Extension
UNIVERSITY OF WISCONSIN–MADISON

DISCOVERY FARMS
WISCONSIN

Nitrogen Use Efficiency:

Statewide NUE benchmarking for CORN GRAIN and SILAGE

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INTRODUCTION

Efficient use of nitrogen (N) is essential for crop production, whether the N source is commercial fertilizer, manure, legumes or some combination. Assessing the efficiency of N application on a per field basis is a valuable first step in evaluating your N fertilizer management plan.

Nitrogen use efficiency (NUE) calculations can be relatively simple and offer insight into how N management can be altered to achieve economically optimum yields while reducing nutrient losses to the environment. However, measuring your NUE is only useful if there are appropriate benchmarks for comparison. Wisconsin's unique management practices and soil types create a need for Wisconsin-specific benchmarks.

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DISCOVERY FARMS' NITROGEN USE EFFICIENCY PROJECT

In 2015, UW Discovery Farms launched the Nitrogen Use Efficiency Project supported by a grant from the Natural Resources Conservation Service Conservation Innovation Grants program. The goals of the project are to—

1. **establish state and NUE benchmarks for Wisconsin-specific cropping systems**
2. **determine if the measures can complement nutrient management planning**
3. **evaluate how farmers can use NUE as a tool when deciding to change N management practices**

Discovery Farms collaborated with farmers to measure NUE on fields across Wisconsin. Rather than suggesting in-season N adjustments or changing N recommendations for corn production in Wisconsin, the project assists farmers in assessing their N management practices based on field, season or soil type.

Pre-plant soil sampling for nitrate and ammonium.

Table 1. Project regional distribution and field types

NUE PROJECT REGIONAL DISTRIBUTION			
	Participants	**Fields**	**Years in Program**
Dry Run	11	45	2015-2017
Jersey Valley	10	49	2015-2017
Southeast	8	42	2015-2017
Yahara	4	11	2015-2016
Elk Creek	10	41	2016-2017
Northeast	14	25	2016-2017
TOTAL	57	213	

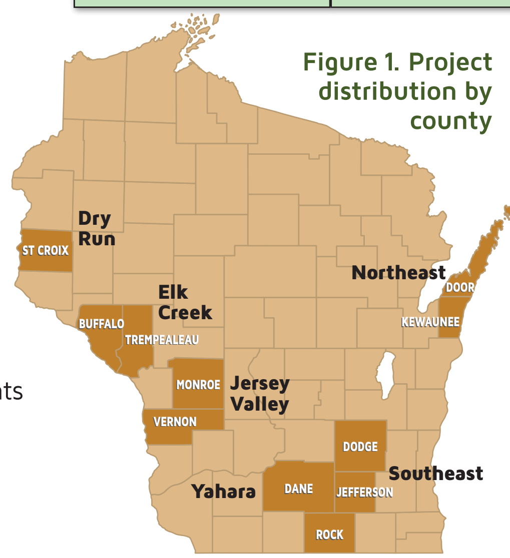


Figure 1. Project distribution by county

From 2015-2017, UW Discovery Farms monitored 57 farms across Wisconsin to include in its dataset 128 corn fields harvested for grain and 85 corn fields harvested for silage. Fields spanned various regions, soil types and farm management systems that represent the diversity of Wisconsin agriculture. Management practices include a range of N sources, cover crop usage, tillage practices and crop rotations, as represented in the table below.

128 GRAIN FIELDS

Manure	No manure
60	68

Cover crop	No cover crop
25	103

No-till	Reduced-till	Conventional-till
57	16	55

Grain following alfalfa*	Grain following corn	Grain following soybean	Grain following other crop
16	45	52	15

85 SILAGE FIELDS

Manure	No manure
68	17

Cover crop	No cover crop
23	62

No-till	Reduced-till	Conventional-till
37	11	37

Silage following alfalfa*	Silage following corn	Silage following soybean	Silage following other crop
18	57	3	7

*For fields following alfalfa, a 90 lb N/ac credit was assigned when calculating NUE measurements.

Shredding corn to test silage for N content and moisture.

