines from the CNRC) as the suggested rates are automatically "adjusted" yearly due to inclusion of new N rate trials which reflect current weather condition effects on N response and rate need. While N rates from the CNRC have gone up in recent years, the MRTN rates have remained within the long-standing ranges of 100-150 lb N/acre for corn following soybean and 150-200 lb N/acre for corn following corn (such rate guidelines go back to the 1970's, ISU publication Pm-905, 1979; and are in ISU publication Pm-1714, 1997). These MRTN rates, remaining within those N rate ranges, is an indication that despite large increase in corn yield (from the 1970's to current) N fertilization rate requirements have not changed concurrently with yield.

Due to several recent years of high springtime rainfall, farmers and crop advisers have been challenged to determine when additional N application is needed. To help answer that question, economic optimum N rate (EONR) data from long-term N rate study sites (1999-2013, continuous corn and corn rotated with soybean) at seven ISU Research and Demonstration Farms were analyzed against the amount of rainfall received at each study location. Rainfall periods starting in late summer through July were analyzed. The rainfall periods (with total amount received) that best indicated potential need for a higher N rate, at least 20 lb N/acre greater than the MRTN rate compared to the specific site-year EONR, was cumulative April + May + June rainfall ≥ 16 inches at the combination of Ames, Armstrong, Kanawha, Nashua, and Sutherland sites; and cumulative March + April + May + June rainfall ≥ 17 inches at the combination of Chariton and Crawfordsville sites (south to southeast Iowa). The "at least 20 lb N/acre deficit buffer" was used for two reasons. One, uncertainty in the evaluation process and determination of exact EONR; and two, having a large enough N amount to make an application worthwhile. The correct determination of adequate or N shortage for the Ames, Armstrong, Kanawha, Nashua, and Sutherland sites was 81%, and just for determination of N shortage was 67%. The correct determination of adequate or N shortage for the Chariton and Crawfordsville sites was 69%, and just for determination of N shortage was 72%.

The cumulative springtime rainfall is not a perfect indicator that additional N would be needed, but certainly has high enough success frequency for use as a decision aid in wet springs. One can easily track rainfall accumulation starting in March or April (depending on location), and be ready as cumulative amounts approach the 16 or 17 inch total. Unfortunately, the June rainfall amount needs to be in the cumulative total. Not including the June rainfall drastically reduced the success in predicting N application need. It makes sense that June wetness would be important as soil temperatures are warm and denitrification (a significant N loss mechanism on many Iowa soils) potential in June is an important component of N loss. This springtime cumulative rainfall approach, however, does not provide needed application rate. Interestingly, compared to the suggested MRTN rate, only 26% of the site-years for the Ames, Armstrong, Kanawha, Nashua, and Sutherland sites were there EONR's at least 20 lb N/acre greater than the MRTN; but 43% of the site years for Chariton and Crawfordsville. The almost double occurrence at Chariton and Crawfordsville are reflective of the higher rainfall area of Iowa, especially high rainfall approximately the last 10 years, and soils with poor internal drainage. Starting the cumulative rainfall in March also makes sense as those are southern locations.

Summary

Because of the complex and open soil system, it difficult to produce high-yielding corn and soybean crops in Iowa agricultural systems without impacting soil N, soil carbon, and N loss to the environment. Proven soil management and N fertilization practices, such as using economic optimal N rates, should be used to support soil N and soil carbon, and optimize crop yields. Environmental concerns with nitrate in surface and drinking water sources is also an on-going issue. Nitrogen application rate has economic and environmental consequences (Figure 6), therefore, rate decisions should be made carefully. Avoidance of effects from excess rainfall should not be attempted through routine application of high N rates as that will have serious negative impact on profit and water quality. Instead, apply suggested rates for specific corn rotations, N prices, and corn prices. Then, if excessively wet springtime conditions develop, evaluate the amount of rainfall and potential need for additional in-season application.

Table 1. Nitrogen rate guidelines in Iowa for different N and corn grain prices.

Price Ratio[1]	Corn Following Soybean Rate[2]	Corn Following Soybean Range[3]	Corn Following Corn Rate[2]	Corn Following Corn Range[3]
$/lb:$/bu	---------- *lb N/acre* ----------		---------- *lb N/acre* ----------	
0.05	157	143 - 173	217	198 - 240
0.10	137	126 - 149	190	178 - 201
0.15	122	113 - 133	175	162 - 185
0.20	111	101 - 120	156	145 - 167

[1] Price per lb N divided by the expected corn price. For example, N at $0.40/lb N and corn at $4.00/bu is a 0.10 price ratio. Corn held at $4.00/bu for all price ratios.

