HortScience 57(11):1387–1396. 2022. https://doi.org/10.21273/HORTSCI16656-22

Choosing Nitrogen Application Rate Recommendation Given Florida's Regulatory Water Policy

Fei He
Food and Resource Economics Department, University of Florida, Gainesville, FL, USA

Tatiana Borisova
U.S. Department of Agriculture, Washington, DC, USA

Kevin Athearn and Robert Hochmuth
North Florida Research and Education Center—Suwannee Valley, University of Florida, Live Oak, FL, USA

Charles Barrett
Formerly at North Florida Research and Education Center—Suwannee Valley, University of Florida, Live Oak, FL, USA

Keywords. agricultural water quality policy, agricultural best management practices, Florida, carrots, net return, risk

Abstract. **State and federal policies in the United States focus on agricultural best management practices (BMP)—such as improving nutrient management—to address water quality issues. BMP development is a challenging process as a new BMP may also affect farm profitability. This article explores the economic feasibility of nitrogen (N) management programs, including nitrogen application rates (N rates), given alternative scenarios for current nitrogen use and producer risk perceptions of carrot production in Florida. In this study, eight alternative N rates are ranked to find the economically optimal BMP. Carrot profitability is determined based on carrot yields per hectare, input costs, and carrot sale prices, using data from a 2-year carrot production experiment. The analysis applied stochastic simulation to account for the uncertain factors by using Simetar Add-In for Excel. We found that 224 kg·ha^{-1} N fertilizer rate is the most preferred by the producers among the eight rates considered. According to Florida's agricultural water policy, BMP recommendations should balance water quality improvements and agricultural productivity. We consider the potential reduction of nitrogen fertilizer rate BMP from 224 kg·ha^{-1} to 168 kg·ha^{-1} and show that the effect of such reduction depends on producers' current fertilizer application rates and their risk aversion levels. For example, reducing the N fertilizer rate from 336 kg·ha^{-1} to 168 kg·ha^{-1} decreases mean net returns by only 2% ($49/ha). In contrast, reducing the nitrogen fertilizer rate from 224 kg·ha^{-1} to 168 kg·ha^{-1} reduces the mean net returns by $151/ha, with an almost 10% reduction in the certainty equivalent of the net returns (for extremely risk-averse producers). Overall, if most producers in the region are very or extremely risk-averse, and if most of them operate close to the optimal level of fertilizer use, then setting the more restrictive BMP of 168 kg·ha^{-1} N can be perceived as undermining their economic profitability and require significant cost-share incentives to ensure targeted 100% adoption of BMP recommendations.**

In the United States, the individual states have the primary authority to regulate agricultural water pollution through agricultural best management practices (BMPs) [33 U.S.C. §1329(a)(1)(C)]. While program design varies among the states (Majsztrilk and Lea-Cox, 2013; Merhaut et al., 2013), most states rely on voluntary policies supported by cost-share programs. A few states (e.g., Maine, North Carolina, Maryland, and Pennsylvania), however, employ a regulatory approach that specifies agricultural practices to be used, such as bans on manure and fertilizer applications, setback standards on river banks, or required BMP program participation (Baerenklau et al., 2016; Kling, 2013). Even though the literature calls for precision conservation strategies to account for site-specific conditions (Baylis et al., 2022; Claassen and Ribaudo, 2016), such tailored practices and prohibitively costly to monitor and enforce when they are combined with the regulatory approach (Claassen, 2012; Claassen et al., 2014). As a result, a regulatory framework usually relies on uniform requirements applied across locations and periods.

This study discusses the choice of nitrogen fertilizer application rate recommendation as a part of Florida's uniform nitrogen application policy requirement. Specifically, we used an emerging crop in North Florida—carrot—as a case study and identified producers' most preferred nitrogen (N) application rate among eight rates considered in the production experiment (Hochmuth et al., 2021). We then explored potential economic impacts for the producers from setting a more restrictive N application rate as the policy recommendation. Perhaps not surprisingly, we found that if the current level of fertilizer use significantly exceeds the economically optimal levels, the impact of the restrictive policy requirement on producers' returns is relatively small. In other words, if producers significantly exceed the optimal N rate, they may gain from reducing N applications even if the reduction results in a below optimal N rate. However, if the current N rate is close to the optimal, reducing fertilizer use beyond this level to meet the policy recommendations would lower producers' returns substantially, potentially requiring economic incentives (Mack et al., 2017). Producers' risk preferences also affect their ranking of alternative N application rates. Overall, this study contributes to the literature on selecting N application rate recommendations considering producers' risk preferences and production and market uncertainties, given that such recommendations are part of a regulatory policy framework.

Study area. Florida is one of the top 20 U.S. agricultural states, leading the United States in the production of citrus, fresh market vegetables, floriculture, and sugarcane (Hudson, 2021), with almost $6 billion in total crop cash receipts in 2020 [U.S. Department of Agriculture (USDA), Economic Research Service (ERS), 2021]. At the same time, Florida is a prime water-based tourism destination (U.S. Bureau of Economic Analysis, 2017), with tourism activities dependent on visitors' perceptions of water quality and availability. Agricultural activity is a primary source of water pollution in several Florida regions [Basin Management Action Plans, Florida Department of Environmental Protection (FDEP), 2021]. The state strives to develop balanced water quality policies that protect water resources while also allowing for a thriving agriculture-based economy.

Florida water quality policy requires producers in many of its regions to implement all the relevant BMPs from the state-adopted manuals, the alternative being a potentially costly monitoring program to prove producers' activities do not have negative impacts on water resources. The Florida's BMP program is different from that implemented by the USDA NRCS conservation practices nationwide. Whereas USDA programs are voluntary (USDA, Natural Resources Conservation Service, undated), Florida's program includes enforcement actions for nonparticipants operating in areas with state-adopted watershed management plans (Basin Management Action Plans). Alternatively, producers can use monitoring to prove no impact on water resources [Fla. Stat. 403.067(7)(b)2g].

Although the practices included in the Florida program are referred to as BMPs, they may include practices that are not driven by producers' improved efficiency of production input use or gaining producers' private benefits but instead be intended primarily to protect the environment. Florida's agricultural BMPs are intended to "benefit water quality and water conservation while maintaining or even enhancing agricultural production" [Florida Department of Agriculture & Consumer Services (FDACS), 2022], and they must "reflect a balance between water quality improvements and agricultural productivity" [Section 373.4595(2)(a), Florida Statutes]. This definition is usually interpreted as requiring the BMPs to be economically feasible for producers. Therefore, if a BMP can significantly influence agricultural profitability, the BMP implementation costs are expected to be compensated through a cost-share program.

In this article, we used the N application rate for carrot production in North Florida as a case study to show that producers' N application rates and risk perceptions can impact the perceived economic feasibility of a BMP. If producers perceive the BMP impact on profitability as high, then incentive payments, combined with monitoring and enforcement, may be needed to ensure BMP adoption.

Carrot was selected because it is an emerging crop in the region and has no specific BMPs yet included in the state's vegetable and agronomic crop BMP manual (FDACS, 2015). Carrot production in Florida has been growing, with an almost 100% increase in carrot production area between 2012 and 2017. Although the total carrot production area is still small (i.e., 1722 ha in 2017), there is significant interest in the crop, especially in North Florida, where carrot could potentially increase the agricultural returns. The study area is primarily rural, with a patchwork of small- and medium-sized farms along with several large farms, where most producers, regardless of size, are seeking revenue-enhancing opportunities. The average household income in the region is below the Florida average, and the poverty rate is above the state average. For comparison, the 2019 median household income was $47,800 in Suwannee County (which is at the heart of the study area), with 17.1% of the population living in poverty. Statewide, 2019 median household income was $55,700, with 12.7% of persons living in poverty (U.S. Census Bureau, 2020). New crops that can enhance the agricultural economy are of considerable interest for the region.

The effective management of water resources is also a priority in the region, given its karst geology and unique freshwater springs that support a tourist-based economy. Total maximum daily load (TMDL) for the Suwannee River and associated springs was adopted in 2008 (FDEP, 2018). Given the sensitive spring ecology, the nitrate water quality goal is 0.35 mg/L for the Suwannee River and associated springs. In 2020, more than 85% of the nitrogen loading to groundwater in the springsheds was attributed to agricultural fertilizer and livestock waste. Achieving the 35% to 58% leaching reductions stipulated in the regional TMDL goal can require substantial reductions in the nitrogen fertilizer application rates and, possibly, net returns. The total load reduction required to meet the goal at the spring vents is estimated to be 1,848,813 kg of N per year (kg-N/yr) (FDEP, 2018). Overall, the state is seeking to identify the BMPs that could balance the economic and environmental priorities.

Method

Economic and production uncertainty affects producers' choices. In the absence of regulations, producers may prefer N application rates that increase the chance of high payoffs or reduce variability and avoid risks (Dillon, 1971; Hardaker, 2006; Ladányi, 2008; Paulson and Babcock, 2010). In this study, simulations were used to explore the carrot net return distributions given different N application rates. Simulations were chosen over other research methods of N rate analysis, such as examining yield and profit goals, incremental agronomic N efficiency, incremental gross return above fertilizer cost, or production function estimation (Dobermann et al., 2004; Havlin, 2004; Murrell, 2004; Neeteson and Wadman, 1987; Sutherland et al., 1986; Webb, 2009). Simulations allowed us to account explicitly for the risks and producers' risk preferences (Mun, 2006; Richardson et al., 2007). Specifically, we accounted for production risks associated with carrot yield variability and for marketing risks linked to carrot sales and nitrogen fertilizer prices.