NUE MEASUREMENTS

Generally, efficiencies are calculated as ratios of outputs to inputs (i.e., crop removal to nutrient application). Our goal in corn production is to maximize the use and uptake of N inputs while achieving economically viable yields. This in return will mitigate losses to the environment.

To maximize efficiency, we need to obtain the maximum value of outputs per unit value of all N inputs which can be in the form of fertilizer, manure and legumes. A higher NUE value results from the most appropriate N rates and sources and benefits from improvements to N application timing and placement. High efficiencies can be achieved with low rates of N; so, it is important to consider your efficiency in the context of your corn yields and the net return on the fertilizer applied.

The Discovery Farms' NUE project gathers data from partnering farmers' fields to calculate NUE. There are four separate calculations that represent aspects of NUE:

- Partial Factor Productivity (PFP)
- Partial Nutrient Balance (PNB)
- Agronomic Efficiency (AE)
- Uptake Efficiency (UE)

Partial Factor Productivity (PFP) and Partial Nutrient Balance (PNB)[3]

PFP and PNB are simple calculations of NUE that can be conducted on any field. They are useful assessment tools that you can use to compare NUE from year to year or field to field. Additionally, by comparing individual values to regional benchmarks for PFP and PNB, you can determine if there are potential gains in NUE on your farm.

PARTIAL FACTOR PRODUCTIVITY (PFP):
Is this cropping system productive in comparison to its nitrogen application?

$$\text{PFP} = \frac{\textbf{Yield}\ \text{(lbs/ac)}}{\textbf{N applied}\ \text{(lbs/ac)}}$$

Higher PFP means more efficient use of applied N

PARTIAL NUTRIENT BALANCE (PNB):
How much nitrogen is being taken out of the system in comparison to how much is applied?

$$\text{PNB} = \frac{\textbf{N content of harvested portion of crop}\ \text{(lbs/ac)}}{\textbf{N applied}\ \text{(lbs/ac)}}$$

Ideal = around 1
<1= nutrient surplus (more N applied than removed in crop)
>1= potential mining of soil organic matter (less N applied than removed in crop)

Corn grain and stover are weighed and analyzed for N content and moisture.

Agronomic Efficiency (AE) and Uptake Efficiency (UE)[3]

AE and UE are more detailed measurements of NUE and utilize a zero-N test strip to measure the actual use of the N that was applied to the field.

A zero-N test strip is a small portion of the field: a minimum length of 100 ft by 25 ft in width or the width of the applicator. For a zero-N strip to be most effective, it should not receive any N from fertilizer or manure. Though ideally farmers would also avoid applying starter fertilizer to the test strip, it is acceptable to have starter N fertilizer applied with the planter as long as it is no more than 30 lbs N/ac. Furthermore, the zero-N strip should be placed in an average performing area of the field so as to best represent the entire field. Zero-N test strips are compared to adjacent strips where regular N applications occur.

Benefits of a zero-N test strip:

- This is a good assessment for farmers who are wondering if changes in management practices (e.g., cover cropping, manure applications or reduction in tillage) are affecting the soil's ability to supply N or to make site-specific management decisions based on soil type differences and field specificity. Monitoring yield in the zero-N test strip serves as a good indicator of soil health.
- Understand how much N was used by the crop. Conversely, zero-N test strips also provide you with the knowledge of how much N the crop did not use and which may have been lost to groundwater or from denitrification.
- Measure the true economic value of the N applied in each year. The true economic value of N applied is connected to the gain in yield, not the total yield.

AGRONOMIC EFFICIENCY (AE): Did the nitrogen applied improve productivity?

$$AE = \frac{\text{Yield - Yield of zero-N test strip (lbs/ac)}}{\text{N applied in field - N applied in zero-N test strip (lbs/ac)}}$$

Higher AE means more efficient use of N

UPTAKE EFFICIENCY (UE): How much of the nitrogen applied was taken up by the entire crop?

$$UE = \frac{\text{Total plant N uptake in aboveground biomass - Total plant uptake in aboveground biomass in zero-N test strip (lbs/ac)}}{\text{N applied in field - N applied in zero-N test strip (lbs/ac)}}$$

Typical values range 30-50%
50-80% can be achieved with best management practices

