# Can we reduce nitrogen applications to corn?

# Farmer cooperators:

* Rachel and Alec Amundson (Osage, IA)
* Nathan Anderson (Aurelia, IA)
* Jon Bakehouse (Hastings, IA)
* Pete Bardole (Jefferson, IA)
* Sam Bennett (Galva, IA)
* Vaughn Borchardt (Fenton, IA)
* Jack Boyer (Reinbeck, IA)
* Chris Deal (Jefferson, IA)
* Wade Dooley (Albion, IA)
* Bill Frederick (Jefferson, IA)
* Wayne Fredericks (Osage, IA)
* Robert Harvey (Redfield, IA)
* Kevin Prevo (Bloomfield, IA)
* Tim Sieren (Keota, IA)
* Kevin Veenstra (Grinnel, IA)
* Marissa Waldo (Cascade, IA)

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PFI Contact: Stefan Gailans, (515) 232-5661, stefan@practicalfarmers.org

Funding: XX

# In a Nutshell:

* Farmer cooperators performed 17 replicated strip trials testing their typical nitrogen rate against that rate reduced by 15-45%
* Key Findings
  + All sites experienced drier-than-average growing seasons
  + Nine of the 17 trials saw potential for financial savings when reducing their N rates

PHOTO + CAPTION

# Background

In 1987 Practical Farmers of Iowa (PFI) formally established the Cooperators’ Program, which continues to be a hallmark of PFI programming. Many farmers at that time wanted to know if they were applying too much nitrogen (N) fertilizer to their corn crops – the newly minted Cooperators’ Program provided the framework for farmers to scientifically answer this question. From 1988-1993 farmer cooperators conducted 57 trials that compared corn yields and financial outcomes at their typical nitrogen (N) fertilizer rate with those at a reduced N rate of their choosing. Across sites, the average difference between typical and reduced rates was 56 units of N per acre, corresponding to an average 42% reduction from farmers’ typical rates. In 88% of those trials (50 of the 57), the farmers found they could save money by applying the lower N rate.

**Thirty years later, farmers are again interrogating their N rates.** In this round, farmers are wondering if the soil health-building practices they have implemented (reduced tillage, cover crops, diversified rotations, etc.) will allow them to reduce their typical N rates.

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| One of my biggest questions for several years has been whether I was being too aggressive with the amount of nitrogen I was using. This trial will allow me to explore that important question. - Chris Deal |

While many farmers wonder if they can leverage healthier soils to reduce their N rates, few have had the opportunity to test lower N rates in a structured setting.

This newest round of N trials began in fall 2021 in preparation for the 2022 growing season. The first year included farmers recruited by PFI staff who self-identified as using soil health-promoting practices for at least five years. Using a replicated strip-trial design, farmers compared yields and finances at their usual N rate with those observed at a reduced rate. Based on the trials conducted 30 years ago, PFI staff suggested farmers try reducing their N application by **50 pounds of N per acre**. While this is an aggressive reduction in many systems, one goal of the trial was to push farmers to explore N rates outside of their comfort zone.

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| [The most valuable aspect of conducting this trial is that I] normally wouldn’t have even tried reducing by 50 units. -Jon Bakehouse |

If farmers can maintain corn yields and/or save money at the reduced N rate, results might spark confidence to reduce (or at least question) fertilizer rates going forward, much like what happened for the original cohort of farmers who trialed fertilizer rates. If the reduced N rate lowers corn yields and loses money, farmers will still have gained valuable information: They can be more confident that their typical rate is the right rate for their farm, but maybe new long-term practices could help reduce it in the future. Additionally, while individual trials are immensely useful for farmers, aggregating many trial results can provide a more powerful dataset to help farmers evaluate their N rates.

We get one shot at the best crop every year, and the logical thing to do seems to be to give the crop everything it needs (and more) to maximize yields. This trial will put together a good set of farm-scale data to give farmers the confidence to dial in their N rate to improve profitability and water quality.

-Sam Bennett

# Methods

## Design

All farmers used two treatments:

1. Typical - A typical N fertilizer rate applied to a corn crop
2. Reduced - An N fertilizer rate less than the typical rate

Treatments were applied in strips starting in fall 2021 to fields destined to be planted in corn for the 2022 growing season (**Figure 1**). All treatments were replicated at least four times, resulting in a total of at least eight plots in each farmer’s trial.

