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Precise Nitrogen Recommendations Improve Economic and Environmental Outcomes in Arkansas Rice Production

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Precise Nitrogen Recommendations Improve Economic and Environmental Outcomes in Arkansas Rice Production

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Abstract

Soil testing has become an increasingly important tool in making agronomically efficient production management decisions. N-STaR is a N test used in rice production and is unique in its ability to selectively quantify soil organic-N compounds which are readily mineralizable for plant N uptake and contribute to growth and yield. This study uses historical (2002–2018) adoption rates of N-STaR, which is funded through Rice Checkoff funds, to calculate the total cost savings from N-STaR adoption. These cost savings alone would be the “typical” benefits used in a benefit-cost ratio of a public ally funded research program like N-STaR. However, we use an LCA to quantitatively compare the cradle-to-farm gate environmental impacts of replacing traditional blanket rice N recommendations with field specific N recommendations via N-STaR adoption. The summation of these two (cost savings and reduced environmental impacts) are aggregated and compared to the amount of money that the Arkansas Rice Checkoff program has invested in N-STaR research and dissemination. The results of this study indicate that for every dollar that producers spend on N-STaR tests, as well as accounting for their checkoff contributions, they receive an average benefit of $15.74 and $53.66 without and with ecosystem services, respectively. Unlike yield-enhancing research that can have quick tangible benefits, input reduction research typically leads to marginal reductions in costs which producers can easily misidentify as simply adopting best management practices. That being said, there are often acknowledged but seldom quantified benefits associated with input-savings technologies such as N-STaR, specifically related to fertilizer, such as the avoided environmental impacts provided via N reduction. Our findings suggest that by overlooking the environmental benefits of N-STaR adoption, the benefit-cost ratio would be underestimated by 286%.

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Dedication

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Introduction

The nature and extent of N losses in agriculture have long been documented to be socially, and perhaps privately, inefficient due to inaccurate levels of N usage (Fuglie & Bosch, 1995). Social inefficiencies arise because of the resulting environmental costs of overusing N, and private inefficiencies are associated with producers over applying N and thus reducing profits. The benefits of soil health can be categorized into several distinct categories: agronomic, environmental and economic benefits (Robertson & Vitousek, 2009; Rütting et al., 2018; Stevens, 2015).Environmental benefits are those that contribute to the resilience of the area without affecting agricultural yield such as reducing nitrogen inputs (Fuglie & Bosch, 1995) and mitigating loss of reactive nitrogen to the environment (Ribaudo et al., 2011). Agronomic benefits of managing soil health can be thought of as those that manifest specifically in increased crop yield. Producers realize economic benefits such as reduced costs, whereas external benefits are realized by external parties, such as consumers and the general public. Ideally, soil tests would produce benefits for all four dimensions simultaneously; however, this is not always the case. Increased yields do not always equate to increased profits if the marginal cost of additional fertilizer (to increase yields) is greater than the marginal revenue associated with the increased yields. Further, additional fertilizer recommendations may lead to higher yields and economic profits but at the expense environment damage if the additional yield/profit decreases the input use efficiency. Understanding the interaction of the four categories of potential benefits and costs associated with soil testing/recommendation programs can improve the overall impact assessment of investments in such environmentally beneficial and agronomically productive technology.

Soil testing has become an increasingly important tool in making agronomically efficient production management decisions. Soil testing has one of the largest and most easily identifiable impacts on a soil's ability to support life, determine agricultural yield, display environmental resiliency, and further ecosystem sustainability (Fuglie & Bosch, 1995). These impacts make soil testing a valuable resource for lending pertinent information about soil health to stakeholders in agricultural production. Providing producers with better tools to estimate economically optimal soil nutrient rates allows them to manage N applications in a more sustainable (environmental) and economically (profits) way (Cassman et al., 1998; Sela et al., 2016). Kastens & Dhuyvetter (2011) find that the gross benefit (including cost of testing) of a single composite soil sample for dryland rotation of wheat-corn-fallow rotation in Kansas was $3.26/acre/crop. Although the authors estimate relatively large benefits, they also report that only 35% of Kansas corn producers and 14% of Kansas milo producers actually use soil testing. In Oklahoma, Zhang et al. 2008 found that soil testing was done on only 3.5% of wheat acres. Kastens & Dhuyvetter conclude their findings by stating "if the profits were that obvious, we'd all be doing soil sampling". They conclude, like many others, that one of the largest impediments to soil sampling adoption is that accurately predicting yield response to fertilizer is notoriously difficult (Cassman et al., 1998, 2002; Dellinger et al., 2008; Dhital & Raun, 2016; Morris et al., 2018).

Another potential rationale for the low adoption of soil testing is that the real and perceived costs of measuring soil health are an effective detriment to many producers who might otherwise be interested in the information (Biardeau et al., 2016). In economic terms, Stigler (1961) described this phenomenon as a "search cost," where obtaining and observing information (in this case soil health) is itself costly either financially (from a cost perspective, either real or perceived) or behaviorally (from a time and opportunity cost aspect). This finding is backed by de Bruyn and Andrews (2016) who found that only 30% of US agricultural producers participate in any type of soil testing despite the recognition of soil health as a critical variable in the ecosystem. They conclude that there are a number of barriers to collecting and acting on soil test information, including a lack of resources (monetary and human) at multiple scales, a lack of education to understand the need for a soil test, and privacy issues associated with sharing information.

In the absence of soil testing, either due to lack of availability or lack of participation, producers often opt to apply “insurance N” in production. Babcok and Blackmer (1992) describes “insurance N” as extra N applied to enable producers to benefit from situations where conditions are favorable for unusually large yield responses to N and therefore unusually large profits from fertilization. Without the use of soil testing, “insurance N” is often applied, and often reduced profits occur. Not surprisingly, Babcok and Blackmer found that the application of insurance N was not a good economic investment and the economic risk associated with under-applying N was not greater than the economic risk associated with over-applying N. Thus, the notion of insurance N is expected to increase amounts of N lost to the environment and create environmental damage without a sufficient economic benefit (Schlegel et al., 1996; Watkins et al., 2010).