Carrot net returns (R) were estimated on a per-hectare basis as the difference between total revenues and costs using the following equation:

$$\begin{aligned} R(N) = {} & Y_u(N, \epsilon) * 0 + Y_c(N, \eta) * P_c \\ & + Y_j(N, \delta) * P_j - N * C_N \\ & - n(N) * C_M - C_f, \end{aligned}$$

where N refers to the nitrogen application rate (kg·ha^{-1} N). Nitrogen fertilizer can influence the size of carrot roots (Hochmuth et al., 1999; Moniruzzaman et al., 2013). In this study, Y_u, Y_c, and Y_j refer to unmarketable, cello, and jumbo yields, respectively (kg·ha^{-1}). Large-sized (jumbo) carrots are sold to institutions and receive lower prices than middle-sized (cello) carrots that target retail markets. Small-sized carrots are defined as unmarketable. The yields depend on the N rate and random variables, ϵ, η, and δ, which reflect variations in yield, depending on soil characteristics, weather, and other uncertain factors. Note that the random variables are jointly distributed because unmarketable, cello, and jumbo carrots are components of the same total yield. In turn, P_c and P_j are the prices of cello and jumbo carrots ($/kg), respectively, and are modeled as random variables. Next, C_N denotes the nitrogen fertilizer price (ammonium nitrate, $/kg), which is assumed to be a random variable. Next, $n(N)$ is the number of times the nitrogen fertilizer is applied to the field over a production season, and C_M is the cost of each N application (other than the cost of the fertilizer itself, $ per application). The number of applications, n, increases stepwise with N, as in the approach used in the University of Florida's production experiment. Finally, C_f denotes other costs ($/ha) that are assumed to be fixed.

The Monte Carlo simulation method is a sampling technique that allows converting the probabilities of the model input variables into the probability distributions for the model output. For randomly selected values from the input variable distributions, the model output is calculated many times (once for each set of the input variable values), thus quantifying the probability of each output value (Amigun et al., 2011). The Monte Carlo simulation method was implemented in Simetar Add-In for Excel (Richardson, 2008), with 1000 iterations of all random variables affecting the carrot net returns.

Producers hold different perceptions for risky situations, and the degree of risk aversion influences producers' N rate decisions (Hardaker et al., 2015; Kingwell, 2011; Pannell et al., 2000). Studies have shown that most producers are risk-averse (Henrich and McElreath, 2002; Kimball, 1988; Menapace et al., 2013); that is, producers prefer outcomes that are known with certainty and are willing to pay to reduce the uncertainty. We accounted for producer preferences over various distributions of net returns by using the stochastic efficiency with respect to a function (SERF), which is a utility-based ranking tool developed for Simetar Add-In for Excel (Hardaker et al., 2004; Richardson, 2008). Specifically, SERF was used to order producers' preferences among alternative fertilizer rates and net return distributions based on certainty equivalents (CE). A certainty equivalent of a gamble is the amount of money for which, if a choice between the money and the gamble is given, the person is indifferent between the two (Guyse, 2001). In other words, a certainty equivalent is the amount of money a producer would perceive as equivalent to the distribution of the net returns. The most preferred decision has the highest CE (Hardaker and Lien, 2010)

Received for publication 30 Apr 2022. Accepted for publication 28 Jul 2022.

Published online 6 Oct 2022.

This paper is largely based on Fei He's MS thesis, which she completed as part of her degree requirements in the Food and Resource Economics Department, University of Florida.

This study is partially funded by the project "Floridan Aquifer Collaborative Engagement for Sustainability" (FACETS), supported by the National Institute of Food and Agriculture, United States Department of Agriculture, under award number 2017-68007-26319. This research was also supported in part by the U.S. Department of Agriculture, Economic Research Service. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy. We appreciate the review and feedback for the manuscript from Dr. Wendy Graham, Swisher Eminent Scholar, Director of the University of Florida Water Institute, and the principal investigator of FACETS project.

F.H. is the corresponding author. E-mail: he.fei@ufl.edu.

This is an open access article distributed under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/).

because it indicates that the producer would only forgo a risky gamble for a high, fixed amount of money. For a risk-neutral producer, CE is equal to the mean net return. The higher the degree of risk-aversion, the smaller the CE that the producer is willing to accept instead of the risky production returns. Additional discussion of CE is presented in Supplemental Material 1.

The calculation of CE requires assumptions about the producers' utility functions and risk-aversion levels. The negative exponential utility function is a nondecreasing and concave utility function commonly used to model decisions and to account for risk aversion (Saha, 1993). The negative exponential utility function can be expressed as

$$U(w) = -e^{(-rw)},$$

where r is the producers' absolute risk aversion coefficient, and w is producers' wealth. As in similar studies (Hardaker et al., 2004; Smith et al., 2012), we assumed that wealth is equal to the average simulated carrot net return. Further, we assumed constant absolute risk aversion (CARA), implying that producers' risk aversion does not change with wealth (Babcock and Blackmer, 1992; Lien, 2002; Hardaker et al., 2004). In this study, a range of risk-aversion levels has been modeled considering the relative risk aversion coefficient (RRAC) values between 0.0 and 4.0, to represent risk perceptions, ranging from risk-neutral to extremely risk-averse (Hardaker et al., 2015). According to the Arrow–Pratt measures of risk aversion coefficient, the absolute risk aversion coefficient (ARAC) can be calculated using the relative risk aversion coefficient (RRAC) divided by farmers' wealth (Hardaker et al., 2004).

Data: carrot production experiments. Carrot yield and N rates are based on the production experiment conducted during the 2016–17 and 2017–18 production seasons at the University of Florida (Hochmuth et al., 2021). To partially address the concern that a 2-year production experiment is too short to capture the whole range of possible weather conditions during production season, we verified our yield analysis against the data from another production experiment implemented in the 2018–19 production season in the same area, as discussed next.

The 2-year carrot production experiments conducted at the University of Florida's North Florida Research and Education Center (Suwannee Valley) focused on evaluating N rates using the 4-Rs principles—right rate, right source, right placement, and right timing (Hochmuth et al., 2018, 2021; Mikkelsen, 2011; Santos, 2011). Two fresh market carrot cultivars—Choctaw and Maverick—were planted. For each cultivar, eight N rates were applied: 56, 112, 168, 224, 280, 336, 392, and 448 kg·ha^{-1} N. Because carrot is an emerging crop in North Florida, N application rates used by producers in the region vary widely. Generally, it is anticipated most producers apply between 224 and 392 kg·ha^{-1} N. The production experiment was designed to cover and exceed the range of N rates used by the producers.

All the other inputs were applied using cultural practices typical for the region. Following the standard design of production trials, plots were arranged in a split-plot design with four replications. In addition, preplant broadcasts of potassium, micronutrients, and lime were applied to the field based on soil test results. After planting, N applications involved ammonium nitrate at an appropriate schedule. This experiment relied on the dry nitrogen fertilizer application banding method. No N was applied to the row middles as it would be in any less efficient applications. Soil moisture sensors (SMS) were used to optimize irrigation scheduling and rates.

The crop was harvested in April, during weeks 23 and 24 after planting. At harvesting, 15 roots were randomly selected from each experimental plot, and the diameter, length, and weight of each of the 15 roots were measured. For commercial carrot production, qualities that include root size and uniformity can be used to classify marketable and unmarketable carrot yields (University of Georgia Extension, 2012). On the basis of the information from Florida carrot producers, carrots with a caliper of less than 1.4 cm were defined as unmarketable. Carrots with a caliper that exceeded 3.8 cm were sold as jumbo carrots at a lower price [Hochmuth et al., 1999; USDA, Agricultural Marketing Service (AMS), 2020]. Carrots with a caliper between 1.4 and 3.8 cm were sold as cello carrots at a higher price. This analysis used the marketable proportions of 15 roots sampled from each plot to estimate the total marketable yields in each plot; cello and jumbo yields were calculated using the same method.

In turn, the 2018–19 carrot production experiment was conducted at the University of Florida research field in the same region. The goal of the experiment, however, was to analyze the interaction of N fertilizer application rate and irrigation scheduling method on carrot yield. The experiment followed a randomized complete block design with split plots on 1.5 ha. Maverick cultivar carrots were planted, with only three N fertilizer rates: 112, 224, and 336 kg·ha^{-1} N. Preplant application rate was 28 kg·ha^{-1} N, and the remaining N fertilizer was applied over eight separate applications about every 2 weeks. The experiment included four irrigation treatments: calendar-based, irrigation app decision support system, SMS, and no supplemental irrigation. The carrots were harvested during week 24 after planting. No measurements of carrot caliper were made, and the marketable yield's proportion in the total yield was based on the results of the experiment described earlier. Given the difference in the design of this production experiment, its result is used for yield verification purposes only.

Productions costs were based on the University of Florida Extension carrot production budget developed for North Florida (Athearn, 2019). The carrot production experiment used ammonium nitrate (34–0–0). Figure 1 shows the historical ammonium nitrate fertilizer price for 1980–2014, with all the prices adjusted to May 2018 using the consumer price index (U.S. Bureau of Labor Statistics, 2022). The average price of N during this period was \$1.36/kg/ha, the maximum price was \$2.04/kg, and the minimum price was \$0.88 kg. On the basis of the historical prices, a nonparametric empirical distribution for nitrogen fertilizer prices was derived using Simetar Add-In for Excel (Richardson, 2008).