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****Figure 1. An example of a farmer’s treatment layout testing two nitrogen (N) fertilizer treatments for this trial.** On average, strips were 30 feet wide and 1,500 feet long resulting in an average strip size of 1.2 acres.**

## Measurements

Corn yields were measured and reported by each farmer, along with the percent moisture of the harvested grain. All yields were converted to 15.5% moisture for this report. Additionally, approximate prices paid for N sources and price received per bushel of corn were reported for some farms.

## Data Analysis

Note that more details on data analysis can be found in the **Detailed Methods** section at the end of this report.

### Weather

To provide context for the results, weather data was downloaded from the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources (POWER) project (<https://power.larc.nasa.gov/>) for each farmer’s trial.

### Yields

At each trial, differences in yields at the typical and reduced N rate were assessed for statistical significance using a statistical model. The model tested for the effect of the N treatment, while accounting for possible natural yield gradients in the field. Significance was assigned using a 95% confidence level threshold, meaning if there was a significant difference in yields, we would expect the same result in 95 of 100 trials.

### Finances

Nitrogen prices depend on several factors including the form of N, the timing of the purchase, and the location of the purchase. Similarly, the price received for corn fluctuates throughout the year. Due to this variation, as well as the limited control producers have over the price paid for N and the price received for corn, we used three price scenarios to compare financial outcomes of the typical and reduced N treatments: best-case savings, midpoint savings, and worst-case savings (**Table 1**).

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| ****TABLE 1. Summary of price scenarios for financial analyses**** | | | |
|  | **DESCRIPTION** | **N COST** | **CORN PRICE RECEIVED** |
| Best-case savings | Expensive N, low corn revenue | $1.20/lb N | $5.70/bu |
| Midpoint savings | Midpoint N, midpoint corn revenue | $0.90/lb N | $6.59/bu |
| Worse-case savings | Cheap N, high corn revenue | $0.60/lb N | $7.48/bu |

A partial budget using a given price scenario was performed for each strip, and the difference in partial budget between treatments was calculated for each replicate. A positive value represents a financial savings at the reduced N rate. This process was done separately for the three price scenarios. To assess the significance of treatments on finances, a statistical model was used to assess whether the financial outcome in each scenario was significantly different from $0 per acre at 95% confidence levels.

# Results and Discussion

### Treatments

Sixteen producers conducted a total of 17 independent N trials. The chosen treatments reflected the diversity in farming systems, with typical N rates ranging from 108-264 lb N/ac and reduced N rates ranging from 59-200 lb N/ac (**Figure 2**). When averaged over all trials, typical and reduced N rate treatments were 175 lb N/ac and 124 lb N/ac, respectively.

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****Figure 2. Seventeen trials tested two nitrogen (N) application treatments in the 2022 growing season.** A cooperator’s typical N rate (**dark green** bar), chosen reduced N rate (**light green** bar), and the reduction relative to the typical rate (white text).**

### Weather

All 17 trials saw a very cool April, followed by a warm and progressively drier growing season (**Figure 3**).

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****Figure 3. Individual cooperator site weather compared to 30-year historical averages for that site. (**Left) Average monthly air temperature deviations and (right) cumulative precipitation deviations.**

Overall, although all sites experienced a hot and dry growing season, the diversity in N application amounts, sources, methods, and timing as well as cropping system history contributed to varied outcomes for each cooperator.

### Finances

The financial outcomes of reducing N varied by trial (**Figure 4**). Eight of the 17 trials (47%) saw statistically significant financial losses under all price scenarios, two trials (12%) saw statistically significant financial gains in all price scenarios, and the remaining seven trials (41%) had outcomes that were sensitive to the price scenarios.

As an example of a price-sensitive outcome, in the ‘worst-case savings’ scenario (see **Table 1**) Pete Bardole lost ~$3/ac for every unit of N he reduced, resulting in a total loss of ~$150/ac in his reduced N treatment. However, in the ‘best-case savings’ scenario Bardole saved ~$0.50/ac for every unit of N he reduced, for a total savings of ~$30/ac in the reduced N treatment. Therefore, depending on the prices he paid for N and price he received for his corn, his financial outcome was likely somewhere between losing $150/ac and saving $30/ac.