Nitrogen rate recommendations for rice have traditionally been based on a combination of information regarding cultivar, soil texture, and crop rotation (Watkins et al., 2010; Roberts et al., 2011; Roberts et al., 2012). Generic N rate recommendations such as 150 lb/ac for silt loam soils and 180 lbs/ac for clay soils are the result of variety or cultivar by N rate trials conducted across a series of environments which are averaged to determine the N rate most likely to maximize yield within a given geographic region. One downside to these generic N rate recommendations is the fact that they both over-estimate and under-estimate the N rates for a significant portion of grower fields as very few production fields are equivalent to the “average” N rate determined for a given cultivar and soil type. Field-specific N rates for row crops, including rice, have long been the goal of soil fertility researchers. To provide field-specific N rates development a reliable and reproducible soil-based test was needed (Bushong et al., 2008).

Prior to the development of the Nitrogen Soil Test for Rice, or N-STaR, there were limited soil-based N tests that could provide field-specific N fertilizer rates for rice production in the United States and none which were deep soil N tests (Roberts et al., 2011). Beginning in 2006, scientists with the University of Arkansas System Division of Agriculture worked to develop N-STaR, which provides field-specific N rates for rice produced on a wide variety of soil textures, previous crops, and environments (Roberts et al., 2011; Fulford et al., 2019). The N-STaR method provides producers with a N rate recommendation based on the current plant-available N and potentially mineralizable N in the soil profile. Comparison of N-STaR to other soil-based N tests such as soil total N and the pre-sidedress nitrate test (PSNT) reveals some unique differences. When compared to soil total N, N-STaR is more specific and only quantifies 8% to 25% of the total N contained in the soil, depending on the soil’s native N fertility. On the other hand, N-STaR quantifies more compounds than the standard PSNT, which estimates only the amount of NO_3-N in the soil and can have spatial and temporal variability within fields due to its potential for loss via leaching or denitrification. N-STaR’s is unique in its ability to selectively quantify soil organic-N compounds which are readily mineralizable for plant N uptake and contribute to rice growth and yield.

Following the advent of N-STaR field-specific N rates based on soil N availability, field testing was needed to validate the new N rates as they were often 25-50% less than N rate recommendations based simply on the cultivar, soil texture, and previous crop (the traditional recommendations of 150 lbs/ac for silt loam and 180 lbs/ac for clay soils). It has been suggested anecdotally from extension staff that rice producers and crop consultants across Arkansas expressed concern about reductions in N rate recommendations leading to significant yield losses.

Field validation of the N-STaR N recommendation rates involved a comparison of field-specific N rates predicted using the N-STaR method to the standard N rate based on the cultivar, soil texture, and previous crop. Roberts et al. (2012) determined that field-specific N rates predicted using the N-STaR method produced yields that were equivalent to or greater than the standard recommendation in all 14 site-years researched on silt loam soils in Arkansas. Closer examination of the data indicated that when N rates were significantly reduced (25-118 kg of N per hectare less than standard recommendation) using the N-STaR program predicted N rates, yields were often statistically maintained (9 of 14 sites) or statistically increased (4 of 14 sites). The ability to produce comparable or increased yields with significantly reduced N application rates can be attributed to several factors either individually or in combination, but are the direct result of increased disease, specifically rice blast (Long, Lee and TeBeest, 2000; Talbot et al., 1997 and Pooja and Katoch, 2013) and lodging pressure (Zhou et al., 2019; Li et al., 2013 and Duy et al., 2004) that arise when N is overapplied to rice (Roberts et al., 2012).

The N-STaR approach relies on the ability of chemical soil test methods to predict the native N supplied by the soil throughout the growing season and predict the fertilizer N rate needed to maximize rice grain yield. When N-STaR samples are taken correctly and N fertilizer applications are made in a timely and efficient manner, rice grain yield can be maintained or increased with significant reductions to N inputs reducing the cost of production for rice producers that use the program. Results from Robert et al. (2012) highlight the potential for significantly lower N rates across a wide range of soils and production systems with no statistical reduction in rice yields. Yield data obtained from the Roberts et al. (2012) study support the findings of Watkins et al. (2010), which suggested that rice yields could be maintained with significant reductions in N rates. Without the development of a soil-based N test, like N-STaR, there was no way to predict the magnitude of the N rate reduction on a field-specific basis.

Public funding of Agricultural Research and Development

The Arkansas Rice Checkoff, which funded the creation and implementation of N-STaR, allocates funds collected by an assessment of 1.35 cents per bushel of rice grown in Arkansas paid by the grower, and an assessment of 1.35 cents per bushel paid by the first point-of-sale buyer. The funds raised by the grower assessment are reserved for research programs like N-STaR, while buyer funds are reserved for domestic and international promotion and market development activities. This study focuses on the 1.35 cents paid by the grower and attempts to quantify the benefits that growers receive from this contribution and the fees to use the N-STaR program. As public funds, which were used to create N-STaR, are more commonly being used for projects that focus on more efficient uses of production resources, it becomes even more important to capture the net present value benefits of saved resources and avoided environmental damage.

Traditional benefit cost ratios (BCRs) for soil testing would solely focus on savings from N purchases and subsequent application. Any savings with regards to N applications can have a large impact on profitability as N costs are the third highest single cost of rice production in

2021, only behind herbicides and irrigation (UAEX, 2021a). However, failing to internalize the reduced environmental damages/impacts provided by N soil testing may underestimate its true benefits and ultimately result in the misallocation of future funds because of this underestimation. As environmental concerns grow in production agriculture, commodity yield ceilings are approached, and more commodity board, public, and private monies flow into input-reducing research, accounting for environmental benefits and foregone damages is becoming more important.