Historical weekly prices for cello and jumbo carrots grown in Georgia were analyzed as the most relevant for North Florida production. USDA reported weekly prices from 2014 to 2018, with no price data before 2014 (USDA-AMS, 2021). A typical North Florida harvesting season is from March to May, so weekly prices for this period were selected and adjusted using the consumer price index (U.S. Bureau of Labor Statistics, 2022). Note that the number of weeks for which the price observations were available differs among years and between cello and jumbo carrots. Overall, the jumbo carrot sale price was highly variable, with the price ranging from \$0.33/kg in May 2017 to \$0.84/kg in Mar 2018. The cello carrot sale price varied less, ranging from \$0.57/kg in May 2014 to \$0.81/kg in May 2016. The trends of the weekly sale prices for both cello and jumbo carrots differed among the years (Fig. 2 and Fig. 3, respectively). Overall, the cello and jumbo prices were correlated, with a correlation coefficient equal to 0.567 (i.e., both prices generally rose and fell together). The historical mean of the cello carrot price was \$0.66/kg, whereas the mean of the jumbo carrot price was \$0.57/kg. On the basis of the historical prices, a nonparametric empirical distribution for the prices was derived using Simetar Add-In for Excel. The prices were observed to be jointly distributed, and a multivariate empirical distribution (MVE) that accounts for the correlation among the two prices was used (Richardson, 2008).

Analysis. We combined the two carrot cultivars and two production seasons from the 2016–17 and 2017–18 production experiments (based on the results of t, F, and two-sample Kolmogorov–Smirnov (K-S) tests for yield compared between production seasons and cultivars). To represent the price difference between cello and jumbo carrots accurately, this analysis used the cello, jumbo, and unmarketable yield proportions based on the 15 roots sampled from each plot. Table 1 shows the summary statistics for the yield, and Fig. 4 shows the average proportion of the yields for each N rate. The N rate of 224 kg·ha^{-1} resulted in the highest mean for the total yield [mean = 69,469 kg·ha^{-1}, coefficient of variation (CV) = 8.3%] and marketable yield (mean = 69,265 kg·ha^{-1}, CV = 8.4%). However, the results indicated that the mean and variance of total yield and marketable yield for 224 kg·ha^{-1} N are not statistically different from 168, 280, 336, 392, and 448 kg·ha^{-1} N at the 95% confidence level ($P > 0.05$).

We verified our results against the data from the 2018–19 production experiment, focusing on the SMS-based irrigation treatment (i.e., four

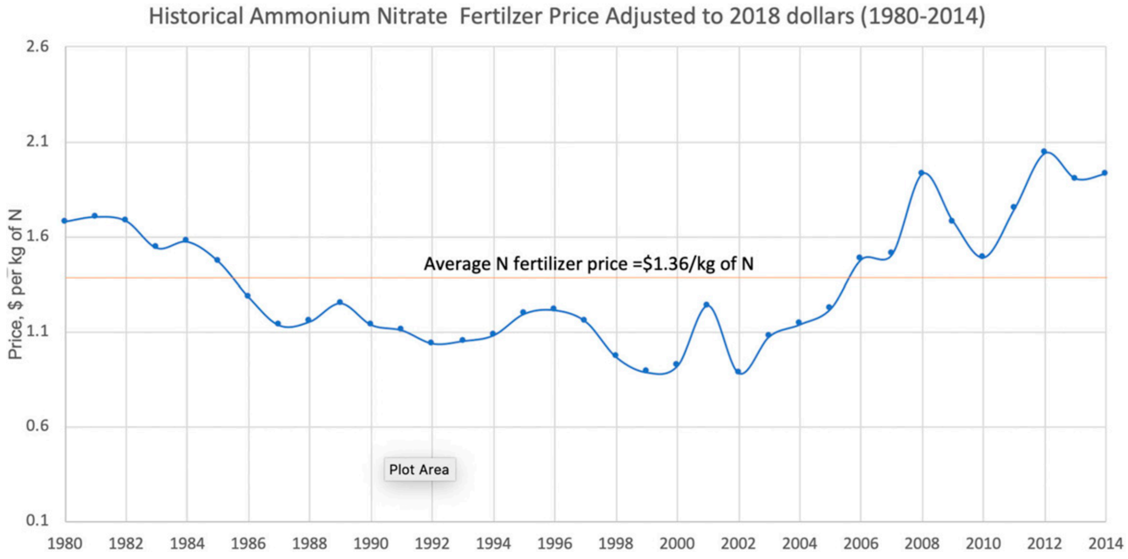

Fig. 1. Historical ammonium nitrate fertilizer price. Historical ammonium nitrate fertilizer price adjusted to May 2018 dollars. Data after 2014 are unavailable. Source: U.S. Department of Agriculture, Economic Research Service (2019).

plots for each N application rate treatment). The t and F tests indicated that the yield of 112, 224, and 336 kg·ha^{-1} N for the two experiments was not statistically different.

Net return analysis. To explore the effect of the N rate on carrot net returns, we obtained the net returns distribution for the eight rates by simulating carrot yield, carrot price, and nitrogen fertilizer price. Multivariate empirical distributions for each N rate were based on total yield and yield proportions observed in the production experiment. A nonparametric empirical distribution based on 1980–2014 data were used to simulate nitrogen fertilizer prices. Historical weekly sales prices for cello and jumbo carrots were found to be positively correlated. Therefore, a MVE was developed, accounting for the correlation among the sale prices. In addition, unmarketable, cello, and jumbo yields were simulated using MVE to account for the correlation among the three yields under each N rate.

The summary statistics for carrot stochastic net returns are shown in Table 2, and the box-plot diagram of the statistics is presented in Fig. 5. Results show 224 kg·ha^{-1} N has the highest mean compared with the other N rates, although the t, F, and K-S tests indicated that the mean, variance, and distribution of the simulated net returns for 224 kg·ha^{-1} N and 280 kg·ha^{-1} N were not statistically different at the 95% confidence level ($P < 0.05$). Further, the mean simulated net return for 224 kg·ha^{-1} N was different from 168, 336, 392, and 448 kg·ha^{-1} N ($P < 0.05$). In other words, setting a BMP requirement of 224 kg·ha^{-1} N should improve or leave unchanged the average net return for all producers.

The stoplight charts in Fig. 6 summarize the stochastic returns for various N application rates for risk-neutral producers. The chart shows the probability of getting returns less than $1000/ha and greater than $2500/ha, where the lower and upper cutoff values are used for illustration purposes only to compare the nitrogen application rates and highlight the differences among their outcomes. The chart shows that for the rate of 224 kg·ha^{-1} N, the return stays above $1000/ha, and there is also a 54% chance for the return to exceed $2500/ha. The probability of high returns above $1000/ha is slightly lower for the other nitrogen application rates. For example, given 168 kg·ha^{-1} N, the probability of getting $2500/ha is 49%, and there is also a 2% risk that the return falls below $1000/ha.

The cumulative distribution functions (CDFs) of simulated net returns given the eight N rates are presented in Fig. 7A–C. In the figures, the CDFs that shifted to the right indicate higher cumulative probabilities of large net

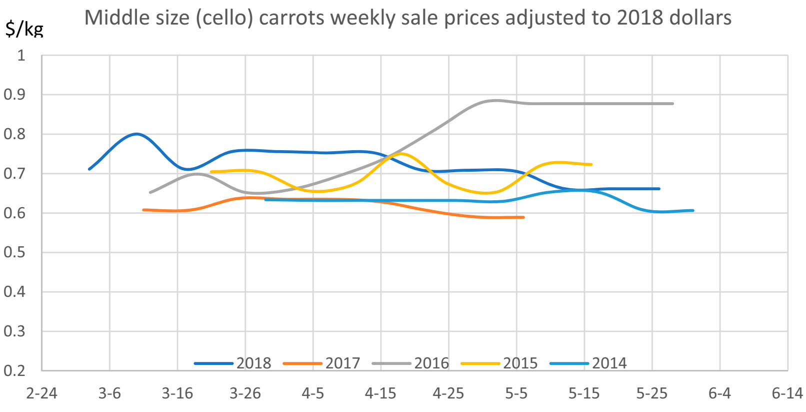

Fig. 2. Middle size (cello) carrot sale prices. Georgia data, adjusted to May 2018 dollars. Source: U.S. Department of Agriculture, Agricultural Marketing Service (2021).

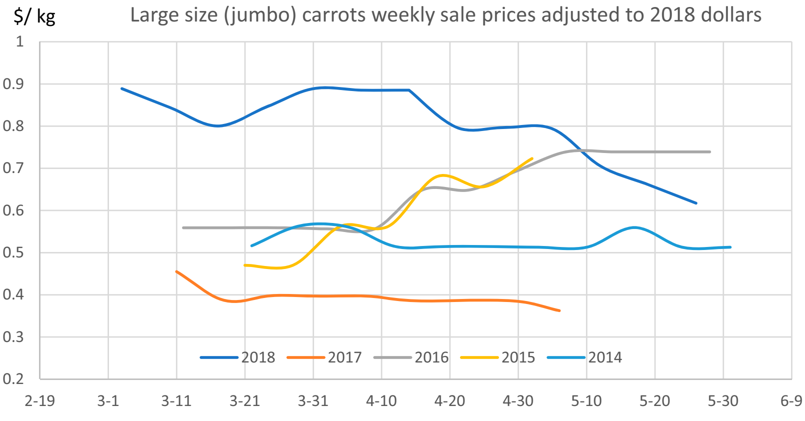

Fig. 3. Large (jumbo) carrot sale prices. Georgia data, adjusted to May 2018 US dollars. Source: U.S. Department of Agriculture, Agricultural Marketing Service (2021).

Table 1. Summary statistics of carrot yield (two seasons and two cultivars).