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****Figure 4. Financial impacts of reducing nitrogen rates under a range of price scenarios.** Best-case (top of vertical bar), worst-case (bottom of bar) and midpoint 2022 price scenarios **(triangles**), with blue bars indicating a statistically significant (95% confidence level) financial advantage in all scenarios, tan bars indicating outcomes were sensitive to price scenarios, and orange bars indicating a statistically significant financial loss in all scenarios. The x-axis labels present each **farmer** and the amount they reduced their typical N rate to achieve the reduced N treatment (see **Figure 3**).**

### Yields

Eleven of the 17 trials (65%) saw statistically significant reductions in corn yields at the reduced N rate. However, it important to note that statistical significance in yield declines is not related to financial outcomes (**Figure 5**). Statistical significance is a function of both the magnitude of the difference in treatments, as well as how variable the yields in the field were. It helps readers and farmers decide how much to ‘trust’ the yield changes, which can help with fine-tuning future N management decisions. For example, Nathan Anderson’s reduced N treatment corn yielded 3 bu/ac less than his typical N treatment corn (**Figure 5**). While he can be confident that reduction was real (it is statistically significant), he also saw a statistically significant financial savings (**Figure 4**). For comparison, Sam Bennett saw a similar reduction in corn yield at the reduced N rate, but the reduction was not statistically significant so he can question how ‘real’ the reduction was. While Anderson and Bennett may have different conclusions about the impact of the reduce N treatment on corn yields, they both saw a significant financial savings of around $32/ac at the reduced N rate.

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****Figure 5. Change in corn yield (bars) and financial outcomes (text and colors) with reduced nitrogen (N) application.** The y-axis shows the farmer with amount of N reduced, **orange** indicates a trial with a significant financial loss at the reduced N rate, **dark blue** represents trials showing a significant financial savings (see Figure 4 for financial scenarios).**

### Reflections

Of the 17 trials conducted, two (12%) likely saved money in the reduced N treatment (dark blue bars in **Figures 4 and 5**), while seven (41%) may have seen savings under certain price scenarios (tan bars in **Figures 4 and 5**). Eight (47%) likely lost money in the reduced N treatment. For the nine trials (53%) that saw potential for financial savings under the reduced N treatment, a less aggressive reduction may be worth exploring.

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| I thought the yield reduction would be higher. -Pete Bardole |

It is clear these results were valuable for the farmers. Many expected the yield reductions to be larger. The weather certainly played a part in the results - in general dry conditions render corn less responsive to N inputs, so it is important to remember 2022 results are not necessarily predictive of future outcomes. It is clear the farmers conducting these trials fully embrace this caveat.

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| This was one trial on one farm for one year. The real value comes by increasing the "n" (i.e. number of samples) for these trials. – Chris Deal |

However, all the farmers gained useful experience in reduced N rates. As the first year of a multi-year project wrapped up, farmers were already looking forward to increasing the number of datapoints collected under this project’s umbrella. As more farmers contribute their data to this project, the power of the results will only continue to grow.

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| My search for optimum N rates isn't over yet. – Bill Frederick |

# Appendix A. Rachel and Alec Amundson, Osage IA

“[We] had some understanding of how to cut N when planting into clover,

this was a great way to verify our thinking.”

The financial outcome showed **potential savings**. A 49 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

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**Figure A1. Summary of trial results**

*Historical cropping system (5 year):* Strip-till, corn, soybeans, rye cover crop

*Previous crop:*  Oats/red clover cover crop

*Winter/spring grazing:* XX

*Replications and plot size:* 4 reps, 1.7 acres per replicate

*Corn planting/harvest date:*  May 14, 2022/October 23, 2022

*Corn row spacing/planting density:* 30 inch; 33,000 seeds/ac

*Nitrogen sources and application timing:* Chemical sources; fall, spring, and side-dress

# Appendix B. Nathan Anderson, Aurelia IA

“I hope my research site, combined with other farmer-cooperator sites…can reform the narrative around nitrogen fertilization and use for the benefit of farmers and the environment.”