[2] Rate is the lb N/acre that provides the Maximum Return To N (MRTN). All rates are based on results from the Corn N Rate Calculator as of July 21, 2014 (http://extension.agron.iastate.edu/soilfertility/nrate.aspx).

[3] Range is the range of profitable N rates that provides a similar economic return to N (within $1.00/acre of the MRTN).

Table 2. Proposed nitrogen rate guidelines in Southeast Iowa for different nitrogen and corn grain prices.

Price Ratio[1]	Corn Following Soybean Rate[2]	Corn Following Soybean Range[3]	Corn Following Corn Rate[2]	Corn Following Corn Range[3]
$/lb:$/bu	---------- *lb N/acre* ----------		---------- *lb N/acre* ----------	
0.05	174	155 - 197	240	229 - 240
0.10	145	132 - 160	211	192 - 232
0.15	134	121 - 141	184	177 - 198
0.20	121	109 - 131	181	168 - 186

[1] Price per lb N divided by the expected corn price. For example, N at $0.40/lb N and corn at $4.00/bu is a 0.10 price ratio. Corn held at $4.00/bu for all price ratios.

[2] Rate is the lb N/acre that provides the Maximum Return To N (MRTN). All rates are based on research trials in the Corn N Rate Calculator as of July 21, 2014 for the proposed southeast Iowa region (http://extension.agron.iastate.edu/soilfertility/nrate.aspx).

[3] Range is the range of profitable N rates that provides a similar economic return to N (within $1.00/acre of the MRTN).

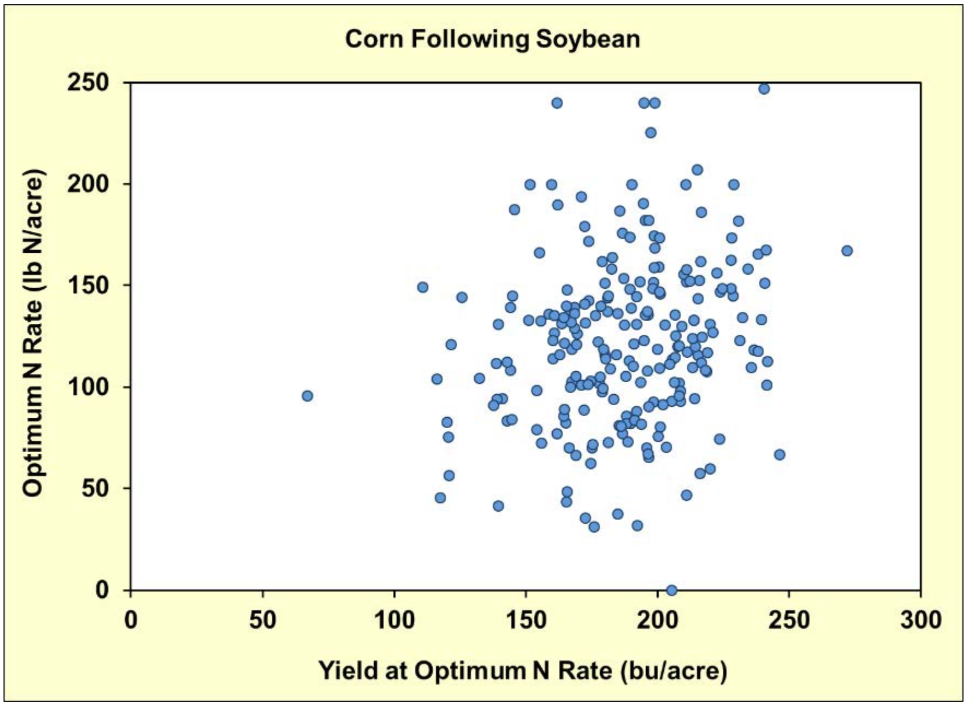

Figure 1. The lack of relationship between corn grain yield level and the optimum N rate, example for corn following soybean in Iowa.