Figure 2. NUE calculation example

	N applied (lb/ac)	N removed in grain (lb/ac)	Total N uptake (lb/ac)	Yield (bu/ac) at 15.5% moisture	Yield (lb/ac)* at 15.5% moisture
Zero-N test plot	0	82	105	170	9,520
With-N test plot	198	146	193	248	13,888

*This value is calculated by multiplying the yield in bu/ac by 56.

$$\text{PFP} = \frac{\text{Yield (lbs/ac)}}{\text{N applied (lbs/ac)}} = \frac{13{,}888}{198} = 70$$

$$\text{PNB} = \frac{\text{N content of harvested portion of crop (lbs/ac)}}{\text{N applied (lbs/ac)}} = \frac{146}{198} = 74\%$$

$$\text{AE} = \frac{\text{Yield - Yield of zero-N test strip (lbs/ac)}}{\text{N applied - N applied in zero-N test strip (lbs/ac)}} = \frac{13{,}888 - 9{,}520}{198 - 0} = 22$$

$$\text{UE} = \frac{\text{Total plant N uptake in aboveground biomass - Total plant uptake in aboveground biomass in zero-N test strip (lbs/ac)}}{\text{N applied (lbs/ac)}} = \frac{193 - 105}{198 - 0} = 44\%$$

Calculating NUE Values

The example above of data collected for a field shows that the farmer is producing 70 lbs of grain (1.25 bu) per lb of N applied, and that the N removed in grain is 74% of the N applied. It also indicates that the soil is supplying a fair amount of N, as the N fertilizer only increases the grain production by 22 lbs (0.4 bu) per lb of N applied, and only 44% of the N applied was taken up by the crop. All of this information suggests adequate efficiency, but with an opportunity to test other N management practices to decrease N input.

Curious how to utilize numbers from your yield monitor to calculate PFP or AE?

GRAIN

To calculate PFP and AE for GRAIN, yield must be converted from bushels per acre to pounds per acre of corn grain at 15.5% moisture.

To convert grain yield in bu/ac at the harvested moisture, multiply by the percent dry matter (DM) and then divide by 0.845 to convert to 15.5% moisture. To convert this yield to lb/ac, multiply by 56.

EXAMPLE: If you yield monitor reads 222 bu/ac at 17% moisture

STEP 1: 222 bu/ac x (100-17)/100 / 0.845 = 218 bu/ac at 15.5% moisture

STEP 2: 218 bu/ac x 56 lb/bu = 12,208 lb corn grain at 15.5 % moisture

SILAGE

To calculate PFP and AE for SILAGE, yield must be converted from tons per acre to pounds per acre of corn silage at 0% moisture.

To convert silage yield in tons/ac at the harvested moisture, multiply by the percent dry matter (DM) to convert to 0% moisture. To convert this yield to lb/ac, multiply by 2000.

EXAMPLE: If your yield monitor reads 24 t/ac @ 66% moisture

STEP 1: 24 t/ac x (100-66)/100 = 8.16 t/ac at 0% moisture

STEP 2: 8.16 t/ac x 2000 lb/t= 16, 320 lb corn silage at 0% moisture

USING NITROGEN USE EFFICIENCY ON YOUR FARM

NUE is a valuable assessment tool for farmers to compare the effectiveness of their current N management plans with that of other farms in the state. By monitoring farms across all of Wisconsin and fields that have various soil types, N sources and farm management techniques, the established NUE benchmarks are representative of Wisconsin's corn grain and corn silage systems. However, it is important to first understand what factors may impact a field's efficiency.

Understanding the context of your field's NUE

While NUE is driven by yield (or N removed) and N applied, many other factors can contribute to a higher or lower efficiency. Recognizing how these factors can affect a field's NUE is a crucial first step to determining how to improve a field's N use.

SOIL

Soil type and texture greatly influence how N moves and cycles through the soil. Soil types dominated by sand, silt or clay fractions are all represented in the Discovery Farms dataset, and while NUE values were not significantly different based on soil type, it is useful to understand how soil texture may affect NUE. In sandy soils N will have greater mobility, so there is a higher risk of leaching as water moves through the soil profile. Fine-textured soils can retain more moisture and have less risk of nitrate leaching, however in soils that have poor drainage, there is greater risk of losing nitrate through denitrification under waterlogged conditions. In addition, soils with greater soil organic matter (SOM) will likely supply more N than those with lower SOM. This will affect the AE and UE values as higher yields and N uptake can be obtained with no N.