The financial outcome showed **potential savings**. A 53 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

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**Figure B1. Summary of trial results**

*Historical cropping system (5 year):* Corn, soybeans, rye cover crops

*Previous crop:*  Corn

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 2.11 acres per rep

*Corn planting/harvest date:*  May 19, 2022/October 14, 2022

*Corn row spacing/planting density:* 30 inch; 35,500 sd/ac

*Nitrogen sources and application timing:* Turkey litter, chemical; winter, at planting, side-dress

# Appendix C. Jon Bakehouse, Hastings IA

“[These trials will] give me confidence to either reduce N rates or be secure in the knowledge we aren’t over-applying nutrients”

The financial outcome showed **losses**. A 56 lb N/ac reduction would not have saved money this year.

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**Figure C1. Summary of trial results**

*Historical cropping system (5 year):* Not provided

*Previous crop:*  Soybeans

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 0.8 acres per rep

*Corn planting/harvest date:*  May 11, 2022/September 29, 2022

*Corn row spacing/planting density:* 30 inch; 34,000 sd/ac

*Nitrogen sources and application timing:* Spring applied UAN(28) ATS, UAN(32) with N-Fixx

# Appendix D. Pete Bardole, Jefferson IA

“I thought the yield reduction would be higher”

The financial outcome showed **potential savings**. A 50 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

**Figure D1. Summary of trial results**

*Historical cropping system (5 year):* Strip-till corn, no-till soybeans, oats/turnip cover crop

*Previous crop:*  Soybeans

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 0.8 acres per rep

*Corn planting/harvest date:*  April 23, 2022/October 3, 2022

*Corn row spacing/planting density:* 30 inch; 34,000 sd/ac

*Nitrogen sources and application timing:* Fall applied NH3 (varied), spring applied UAN(32)

# Appendix E. Sam Bennett, Galva IA

“I knew we could grow good corn with less N, but knowing what happens when corn runs out of N, I habitually over apply fertilizer. This trial helped give me the confidence to take a deeper look at what rates I'm planning to apply.”

The financial outcome showed **savings**. A 50 lb N/ac reduction saved money this year, but this was likely influenced by the drought which rendered yields less responsive to N.

**Figure E1. Summary of trial results**

*Historical cropping system (5 year):* Strip-till corn, no-till soybeans, rye cover crop

*Previous crop:*  Soybeans

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 0.8 acres per rep

*Corn planting/harvest date:*  May 8, 2022/October 18, 2022

*Corn row spacing/planting density:* 30 inch; 34,000 sd/ac

*Nitrogen sources and application timing:* Fall NPKS, spring side-dress UAN(32) w/inhibitor

# Appendix F. Vaughn Borchardt, Fenton IA

**“**Probably should've had an additional 20# check.”

The financial outcome showed **losses**. A 20 lb N/ac reduction would not have saved money this year.

**Figure F1. Summary of trial results**

*Historical cropping system (5 year):* Strip-till corn, no-till soybeans

*Previous crop:*  Soybeans

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 1.63 acres per rep

*Corn planting/harvest date:*  May 11, 2022/October 25, 2022

*Corn row spacing/planting density:* 30 inch; 33,500 sd/ac

*Nitrogen sources and application timing:* Fall application, spring UAN(32), side-dress

# Appendix G. Jack Boyer, Reinbeck IA

When asked what was the most valuable aspect of conducting this trial, Jack replied simply: “Cost reduction.”

The financial outcome showed **savings**. A 50 lb N/ac reduction saved money this year, but this was likely influenced by the drought which rendered yields less responsive to N.

**Figure G1. Summary of trial results**

*Historical cropping system (5 year):* No-till rye, multispecies cover crops, no-till soybeans

*Previous crop:*  Rye/soybean relay crop

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 1.4 acres per rep

*Corn planting/harvest date:*  May 15, 2022/October 18, 2022

*Corn row spacing/planting density:* 30 inch; 34,000 sd/ac

*Nitrogen sources and application timing:* Spring, side-dress UAN(32)

# Appendix H. Chris Deal, Jefferson IA

“One of my biggest questions for several years has been whether I was being too aggressive with the amount of N I was using. This trial allowed me to explore that important question.”