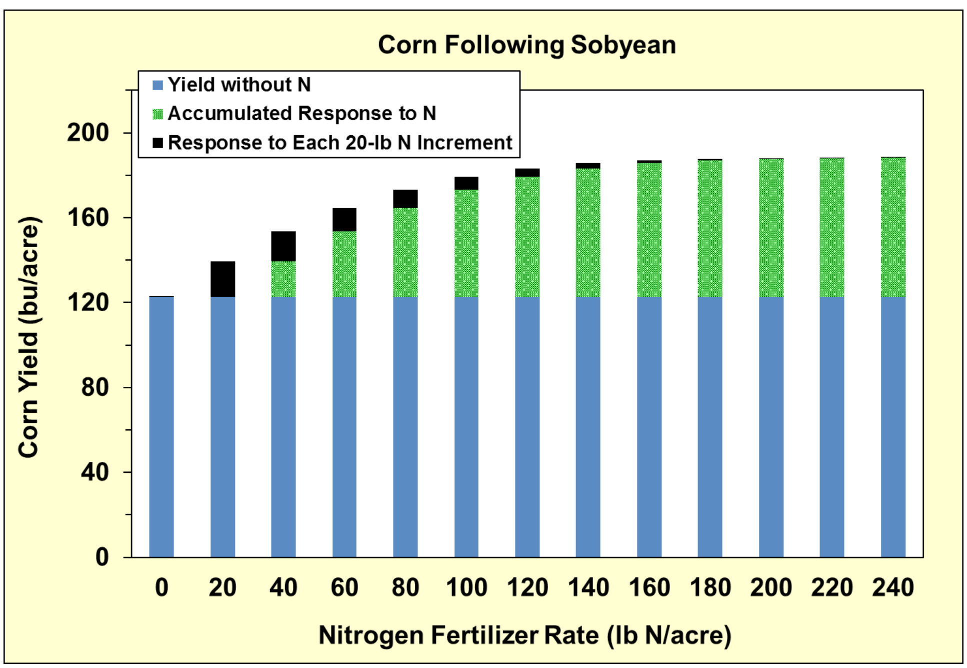

Figure 2. Diminishing returns in yield response to fertilizer N as rate increases. The MRTN rate for this Corn N Rate Calculator dataset was 137 lb N/acre (0.10 price ratio).

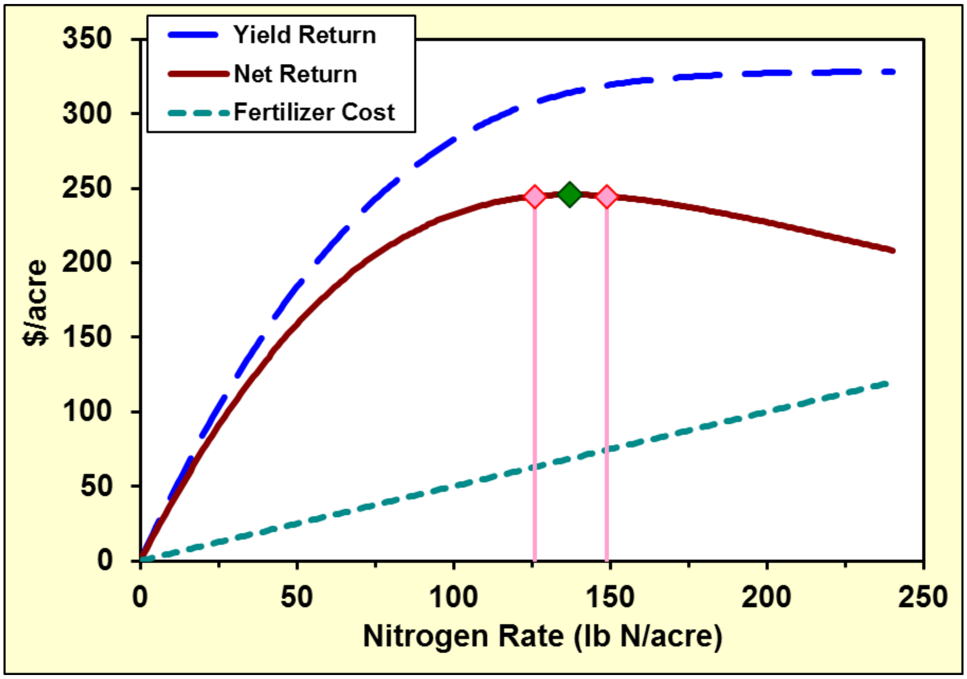

Figure 3. Net economic return to N fertilizer rate for corn following soybean, Iowa data from the Corn N Rate Calculator dataset (0.10 price ratio). The MRTN rate, and most profitable range indicated on the net return line.

