Energy Conservation in Corn Nitrogen Fertilization

Iowa has a strong tradition of crop production, especially corn. Achieving optimum corn yields requires nitrogen (N) fertilization in most crop rotations. Unlike buying diesel for tractors, fertilizer energy is not directly purchased; but the energy consumed during the production of N fertilizer is considerable. In particular, the amount of natural gas used to produce N fertilizer means that pricing is affected by the supply and price of natural gas.

At recommended rates, N fertilizer application is the largest energy input for corn production. This publication will address the utilization of N (and other) fertilizers to maximize returns on energy consumed in N manufacturing, transportation, and application for corn production.

Energy use in nitrogen fertilizer manufacture

Nitrogen fertilizers are predominantly produced using the Haber-Bosch process. Nitrogen gas (N2) is combined with hydrogen (H_2) to form ammonia (NH_3). Nitrogen gas comes from the air and hydrogen typically from natural gas. Production of N fertilizers is very energy intensive and natural gas is the main energy source. Combining the N and H to form NH_3 requires considerable natural gas, both as the hydrogen feedstock and as energy for heat required during the process. Other fertilizers containing N are predominantly made from ammonia, including:

- Urea – $CO(NH_2)_2$
- Urea-ammonium nitrate solutions
- Ammonium nitrate – NH_4NO_3
- Ammoniated phosphates – MAP ($NH_4H_2PO_4$); DAP [$(NH_4)_2HPO_4$]

Due to the consumption of natural gas as an energy source and as feedstock in ammonia production, the price of N fertilizer is typically related to supply and price of natural gas. A modern ammonia production plant requires net energy consumption of approximately 29.7 million BTUs per ton of N (Kongshaug and Jenssen). Upgrading ammonia to other N fertilizers requires even more energy: 35.9 million and 31.4 million BTUs per ton for urea and urea/ammonium nitrate manufacture, respectively.

Table 1. Energy required to manufacture N fertilizer, and equivalent amount of energy expressed per 100 cubic feet of natural gas (per ton) or gallons of diesel fuel (per pound).

	Millions of BTUs/ton N	Natural gas equivalent ccf/ton N	Diesel fuel equivalent gallon/pound N
Modern			
Ammonia	29.7	29.7	0.107
Urea	35.9	35.9	0.129
Urea ammonium nitrate (UAN)	31.4	31.4	0.113
Ammonia average, 1998	39.8	39.8	0.143

Older ammonia production plants are less efficient. In 1998, the average U.S. plant required 39.8 million BTUs per ton N. Efficiency gains in production of ammonia have improved the energy use for N fertilizers and corn N fertilization as newer technology has become available.

Energy use in phosphorus and potassium fertilizer manufacture

Phosphorus and potassium (K) are also important fertilizers for corn production. The energy use in modern manufacturing technology of commonly used P and K fertilizers is much less than N. In fact, the net energy balance for the production of MAP and DAP show that the accumulated energy produced is greater than energy consumed (-14.1 GJ/mt P2O5 or -0.044 gallon diesel fuel equivalent per pound P_2O_5) (Kongshaug and Jenssen). This occurs due to several processes in manufacturing that release energy. Net energy consumption (balance) in manufacturing potassium chloride (muriate of potash) is 2.5 GJ/mt K_2O or 0.008 gallons diesel fuel energy equivalent per lb K_2O. At typical K application rates for corn, the diesel fuel equivalent per acre is quite low compared to N fertilization, even considering additional energy for transport and application.

Corn N fertilization requirement

Production of optimal corn yields requires N fertilization in most crop rotations. For example, the yield increase due to N application rate for corn following soybean (SC) and corn following corn (CC) is shown in Figure 1. Soybean in the cropping rotation results in a soil system that supplies greater crop-available N. Therefore, the rotation of SC is more efficient with fertilizer N use due to higher yield and lower N application rate requirement. This has important implications for energy use in corn production. The typical corn yield advantage for SC is 15% greater than for CC, and the N rate is 30 to 50 pounds N/acre lower.

Nitrogen rate recommendations in states across much of the Corn Belt come from the online Corn Nitrogen Rate Calculator [http://extension.agron.iastate.edu/soilfertility/nrate.aspx]. Crop rotation and economics (price of nitrogen and corn) determine recommended rates, referred to as the **M**aximum economic **R**eturn **T**o **N**itrogen (MRTN). For example, at a 0.10 N:corn price ratio (example $0.35/pound N:$3.50/bushel corn), suggested rates for Iowa corn production are 125 pounds N/acre with SC (Figure 2) and 177 pounds N/acre with CC (Figure 3). Corn grown in rotation with forage legumes, such as established alfalfa, has an even greater advantage as there is little to no N fertilization need in the first year, and reduced rate requirement for the second year of corn.