The financial outcome showed **potential savings**. A 50 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

**Figure H1. Summary of trial results**

*Historical cropping system (5 year):* No-till soybean and corn, rye/wheat cover crops

*Previous crop:*  Soybean

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 2.8 acres per rep

*Corn planting/harvest date:*  May 17, 2022/October 26, 2022

*Corn row spacing/planting density:* 30 inch; 36,400 sd/ac

*Nitrogen sources and application timing:* Fall, variable spring UAN(32), variable side-dress UAN(32)

# Appendix I. Wade Dooley, Albion IA

**“**[I] need to continue testing the hypothesis, perhaps at lower ratios of difference.”

The financial outcome showed **losses**. A 65 lb N/ac reduction would not have saved money this year.

**Figure I1. Summary of trial results**

*Historical cropping system (5 year):* Not reported

*Previous crop:*  Not reported, multi-species summer-planted cover crop

*Winter/spring grazing:* XX

*Replications and plot size:*  4 reps, 30 feet wide, length not reported

*Corn planting/harvest date:*  May 17, 2022/not reported

*Corn row spacing/planting density:* 30 inch; 33,000 sd/ac

*Nitrogen sources and application timing:* Spring UAN(32)

# Appendix J. Bill Frederick, Jefferson IA

“My search for optimum N rates isn't over yet.”

The financial outcome showed **potential savings**. A 50 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

**Figure J1. Summary of trial results**

*Historical cropping system (5 year):* Not reported

*Previous crop:*  Soybeans and winter wheat cover crop (aerially applied)

*Winter/spring grazing:* Yes

*Replications and plot size:*  4 reps, 50 feet wide, length not reported

*Corn planting/harvest date:*  May 22, 2022/October 13, 2022

*Corn row spacing/planting density:* 20 inch; 37,000 sd/ac

*Nitrogen sources and application timing:* Fall anhydrous ammonia w/N-serv

# Appendix K. Wayne Fredericks, Osage IA

Wayne Fredericks is ‘very likely’ to refer participating in PFI research trials to a friend or other farmers.

The financial outcome showed **potential savings**. A 60 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

**Figure K1. Summary of trial results**

*Historical cropping system (5 year):* No-till soybeans, strip-till corn, cereal rye cover crops

*Previous crop:*  Soybeans and cereal rye + winter camelina cover crop

*Winter/spring grazing:* None

*Replications and plot size:*  4 reps, 0.6 acres

*Corn planting/harvest date:*  May 7, 2022/October 19, 2022

*Corn row spacing/planting density:* 30 inch; 34,680 sd/ac

*Nitrogen sources and application timing:* Fall, spring, side-dress with UAN(32)

# Appendix L. Robert Harvey, Redfield IA

“I'm hoping to involve my daughter and use this experience as an opportunity to interest her in the farm operation.”

The financial outcome showed **losses**. A 49 lb N/ac reduction would not have saved money this year.

**Figure L1. Summary of trial results**

*Historical cropping system (5 year):* No-till soybeans, strip-till corn, cereal rye cover crops

*Previous crop:*  Soybeans and cereal rye cover crop

*Winter/spring grazing:* None

*Replications and plot size:*  4 reps, 0.4 acres

*Corn planting/harvest date:*  April 27, 2022/October 19, 2022

*Corn row spacing/planting density:* 30 inch; 32,000 sd/ac

*Nitrogen sources and application timing:* Spring, variable side-dress UAN(32)

# Appendix M. Kevin Prevo, Bloomfield IA

While Kevin wanted to help others, he also “gained knowledge and had fun!”

The financial outcome showed **losses**. A 46 lb N/ac reduction would not have saved money this year.

**Figure M1. Summary of trial results**

*Historical cropping system (5 year):* Soybeans, corn, cereal rye cover crops, grazing, manure

*Previous crop:*  Soybeans and cereal rye cover crop

*Winter/spring grazing:* Not reported

*Replications and plot size:*  4 reps, 1 acre

*Corn planting/harvest date:*  May 9, 2022/September 25, 2022

*Corn row spacing/planting density:* 30 inch; 32,000 sd/ac

*Nitrogen sources and application timing:* Fall manure, variable spring side-dress UAN(32)

# Appendix N. Tim Sieran, Keota IA

“[My satisfaction with this trial’s results] was limited by the dry conditions.”