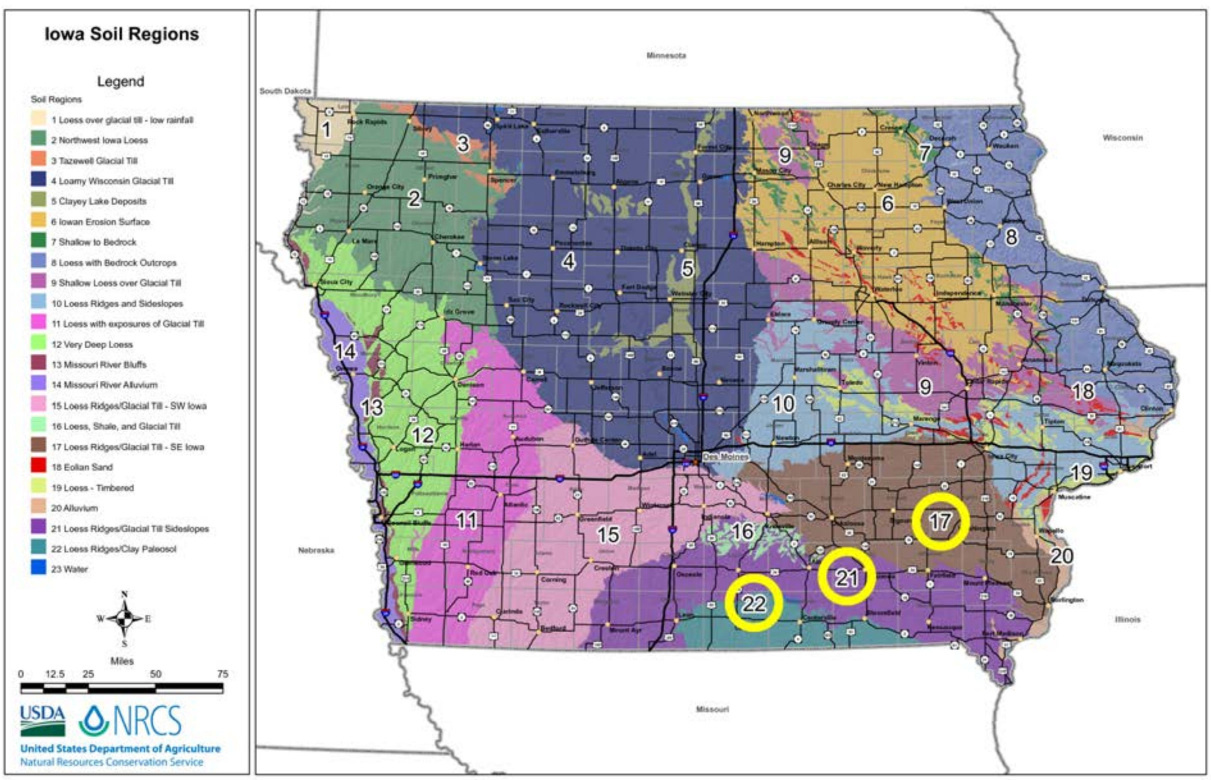

Figure 4. Iowa soil region map (USDA-NRCS) with the proposed southeast region soil areas highlighted. The general proposed area for the southeast Iowa CNRC region includes soil region 21, loess ridges/glacial till sideslopes; region 22, loess ridges/clay paleosol; and approximately the south half of region 17 (generally south of highway 92), loess-ridges/glacial till.