Wisconsin benchmarks can aid producers in checking nitrogen use efficiency of their own fields.

WEATHER

Weather plays a crucial role in the N cycle, so annual weather patterns or regional differences are important factors to note. A cooler, longer spring could delay N transformations into a plant-available form and increase the need for higher N rates. Heavy rains on sandy soils could lead to N leaching, and rains on poorly-drained soils could have higher rates of denitrification, both of which negatively impact NUE. Nitrates leach more rapidly from sandy soils than from finer-textured soils because sandy soils have lower water-holding capacity.[2] Beyond its effects on N cycling, weather can also be responsible for particularly high or low yields, which is a significant determination of a field's NUE in any given year.

RESIDUAL N

Fields that utilize manure, legume cover crops (e.g., red clover), and perennial legumes (e.g., alfalfa) as a N source are more likely to have residual N in the soil from season to season. Pre-plant nitrate test (PPNT) and pre-sidedress nitrate test (PSNT) are useful tools to assess how much N is in the soil from the previous season, with PPNT being valuable to assess carry over N and the PSNT used to confirm manure or legume N credits.[1] Soils with high nitrate values regardless of source can produce higher yields when no additional N is applied, thus leading to lower AE and UE values if the N rate is not adjusted accordingly. Therefore, you should always evaluate each field's AE and UE based on PPNT and PSNT values for context. If AE or UE is exceptionally low, high PPNT or PSNT values may be the cause. If they are, this shows the importance of crediting other N sources. If the PPNT or PSNT values were not high, it would indicate the soil itself is supplying a large amount of N, and fertilizer rates could be cut back.

A zero-N test strip is a great way to account for the circumstances that impact NUE values. The zero-N test strip indicates the yield achieved with residual and mineralized N in the soil,

The 4Rs of nutrient management can increase your NUE.

Changes in the 4Rs[4] of nutrient management can increase productivity, while reducing costs and risk to the environment.[1] The 4Rs are defined as:

- ***Right*** **rate**
- ***Right*** **source**
- ***Right*** **placement**
- ***Right*** **timing**

Experimenting with changes to rate, source, placement and timing of your nitrogen, with continued NUE assessments, is a great next step to fine tuning your N management plan.

therefore NUE values that utilize these data demonstrate the true economic efficiency of the N added to the system through fertilizer and manure.

Evaluating NUE for future N management decisions

Deciding if, or what, change should be made to one's N management plan can be challenging. By comparing a field's NUE to that of other farms in the region one can assess whether the next step should be a change in management or continued monitoring. With the Wisconsin-specific data that Discovery Farms has developed, and will continue to improve upon, benchmarks can be used to evaluate a field's NUE values relative to averages. Benchmarks and guidance on how to adjust N management plans to improve NUE can be found on the following pages.

Collecting samples of corn grain and silage for testing.

Wisconsin-specific benchmarks for NUE measurements

Three years of data collection and calculation provided a large enough sample size to establish Wisconsin-specific benchmarks for partial factor productivity (PFP) and partial nutrient balance (PNB). Although agronomic efficiency (AE) and uptake efficiency (UE) were calculated on all fields that incorporated a zero-N plot, to be relevant, a larger sample size for these measurements is needed.

The Discovery Farms NUE Project is ongoing. PFP and PNB benchmarks will be updated and AE and UE benchmarks will be developed as more data is collected in the state.

To evaluate your field's NUE, first determine the field's NUE relative to the established benchmarks below. Then use the matching decision tree (pages 10-11) to determine if a management change should be made, and if so, what type of change can be implemented to increase efficiency.

CORN GRAIN BENCHMARKS

The corn grain benchmarks for the low use efficiency, low-mid use efficiency, mid-high use efficiency, and high use efficiency are defined in table 2.