Seven N Rate by Crop Rotation Sites (60 Site-Years)
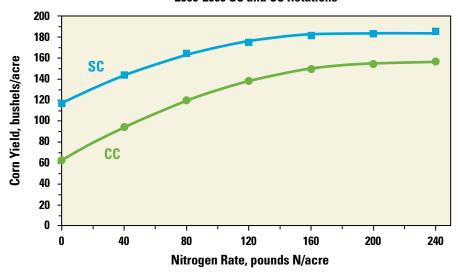**2000-2009 SC and CC Rotations**

Figure 1. Corn yield response to fertilizer N application rate for seven sites across Iowa in 2000-2009, corn following soybean (SC) and corn following corn (CC). Data from J.E. Sawyer and D.W. Barker, Iowa State University, Department of Agronomy.
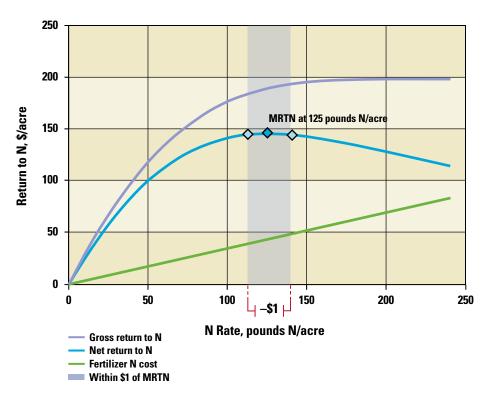

Figure 2. Recommended N rate (MRTN) for corn following soybean in Iowa with N at $0.35/pounds N and corn at $3.50/bushel (Corn Nitrogen Rate Calculator, 2009).

Nitrogen fertilizer application has a large impact on energy use in corn production and using recommended N rates minimizes energy consumption. While applying N rates below optimum would further reduce energy input, yield loss would occur, thereby reducing economic return. Applying more N than is optimal wastes energy because corn yield does not increase above the maximum response (Figure 1), and is therefore an economic and energy loss. In addition, there is increased potential for nitrate loss to tile drainage and groundwater. It makes economic, environmental, and energy sense to apply recommended and not excessive N rates.
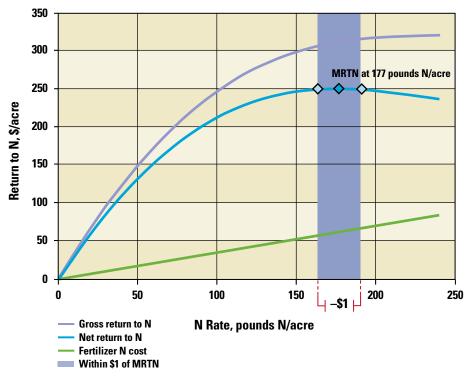

Figure 3. Recommended N rate (MRTN) for corn following corn in Iowa with N at $0.35/pound N and corn at $3.50/bushel (Corn Nitrogen Rate Calculator, 2009).

Energy use in nitrogen fertilizer application for corn

As mentioned above, at recommended rates, N fertilizer application is the largest energy input into corn production. For example, with SC at 125 pounds N/acre applied as ammonia, the diesel fuel energy equivalent for N manufacture is 13.3 gallons and with CC at 177 pounds N/acre is 18.9 gallons. There is additional energy use in fertilizer transport and application. For ammonia, the energy for transportation is roughly 1,100 BTU/pound N and for application 1,000 BTU/pound N (Hoeft and Siemens). Energy for transport and application varies somewhat for different fertilizer products due to analysis and method of application. For the rate examples above in each rotation, and N application as ammonia, the energy use for transport and application is much lower than for manufacturing. For SC at 125 pounds N/acre is 1.9 gallons diesel fuel equivalent and for CC at 177 pounds N/acre is 2.7 gallons diesel fuel equivalent. The total energy use as diesel fuel equivalent for corn N fertilization is then 15.2 gallons for 125 pounds N/acre and 21.6 gallons for 177 pounds N/acre.

As illustrated, optimal use of N fertilizer can have a sizeable positive impact on energy consumption for corn production. In addition, rotating corn with forage legumes can greatly reduce the energy input due to N supply from the rotation where sunlight and the symbiotic relationship between Rhizobia sp. and the forage legume crop provides the energy input (via sunlight and photosynthesis) for the N supplied to a future corn crop.

Summary

Optimal use and management of N (and other) fertilizers is important to maximize return to the energy consumed in the manufacture, transportation, and application for corn production. Efficiency gains can be achieved by avoiding losses during and after field application, applying recommended rates, and substituting manure and legume N where energy has already been captured. Choice of N application rate is important for maximizing economic return and minimizing environmental loss. It is also important for maximizing net energy return through crop capture of sunlight and grain/stover production. For additional information, see Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn (PM 2015). [http://www.extension.iastate.edu/Publications/PM2015.pdf]

References

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Energy consumption and greenhouse gas emissions in fertilizer production. G. Kongshaug (original author, 1998) and T.K. Jenssen (amended, 2003). International Fertiliser Society Meeting, London, United Kingdom.