Beyond estimating the traditional economic cost savings from soil testing, few studies quantify and monetize additional ecosystem benefits derived from soil testing implementation. In this case, reduced N application rates from N-STaR adoption leads to less nitrification and input (a second aerial application of N) use, which supports ecological improvements by reducing global warming potential (GWP) and other environmental impacts. In previous studies, Life Cycle Assessment (LCA) has been implemented to provide this additional analysis of benefits based on reduced input use (Nalley et al., 2016; Shew et al., 2019, Shew et al. 2021). This study uses an LCA to monetize the environmental improvements from historical N-STaR adoption which can provide a more holistic estimation of N-STaR benefits. Quantification of environmental impacts (like those estimated in this study), which are non-market goods/services in terms of a monetary unit (that is, a single score), facilitates comparison amongst alternate management technologies (Pizzol et al., 2015)

This study uses historical (2002–2018) adoption rates of N-STaR funded through Rice Checkoff funds to calculate the total cost savings from N-STaR adoption. These cost savings alone would be the “typical” benefits used in a benefit-cost ratio. However, we use an LCA to quantitatively compare the cradle-to-farm gate environmental impacts of replacing traditional blanket rice N recommendations (180 lbs/ac for clay soils and 150 lbs/ac for silt loam soils, UAEX, 2021b) with field specific N recommendations via N-STaR adoption. The summation of these two (cost savings and reduced environmental impacts) are aggregated and compared to the amount of money that the Arkansas Rice Checkoff program has invested in N-STaR research and dissemination. Further, a "producer level" BCR is estimated on a per acre metric only using the cost of NSTaR testing (variable cost) ignoring the funds allocated to the checkoff program (fixed costs). The results from this study can be used by policy makers, producers, and agricultural scientists to make more holistically informed program evaluations of public research. Environmental benefits from soil testing via reduced input use have historically been acknowledged but seldom quantified in previous BCR studies. The contribution of this study is that when decision-makers evaluate input-reducing research, like N-STaR, they should look deeper than the cost savings incurred and consider the holistic impact including environmental services created/reduced.

Materials and Methods

Changes in N Rates per Acre

The first step in estimating the economic benefits of N-STaR adoption was to estimate changes in N application rates from the standard UofA recommendation of 180 lb/ac for clay soils and 150 lbs/ac for silt loam soils to field specific N-STaR recommendation rates. Between 2013 and 2019, 1,129 producers sent soil samples from their rice fields to be processed by the N-STaR lab at the University of Arkansas. Once the lab processed individual soil samples, producers were given a recommendation rate per acre based on soil type that could be above or below the standard rate of 150 or 180 lbs/ac. Thus, change per acre in N application rate ($\Delta \mathrm{F}_{tfs}$) for year *t* on farm *f* and soil type *s* is equivalent to:

$$\Delta \mathrm{F}_{tfs} = NSTaR \quad Rec_{tfs} - R_s \tag{1}$$

where R_s is the standard University of Arkansas recommendation N rate for soil type *s* (150 lb/ac for silt loam and 180 lbs/ac for clay) total and $NSTaRRec_{tfs}$ is the specific N-STaR rate for farm *f* in year *t* with soil type *s*. It should be noted that $\Delta \mathrm{F}_{tfs}$ can be positive (when N-STaR recommends more than the standard University of Arkansas rate) or negative (when N-STaR recommends less than the University standard rate).

New Adoption of N-STaR Acres

To estimate total new acres that use N-STaR for year *t*, we use the total number of samples submitted to the N-STaR lab to estimate total adoption for each year *t* (ranging from 2013-2019). When producers submit their soil samples to the N-STaR lab they are not obliged to reveal their total rice production acres. Further, many producers will only soil test on parts of their farm and use those recommendations for their entire rice operation. Thus, it is necessary to simulate farm size to obtain an estimated total rice acreage that implemented the N-STaR recommendations from equation 1. A triangular distribution was used and consisted of a minimum farm size of 205 acres, a mean size of 619 acres (the average size rice farm in Arkansas) and a maximum size of 2,500 acres. There are rice farms in Arkansas that operate more than 2,500 acres, but this truncation allowed for more conservative estimates. As such, to estimate the total new rice acres implementing N-STaR in year *t* (N^*A_t) the following equation (2) was used to estimate the farm size FS:

$$FS = TriangularDist(205, 619, 2500) \tag{2}$$

In an attempt to estimate total new N-STaR acres in year *t* (N^*A_t), the total number of submitted N-STaR tests for each year *t* (N^*Test_t) is multiplied by the simulated farm size (FS) for each farm *f* as in equation (3):

$$N^*A_t = \sum(N^*Test_t * FS) \tag{3}$$

Thus, a distribution was created for the total number of new N-STaR acres per year *t* (N^*A_t).

Recycled Recommendation from N-STaR

Because there is a cost associated with soil testing, including N-STaR, rice producers will often recycle previous fertilizer recommendation the next production season. In order to account for this recycling rate of recommendations we needed to estimate how many acres of last year's N-STaR adoption used the same recommended rate. That is, if a producer uses the same N-STaR recommendation for two years (t and t+1) and only sends one soil test into the N-STaR lab for recommendations we would inherently underestimate benefits. As such, a recycled fertilizer recommendation rate ($RecRate$) is estimated. A triangular distribution was used to simulate the recycled N-STaR acreage with a minimum value of 0.50, a mean value of 0.65 and a maximum value of 0.90. These distribution values were derived by talking with county extension agents throughout Arkansas.

$$RecRate = TriangularDistn(.50, .65, .90) \tag{4}$$

The total number of estimated recycled N-STaR ($NSTaR \quad RecA_t$) acres in year *t* was found by estimating the total number of N-STaR acres last year (N^*A_{t-1}) multiplied by the recycling rate of estimated recycled N-STaR acres ($RecRate$) from equation (4):

$$NSTaR \quad RecA_t = (N^*A_{t-1}) * RecRate \tag{5}$$

Newly adopted N-STaR acres for each year *t*, (N^*A_t) from equation (3) and recycled N-STaR acreage from year *t*-1 ($NSTaR \quad RecA_t$) were then summed to estimate the total number of N-STaR acres ($NSTaR \quad T_t$) for each year *t* with equation (6).

$$NSTaR \quad T_t = NSTaR \quad A_t + NSTaR \quad RecA_t \tag{6}$$

Equation 6 results in a distribution of total N-STaR acres in year *t*, as it is a function of multiple simulated distributions (recycling rate and farm size).

The distribution of estimated N savings for each year *t* ($NSavings_t$) is found by multiplying the simulated distribution of N savings from equation 1, ΔF_{fst}, by the distribution of total N-STaR acreage (new and recycled) from equation 6.

$$NSavings_t = \sum \Delta F_{tsf} \quad * NSTaR \quad T_t \tag{7}$$

Thus, equation 7 provides a distribution of total N savings (in pounds) per year *t*.