Table 2. Corn grain benchmark efficiency ranges

CORN GRAIN BENCHMARKS	LOW USE EFFICIENCY (DECISION TREE BOX 1)		LOW-MID USE EFFICIENCY (DECISION TREE BOX 2)		MID-HIGH USE EFFICIENCY (DECISION TREE BOX 3)		HIGH USE EFFICIENCY (DECISION TREE BOX 4)	
	PFP	PNB	PFP	PNB	PFP	PNB	PFP	PNB
lb grain/lb N at 15.5% moisture	0-58	0-0.60	59-72	0.61-0.77	73-85	0.78-0.88	>85	>0.88
bu grain/lb N at 15.5% moisture	0-1.04		1.05-1.29		1.30-1.52		>1.52	

CORN SILAGE BENCHMARKS

The corn silage benchmarks for the low use efficiency, low-mid use efficiency, mid-high use efficiency, and high use efficiency are defined in table 3.

Table 3. Corn silage benchmark efficiency ranges

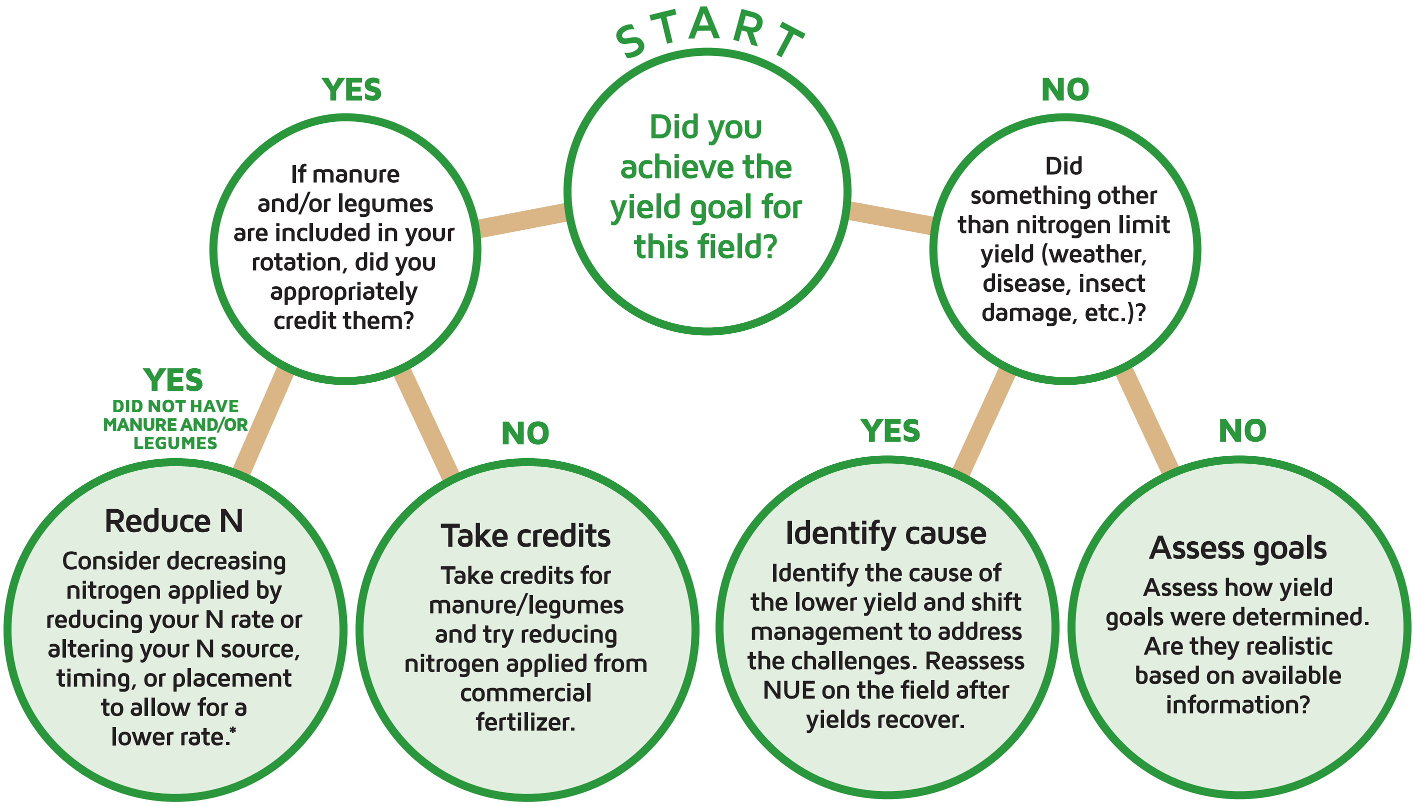
CORN SILAGE BENCHMARKS	LOW USE EFFICIENCY (DECISION TREE BOX 1)		LOW-MID USE EFFICIENCY (DECISION TREE BOX 2)		MID-HIGH USE EFFICIENCY (DECISION TREE BOX 3)		HIGH USE EFFICIENCY (DECISION TREE BOX 4)	
	PFP	PNB	PFP	PNB	PFP	PNB	PFP	PNB
lb silage/lb N at 0% moisture	0-80	0-0.92	81-95	0.92-1.08	96-108	1.08-1.29	>108	>1.29
tons silage/lb N at 0% moisture	0-0.040		0.041-0.047		0.048-0.054		>0.054	
tons silage/lb N at 65% moisture	0-0.114		0.115-0.136		0.137-0.154		>0.154	