N rate (kg·ha^{-1})	Sample size	Cello yield Mean^{i} (kg·ha^{-1})	Cello yield Min (kg·ha^{-1})	Cello yield Max (kg·ha^{-1})	Cello yield *SD*	Jumbo yield Mean^{i} (kg·ha^{-1})	Jumbo yield Min (kg·ha^{-1})	Jumbo yield Max (kg·ha^{-1})	Jumbo yield *SD*	Unmarketable yield Mean^{i} (kg·ha^{-1})	Unmarketable yield Min (kg·ha^{-1})	Unmarketable yield Max (kg·ha^{-1})	Unmarketable yield *SD*
56	16	35,018 a	17,184	48,412	8,123	624 a	0	7,690	1,758	69 a	0	839	192
112	16	47,931 b	29,338	65,300	8,647	5,394 ab	0	24,109	7,511	258 a	0	1,879	517
168	16	56,652 bc	23,939	74,307	12,614	11,005 b	0	46,990	13,130	0 a	0	0	0
224	16	62,334 d	49,596	77,121	6,498	6,879 ab	0	23,790	7,514	203 a	0	3,250	725
280	16	60,148 d	45,105	72,055	7,687	8,722 ab	0	31,453	7,615	54 a	0	860	192
336	16	59,734 d	43,881	76,558	9,665	8,767 ab	0	33,803	8,798	0 a	0	0	0
392	16	59,904 d	37,517	67,552	7,075	5,782 ab	0	28,885	8,184	0 a	0	0	0
448	16	59,055 d	49,199	70,709	6,198	5,144 ab	0	18,750	5,913	151 a	0	1,702	402

[i] Within each column, values followed by the same letter indicate means are not significantly different ($P \leq 0.05$) with means separation by Tukey–Kramer test. Values followed by the different letter within the column indicate means are significantly different ($P \leq 0.05$) with means separation by Tukey–Kramer test.

SD = standard deviation.

returns. With the probability of 71.6%, the fertilizer rate of 224 kg·ha^{-1} N results in the highest net returns among all the rates. In other words, for any chosen net return target, the rate of 224 kg·ha^{-1} N has a higher chance of reaching and exceeding that net return target compared with the other N rates ∼70% of the time.

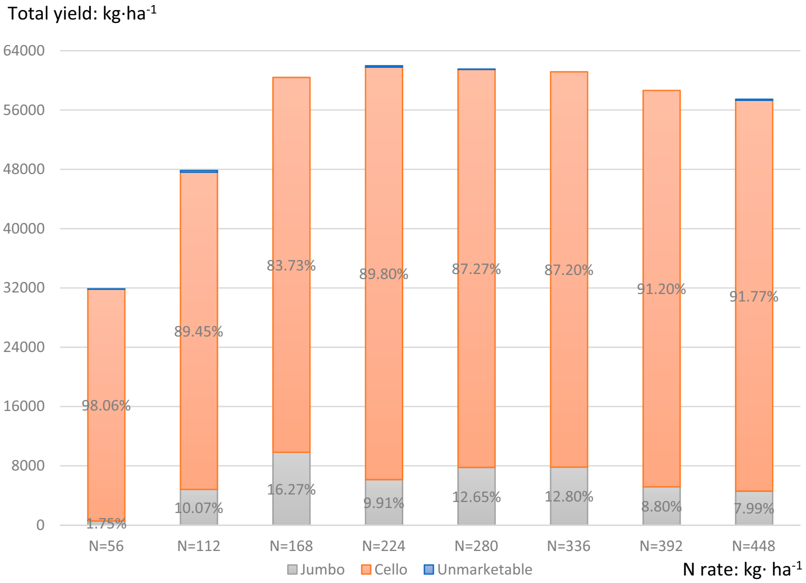

Fig. 4. Average proportion of unmarketable yields, cello yields, and jumbo yields observed in the production experiment.

The change in the mean net returns is calculated assuming alternative N rates set as the recommended BMP (Table 3). The change depends on the baseline N rate. For example, the rate of 168 kg·ha^{-1} N increases net returns for producers using 392 or 448 kg·ha^{-1} N. At the same time, for producers using less than 392 kg·ha^{-1} N, such a BMP recommendation would reduce net returns, with the reduction being between ∼2% and 6% of the baseline producers' net returns (or between $49/ha and $151/ha).

Table 2. Summary statistics of stochastic net returns.

N rate (kg·ha^{-1})	Sample size	Mean^{i} ($/ha)	95% CI ($/ha)	Median ($/ha)	Minimum ($/ha)	Maximum ($/ha)	*SD*	*CV*
56	1,000	1,040 a	1,001–1,079	995	−195	3,320	1,561	60.0%
112	1,000	1,920 b	1,872–1,968	1,809	399	4,915	1,920	40.0%
168	1,000	2,585 c	2,529–2,641	2,506	433	5,779	2,253	34.9%
224	1,000	2,736 d	2,683–2,790	2,574	1,231	5,969	2,166	31.7%
280	1,000	2,679 cde	2,623–2,734	2,516	980	6,037	2,238	33.4%
336	1,000	2,634 ce	2,581–2,687	2,506	909	5,489	2,143	32.5%
392	1,000	2,531 cef	2,481–2,589	2,365	820	5,080	1,994	31.5%
448	1,000	2,423 fg	2,372–2,474	2,279	978	5,655	2,063	34.1%

[i] Within the column, values followed by the same letter indicate means are not significantly different ($P \leq 0.05$) with means separation by Tukey–Kramer test. Values followed by the different letter within the column indicate means are significantly different ($P \leq 0.05$) with means separation by Tukey-Kramer test.

CI = confidence interval; *CV* = coefficient of variation; *SD* = standard deviation.

Producers' risk aversion levels and the choice of fertilizer application rates. The N rate of 224 kg·ha^{-1} was the most preferred rate for risk-neutral and risk-averse producers, and 280 and 336 kg·ha^{-1} N were the second and third most preferred choices, respectively (see Table 4 and Fig. 8). Therefore, if the choice of Florida's recommended BMP is primarily driven by producers' economic gains, the rate around of 224 kg·ha^{-1} will be selected among the eight rates considered. In fact, Hochmuth et al. (2021) identified the rate of 206 kg·ha^{-1} N as the rate that maximizes the yield. Therefore, our analysis is generally consistent with their recommendations, although we focus on economic returns rather than the maximum yield.

Producers' risk-aversion levels did not change the order of preferences for the three most preferred rates. In contrast, producers' preferences for 168 and 392 kg·ha^{-1} N depended on producers' risk aversion. The risk-neutral and moderately risk-averse producers preferred 168 over 392 kg·ha^{-1} N, whereas the very risk-averse and extremely risk-averse producers preferred 392 kg·ha^{-1} N. Table 2 shows that nitrogen fertilizer is a risk-reducing input in the range between 56 and 392 kg·ha^{-1} N, with the *CV* generally decreasing with the increase in the nitrogen application rate. Very risk-averse and extremely risk-averse producers have strong preferences for low variability in the outcomes; therefore, they can prefer higher nitrogen application rates. Existing literature disagrees about the effects of producers' risk aversion on nutrient application rates and conservation practice adoption (Prokopy et al., 2019; Sheriff, 2005). However, several studies report that higher risk-aversion can be associated with low or delayed adoption of conservation practices (e.g., Belknap and Saupe, 1988; Kim et al., 2005; Varner et al., 2011), and our study is consistent with these findings.

If environmental priorities were to drive the Florida policy BMP development, BMP N recommendations would be set below the most preferred rate of 224 kg·ha^{-1} N. As

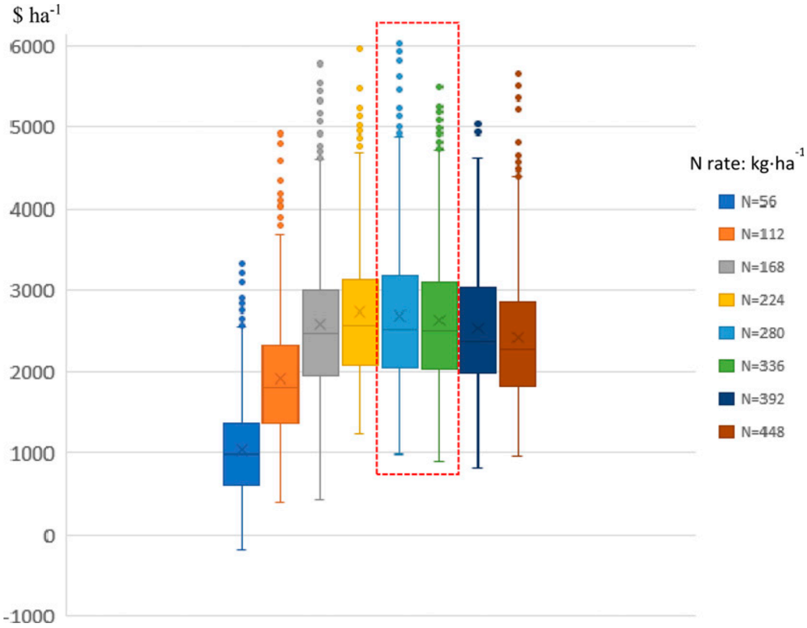

Fig. 5. Box plots of the simulated net returns. For each nitrogen application rate, the three black horizontal lines in the boxes indicate the 25th percentile (bottom), median (line across boxes), and 75th percentile yield (top). The cross marks in the boxes are the mean yields. The upper bars outside the boxes are the largest data elements that are ≤1.5 times the interquartile range. The lower bars are the smallest data elements that are larger than 1.5 times the interquartile range. The interquartile range is the difference between the 75th percentile and 25th percentile. Results for the N rate between 224 and 280 kg·ha^{-1} are highlighted.

discussed earlier in this study, in Suwannee River Basin and associated springs, more than 85% of the nitrogen loading to groundwater in the spring sheds was attributed to agricultural fertilizer and livestock waste in 2020, and up to 35% to 58% watershed-wide leaching reductions goal is stipulated in the regional TMDL. Table 5 shows that if 168 kg·ha^{-1} N were selected as the Florida policy-recommended BMP rate, then the perceived impact from this BMP requirement would depend on producers' risk aversion. For extremely risk-averse producers, such a requirement would decrease the certainty equivalent by ∼10%, or $229 per hectare (depending on the baseline N rate), providing an argument that such a BMP is not economically feasible unless a cost-share payment is provided. For comparison, the reduction in CE would be 2% to 6% for risk neutral producers using 224, 280, or 336 kg·ha^{-1} N.

