# ENERGY RETURNS TO SITE-SPECIFIC NITROGEN FERTIZER MANAGEMENT IN COTTON

**Kevin Bronson**
**Texas A&M Agrilife Research and Texas Tech University**
**Lubbock, TX**
**Adi Malapati**
**Texas A&M Agrilife Research**
**Lubbock, TX**
**Peter Scharf**
**University of Missouri**
**Columbia, MO**

## Abstract

Nitrogen fertilizer production is one of the largest energy inputs in cotton production. Site-specific N management (SSNM) has potential to improve energy returns to N fertilizer. We examined two case studies to test the hypothesis that SSSM can increase energy returns to N. We used cottonseed feed value as the output. In a center pivot site, grid soil sampling and ground rig application, SSNM and blanket N fertilization resulted in negative energy returns to N fertilizer application. This was due to small N response in cotton seed and relatively high N fertilizer rates. In a second case study, a subsurface drip irrigation (SDI) system with canopy reflectance based SSNM was tested. This system had relatively low N fertilizer rates and high cotton seed responses to N. Positive energy returns to N fertilizer were observed in the SDI, with reflectance-based SSNM yielding more energy than soil test based N management.

## Introduction

Nitrogen (N) is the most limiting essential element and the nutrient required in the largest amounts in row crop production. Nitrogen fertilizer use, together with improved cultivars, has contributed heavily to the Green Revolution and to worldwide cereal production keeping pace with population growth (Borlaug and Doswell, 1995; Borlaug, 2003). Consumption of N fertilizer has increased worldwide by 80 times since 1920 (Gellings et al., 2004). In the US, corn, wheat, soybean, and cotton use 70 % of total fertilizer used, with corn accounting for 50 % of the N fertilizer use (The Fertilizer Institute, , 2009).

Although NUE in terms of N fertilizer recovery by row crops is low (Raun and Johnson, 1999), agronomic NUE (i.e. increase in grain yield per unit of applied N), has increased by 36 % in corn since 1980 (Cassman et al., 2002). Much of this improvement is due to cultivar development, but higher plant populations and improved soil management such conservation tillage contributes as well. Improved N management practices include less fall-applied N fertilizer and more split N applications (Cassman et al., 2002).

Another important reason that NUE should be improved in US agriculture is that most (52 %) of the N fertilizer used in USA was imported in 2007 (USDA-ERS, 2009). In 1992, only 25 % of N fertilizer used in the US was imported (The Fertilizer Institute, 2009). This reflects a trend the last 15 years of decreasing N fertilizer production in the US and increased reliance of importation of N fertilizer from countries like Russia, Ukraine, Egypt, and Trinidad. The reason for this is that the costs of natural gas extraction in other countries are low. US trade deficits from fertilizer (like fossil fuels) can therefore be improved if N fertilizer is applied more efficiently.

Best management practices for N fertilizer include $NO_3$ soil testing, proper timing of application, fertigation, and realistic yield goals (Gellings et al, 2004; Yabaji et al., 2009; Murrell et al., 2004). Site-specific N management (SSNM) has been the subject of a large amount of research the last 15 years due to its great potential to improve N use efficiency. Precision agriculture entails applying spatial variable rates of inputs on a field as a function of soil type, soil test, yield goals, or landscape position. Nitrogen fertilizer is one of the prime inputs targeted in geographical information systems (GIS)-based, site-specific row crop production.

The energy costs and energy balance of N fertilizer management of cropping systems is a critical area that is grossly under-studied. Nitrogen (N) fertilizer is the largest energy input into row crop production at about one-third (Hood and Kidder, 1992). Table 1 shows the amount of energy used in the production of common N fertilizers. Most of the energy cost is in the production of N fertilizer, and only a small proportion of energy is expended for transport and application.

Site-specific N management may be a way to improve the energy balance/returns in row crop agriculture. With respect to N fertilizer inputs, SSNM can increase the net energy output if either:

1) N fertilizer use is reduced, without hurting yields, or
2) N fertilizer use is maintained or increased, but that yield responses to N are greater.