BOX 1

LOW USE EFFICIENCY

Grain: PFP 0-58 / PNB 0-0.60 Silage: PFP 0-80 / PNB 0-0.92

A field with an NUE value less than the first quartile has an efficiency value in the lower 25% of monitored fields. Use the series of questions to determine ways to increase efficiency.



*See the low-medium use efficiency box below for suggestions on how to decrease N rate.

BOX 2

LOW-MEDIUM USE EFFICIENCY

Grain: PFP 59-72 / PNB 0.61-0.77 Silage: PFP 81-95 / PNB 0.92-1.08

A field with an NUE value between the first quartile and the median has an efficiency value in the lower 25%-50% of monitored fields. In this context, the majority of farm fields have greater NUE suggesting that there are opportunities to improve.

NUE can be increased by reducing N rates through changes in nitrogen or general field management, as long as yields aren't decreased below yield goals. Try to reduce rates by implementing one of the following practices.

- Move fall applications of N to spring or in-season and avoid applications on frozen soil.
- Split spring nitrogen into more than one application.
- Use N inhibitor products when appropriate.
- Consider using controlled release N on sandy soil.
- Test small reductions (10-20%) in N applications.
- Evaluate other management practices (soil and pest) and their impacts on yield.

With continued NUE assessments on this field, you can monitor the impacts of the new management on NUE.

BOX 3

MEDIUM-HIGH USE EFFICIENCY

Grain: PFP 73-85 / PNB 0.78-0.88   Silage: PFP 96-108 / PNB 1.08-1.29

A field with an NUE value between the median and the third quartile has an efficiency value in the upper 50%-75% of monitored fields. With an above average NUE, this is a good range to fall within.

Changes in the 4Rs should be evaluated in small areas and costs associated with management changes should be considered along with potential cost savings of N. These fields should have periodic NUE assessments for continued evaluation to assess impacts of weather or any management shifts made from year to year.