Nitrogen Cost Savings

In order to estimate cost savings of utilizing N-STaR, average N price in year *t* (FP_t) was found using the price of nitrogen (NP_t) per metric ton per year *t*, from Oakley Fertilizer located in Beebe, Arkansas (2021), divided by the percentage of nitrogen (urea) comprising the applied fertilizer (46%).

$$FP_t = \frac{{NP_t}/{2000}}{0.46} \tag{8}$$

The N cost savings in year *t* ($NCostSavings_t$), of utilizing N-STaR is the product of the distribution of total amount of N saved ($NSavings_t$) via N-STaR adoption in equation 7 and fertilizer price per pound in year *t* (FP_t) in equation 9:

$$NCostSavings_t = NSavings_t * \ FP_t \tag{9}$$

Application Savings via N-STaR Adoption

Given the flooded nature of rice production, a second application of N fertilizer is done aerially. Rice cultivars are split between two primary groups: purelines (conventional varieties) and hybrids. These two groups of rice cultivars vary greatly in regard to their seeding rates, yield potential, stress tolerance, nitrogen (N) response and disease resistance. Research has shown that via NSTaR adoption maximal rough rice yield and milling yield (grain quality) for conventional cultivars can be achieved with a single preflood (SPF) N application, whereas hybrid cultivars require a preflood and late-boot N application, regardless of whether NSTaR has been adopted to maximize these grain yield parameters. Although preflood N applications set the overall yield potential for both conventional and hybrid rice cultivars, the late-boot N application is required by hybrid cultivars to maximize not only yield and milling potential, but helps to reduce lodging as well. With the adoption of NSTaR, conventional cultivars can eliminate the necessity of a second aerial application of N in some instances. Surveyed Arkansas extension agents estimate (Roberts, 2021) that 65% of producers who sow conventional rice varieties apply a second aerial application of N. N-STaR recommendation rates are based on a single application of N and thus eliminate the need for the second aerial application on 65% of annual inbred acres. As such, 65% of conventional producers that adopt N-STaR would see a reduction in costs associated with the second aerial application of N. To estimate these savings, information on yearly variety plantings is needed to disaggregate between conventional and hybrid varieties. The percentage of state acreage in year *t* sown to conventional varieties (IC_t) was obtained from extension publications (BR Wells, various years).

Total cost savings from N-STaR adoption via reduction in aerial application costs in year *t* (CD_t) is calculated using the total N-STaR acres N^*T_t from equation (6), the percentage of acres sown to conventional rice varieties in year *t* (IC_t), the estimated percentage of conventional producers that apply two aerial applications (65% which is independent of year), and the aerial application cost (not including the cost of N) per acre, which is estimated at $8 (IOTC, 2021).

$$CD_t = \$8 * (IC_t * 0.65 * \; NSTaR \quad T_t) \tag{10}$$

Total Cost Savings

The cost for N-STaR testing is 1$/acre (samples provided are for a specific acre), and as such the total cost of testing for N-STaR paid by rice producers per year *t* (CT_t) is equivalent to the total new N-STaR acres per year *t* (N^*A_t) from equation (3) (note this is not total N-STaR acres in year t (N^*T_t) as estimated in equation 6 as it would double count acreage due to the recycling rate of N-STaR).

$$CT_t = NSTaR \quad T_t * \$1 \tag{11}$$

The Total Savings ($TSavings$) from N-STaR adoption in year *t* is the sum of Nitrogen cost savings ($NSavings$) from equation (9), the reduction in aerial application costs in year *t* (CD_t) from equation (10), minus the cost of N-STaR testing in year *t* (CT) from equation (11).

$$TSavings_t = NSavings_t + CD_t - CT_t \tag{12}$$

Ecosystem Benefits

Similar to previous literature (Durand-Morat et al., 2018; Shew ID et al., 2019), this study used the Stepwise Life Cycle Impact Assessment framework, which combines human and environmental effects in an economic valuation scheme (Weidema et al., 2008 and Weidema 2009). An evaluation was conducted for the counterfactual scenario of no adoption of N-STaR. That is, what would the additional environmental damage have been if there was no adoption of N-STaR in Arkansas? The functional unit, 1 kg of rice, serves as the basis for comparative evaluation. The differences in N and fuel usage via aerial application associated with N-STaR and non-N-STaR rice are used to simulate and compare environmental impact scenarios. All other inputs, including pesticide and herbicide usage, are assumed to be the same across scenarios. Inputs for each scenario were derived from the University of Arkansas Extension budgets (UAEX, 2020).

The lifecycle impact categories included in the stepwise method are described in Table A1. Midpoint and endpoint characterization factors are provided (Weidema 2009 and Weidema 2015). Normalization and weighting factors based on 1995 European Union per-capita emissions are given. The Stepwise method bases damage characterization to account for both human health and ecosystem quality. Effects to human health are quantified by quality-adjusted life years (QALY), a measure of costs associated with morbidity and mortality, and ecosystem quality is quantified by biodiversity-adjusted hectare years (BAHY), a measure of costs associated with biodiversity loss. Costs associated with QALY and BAHY are calculated based on contributing factors to the midpoint impact categories. Using a budget constraint argument and an estimate of average global income, it is argued that the maximum average funds available to reach full-quality of human life in a year is 72,776 (2017 USD) (Weidema 2009); further, one BAHY is equivalent to 1/14 QALY (Weidema 2009 and Weidema 2015). The results presented as costs can be interpreted as the estimated expense to balance the environmental and human health externalities, that is, to restore full QALYs and BAHYs based on the "ability to pay" (Weidema 2009).

The environmental benefits (EB) for year *t*, in dollars, from N-STaR adoption can be calculated in equation (13):

$$EB_t = [ECT - ECN] * \sum A_t Y_t. \tag{13}$$

where ECT is the environmental cost of producing one kg of traditional paddy rice and ECN is the environmental cost of producing one kg of rice with N-STaR. A_{tl} is the N-STaR acreage in in year *t* and *Yt* is the state average yield (NASS, 2020) in kilograms in year *t*. The environmental benefits must be calculated based on total number of kilograms produced under N-STaR production practices given the metric for the LCA is in kilograms of rice.