Few studies have looked at energy balance as a function of N fertilization. Kuesters and Lammel (1999) reported a five-fold gain in amount of energy through N fertilization of wheat and sugar beets in Germany. This was despite that the optimal N fertilizer rates (143 lb N $ac^{-1}$ in wheat and 107 lb N $ac^{-1}$ in sugar beet) were 40 % of the total energy input. Hulsbergen et al. (2002) conducted similar studies with wheat, sugar beets, potatoes, and barley. They reported that the N fertilizer rate needed for maximum net energy output was higher than the N rate that gave the greatest energy output/input ratio.

Many studies have assessed the net energy return to ethanol production from corn production, considering the energy from N fertilizer production. Shapouri et al. (2002) reported that 8 of 10 of these studies calculated a positive energy value of producing ethanol from corn grain. However, in several of the studies with positive energy values (Lorenz and Morris (1995); Shapouri et al., (1995) and Tillman et al (2006) the energy credit from coproducts such as gluten meal, gluten feed and corn oil were needed to produce a positive energy balance. These studies did address the increase in ethanol production from the application of N fertilizer compared to no N fertilizer as the Kuesters and Lammel (1999) and Hulsbergen et al. (2002) studies did for net energy production.

To our knowledge, no efforts have been made to employ GIS-based SSNM to improve energy costs and efficiency. We will now examine two case studies for cotton in Texas. Specifically we will address the energy returns (including the outputs fuel and feed) to N fertilizer, particularly SSNM compared to blanket N fertilizer recommendations.

## Methods and Results

### Center-pivot irrigation

The description and results of this study were published in Bronson et al. (2006). The study site is near Lamesa, TX, approximately 60 miles south of Lubbock, TX and consists of 35 ac under a 120 ac center pivot irrigation system. The soil at this site is an Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic, Aridic Paleustalf). The experimental design was a randomized complete block with three replicates.

There were three N treatments: zero-N, blanket-rate-N and variable-rate-N. The N management plots were eight rows wide. In March of each year, soil samples were taken at DGPS (differential global positioning system) referenced points within the 35-ac experimental area. On average, the density of DGPS-referenced soil sampling was 0.5 ac grid. Ten subsamples of the 0-6-in depth were taken by hand soil probe within 9 ft radius of each DGPS point. Two subsamples were taken of the 6-12, 12-24, and 24-36-in. depths with a Giddings soil sampling machine (Giddings Machine Co., Fort Collins, Co), also within 9 ft. of the DGPS point. Soils from all depths were analyzed for KCl-extractable $NO_3$-N (Adamsen et al., 1985). The N fertilizer rate for both the blanket-N and variable-rate-N treatments was calculated using an N supply requirement of 120 lb N $ac^{-1}$ for a constant yield goal of 1250 lb lint $ac^{-1}$ (Zhang et al., 1998). The N supply requirement of 120 lb N $ac^{-1}$ is the N fertilizer rate minus extractable soil $NO_3$-N in 0-24 in. soil. Nitrogen was applied as urea ammonium nitrate (32 % N) with a liquid fertilizer system, fitted with spoke applicators. Half of the N fertilizer was applied at 3 weeks after planting and half was applied at 5 to 6 weeks after planting (early fruit set or squaring). The blanket rate of N fertilizer was based on the average 0-24 in. soil $NO_3$-N content of the nine blanket-N plots. Inverse distance interpolation of 0-24 in. $NO_3$-N values from all 135 DGPS points was used to create variable-rate application maps in 2002. In 2003 and 2004, to avoid influence of adjacent zero-N or blanket-N plots, only soil $NO_3$-N values from the variable-rate plots were used in making one-dimensional variable-rate application maps. The ground fertilizer applicator, which was fitted with an Ag-Chem/Soil Tec Inc. (Ag-Chem Equipment Co., Inc., Minnetonka, MN) Fertilizer Applicator Local Controls Operating Network (FALCON™), is described in Yang et al. (2001) and Bronson et al. (2003).

In May of 2002 and 2003, 'Paymaster 2326 Roundup Ready®' cotton was planted into glyphosate-[isoprophylamine salt of N-phosphomonomethyl) glycine] terminated rye in 40-in. rows at a seeding rate of 16 lb $ac^{-1}$. In May 2004, the higher-yielding 'FiberMax® 989 Roundup Ready®' was planted at the same seeding rate. Hand harvesting of lint and seed were done on 6 ft. of row at each DGPS-referenced point in October of each year.