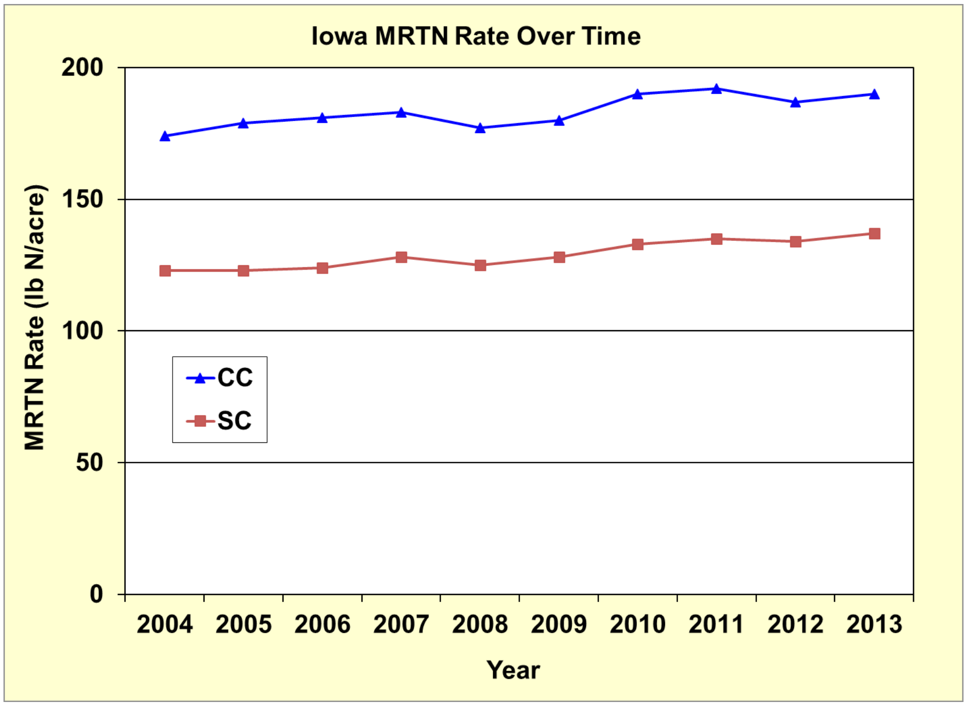

Figure 5. Change in MRTN rate in Iowa over time (CC, corn following corn and SC, corn following soybean).

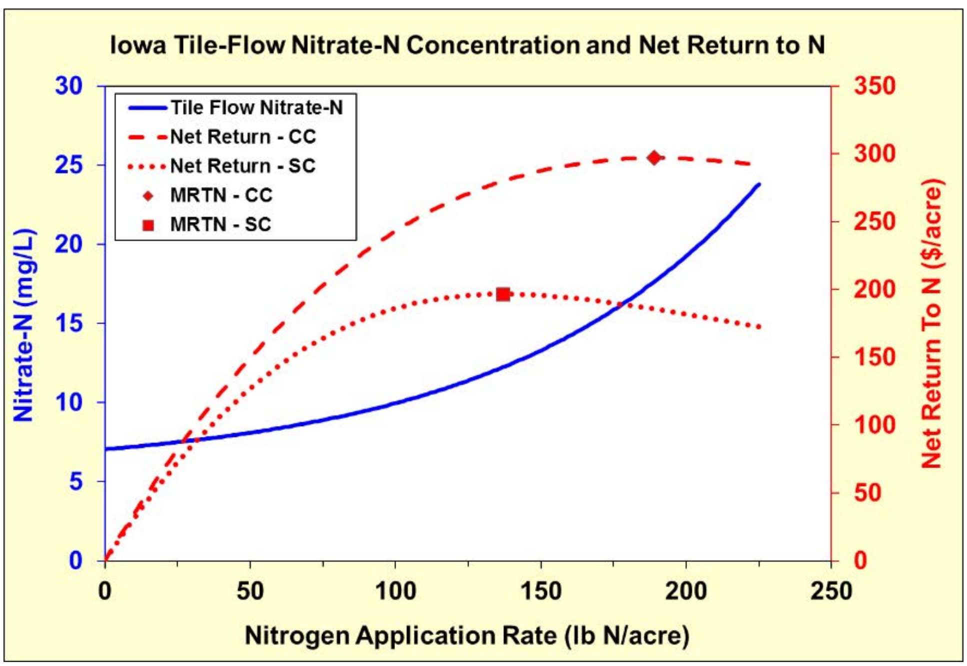

Figure 6. Tile-flow annual average flow-weighted nitrate-N concentration, which is the same for continuous corn (CC) and corn following soybean (SC), and net economic return to N across rates for CC and SC in Iowa. The maximum return to N (MRTN) for each rotation is indicated by the symbol (adapted from Sawyer and Randall, 2008).