Total benefits (*TBt*) in dollars, at the state level in year *t* associated with historical N-STaR adoption attributed can be estimated in equation (14):

$$TB_t = TSavings_t + EB_t \tag{14}$$

where $TSavings_t$ is the sum of nitrogen and crop duster cost savings and the cost of testing from equation 12 and EB_t are the environmental benefits derived by the LCA from N-STaR adoption in year *t*.

Benefit Cost Ratio

As public funding becomes increasingly scarce and more competitive, holistic valuations on the benefits of public good conservation are increasingly important for project funding decisions. A such, equation 15 estimates the benefits that rice producers receive in year *t* in the form a benefit cost ratio (BCR_t) from their investments (via checkoff funds and the $1 per acre N-STaR testing fee) through N-STaR research and Total Arkansas Rice Checkoff funding, which supports the N-STaR program, in year *t* (RC_t) allocated to N-STaR research is compared to the total benefits derived from adoption in year *t* (TB_t) to estimate a benefit cost ratio (BCR_t). ultimate adoption.

$$BCR_t = \frac{TB_t}{RC_t} \tag{15}$$

Results

N Savings from N-STaR Adoption

Table 1 indicates the average recommended change by year for N application rates (lbs/ac) from N-STaR testing ranging from a low of -19.44 in 2019 to a high of -43.68 in 2017. The average recommended change from N-STaR sampling across the entire time period was a reduction of 31.08 lbs/ac. Table 1 also includes the percentage of samples which resulted a recommendation of a reduction or increase in N application per acre as a result of N-STaR testing. In each year a minimum of 75% of samples tested suggested a decrease in N application rates per acre. These results are based on the naïve assumption that producers who used N-STaR testing were initially following the blanket recommendations put forth by the Arkansas Division of Agriculture of 180 lbs/ac for clay soils and 150 lbs/ac for silt loam. Given the fact that N-STaR does not ask producers what their initial N rate was per acre, this assumption was warranted.

Table 1. Total N-STaR Tests and Recommended Change (lb/ac) in N Application via N-STaR Testing.

Year (t)	Number of N-STaR Tests[a] ($N^{*}Test_t$)	Largest Reduction in N (lbs/ac) from Blanket Recommendation[b]	Average Change in N (lbs/ac) from Blanket Recommendation[b]	Largest Increase in N (lbs/ac) from Blanket Recommendation[b]	Triangular Distribution Mean[c] ($\Delta\mathrm{F}_{tf}$) (lbs/ac)
2013	304	-125	-30.08	25	-43.36
2014	233	-120	-25.71	15	-43.57
2015	117	-105	-33.61	15	-41.20
2016	176	-115	-33.49	15	-44.50
2017	152	-105	-43.68	15	-44.56
2018	62	-120	-31.11	15	-45.37
2019	73	-90	-19.44	15	-31.48

[a] Number of N-STaR tests submitted each year.
[b] Traditional N recommendations (180 lbs/ac for clay soils and 150 lbs/ac for silt loam)
[c] From the triangular distribution mean from equation (1)

Table 2 shows the simulated average N-STaR acreage ranging from a low 341,392 acres in 2013 (N-Star's first year) to a high of 525,034 acres in 2017. To put these estimates in context, the estimated 374,718 N-STaR acres in 2019 would represent 34.83% of the total 1.08 million rice acres planted in Arkansas that year, with the majority (78%) of those acres being recycled recommendations for previous years.

Table 2. Estimated New, Recycled and Total N-STaR Acers from 2013-2019

Year (t)	Average New N-STaR Acres [a] ($NSTaR\ \ A_t$)	Average Recycled N-STaR Acres [b] ($NSTaR\ \ RecA_t$)	Average Total N-STaR Acres [c] ($NSTaR\ \ T_t$)	Percentage of Total Arkansas Rice Crop[d]
2013	341,392	0	341,392	29.40
2014	261,659	233,285	494,944	34.35
2015	131,391	338,211	469,602	40.45
2016	197,648	320,895	518,543	33.54
2017	170,696	354,338	525,034	40.05
2018	69,626	358,773	428,399	28.83
2019	81,979	292,739	374,718	34.83

[a] Average new N-STaR acres in year *t* is estimated from equation (3)
[b] Average recycled N-STaR acres in year *t* is estimated from equation (5)
[c] Average total N-STaR Acres in year *t* is estimated from equation (6)
[d]Percentage of total planted rice acreage in Arkansas (USDA NASS, 2021).

Table 3 summarizes the average changes in N application (total lbs) from N-STaR adoption ranging 11,796,133 pounds in 2019 to 23,395,502 pounds in 2017, with an average of 19,059,761. Putting the estimated average savings in N application (19,059,761) in context, that is the equivalent of reducing fertilized clay rice acres (which require 180 lbs/ac) by 105,888, or 127,065 silt loam acres (which require 150 lbs/ac).

Table 3. Total Estimated Nitrogen Savings from N-STaR Adoption

Year (t)	Average Total N-STaR Acres [a] ($NSTaR\ \ T_t$)	Average Change in Fertilizer Application [b] (ΔF_{tf}) (lbs/ac)	Average N Savings [c] ($NSavings_t$) (lbs)
2013	341,392	-43.36	14,802,757
2014	494,944	-43.57	21,564,690
2015	469,602	-41.20	19,347,619
2016	518,543	-44.50	23,075,163
2017	525,034	-44.56	23,395,502
2018	428,399	-45.37	19,436,464
2019	374,718	-31.48	11,796,133

[a] Average total N-STaR acres from Table 2
[b] From triangular distribution on Table 1
[c] Estimated from equation (7)

Table 4 illustrates the total N cost savings as a function of N-STaR adoption and N fertilizer prices annually. Although the largest application savings was estimated in 2017 at 23,395,502 pounds, the largest total N cost savings was in 2014 at of $10,633,501 which was a function of the relatively high N cost, estimated at $0.49 dollars per pound of active N. Table 4 highlights that both adoption of N-STaR as well as variance in N price drives the total benefits of N-STaR adoption. The average cost savings from reductions in N application based on the N-Star advised rate for the 2013-2019 time period was 6.96 million dollars annually.