The hand samples were ginned on a one-saw plot gin equipped with a one-stage lint cleaner at the Texas A&M Research and Extension Center in Lubbock to give a unique percentage turnout of lint for each DGPS point. Gross energy value of cottonseed was calculated from crude protein, ether-extractable fat, crude fiber and total digestible nutrients of cottonseed (National Research Council, 1984).

Averaged across the three years, N fertilizer responses in cottonseed yield and protein above the zero-N treatment were observed (Table 3). There was no difference between blanket and variable-rate N in seed yield, protein or fat. Nitrogen fertilizer rates were similar between the two N fertilized treatments. Fat yield averaged 342 lb $ac^{-1}$ and was not affected by N. Gross energy from cottonseed was significantly greater with blanket-rate N than the zero-N. However, when the energy from N fertilizer production was subtracted (Table 2) to give net energy yields, the two N-fertilized treatments resulted in 21 % less energy than the non-fertilized plots (Table 3). The main reason for this negative return to N fertilizer in Texas cotton is that the "delta yield" or cottonseed response to N was only 10% or about 1351 lb $ac^{-1}$. However, profitable lint returns to N fertilizer of $ 6- 10 $ac^{-1}$ were observed in 2003 and in 2004 (Bronson et al., 2006).

**Drip irrigation**

This was conducted at the Texas A&M Research and Extension Center farm near Lubbock, TX on an Acuff sandy clay loam (fine-loamy, mixed, superactive, thermic, Aridic Paleustoll) from 2007 to 2009 was published in an M.S. thesis (Nusz, 2009). AFD 5065 B2F cotton was planted in mid May and harvested in late October. The experimental design was a randomized complete block design, one-way factorial with three replications or blocks. Blocks consisted of 40, 40-in. rows that were 600 ft. long. Each block was divided into five, 8-row plots that were randomly assigned to the five N-fertilized treatments (Table 1)

Table 1. Nitrogen treatments.

| N Treat. | N rate | Other details |
|---|---|---|
| 1 | 0.5 X soil test based | Soil test algor = 120 lb N $ac^{-1}$ – 24 in. soil $NO_3$ – irrig. water $NO_3$ |
| 2 | 1.0 X soil test based | Soil test algor = 120 lb N $ac^{-1}$ – 24 in. soil $NO_3$ – irrig. water $NO_3$ |
| 3 | 1.5 X soil test based | Soil test algor = 120 lb N $ac^{-1}$ – 24 in. soil $NO_3$ – irrig. water $NO_3$ |
| 4 | Reflectance based | Starts out at 0.5 X, referenced to 1.0X |
| 5 | Reflectance based | Starts out at 1.0 X, referenced to 1.5X |
| 6 | Zero-N | 1 replicate/station only |

However, for the purposes of this chapter's emphasis on energy, we will only address treatments 2, 4, and 6. Each 8-row plot has its own irrigation and fertilizer injection station. Nitrogen fertilizer rate of was based on an N requirement for a 1250 lb lint $ac^{-1}$ yield, which is 120 lb N $ac^{-1}$. The amount of $NO_3$-N extracted in initial, spring soil samples from 0-60 cm and estimated 20 lb N $ac^{-1}$ in irrigation water (12 in.of irrigation with 11 ppm $NO_3$-N water was anticipated) and 10 lb N/ac as 10-34-0 P starter fertilizer were subtracted from the 120 lb N $ac^{-1}$ requirement to give a growing season N fertilizer requirement to be injected that across three years averaged 63 lb N $ac^{-1}$ (Table 3). Nitrogen fertilizer was injected into the drip system five days a week, between late June (early square) and early August (mid bloom). In the reflectance-based strategy treatment, the N injection rate was initially set to the 50 % of the soil test treatment. Every week canopy reflectance measurements were made with a Crop Circle radiometer (Holland Scientific Inc., Lincoln, NE) at 40 inch. above the canopy on one row per plot.