Results

We show that for the case of carrot produced with the banding fertilizer application method in North Florida, the rate of 224 kg·ha^{-1} N is the most preferred among the eight rates between 56 and 448 kg·ha^{-1} N considered in the recent production experiments. The rates of 224 and 280 kg·ha^{-1} N perform equally well in terms of the mean and variance of carrot net returns. However, the rate of 224 kg·ha^{-1} N is the most preferred rate for all levels of producers' risk aversion. Therefore, a rate around 224 kg·ha^{-1} N can be recommended as a BMP for carrot production, assuming the banding fertilizer application method is used.

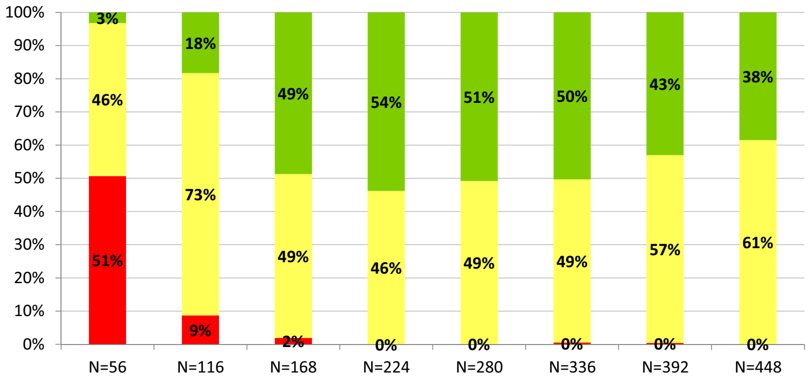

Fig. 6. Stoplight charts for probabilities of returns less than $1000/ha and greater than $2500/ha for different nitrogen application rates for risk-neutral producers.

Our result is generally consistent with the recommendation of 206 kg·ha^{-1} N in Hochmuth et al. (2021). However, we extend their analysis in two ways. First, we focus on the analysis of net returns rather than yields. Second, we examine how producers' risk aversion levels affect producers' willingness to adopt a low nitrogen application rate of 168 kg·ha^{-1} N if it is prescribed by the state rules. In Florida, the BMP definition requires the practice to "benefit water quality and water conservation while maintaining or even enhancing agricultural production" (FDACS, 2022). The definition in Florida Statutes requires BMPs "to be the most effective and practicable on-location means, including economic and technological considerations, for improving water quality in agricultural and urban discharges" and for BMPs to "reflect a balance between water quality improvements and agricultural productivity" [Section 373.4595(2) (a), Florida Statutes]. This definition is frequently interpreted as no or minimal negative impacts of the BMPs on producers' net returns, with cost-share or incentive programs offered to compensate for costs associated with the policy-recommended BMPs. Given the significant nutrient loading reductions required to achieve the water quality goal in the study region, some stakeholders may call for recommending N rates below 224 kg·ha^{-1} N as the BMP. For example, environmental advocacy groups were calling for 70% reduction in fertilizer use in the region (Florida Springs Institute, 2016). However, we show that even the rate of 168 kg·ha^{-1} N (which is 25% below the most preferred rate of 224 kg·ha^{-1} N) may not fit the Florida policy BMP definition of "maintaining or even enhancing agricultural production" (unless cost-share funds are provided to encourage the adoption). Although the rate can potentially improve net returns for producers using 392 kg·ha^{-1} or more, for those using 224 kg·ha^{-1} the rate will decrease net returns by $151/ha, and it can decrease the certainty equivalent by up to $229/ha, or by almost 10%. Overall, if most producers in the region are very or extremely risk-averse, and if most of them operate close to the optimal level of fertilizer use, then setting the more restrictive BMP of 168 kg·ha^{-1} N can be perceived as undermining producers' economic profitability. Assuming the negative exponential utility function, producers may need to be compensated up to $229/ha to ensure 100% adoption of such a recommendation.

Note that the analysis reported in this study has important limitations. The BMP recommendation presented here assumes a specific fertilizer application method. The production experiments used the banding method where dry nitrogen fertilizer is banded on the bed tops, and it is applied up to eight times per season. A common practice for carrot producers, however, is to apply at least part of the fertilizer via broadcasting through the pivot irrigation system. The fertilizer broadcasting method is characterized by a lower fertilizer use efficiency because part of the fertilizer is applied to the spacing between the rows. On the basis of the analysis of a typical producer field configuration, the area

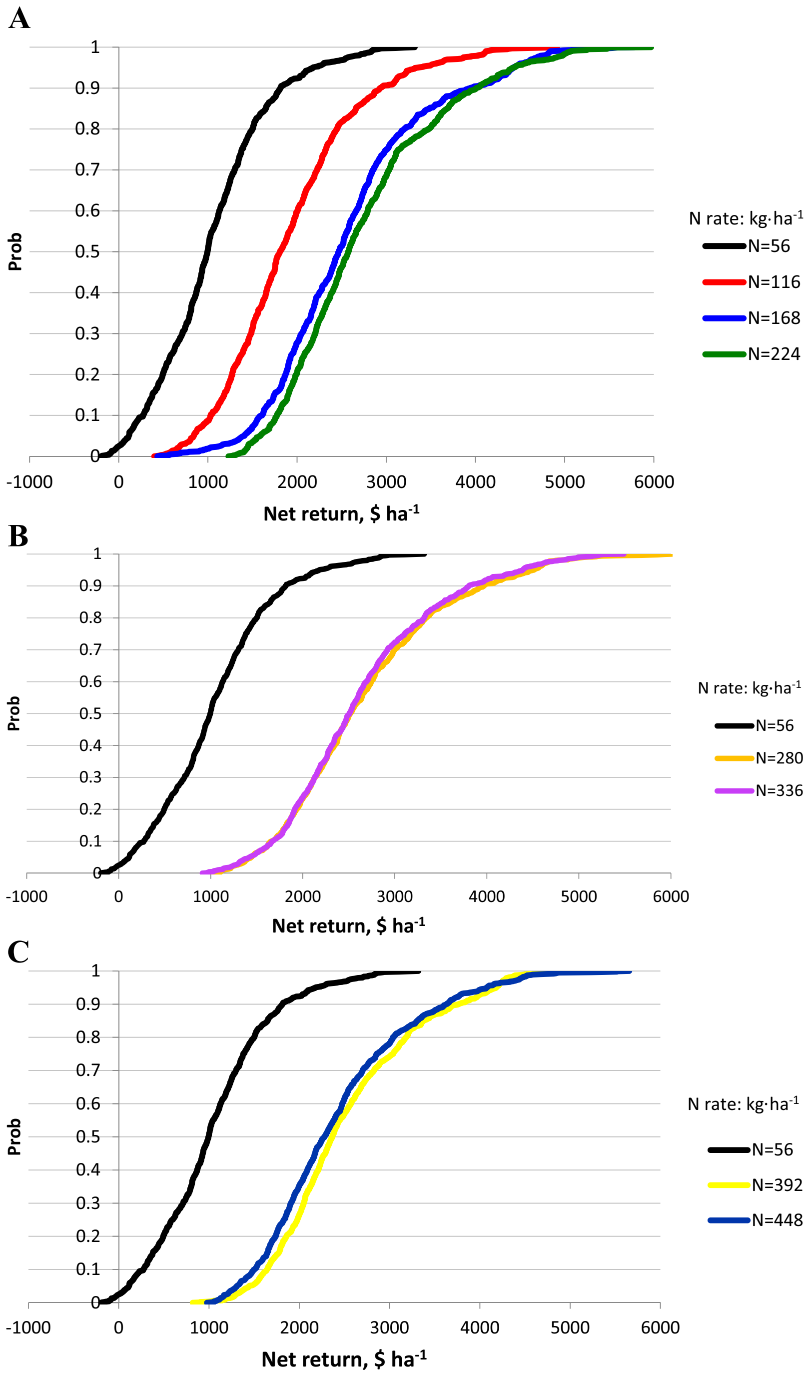

Fig. 7. (**A**) Cumulative distribution function of simulated net return. (**B**) Cumulative distribution function of simulated net return. (**C**) Cumulative distribution function of simulated net return.

between the rows takes up to ~20% of the total field area. Therefore, up to 20% of the fertilizer applied by the broadcasting method is more likely to be lost to leaching. To compensate for these losses, producers may choose a higher rate of fertilizer application. The upfront cost of banding equipment is likely an obstacle to getting producers to change from the broadcasting method to the more efficient banding method. Therefore, if 224 $kg \cdot ha^{-1}$ N is recommended as the carrot BMP, cost-sharing should be offered to help producers convert to the fertilizer banding method.

Additionally, the marketable yields and net returns presented in the study may be higher than observed in the field. Although the results reported are comparable with the Georgia production budgets (University of Georgia Extension, 2012), discussions with Florida producers show that there may be a higher grading standard for carrots in the region, with up to 30% of the harvested yield being culled. This study assumed that 99.84% of the harvested yield was marketable.