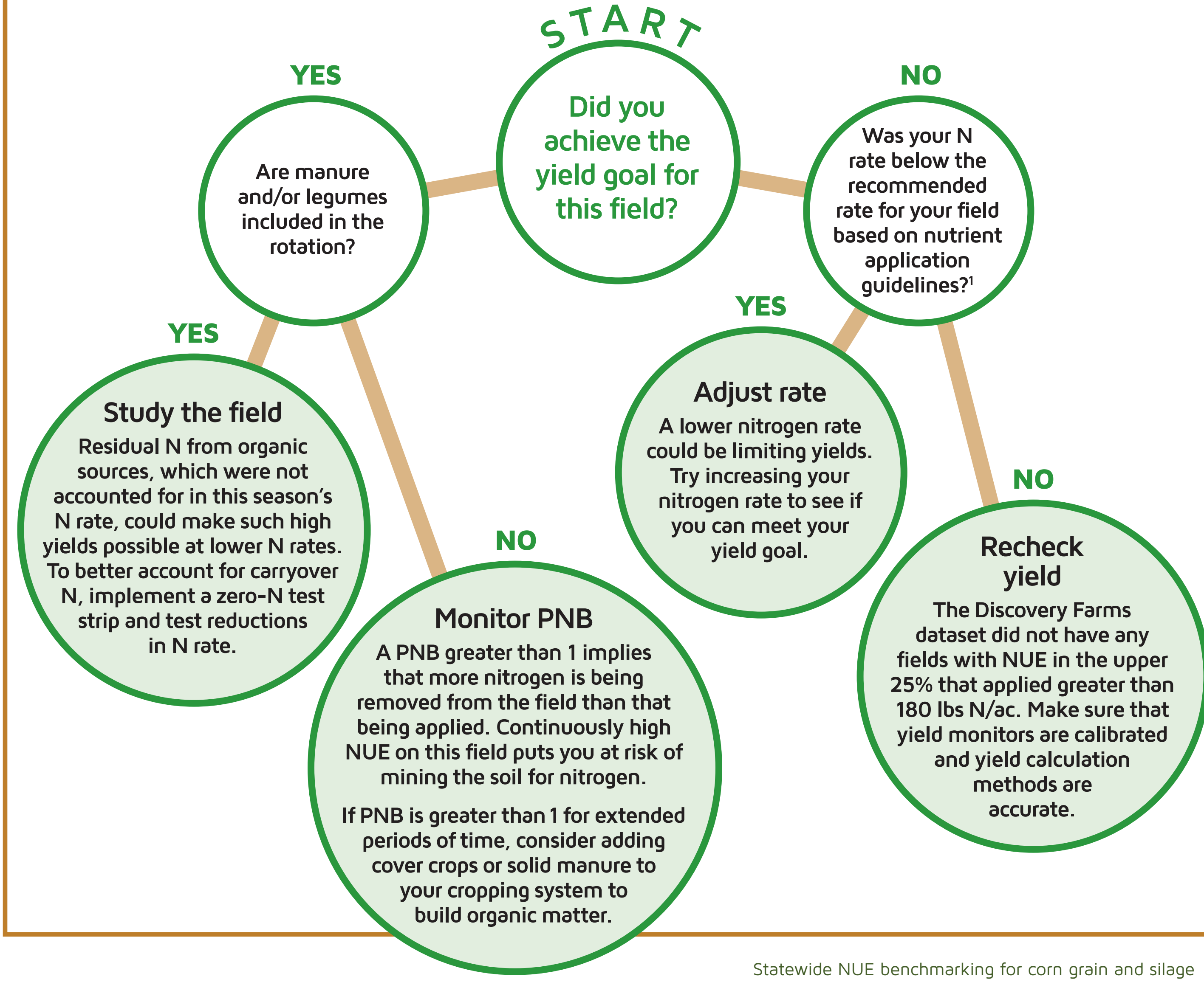
BOX 4

HIGH USE EFFICIENCY

Grain: PFP > 85 / PNB > 0.88   Silage: PFP > 108 / PNB > 1.29

A field with an NUE value between the third quartile and maximum value has an efficiency value in the highest 25% of monitored fields. A very high NUE value can be misleading as it can imply that low N rates are limiting yields. Additionally, PNBs greater than 1 can suggest N mining of the soil.

Use the series of questions to interpret your high NUE and determine what (if any) changes in management should be considered.



"A lot of farmers, as I also did, apply a certain amount of N to all fields. After seeing NUE, you realize that you shouldn't. You can save N dollars without yield sacrifice and prevent N from entering the environment." *– NUE Project Participant*

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Nitrogen Use Efficiency:

Statewide NUE benchmarking for CORN GRAIN and SILAGE

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This publication is available in pdf format at uwdiscoveryfarms.org and available from the UW Discovery Farms office, PO Box 429, Pigeon Falls, WI 54760, 715-983-5668

Thank you to the many reviewers who contributed to this publication.

For over a decade, UW Discovery Farms has worked with Wisconsin farmers to identify the water quality impacts of different farming systems around the state. The program, which is part of the UW–Madison Division of Extension, is under the direction of a farmer-led steering committee and takes a real-world approach to finding the most economical solutions to agriculture's environmental challenges. If you are interested in learning more about UW Discovery Farms, visit www.uwdiscoveryfarms.org, email erica.olson@wisc.edu or call 715.983.5668.

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