Normalized difference vegetative index (NDVI) was calculated as:

$$(\text{Reflectance at 880 nm}-\text{Reflectance at 590 nm})/(\text{Reflectance at 880 nm}+\text{Reflectance at 590 nm})$$

When the NDVI in the reflectance-based strategy 1 treatments fell significantly below the NDVI in the soil test based management treatment, the N injection rate was increased to the soil test treatment N injection rate. Sulfuric acid (25 % $H_2SO_4$) was injected continuously to lower the pH of the well water from pH 7.7 to pH 6.8, and prevent precipitate formation and clogging of emitters. Hand harvesting of lint and seed were done on 6 ft. of row at three DGPS-referenced points in each 600 ft. long plot in October of each year. The hand samples were ginned and to give unique percentage turnout of lint and seed for each DGPS point. In the absence of fat and digestible nutrients data, gross energy value of cottonseed was calculated from relationships between seed yield and gross energy in the center pivot case study for N-fertilized and zero-N plots.

In higher yielding drip-irrigated cotton, the energy picture is very different than in the lower-yielding center pivot site. Averaged across three years, 3-yr. study, N fertilizer resulted in significant seed yield increases (Table 4). Above the zero-N seed yield of 1788 lb $ac^{-1}$, reflectance-based N management and soil test based management resulted in a 39 and 33 % "delta yields", respectively. A thirty one % reduction in N fertilizer application was achieved with the reflectance based approach vis a vis the soil test strategy. The lower N usage and greater seed yields and delta seed yields resulted in a positive energy return to N fertilizer compared to the zero-N treatment. Notably, the site-specific, reflectance based approach had significantly greater net energy return than the soil test based N management (Table 4).

Table 2. Energy needed for production of common Nitrogen fertilizers (adapted from Hood and Kidder, 1992).

| N fertilizer source | N concentration | Energy in/Nitrogen out |
|---|---|---|
| | % | BTU/lb N (x 1000) |
| Ammonia | 82 | 24 |
| Ammonium sulfate | 21 | 25 |
| Liquid urea ammonium nitrate | 32 | 28 |
| Ammonium nitrate | 34 | 29 |
| Urea | 46 | 30 |

Table 3. Cotton seed, protein, fat and energy yields as affected by variable-rate nitrogen fertilizer management with center-pivot-irrigation Lamesa, TX, 2002-2004.

| Nitrogen Treatment | Nitrogen Applied | Seed Yield | Fat | Protein | Energy from fertilizer | Gross Energy | Net Energy |
|---|---|---|---|---|---|---|---|
| | | -----------------lb $ac^{-1}$--------------- | | | --------------BTU $ac^{-1}$ ($10^6$)----------- | | |
| Blanket | 79 | 1569 a | 345 a | 345 a | 2.6 | 10.1a | 7.5 b |
| Variable | 76 | 1557 a | 342 a | 347 a | 2.5 | 10 a | 7.5 b |
| Zero | 0 | 1428 b | 339 a | 274 b | 0 | 9.4 b | 9.4 a |
| LSD | | 96 | 38 | 46 | | 0.6 | 0.6 |

Table 4. Cotton seed and energy yields as affected by reflectance-based nitrogen fertilizer management in sub-surface drip irrigation, Lubbock TX, 2007-2009

| Nitrogen Treatment | Nitrogen Applied | Seed Yield | Energy from fertilizer | Gross Energy | Net Energy |
|---|---|---|---|---|---|
| | ---------lb $ac^{-1}$------------ | | -------------------BTU $ac^{-1}$ ($10^6$)------------------- | | |
| Soil test based | 63 | 2389 a | 2.1 | 15.3 a | 13.2 b |
| Reflectance based | 44 | 2491 a | 1.5 | 16.0 a | 14.5 a |
| Zero | 0 | 1788 b | 0 | 11.8 b | 11.8 c |
| LSD | | 141 | | 0.9 | 0.9 |

## References

Adamsen, F.J., D.S. Bigelow, and G.R. Scott. 1985. Automated methods for ammonium, nitrate, and nitrite in 2 M KCl-phenylmercuric acetate extracts of soil. Commun. Soil Sci. Plant Anal. 16:883-898.