Table 4. Total N Cost Savings

Year (t)	Total N Savings [a] ($NSavings_t$) (lbs)	Price of Nitrogen per Ton [b] ($ per ton)	Cost of Active N [c] (FP_t) ($ per lb)	Total N Cost Savings [d] ($NCostSavings_t$) (2018 Dollars)
2013	14,802,757	419.79	0.46	$6,754,401.53
2014	21,564,690	453.65	0.49	$10,633,501.63
2015	19,347,619	362.72	0.39	$7,628,009.28
2016	23,075,163	271.81	0.30	$6,817,456.51
2017	23,395,502	257.94	0.28	$6,559,386.70
2018	19,436,464	321.61	0.35	$6,794,523.06
2019	11,796,133	274.00	0.30	$3,513,196.22

[a] Total N Savings in pounds from Table 4
[b] Price of Nitrogen per ton from Oakley Fertilizer (2021) retailer in Beebe Arkansas.
[c] Cost of Active N in ($/lb) estimated from equation (8)
[d] Total N cost savings in 2018 dollars per year t, estimated from equation (9)

Table 5 highlights the cost savings associated with reductions in aerial N application as a result of N-STaR adoption. Similar to the results on Table 4, the results in Table 5 are both a function of N-STaR adoption and exogenous factors, in this case the percentage of total rice acres which were inbred and thus required two aerial N applications. Average cost savings from a reduction aerial applications for the 2013-2019 time period was 1.39 million dollars annually.

Table 5. Cost Savings from Reduction in Aerial N Application Reduction from N-STaR Adoption

Year (t)	Average Total N-STaR Acres [a] ($N^{*}T_t$)	Percentage of Inbred N-STaR Acres [b]	Total Inbred N-STaR Acres [c] (IC_t)	Inbred Acres Switching from Two to One Aerial Application [d]	Savings from N-STaR via Crop Duster Reduction [e] (2018 Dollars)
2013	341,392	0.605	206,542	134,252	$1,074,019
2014	494,944	0.607	300,431	195,280	$1,562,239
2015	469,602	0.612	287,397	186,808	$1,494,462
2016	518,543	0.562	291,421	189,424	$1,515,390
2017	525,034	0.589	309,245	201,009	$1,608,073
2018	428,399	0.589	252,327	164,013	$1,312,100
2019	374,718	0.589	220,709	143,461	$1,147,687

[a]Average total N-STaR Acres per year from Table 3
[b]Percentage total Arkansas rice acres that were sown to inbred varieties (Maiti & Bidinger, 1981)
[c]*NSTaRTt* multiplied by percentage of total rice acers in Arkansas sown to inbred varieties.
[d]An estimated 65% of producers who sown inbred varieties use two aerial N applications.
[e]From equation (10)

Increased N Application

While this study focuses on the average cost savings from N-STaR adoption there were N-STaR samples, on average 12.31% of the cases recommended an increase in N application per acre (Table A2). Unlike those samples that recommended a decrease in N application rates and were assumed to maintain yield (Roberts et al., 2012), a recommended increase in N application would require a yield increase to pay for the additional costs (of both N and sampling) to make the recommended increase in N economically viable. The average increase in N for those 12.31% of total samples that recommended an increase was 11.48 lbs/ac or a 7.65% and 6.38% increase from the blanket recommendation of 150 and 180 lbs/ac for silt loam and clay soils, respectively. Given that N-STaR does not collect producer yield data, Table A2 estimates the percent yield increase, from the state average, that producers would need to experience to cover these additional costs. On average (2013-2019) producers would need to increase yield by 0.55% to cover the costs of the increased N recommendation rate from N-STaR.

Ecosystem Benefits

While the goal of nitrogen testing is to increase N use efficiency, our findings indicate N-STaR adoption is associated with substantial ecosystem benefits. Table 6 presents the numerical results for each of the Stepwise impact categories. The single score is the sum of the estimated external costs associated with the impacts that are associated with the production of 1 kilogram (kg) of paddy rice produced under traditional N recommendations (180 lbs/ac for clay soils and 150 lbs/ac for silt loam) and the average reduction of 31.08 lbs/ac (from Table 1), as well as the reduced ecosystem impacts associated with a decrease in second aerial applications of N via N-STaR adoption. The single score for a kg of traditional rice is estimated at $0.3734 and for N-STaR it was estimated at $0.3603, a reduction of $0.0131 for every kg of rice produced with N-STaR. Global warming- fossil fuels was found as the major contributor to external environmental costs associated of rice production. To quantify the uncertainty of these results, the Simapro modeling platform was used to perform Monte Carlo simulations (MCS) using the available uncertainty information to translate the input uncertainty to output uncertainty. The results suggest a statistically significant difference ($P<0.05$) between the single score for N-STaR and the Baseline models.

Table 6. Ecosystem Impact Scores Using Stepwise LCA per Kilogram of Rice Produced Conventional Nitrogen Recommendations (Baseline) and N-STaR Production

Impact categories	Unit per kg	Scenarios	
		Baseline	N-STaR
End point impact scores			
Single Scores	US$ 2018	0.3734	0.3603[a]
Global warming, fossil	US$ 2018	0.1977	0.1912
Mid point impact scores			
Human toxicity, carcinogens	kg C2H3Cl-eq	9.65E-03	8.94E-03
	US$ 2018	3.84E-03	3.56E-03
Human toxicity, non-carc.	kg C2H3Cl-eq	5.65E-02	5.61E-02
	US$ 2018	2.31E-02	2.29E-02
Respiratory inorganics	kg PM2.5-eq	1.08E-03	1.03E-03
	US$ 2018	1.11E-01	1.05E-01
Ionizing radiation	Bq C 14.eq	3.55E+00	3.46E+00
	US$ 2018	1.07E-04	1.04E-04
Ozone layer depletion	kg CFC11-eq	7.65E-08	7.41E-08
	US$ 2018	1.19E-05	1.15E-05
Ecotoxicity, aquatic	kg TEG-eq.w	3.10E+01	3.06E+01
	US$ 2018	3.44E-04	3.40E-04
Ecotoxicity, terrestrial	kg TEG-eq.s	2.55E+00	2.43E+00
	US$ 2018	4.25E-03	4.06E-03
Nature occupation	m2 years-agr	8.78E-02	8.77E-02
	US$ 2018	1.64E-02	1.64E-02
Global warming, non-fossil	kg CO2-eq	1.38E+00	1.38E+00
	US$ 2018	0.00E+00	0.00E+00
Global warming, fossil	kg CO2-eq	1.58E+00	1.53E+00
	US$ 2018	1.98E-01	1.91E-01
Acidification	m2 UES	7.59E-02	6.98E-02
	US$ 2018	8.86E-04	8.14E-04
Eutrophication, aquatic	kg NO3-eq	6.29E-03	6.25E-03
	US$ 2018	9.63E-04	9.55E-04
Eutrophication, terrestrial	m2 UES	1.84E-01	1.59E-01
	US$ 2018	3.44E-03	2.97E-03
Respiratory organics	pers ppm-h	2.12E-03	2.10E-03
	US$ 2018	8.30E-04	8.22E-04
Photochemical ozone, vegetat.	m2 ppm-hours	1.93E+01	1.91E+01
	US$ 2018	1.08E-02	1.07E-02
Non-renewable energy	MJ-primary	7.11E+00	6.79E+00
	US$ 2018	0.00E+00	0.00E+00
Mineral extraction	MJ-extra	1.90E-02	1.83E-02
	US$ 2018	1.18E-04	1.13E-04

[a]Single score differences (between N-STaR and Baseline) significant at the $P<0.05$ level.

To estimate the total ecosystem benefits of N-STaR adoption, the difference between the ecosystem single scores for N-STaR and the traditional N application rate produced rice ($0.0131) was multiplied by the total kg of rice produced under N-STaR for each year *t*. Table 7 indicates that the average ecosystems services provided by N-STaR adoption was 19.72 million dollars annually. To put this in perspective, this is 283% larger than the annual average cost savings from N reductions ($6.957 million) and 1,418.71% larger than the average cost savings from reductions second aerial applications of N ($1.39 million). The ecosystem values on Table 7 need to be interpreted with some caution. There are currently no markets for these ecosystem services and the benefits are not simply accrued by N-STaR rice producers, but rather by all of society. That being said, these benefits are not trivial and as production agricultural becomes more aware of the value of ecosystem preservation metrics like this may start being used for funding decisions or policy analysis.

Table 7. Ecosystem Benefits (2018 USD) from N-STaR Adoption in Arkansas: 2013-2019

Year	Average N-STaR Acres[a]	Average State Yield (kg/ac)[b]	Ecosystem Services (2018 USD)[c]
2013	341,392	3,429.16	15,277,607
2014	494,944	3,429.16	22,149,180
2015	469,602	3,329.37	20,403,592
2016	518,543	3,138.86	21,240,804
2017	525,034	3,397.41	23,278,200
2018	428,399	3,411.02	19,069,837
2019	374,718	3,392.87	16,591,529

[a]Derived from Table 2
[b]USDA NASS, 2021
[c]From equation (13)

Benefit-Cost Ratio

Table 8 highlights the average total benefits (average N cost savings, average cost savings from reduction in crop dusters and value of environmental benefits) from N-STaR adoption in Arkansas. Average benefits per year were estimated at 28.06 million (2018 USD), of which 70% are ecosystem benefits, 25% N cost savings, and 5% aerial application savings.

Table 8. Average Total Benefits (2018 USD) from N-STaR Adoption in Arkansas: 2013-2019

Year	Average Total N Cost Savings[a]	Average Savings from N-STaR via Crop Duster Reduction[b]	Ecosystem Services[c]	Average Total Benefits[d]
2013	6,754,402	1,074,019	15,277,607	23,106,028
2014	10,633,502	1,562,240	22,149,180	34,344,921
2015	7,628,009	1,494,463	20,403,592	29,526,064
2016	6,817,457	1,515,390	21,240,804	29,573,651
2017	6,559,387	1,608,073	23,278,200	31,445,660
2018	6,794,523	1,312,101	19,069,837	27,176,461
2019	3,513,196	1,147,687	16,591,529	21,252,413
Average	6,957,211	1,387,710	19,715,821	28,060,742

[a]From Table 4
[b]From Table 5
[c]From Table 7
[d]Summation of average total cost savings, savings from reductions in crop duster N applications and ecosystem services.

There are several ways to evaluate the benefit-cost ratio (BCR) of the N-STaR program. First, given producers must pay an estimated one dollar per acre of testing, a simple BCR of direct costs to producers can be estimated. Table 9 indicates that for every dollar that producers spend on N-STaR tests they receive an average benefit of \$18.57 and \$62.43 without and with ecosystem services, respectively. Even at its lowest return (12.44 to 1 in 2019 without ecosystem benefits), it appears that N-STaR testing more than pays for itself for rice producers. However, the results on Table 10 only account for the variable costs of on-farm soil testing and does not account for the fixed costs of mandatory rice check-off contributions which are also used to fund N-STaR.

Table 9. Benefit Cost Ratio of N-STaR for Producers Using Per Sample Costs

Year	Total Benefits Without Ecosystem Services[a]	Total Benefits With Ecosystem Services[a]	Cost of Testing[b]	BCR Without Ecosystem Services	BCR With Ecosystem Services
2013	7,828,421	23,106,028	341,392	22.93	67.68
2014	12,195,741	34,344,921	494,944	24.64	69.39
2015	9,122,472	29,526,064	469,602	19.43	62.87
2016	8,332,847	29,573,651	518,543	16.07	57.03
2017	8,167,460	31,445,660	525,034	15.56	59.89
2018	8,106,624	27,176,461	428,399	18.92	63.44
2019	4,660,884	21,252,413	374,718	12.44	56.72
Average	8,344,921	28,060,742	450,376	18.57	62.43

[a]From Table 8
[b]Equivalent to average number of N-STaR acres (Table 2) and assuming a cost of one dollar per acre testing fee.

The results on Table 10 account for the average additional annual costs of $78,521 which rice producers paid, via the rice check-off program, to fund N-STaR development and dissemination. With the inclusion of the fixed costs associated with N-STaR, the average BCR decreases marginally to 15.74 and 53.66:1, without and with ecosystem benefits, respectively. Average annual total benefits without ecosystem services was estimated at 8.34 million dollars for a total benefit of 58.41 million dollars (Table 9). The inclusion of ecosystem benefits increases average total benefits to 28.06 million dollars for a total benefit of 196.43 million dollars (Table 8). Thus, not accounting for ecosystem benefits underestimates the total benefits of NSTaR by 336%.

The objective of quantifying the environmental benefits of programs like N-STaR is to use the information to shape funding policies and provide incentives for better management of N. Despite these estimated benefits, the inherent drawback of managing environmental externalities is that in many cases producers do not directly benefit from the lower environmental burdens. However, even if producers do not directly derive financial benefits from providing environmental services, their activities provide large benefits to other individuals (Power, 2010). This is true for N reduction programs like N-STaR, as the Mississippi and Atchafalaya (both flowing through rice producing regions of the US) basins combined account for 90% of total N export from the US to the Gulf of Mexico, resulting in the second largest human induced hypoxic zone worldwide, and having negative economic consequences including the decline of commercial fishing and recruitment failure of valuable species (Lu et al., 2020; Jones et al., 2018 and Diaz and Solow, 1999).

Table 10. Benefit Cost Ratio (2018 USD) for N-STaR with Inclusion of Checkoff Fund Contributions and on-farm N-STaR Testing Costs

Year	Check-Off Funds[a]	Producer Cost of Testing[c]	Benefits Without Ecosystem Services[c]	Benefits With Ecosystem Services[c]	BCR Without Ecosystems Services	BCR With Ecosystems Services
2013	$296,778[b]	$341,392	7,828,421	23,106,028	12.27	36.21
2014	$69,833	$494,944	12,195,741	34,344,921	21.59	60.81
2015	$53,882	$469,602	9,122,472	29,526,064	17.43	56.4
2016	$53,359	$518,543	8,332,847	29,573,651	14.57	51.71
2017	$33,294	$525,034	8,167,460	31,445,660	14.63	56.32
2018	$32,500	$428,399	8,106,624	27,176,461	17.59	58.96
2019	$10,000	$374,718	4,660,884	21,252,413	12.12	55.24
Average	$78,521	$450,376	$8,344,921	$28,060,742	15.74	53.66
Total	$549,646	$3,152,632	$58,414,449	$196,425,198	-	-

[a]Arkansas Rice Board Checkoff funds specifically allocated towards N-STaR research (Peterson et al. 2020)
[b]Summation of Rice Board Checkoff funding from 2010-2013. Innovation funding was made available prior to commercial adoption of N-STaR in 2013.
[c]From Table 9

Individual Producer Benefit Cost Ratio

While rice producers are likely concerned with environmental services provided by soil testing, they are primarily driven by the economic returns of the test results. Specifically, producers typically compare the benefits of the test (in this case changes in N recommendations) versus the cost of the soil test (with the case of N-STaR, one dollar per acre). Furthermore, most producers view check-off funds as a fixed (mandatory) cost where soil testing is a variable cost which must cover itself economically. As such, a per acre, yearly BCR can be estimated only focusing on the cost per test ($1), the simulated yearly change in fertilizer usage from N-STaR adoption (equation 1), the price of fertilizer in year *t*, and reduction in aerial application costs (equation 10). Table 11 highlights the simulated mean and 90% confidence interval for a per acre BCR of N-STaR test from 2013-2019. Results indicate that on average for every dollar a rice producer invests in an N-STaR test they receive a return of $18.57 (via a reduction in cost). The yearly variation is driven by both the yearly recommendations of N-STaR to producers who submitted samples as well as yearly fluctuations in fertilizer price. The 90% confidence interval ranges from 0.7 (indicating for every dollar you invest you get a return of 0.70 cents) to $39.7 to one. The lower bound is likely due to the simulation results accounting for those instances when producers were simulated to have an increase in costs due to higher N recommendations but not accounting for any yield gains which may be associated with those higher N rates. The BCR on Table 11 are higher than those on Table 10 (without ecosystem benefits) as Table 11 does not account for check-off funds used for the creation and implementation of N-STaR.

Table 11. Estimated N-STaR Individual Producer Benefit Cost Ratio

Year	5%	Mean	95%
2013	1.08	22.93	48.3
2014	3.94	24.64	50.0
2015	4.03	19.43	36.42
2016	3.78	16.07	30.13
2017	4.13	15.56	27.17
2018	4.01	18.92	36.49
2019	2.62	12.44	24.16
Pooled	0.7	18.57	39.7

Conclusions

Given increased competitiveness and reduction in funding from many public granting agencies, there is a need for a concerted effort to better estimate the holistic impacts to producers and the environment of publicly funded projects. This study examined the benefits from the Arkansas Rice Checkoff program, who funds public rice research, and from individual rice producers who pay for individual soil tests, from their investments made between 2013 and 2019 in N-STaR. Given that rice producers both fund N-STaR via rice checkoff funds (a fixed cost) and via individual soil tests conducted on-farm, we analyze the BCR from both a total (fixed and variable) and variable cost metric. N-STaR was designed to provide field specific N application information and to address the tendency for producers to overapply N. Approximately 88% of N-Star recommendations between 2013-2019 were to reduce N applications and those 12% who were recommended an increase in N per acre (11.48 lbs/ac) likely experienced marginal gains in yield. Unlike yield-enhancing research that can have quick tangible benefits, input reduction research typically leads to marginal reductions in costs which producers can easily misidentify as simply adopting best management practices. That being said, there are often acknowledged but seldom quantified benefits associated with input-savings technologies such as N-STaR, specifically related to fertilizer, such as the avoided environmental impacts provided via N reduction. Our findings suggest that by overlooking the environmental benefits of N-STaR adoption, the benefit-cost ratio would be underestimated by 286%.

While the estimated ecosystem benefits provided by N-STaR are relatively large (compared to the estimated cost savings from adoption), the benefits are not simply accrued by N-STaR rice producers, but rather by all of society. While producers do benefit from a variety of ecosystem benefits, their activities may strongly influence the delivery of services to other individuals who do not control the production of these services. This is especially true for N runoff in the Mississippi River watershed in the United States. The challenge is to use estimates from studies like this to develop policies and incentives that are easily implemented and adaptable to changing ecological and market conditions. Soil N tests have traditionally been evaluated in terms of increased yield; however, they have gained a wider audience, as N runoff implications have gained international focus and soil health is becoming an environmental, human health, and political issue.

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