Last, this study assumed a specific functional form for the producers' utility function, and it used the average simulated net return as a proxy of the total wealth to calculate producers' risk aversion coefficient. Although similar assumptions were made in other published studies, collecting data about the producer's wealth and risk aversion in the study region could enhance the analysis.

Discussion and Conclusion

This study identifies the fertilizer rate of 224 $kg \cdot ha^{-1}$ N as the optimal rate. Because the fertilizer rate is not evaluated continuously, a rate ~224 $kg \cdot ha^{-1}$ N can be considered for future BMP recommendations based on net returns, production, market risks, and producer risk-aversion levels. A key goal of Florida's agricultural water quality policy is to maximize the BMP adoption rate. What adoption rate can one expect if 224 $kg \cdot ha^{-1}$ N becomes the BMP recommendation?

Existing economic studies suggest that the adoption rate will likely be below 100% (e.g., Wade et al., 2015). First, as discussed earlier, the BMP recommendations are based on the dry fertilizer banding application method. On the basis of discussions with producers, we posit that many producers use spreaders and pivot irrigation systems (broadcasting application method) to fertilize their crops. Fertilizer-use efficiency is lower for the broadcasting method; however, conversion to the banding method requires significant investment costs. Existing cost-share programs typically cover up to 75% of the investment costs. The remaining 25% of the cost may still be a significant barrier for some producers.

Second, even if producers use the banding method, their planting and harvesting schedules, soil types, crop rotations, and other characteristics of production may differ from the research experiments. Although the production experiments mimic the common production practices, the experiments are unlikely to account for the whole variety of farm operations (Pannell et al., 2006). Some of these differences may have important implications for carrot yields and producers' net returns; therefore, producers may choose to

Table 3. Reduction in mean net returns for hypothetical BMP N rates, given alternative baseline N application rates.

	Baseline N application rate ($kg \cdot ha^{-1}$)				
Proposed BMP application rate ($kg \cdot ha^{-1}$)	224	280	336	392	448
56	$1,696	$1,639	$1,594	$1,491	$1,383
112	$816	$759	$714	$611	$503
168	$151	$94	$49	NA	NA
224	$0	NA	NA	NA	NA

BMP = best management practices; NA = not applicable.

Table 4. Certainty equivalents for stochastic net returns.

	N rate (kg·ha^{-1})							
Producer risk aversion level (ARAC)	56	112	168	224	280	336	392	448
Risk-neutral (0.0000)	1,040	1,920	2,585	2,736	2,679	2,634	2,531	2,423
Hardly risk-averse (0.0003)	986	1,840	2,475	2,636	2,571	2,535	2,444	2,331
Somewhat risk-averse (0.0007)	912	1,736	2,333	2,509	2,434	2,406	2,332	2,216
Moderately risk-averse (0.0010)	867	1,674	2,249	2,439	2,356	2,331	2,267	2,151
Very risk-averse (0.0013)	824	1,618	2,171	2,376	2,286	2,263	2,208	2,092
Extremely risk-averse (0.0017)	774	1,154	2,079	2,308	2,209	2,187	2,142	2,028

ARAC = absolute risk aversion coefficient.

deviate from the BMP recommendation described previously in this study.

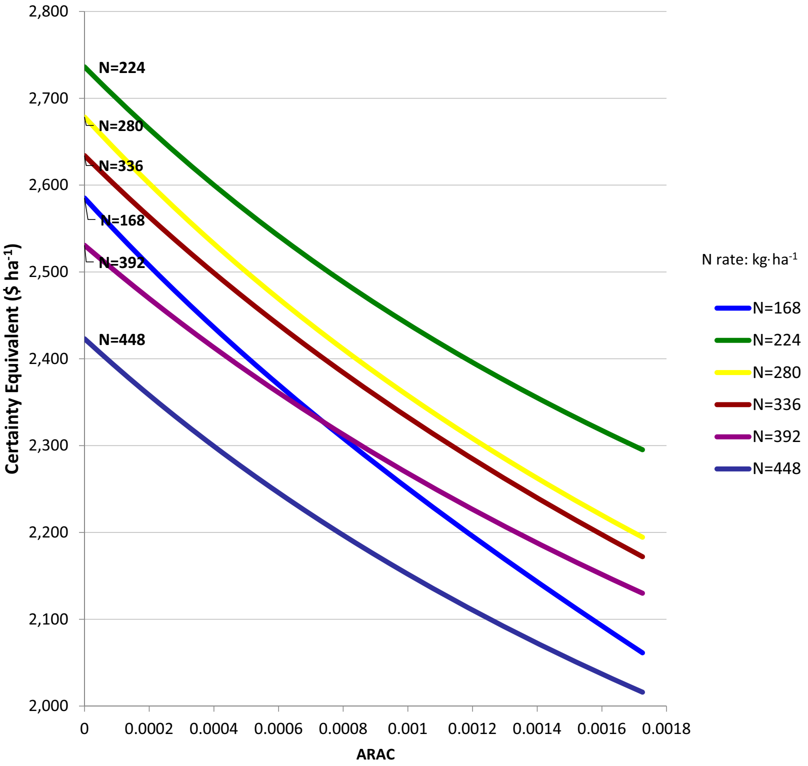

Fig. 8. Stochastic efficiency with respect to a function for alternative nitrogen application rates, given the farmer's absolute risk aversion (ARAC) from 0.0 to 0.0017. For each risk aversion level, the nitrogen rate with the highest certainty equivalent is the most preferred. (Note that the rates of N = 56 and 112 kg·ha^{-1} are omitted for simplicity.)

Third, producers in the study region engage in production contract agreements with a carrot production and marketing company. The carrot company provides specialized equipment (e.g., carrot seeder equipment), pays for the fertilizer and other materials, and harvests the crop. Overall, the side that bears the cost of adjusting the fertilizer rate and application method is determined by the specifics of the contract. There may be incentives for producers to argue for an increase in fertilizer use to ensure maximum yield if the contract results in an extra payment for higher-than-expected yields. Future studies can explore whether it is feasible to require carrot companies to mandate BMP adoption for their contract design with the growers.

Fourth, for the banding method specifically, this study shows that the average payoff is virtually the same for alternative N rates. Therefore, the producers do not have strong economic incentives to switch to the BMP-recommended rate (Pannell, 2006). There may also be hidden opportunity costs associated with changing the N rate and following the BMP recommendations (e.g., the need to retrain personnel and readjust the production system around the new fertilizer application schedule). These opportunity costs, combined with the *flat payoff function* (Pannell, 2006, p. 7), create a disincentive for the conversion.

Yet the BMP recommendations and agricultural water quality policy design may need to account for the potentially significant costs of the "business as usual." For example, spring-based tourism provides a significant contribution to the economy, with the value-added for 15 major springs in the study area estimated at $52.58 million in 2014 (Borisova et al., 2018). Further, Wu et al. (2018) showed that the estimated average spring-based recreation trip was valued by the tourists at $28.91 per person per trip, which can be translated into the total recreational value for four major springs in the study area of about $25 million annually (Borisova et al., 2020; Wu et al., 2018). Continued spring degradation is expected to reduce the value assigned by the tourists to the spring-based recreation trips, the number of visitors, and the resulting tourism contribution to the regional economy.

Overall, although the BMP recommendations derived in this study are based on an array of economic methods, the expectation of a 100% BMP adoption rate is likely overly optimistic, at least in the short run. Economic incentives, performance-based strategies, or strict monitoring and enforcement may be needed to ensure a high BMP adoption rate. Ultimately, meeting the water quality goals in the Suwannee River Basin requires behavioral changes for all key stakeholder groups, including agriculture producers, residents using septic systems, and urban households fertilizing their lawns.

Table 5. Reduction in certainty equivalents given proposed best management practices rate of 168 kg·ha^{-1}, given the baseline fertilizer rates of 224, 280, and 336 kg·ha^{-1}.

	Baseline N rate = 224 kg·ha^{-1}		Baseline N rate = 280 kg·ha^{-1}		Baseline N rate = 336 kg·ha^{-1}		Baseline N rate = 392 kg·ha^{-1}	
	Dollar	%	Dollar	%	Dollar	%	Dollar	%
Risk-neutral	–$151	–5.52%	–$94	–3.51%	–$49	–1.86%	NA	NA
Hardly risk-averse	–$161	–6.11%	–$96	–3.73%	–$60	–2.37%	NA	NA
Somewhat risk-averse	–$176	–7.01%	–$101	–4.15%	–$73	–3.03%	NA	NA
Moderately risk-averse	–$190	–7.79%	–$107	–4.54%	–$82	–3.52%	–$18	–0.79%
Very risk-averse	–$205	–8.63%	–$115	–5.03%	–$92	–4.07%	–$37	–1.68%
Extremely risk-averse	–$229	–9.92%	–$130	–5.89%	–$108	–4.94%	–$63	–2.94%

NA = not applicable.

References

Amigun, B., D. Petrie, and J. Gorgens. 2011. Economic risk assessment of advanced process technologies for bioethanol production in South Africa: Monte Carlo analysis. Renew. Energy 36 (11):3178–3186, https://doi.org/10.1016/j.renene.2011.03.015.

Athearn, K. 2019. Carrot Production Budget. North Florida Research and Education Center, University of Florida, Live Oak, FL.

Babcock, B.A. and A.M. Blackmer. 1992. The value of reducing temporal input nonuniformities. J. Agric. Resour. Econ. 17(2):335–347, https://doi.org/10.22004/ag.econ.30949.

Baerenklau, K., P. Tomich, S. Daroub, A. Drevno, V. Haden, C. Kling, T. Lang, C.Y. Lin, C. Mitterhofer, D. Parker, D. Press, T. Rosenstock, K. Schwabe, Z. Tzankova, and J. Wang. 2016. Appendix 8.1: Experience with nitrogen policy instruments in practice: Case studies, p. 201–231. In: T.P. Tomich, S.B. Brodt, R.A. Dahlgren, and K.M. Scow (eds.). California nitrogen assessment: Challenges and solutions for people, agriculture, and the environment. Agricultural Sustainability Institute, University of California–Davis.

Baylis, K., J. Coppess, B.M. Gramig, and P. Sachdeva. 2022. Agri-environmental programs in the United States and Canada. Rev. Environ. Econ. Policy 16(1):83–104, https://doi.org/10.1086/718052.

Belknap, J. and W.E. Saupe. 1988. Farm family resources and the adoption of no-plow tillage in southwestern Wisconsin. Rev. Agric. Econ. 10(1):13–23, https://doi.org/10.1093/aepp/10.1.13.

Borisova, T., W.A. Hodges, and J.T. Steven. 2018. Economic contributions and ecosystem services of springs in the lower Suwannee and Santa Fe River Basins of north-central Florida. EDIS FE958. UF/IFAS Extension, University of Florida–Gainesville. 3 Aug. 2022. <https://edis.ifas.ufl.edu/pdf/FE/FE958/FE958-4445502.pdf>.

Borisova, T., K. Oehlbeck, X. Bi, T. Wade, A. Hodges, K. Grogan, and F. He. 2020. Economic Value of Florida Water Resources: Contributions of Tourism and Recreation to the Economy. EDIS FE1065. UF/IFAS Extension, University of Florida–Gainesville. https://doi.org/10.32473/edis-fe1065-2019.

Claassen, R. 2012. The future of environmental compliance incentives in U.S. agriculture: The role of commodity, conservation, and crop insurance programs. U.S. Department of Agriculture—Economic Research Service Economic Information Bulletin No. 94. http://doi.org/10.2139/ssrn.2026902.

Claassen, R. and M. Ribaudo. 2016. Cost-effective conservation programs for sustaining environmental quality. Choices 31(3):1–12, https://doi.org/10.22004/ag.econ.241902.

Claassen, R., J. Horowitz, E. Duquette, and K. Ueda. 2014. Additionality in U.S. agricultural conservation and regulatory offset programs. U.S. Department of Agriculture Economic Research Service Economic Research Report Number 170. 3 Aug. 2022. <https://www.ers.usda.gov/webdocs/publications/45244/48525_err170.pdf>.

Dillon, J.L. 1971. An expository review of Bernoullian decision theory in agriculture: Is utility futility? Review of Marketing & Agricultural Economics 39(1):3–80, https://doi.org/10.22004/ag.econ.9670.

Dobermann, A., K. Cassman, A. Mosier, K. Syers, and J. Freney. 2004. Environmental dimentions of fertilizer nitrogen: What can be done to increase nitrogen Use efficiency and ensure global food security?, p. 260–278. In: A. Mosier, J.K. Syers, and J.R. Freney (eds.). Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer. Island Press, London, UK.

Florida Department of Agriculture & Consumer Services. 2015. Water quality/quantity best management practices for Florida vegetable and agronomic crops. 3 Aug. 2022. <https://www.fdacs.gov/content/download/77230/file/vegAgCropBMP-loRes.pdf>.

Florida Department of Agriculture & Consumer Services. 2022. Agricultural best management practices. 3 Aug. 2022. <https://www.fdacs.gov/Agriculture-Industry/Water/Agricultural-Best-Management-Practices>.

Florida Department of Environmental Protection. 2018. Suwannee River basin management action plan (Lower Suwannee River, Middle Suwannee River, and Withlacoochee River sub-basins). 3 Aug. 2022. <https://floridadep.gov/sites/default/files/Suwannee%20Final%202018.pdf>.

Florida Department of Environmental Protection. 2021. Basin management action plans (BMAPs). 3 Aug. 2022. <https://floridadep.gov/dear/water-quality-restoration/content/basin-management-action-plans-bmaps>.

Florida Springs Institute. 2016. A plan to restore the lower Suwannee River Springs. 3 Aug. 2022. <https://floridaspringsinstitute.org/wp-content/uploads/2018/07/2016-Lower-Suwannee-River-Springs-RAP-Executive-Summary.pdf>.

Guyse, J.L. 2001. Certainty equivalence, p. 83–84. In: S.I. Gass and C.M. Harris (eds.). Encyclopedia of Operations Research and Management Science. Springer, New York, NY. https://doi.org/10.1007/1-4020-0611-X_103.

Hardaker, B. 2006. Farm risk management: Past and present. J. Farm Manag. 12(10):593–612.

Hardaker, J.B. and G. Lien. 2010. Stochastic efficiency analysis with risk aversion bounds: A comment. Australian J Agric. Res. Econ. 54(3): 379–383, https://doi.org/10.1111/j.1467-8489.2010.00498.x.

Hardaker, J.B., G. Lien, J.R. Anderson, and R.B.M. Huirne. 2015. Coping with risk in agriculture: Applied decision analysis. 3rd ed. CABI Publishing, Wallingford, UK. http://doi.org/10.1079/9781780645742.0000.

Hardaker, J.B., J.W. Richardson, G. Lien, and K.D. Schumann. 2004. Stochastic efficiency analysis with risk aversion bounds: A simplified approach. Australian J Agric. Res. Econ. 48(2):253–270, https://doi.org/10.1111/j.1467-8489.2004.00239.x.

Havlin, J. 2004. Impact of management systems on fertilizer nitrogen use efficiency, p. 167–178. In: A. Mosier, J.K. Syers, and J.R. Freney (eds.). Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and the environment. Island Press, Washington DC.

Henrich, J. and R. McElreath. 2002. Are peasants risk-averse decision makers? Curr. Anthropol. 43(1):172–181, https://doi.org/10.1086/338291.

Hochmuth, G.J., J.K. Brecht, and M.J. Bassett. 1999. Nitrogen fertilization to maximize carrot yield and quality on a sandy soil. HortScience 34(4): 641–645, https://doi.org/10.21273/HORTSCI.34.4.641.

Hochmuth, G.J., R. Mylavarapu, and E. Hanlon. 2018. The four Rs of fertilizer management. EDIS SL411. UF/IFAS Extension, University of Florida–Gainesville. <https://edis.ifas.ufl.edu/pdf/SS/SS62400.pdf>.

Hochmuth, R., M. Burani-Arouca, and C.E. Barrett. 2021. Yield and quality of carrot cultivars with eight nitrogen rates and best management practices. HortScience 56(10):1199–1209, https://doi.org/10.21273/HORTSCI15983-21.

Hudson, M. 2021. Agriculture in the Sunshine State. U.S. Department of Agriculture, Washington, DC. https://www.usda.gov/media/blog/2019/10/15/agriculture-sunshine-state.

Kimball, B.M.S. 1988. Farmers' cooperatives as behavior toward risk. Am. Econ. Rev. 78(1): 224–232. https://www.jstor.org/stable/1814710.

Kim, S., J.M. Gillespie, and K.P. Paudel. 2005. The effect of socioeconomic factors on the adoption of best management practices in beef cattle production. J. Soil Water Conserv. 60(3): 111–120.

Kingwell, R. 2011. Managing complexity in modern farming. Australian J Agric. Res. Econ. 55(1): 12–34, https://doi.org/10.1111/j.1467-8489.2010.00528.x.

Kling, C.L. 2013. State level efforts to regulate agricultural sources of water quality impairment. Choices 28(3):1–4, https://doi.org/10.22004/ag.econ.159201.

Ladányi, M. 2008. Risk methods and their applications in agriculture. Appl. Ecol. Environ. Res. 6: 147–164, https://doi.org/10.15666/AEER/0601_147164.

Lien, G. 2002. Non-parametric estimation of decision makers' risk aversion. Agric. Econ. 27(1): 75–83, https://doi.org/10.1111/j.1574-0862.2002.tb00106.x.

Mack, R., J. Owen, A. Niemiera, and J. Latimer. 2017. Virginia nursery and greenhouse grower survey of best management practices. HortTechnology 27(3):386–392, https://doi.org/10.21273/HORTTECH03664-17.

Majsztrilk, J.C. and J.D. Lea-Cox. 2013. Water quality regulations in the Chesapeake Bay: Working to more precisely estimate nutrient loading rates and incentivize best management practices in the nursery and greenhouse industry. HortScience 48(9):1097–1102, https://doi.org/10.21273/HORTSCI.48.9.1097.

Menapace, L., G. Colson, and R. Raffaelli. 2013. Risk aversion, subjective beliefs, and farmer risk management strategies. Am. J. Agric. Econ. 95(2):384–389, https://doi.org/10.1093/ajae/aas107.

Merhaut, D.J., L. Corkidi, M. Mochizuki, T. Khunog, J. Newman, B. Faber, and O. Daugovish. 2013. Implementation of best management practices to reduce agricultural total maximum daily loads in the Calleguas Creek and Santa Clara River watersheds: a case study of water contaminant mitigation in California. HortScience 48(9):1109–1112, https://doi.org/10.21273/HORTSCI.48.9.1109.

Mikkelsen, L.M. 2011. The "4R" nutrient stewardship framework for horticulture. HortTechnology 21(6):658–662, https://doi.org/10.21273/HORTTECH.21.6.658.

Moniruzzaman, M., M. Akand, M. Hossain, M. Sarkar, and A. Ullah. 2013. Effect of nitrogen on the growth and yield of carrot (*Daucus carota* L.). Agriculturists 11(1):76–81, https://doi.org/10.3329/agric.v11i1.15246.

Mun, J. 2006. Modeling risk: Applying Monte Carlo simulation, real options analysis, forecasting, and optimization techniques. Wiley, New York.

Murrell, T.S. 2004. Using advanced technologies to refine nitrogen management at the farm scale: A case study from the U.S. Midwes, p. 155–165. In: A. Mosier, J.K. Syers, and J.R. Freney (eds.). Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and the environment. CABI Publishing, Wallingford, UK.

Neeteson, J.J. and W.P. Wadman. 1987. Assessment of economically optimum application rates of fertilizer N on the basis of response curves. Fert. Res. 12(1):37–52, https://doi.org/10.1007/BF01049419.

Pannell, D.J. 2006. Flat earth economics: The far-reaching consequences of flat payoff functions in economic decision making. Rev. Agric. Econ. 28(4):553–566, https://doi.org/10.1111/j.1467-9353.2006.00322.x.

Pannell, D.J. 2017. Economic perspectives on nitrogen in farming systems: Managing trade-offs between production, risk and the environment. Soil Res. 55(6):473–478, https://doi.org/10.1071/SR16284.

Pannell, D.J., B. Malcolm, and B.S. Kingwell. 2000. Are we risking too much? Perspectives on risk in farm modelling. Agric. Econ. 23(1): 69–78, https://doi.org/10.1111/j.1574-0862.2000.tb00084.x.

Pannell, D.J., G.R. Marshall, N. Barr, A. Curtis, F. Vanclay, and R. Wilkinson. 2006. Understanding and promoting adoption of conservation technologies by rural landholders. Aust. J. Expt. Agr. 46:1407–1424, https://doi.org/10.1071/EA05037.

Paulson, N.D. and B.A. Babcock. 2010. Readdressing the fertilizer problem. J. Agric. Resour. Econ. 35(3):368–384, https://doi.org/10.22004/ag.econ.97853.

Prokopy, L.S., K. Floress, J.G. Arbuckle, S.P. Church, F.R. Eanes, Y. Gao, B.M. Gramig, P. Ranjan, and A.S. Signh. 2019. Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature. J. Soil Water Conserv. 74(5): 520–534, https://doi.org/10.2489/jswc.74.5.520.

Richardson, J.W. 2008. Simulation for applied risk management. Agricultural and Food Policy Center, Texas A&M University, College Station, TX.

Richardson J.W., B.K. Herbst, J.L. Outlaw, R. Chope Gill II. 2007. Including risk in economic feasibility analyses: The case of ethanol production in Texas. J. Agribusiness 25:115–132, https://doi.org/10.22004/ag.econ.62291.

Santos, B.M. 2011. Selecting the right nutrient rate: Basis for managing fertilization programs. HortTechnology 21(6):683–685, https://doi.org/10.21273/HORTTECH.21.6.683.

Saha, A. 1993. Risk aversion expo-power utility: A flexible form for absolute and relative risk aversion. Am. J. Agric. Econ. 75(4):905–913, https://doi.org/10.2307/1243978.

Sheriff, G. 2005. Efficient waste? Why farmers over-apply nutrients and the implications for policy design. Rev. Agric. Econ. 27(4):542–557, https://doi.org/10.1111/j.1467-9353.2005.00263.x.

Smith, E.G., G.W. Clayton, J.T. O'Donovan, T.K. Turkington, K.N. Harker, W.J. Henderson, R.H. McKenzie, P.E. Juskiw, L.G. Lafond, W.E. May, C.A. Grant, S. Brandt, E.N. Johnson, and N.J. Edney. 2012. Net return risk for malting barley production in Western Canada as influenced by production strategies. Agron. J. 104(5):1374–1382, https://doi.org/10.2134/agronj2011.0416.

Sutherland, R.A., C.C. Wright, L.M.J. Verstraeten, and D.J. Greenwood. 1986. The deficiency of the "economic optimum" application for evaluating models which predict crop yield response to nitrogen fertiliser. Fert. Res. 10(3):251–262, https://doi.org/10.1007/bf01049355.

University of Georgia Extension. 2012. Commercial production and management of carrots. University of Georgia Extension, Athens, GA. 3 Aug. 2022. <https://extension.uga.edu/publications/detail.html?number=B1175&title=Commercial%20Production%20and%20Management%20of%20Carrots>.

University of Georgia Extension. 2022. Budgets—vegetables: carrots. <https://agecon.uga.edu/extension/budgets.html>.

U.S. Bureau of Economic Analysis. 2017. Outdoor recreation satellite account, U.S. and prototype for states. 3 Aug. 2022. <https://www.bea.gov/news/2019/outdoor-recreation-satellite-account-us-and-prototype-states-2017>.

U.S. Bureau of Labor Statistics. 2022. CPI inflation calculator. 3 Aug. 2022. <https://www.bls.gov/data/inflation_calculator.htm>.

U.S. Census Bureau. 2020. QuickFacts: Suwannee County, Florida. 3 Aug. 2022. <https://www.census.gov/quickfacts/suwanneecountyflorida>.

U.S. Department of Agriculture, Natural Resources Conservation Service. Undated. Environmental Quality Incentives Program. 3 Aug. 2022. <https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/>.

U.S. Department of Agriculture, Agricultural Marketing Service. 2020. Run a custom report. 3 Aug. 2022. <https://www.ams.usda.gov/market-news/custom-reports>.

U.S. Department of Agriculture, Agricultural Marketing Service. 2021. Topped carrots grades and standards. 3 Aug. 2022. <https://www.ams.usda.gov/grades-standards/topped-carrots-grades-and-standards>.

U.S. Department of Agriculture, Economic Research Service. 2019. Fertilizer use and price. United States Department of Agriculture. 3 Aug. 2022. <https://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx>.

U.S. Department of Agriculture, Economic Research Service. 2021. Farm finance indicators, state ranking, 2020: Nominal (current dollars). Crop cash receipts. 3 Aug. 2022. <https://data.ers.usda.gov/reports.aspx?ID=17839>.

Varner, B.T., F.M. Epplin, and G.L. Strickland. 2011. Economics of no-till versus tilled dryland cotton, grain sorghum, and wheat. Agron. J. 103 (5):1329–1338, https://doi.org/10.2134/agronj2011.0063.

Wade, T., C. Roger, and W. Steven. 2015. Conservation-practice adoption rates vary widely by crop and region. U.S. Department of Agriculture, Economic Information Bulletin Number 147, December.

Wu, Q.-Y., X. Bi, K.A. Grogan, and T. Borisova. 2018. Valuing the recreation benefits of natural springs in Florida. Water (Switzerland) 10(10): https://doi.org/10.3390/w10101379.

Webb, M.J. 2009. A conceptual framework for determining economically optimal fertiliser use in oil palm plantations with factorial fertiliser trials. Nutr. Cycl. Agroecosyst. 83(2):163–178, https://doi.org/10.1007/s10705-008-9207-x.

Supplemental Material

Certainty Equivalent Calculation

Farmers hold different perceptions for risky situations; these differences are referred to as the "degrees of risk aversion" or "risk-aversion level." The degree of risk aversion influences farmers' nitrogen rate decisions (Pannell et al., 2000; Kingwell, 2011; Hardaker et al., 2015). Risk-aversion levels are typically classified as risk-averse, risk-neutral, and risk-seeking, based on farmers' different psychological characteristics and their environment (Pannell, 2017). Studies show that most farmers are risk-averse (Henrich and McElreath, 2002; Kimball, 1988; Menapace et al. 2013)—that is, they prefer outcomes that are known with certainty and are willing to pay to reduce the uncertainty. In the economic literature, such risk preferences are usually modeled as a concave utility function, *U*. Certainty equivalent (CE) is the fixed amount of money a farmer would perceive as an equivalent to the distribution of the net returns for a given fertilizer rate. The most preferred decision has the largest CE (Hardaker and Lien, 2010). The calculation of CE requires assumptions about the farmers' utility functions and risk-aversion levels. The negative exponential utility function is a particularly nondecreasing and concave utility function commonly used to model decisions and to account for risk aversion. The negative exponential utility function can represent farmers' utility, expressed as follows:

$$U(w) = -e^{(-rw)},$$

where r is farmers' absolute risk aversion coefficient and w is farmers' wealth. Because information about farmers' wealth is unavailable, we assumed wealth as equal to the average simulated carrot net return following Hardaker et al. (2004) and Smith et al. (2012). Constant absolute risk aversion (CARA) is often assumed when farmers' decisions under risk are analyzed (Babcock and Blackmer, 1992; Hardaker et al., 2004; Lien, 2002). CARA means that farmers' risk aversion does not change with wealth. Further, according to the Arrow–Pratt measures of risk aversion coefficient, the absolute risk aversion coefficient (ARAC) can be calculated using the relative risk aversion coefficient (RRAC) divided by farmers' wealth. In this study, a range of risk-aversion levels is modeled considering RRAC values between 0.0 and 4.0 (to represent risk perceptions, ranging from risk-neutral to very risk-averse). Farmers' wealth, the average simulated net return among eight different N rates, is used to calculate ARAC. Under the negative exponential utility function, the CE is calculated using the following formula (Hardaker et al., 2004):

$$CE_i = \ln\left\{ \left(\frac{1}{T} \sum_{1}^{T} e^{(-r)R_T(Ni)} \right)^{-\frac{1}{r}} \right\},$$

where r is the ARAC, T is the sample size from net return simulations, and R_T (N_i) is the net return yielded by the *i th* nitrogen application rate. Here, T is equal to 1000 because the net return was simulated 1000 times for each N rate. The value of *i* ranges from 1 to 8, representing the eight different N rates used in carrot production experiments.