The financial outcome showed **potential savings**. A 50 lb N/ac reduction was likely too large this year, but there is potential for financial savings with a smaller reduction.

**Figure N1. Summary of trial results**

*Historical cropping system (5 year):* Corn, soybeans, grazed cereal rye cover crop, manure

*Previous crop:*  Soybeans and cereal rye cover crop

*Winter/spring grazing:* Yes

*Replications and plot size:*  4 reps, 20 feet wide, length not reported

*Corn planting/harvest date:*  May 9, 2022/October 24, 2022

*Corn row spacing/planting density:* 30 inch; 36,000 sd/ac

*Nitrogen sources and application timing:* Fall manure, spring UAN(32), variable side-dress UAN(32)

# Appendix O. Kevin Veenstra, Grinnell IA

Without this trial, Kevin may have cut back nitrogen too much too soon.

# Appendix P. Marissa Waldo, Cascade IA

Oftentimes, side-dressing is just assumed to be necessary for an in-season N supply. It was eye-opening to see no significant yield difference.  
between manure-only and manure + side dressing.

# Detailed Methods

### Plot sizes

Not all farmers reported the same dimensions of their strips. Three farmers reported strip sizes in acres, and no assumptions were necessary to determine the strip size. All remaining farmers reported strip widths, but five did not report a strip length. When the strip length was not reported, the average strip length reported (1,500 feet) was assumed. Strip width (in feet) was multiplied by strip length (in feet) and converted to acres.

### Weather data

Each cooperator chose a US Census-recognized town with which to associate the trial. The latitude and longitude of the chosen town were used to retrieve weather data from the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources (POWER) project (<https://power.larc.nasa.gov/>) using the *nasapower* package [1] for R software [2]. Data was downloaded for the period spanning January 1, 1992 through December 31, 2022. Two weather variables were used: (1) cumulative daily precipitation values and (2) the average daily air temperature at two meters above ground level. The weather data was separated into two data sets: one comprising the entire 30 years of data (historical weather data), and one containing only data from January 1 – December 31, 2022 (trial year data).

To provide context for each trial’s temperatures, the historical mean temperature for month at a given site was calculated using the historical weather dataset. The historical value was subtracted from the trial year average temperature for that month to provide an estimate of the deviation from average conditions. For example, in Galva Iowa the historical average temperature in April is 48 deg F. In 2022, the month of April had an average temperature of 44 deg F, resulting in a deviation of -4 deg F (cooler than average). To provide context for precipitation, the cumulative precipitation up to a given day was calculated for each year separately. The historical value was calculated as the average cumulative precipitation received up to a given calendar day. Like the temperature deviation calculation, this historical mean was subtracted from the cumulative precipitation for each calendar day in 2022. Continuing with the Galva Iowa example, Galva historically receives an average of 11 inches of precipitation from January 1 through June 1. In 2022, Galva had received 10.6 inches, for a deviation of -0.4 inches (drier than average).

### Finances

In the 2021/2022 suite of trials, farmers reported nitrogen prices ranging from $0.60/lb N up to $1.20/lb N. Not all farmers reported the price received for corn, so we used USDA National Agricultural Statistics Service (NASS) [3] data as reported by Iowa State University’s Ag Decision Maker (<https://www.extension.iastate.edu/agdm/crops/pdf/a2-11.pdf>), which provides a range in prices received for corn in Iowa for the year 2022.

For each N treatment, the amount of N applied was multiplied by the assumed price paid. The corn yields at 15.5% moisture were multiplied by the assumed price received per bushel. For each trial replicate, the net profit for the typical N treatment was subtracted from the reduced N treatment.

To assess the significance of treatments on finances, one-sample t-test was used to assess whether the financial outcome in each scenario was significantly different from $0 per ac at 95% confidence levels.

To account for the varying amounts of reductions each cooperator chose, for visualizations the savings per acre were normalized by the difference between the N applied at the typical and reduced rates, producing a savings per unit N reduction per acre (with negative savings indicating a financial loss).

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Appendix

Figure of Galva temperature and cumulative precipitation deviation calculations