Borlaug, N.E. 2003. The green revolution: its origins and contributions to world agriculture. J. Bioresource Sci. 4:11022.

Borlaug, N.E. and C.R. Dowswell. 1995. Mobilising science and technology to get agriculture moving in Africa. Development Policy Review. 13:115-129.

Bronson, K.F., J. D. Booker, J.P. Bordovsky, J. W. Keeling, T.A. Wheeler, R.K. Boman, M.N. Parajulee, E. Segarra, and R.L. Nichols. 2006. Site-specific irrigation and nitrogen management for cotton production in the Southern High Plains. Agron. J. 98:212-219.

Bronson, K.F., J.W. Keeling, J.D. Booker, T.T. Chua, T. A. Wheeler, R.K. Boman, and R.J. Lascano. 2003. Influence of phosphorus fertilizer, landscape position and soil series on cotton lint yield. Agron. J. 95:949-957.

Cassman, K.G., A.D. Dobermann, and D.T. Walters. 2002. Agroecosystems, N-use efficiency, and N management. AMBIO 31:132-140.

The Fertilizer Institute. 2009. Supply& demand, energy drive global fertilizer prices. http://www.tfi.org/publications/pricespaper.pdf

Gellings, C. W. and K. E. Parmenter. 2004. Energy efficiency in fertilizer production and use. Efficient use and conservation of energy, Eds. C. W. Gellings and K. Blok, in *Encyclopedia of Life Support Systems* (*EOLSS*). Eolss Publishers, Oxford, UK.

Hood, C. F. and G. Kidder. 1992. Fertilizers and Energy. Fact Sheet EES-58. November 1992. University of Florida, Florida Cooperative Extension Service.

Hülsbergen, K.-J., B. Feil, and W. Diepenbrock. 2002. Rates of nitrogen application to achieve maximum energy efficiency for various crops: results of a long-term experiment. Field Crops Res. 77:61-76.

Kuesters, J. and J. Lammel. 1999. Investigations of the energy efficiency of the production of winter wheat and sugar beet in Europe. European J. Agronomy. 11:35-43.

Lorenz, D. and D. Morris . 1995. How much energy does it take to make a gallon of ethanol? Revised and updated. Institute for Local Self-reliance. Washington D.C.

Murrell, S. 2004. Fertilizer nitrogen BMPs for corn in the North Central Region. Better Crops with Plant Food. 90: 16-18.

National Research Council. 1984. Nutrient Requirements of Beef Cattle, Sixth Revised Edition. National Academy Press, Washington, D. C.

Nusz, J. W. 2009. Remote sensing to improve nitrogen management in subsurface drip irrigation cotton. M.S. thesis. Texas Tech University, Lubbock. .

Raun, W.R. and G. V. Johnson. 1999. Improving N use efficiency for cereal production. Agron. J. 91: 357-363.

Shapouri, H., J.A. Duffield, and M. Wang. 2002. The energy balance of corn ethanol: an update/ USDA Agricultural Economic Report No. 813.

Shapouri, H., J.A. Duffield, and M.S. Graboski. 1995. Estimating the net energy balance of corn ethanol. USDA-ERS. AER-721, 1995.

Tilman, D. J. Hill, and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science. 314:1598-1600.

USDA-Economic Research Service. 2009. Fertilizer trade summary. Http://www.ers.usda.gov/Data/FertilizerTrade/summary.htm

Yabaji, Rajkumari, J.W. Nusz, K. F. Bronson, A. Malapati, J. D. Booker, R.L. Nichols, and T. L. Thompson. 2009. Nitrogen management for subsurface drip irrigated cotton: Ammonium thiosufalte, timing, and canopy reflectance. Soil Sci. Soc. Am. J. 73:589-597.

Yang, C., J.H. Everitt, and J.M. Bradford. 2001. Comparisons of uniform and variable-rate nitrogen and phosphorus fertilizer applications for grain sorghum. Trans. ASAE. 44:201-209.

Zhang, Hailin, Bill Raun, Jeff Hattey, Gordon Johnson, and Nick Basta. 1998. OSU soil test interpretations. Publication no. F-2225, Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater.