Managing Nitrate Levels in Bermudagrass Hay: Implications for Net Returns

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ABSTRACT

Accumulation of nitrates in hay can be toxic to cattle, and managing nitrate levels in hay production could be costly. We determine the price premium a hay producer needs to receive for cattle-safe, low-nitrate hay to continued managing nitrate levels. Profit-maximizing nitrogen rates were determined for two bermudagrass hay producers—one who manages nitrate levels and one who does not manage nitrate levels. The hay producer who manages nitrates applies 56 lb./acre less nitrogen than the producer who does not manages nitrates, and would need to receive a price premium of $9.12/ton for low-nitrate hay to breakeven.

Introduction

In hay production, nitrogen (N) is a vital input to increase yields and to produce uniform yields across multiple harvests within a given year (Connell et al., 2011; Hojjati, Taylor, & Templeton Jr, 1971; Woodard & Sollenberger, 2011). Furthermore, grasses convert N fertilizer into proteins, which increases the quality and value of the hay if used as a feedstuff (Johnson et al., 2001; Prine & Burton, 1956; Woodard & Sollenberger, 2011).





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Despite the economic benefits of increased yields and hay quality from N fertilizer, N fertilizer can be problematic for hay producers if high levels of nitrates accumulate in plant tissue prior to harvest. High nitrate levels can be poisonous to cattle and cause what is commonly referred to as nitrate toxicity (Allison, 1998; MacKown & Weik, 2004; Strickland et al., 1996). Therefore, considering nitrate levels when managing N fertilizer applications in hay production is important.

Research has shown many factors can impact the accumulation of nitrates in several kinds of hay (Bergareche & Simon, 1989; Connell et al., 2011; Crawford, Kennedy, & Johnson, 1961; Gomm, 1979; Lovelace, Holt, & Anderson, 1968; Rudert & Oliver, 1978; Thomas & Langdale, 1980; Veen & Kleinendorst, 1985). For example, excessively low and excessively high temperatures, relative humidity, and rainfall can influence nitrate accumulation in plant tissue (Gomm, 1979; Woods, 2008). Furthermore, nitrates can accumulate in the plant tissue when plants are grown under low light (Veen & Kleinendorst, 1985). Bergareche & Simon (1989) analyzed bermudagrass [*Cynodon dactylon (L.) Pers*] grown in a Mediterranean climate, and found nitrate levels to be highest in the fall and spring (i.e., low temperature growing season) and lowest in mid-summer months (i.e., high temperature growing season). These environmental factors such as short day length, low light intensity, rainfall, and low temperatures are commonly found to explain the accumulation of nitrates in plant tissue (Bergareche & Simon, 1989), which makes it difficult to manage nitrates over multiple harvests since environmental factors change across the harvest months.

The primary cause of nitrate accumulation in hay is attributed to over application of N fertilizer (Rudert & Oliver, 1978; Thomas & Langdale, 1980). If high levels of nitrates are available in the soil, accumulation of nitrates is more likely to occur. In fact, Veen & Kleinendorst (1985) found hay grown under low light accumulates nitrates when there is an ample supply of nitrates in the soil. Thus, nitrate accumulation could become a problem for producers in harvest months when there are high levels of nitrates available in the soil, combined with environmental factors that favor nitrate accumulation.

The primary danger of high nitrate levels in hay is the potential threat to cattle (Allison, 1998; MacKown & Weik, 2004; Strickland et al., 1996). When nitrates are ingested by cattle, nitrates are reduced to nitrite by rumen bacteria (MacKown & Weik, 2004; Strickland et al., 1996) and then are converted to ammonia (MacKown & Weik, 2004; Woods, 2008). When cattle consume high levels of nitrates, the conversion to ammonia does not occur fast enough and nitrates and nitrites enter the bloodstream and converts blood hemoglobin to methemoglobin (MacKown & Weik, 2004; Strickland et al., 1996; Woods, 2008). Methemoglobin is not able to transport oxygen to various body tissues so the animal suffers from hypoxia resulting in animals dying from oxygen starvation or causing bred cows to abort their fetuses (Allison, 1998; MacKown & Weik, 2004). The literature mostly agrees that nitrate levels less than 5,000 ppm are safe for cattle feed (Connell et al., 2011; MacKown & Weik, 2004; Strickland et al., 1996; Undersander et al., 1999). When nitrate levels slightly exceed this threshold, limited amounts of hay could be fed to cattle by mixing the high-nitrate hay with other feeds to dilute nitrate levels (Strickland et al., 1996; Undersander et al., 1999). However, the safest action is not to use the hay as feed.

Cattle production in the southeastern United States is centered on cow-calf operations (McBride & Mathews, 2011). Cow-calf operations depend on forage production to provide the majority of the feed ration. Forage is harvested through grazing or mechanically as hay to be fed when forage availability for grazing is limited. In the southeastern United States, bermudagrass is the most common warm-season grass for hay production and pasture (Connell et al., 2011), and cattle producers depend on it as a primary forage (Agyin-Biriorang, Newman, & Kasozi, 2012; Lacy & Hill, 2008; Woodard & Sollenberger, 2011). Bermudagrass is drought tolerant, responsive to N fertilizer, and has a high water use efficiency, which makes it ideal for the southeastern United States (Connell et al., 2011). Bermudagrass is not considered a high-risk forage for accumulating nitrate levels toxic to cattle (Burns, Wagger, & Fisher, 2009; Evers, Redmon, & Provin, 2004; Strickland et al., 1996); however, research has shown bermudagrass in the southeastern United States can accumulate nitrate levels well beyond the toxic threshold of 5,000 ppm (Carter, 2011; Connell et al., 2011).

Several papers have analyzed the economics of hay production and marketing (Blank, Orloff, & Putnam, 2001; Curtis et al., 2010; Hopper, Peterson, & Burton, 2004; Smith et al., 2012; Ward, 1994). Hopper, Peterson, & Burton (2004) and Ward (1994) estimated hedonic pricing models to determine the price-quality relationship for alfalfa hay. Blank, Orloff, & Putnam (2001) focused on the economics of producing alfalfa hay by determining the optimal harvesting schedule based on yields, quality, and prices. Smith et al. (2012) evaluated the animal and economic impacts of tall fescue toxicosis on cattle production in the southeastern United States. Their grazing study showed tall fescue toxicosis can negatively impact animal performance and reduce cattle producers' net returns. However, no research in the economic literature has determined how nitrate levels in hay might influence hay producers' net returns and profit-maximizing N fertilizer application.

A hay producer has little control over environmental factors that influence nitrate accumulation, but the producer can control the quantity of nitrates available to the plant by controlling the quantity of N fertilizer applied. For instance, if a hay producer only considers prices and yield when selecting an N fertilizer rate and does not consider nitrate levels, the profit-maximizing N fertilizer rate may result in a high probability of nitrate levels exceeding the toxic threshold. Alternatively, if a producer considers nitrate levels along with prices and yield when choosing an N fertilizer rate, the profit-maximizing N fertilizer rate might decrease to insure the hay does not have toxic levels of nitrates. Testing for nitrates in hay can provide producers the necessary information to consider nitrate levels when choosing an N fertilizer rate but testing for nitrate levels and not selling toxic hay will be costly. Therefore, to justify continued nitrate management, producers would need to receive a price premium for low-nitrate, cattle-safe hay that is greater than the cost of nitrate management.

The objective of this research was to determine the price premium a hay producer needs to receive for cattle-safe, low-nitrate hay to continue managing nitrate levels. To achieve the objective, we estimated bermudagrass yield response to N fertilizer for four harvest months, and used a logit model to determine factors that impact the probability of nitrate levels exceeding the toxic threshold. Partial budgets were used to find the profit-maximizing N fertilizer rate for a bermudagrass hay producer who considers nitrate levels when choosing an N fertilizer rate, and for a bermudagrass hay producer who does not consider nitrate levels when choosing an N fertilizer rate. The difference in the expected net returns between producers was used to estimate the price premium. The results present a unique economic perspective on determining the profit-maximizing N rate for bermudagrass hay.

Data

Vaughn's No. 1 hybrid bermudagrass hay yields were collected for three years (2008-2010) from an experiment conducted at the University of Tennessee Highland Rim Research and Education Center located near Springfield, TN. The soils are well drained, dark brown, slightly sloped, and classified as Crider silt loam (fine-silty, mixed, active, mesic Typic Paleudalfs).

The experimental design was a split plot, Latin Square with five replications. The main plots were irrigated and non-irrigated and the subplots were five N fertilizer rates. The bermudagrass plots were harvested each year in June, July, August, and September. N fertilizer was applied in April and reapplied after the June, July, and August harvests at rates of zero, 50, 100, 150, and 200 lb./acre, giving total annual N fertilizer treatments of zero, 200, 400, 600, and 800 lb./acre. Each plot measured nine feet 10 inches wide by 19 feet eight inches long. Elemental and nitrate analyses were performed at the Soil, Plant, and Pest Center in Nashville, TN by N treatment and harvest month. Average yields by N rate and harvest month are presented in Table 1 and Figure 1 shows the range of nitrate levels by probability. The June and July harvests appear to have a chance of nitrate levels exceeding the toxic threshold of 5,000 ppm.

The average price of N ($0.60/lb.), calculated using ammonium nitrate prices from 2008 to 2010 (USDA NASS, 2012b), and the average price of bermudagrass hay ($90/ton) in Tennessee from 2008 to 2010 (USDA NASS, 2012a) were used to calculate net returns for bermudagrass hay production. Harvest costs of $104.80/acre were obtained from the University of Tennessee Bermudagrass Hay Budget (University of Tennessee Agricultural and Resource Economics Department, 2007). The cost of testing forage for nitrates at the University of Tennessee Soil, Plant, and Pest Center was $6 per sample, with a recommendation to submit one sample per 10 bales (assuming 1200 lb. bales). Therefore, the cost of testing the hay depends on yield.

Expected Profit-Maximizing Levels of Nitrogen Fertilizer

Partial budgets were constructed to calculate expected net returns for the profit-maximizing N fertilizer rates by harvest month for two hay producers. One of these producers considers plant-tissue nitrogen found as nitrate (nitrate) levels when choosing an N fertilizer rate and the other hay producer does not consider nitrate levels when choosing an N fertilizer rate. Expected net returns ($/acre) for the producer who does not consider nitrate levels were calculated by multiplying the price ($/ton) of the hay by the yield (ton/acre) minus the cost of N ($/acre) and harvest ($/acre). Bermudagrass yield response to N fertilizer was estimated and the producer chooses the N rate in each harvest period that maximizes expected net returns. The producer, who does not consider nitrate levels, was assumed to sell all hay regardless of the nitrate level.

Expected net returns for the producer who does consider nitrate levels were calculated similarly; however, the producer has an additional cost of testing the hay for nitrates and does not sell hay with toxic levels of nitrates. The producer considers the information provided in hay tests for nitrates when selecting the profit-maximizing N fertilizer rate. The producer refrains from selling hay if nitrate levels exceed the toxic threshold of 5,000 ppm, and adjusts the N fertilizer rate to reduce the probability of toxic nitrate levels. The probability of nitrate levels exceeding toxic levels was estimated as a function of N fertilizer, weather, and harvest period. The probability model is used along with the bermudagrass yield response to N to find the profit-maximizing N fertilizer rate. This producer chooses an N fertilizer rate maximizing expected net returns while reducing the probability of producing hay exceeding the toxic nitrate threshold. The producer can guarantee buyers cattle-safe hay. The difference in the expected net returns between the two producers divided by the annual yield of the nitrate-testing producer is the value of knowing the bermudagrass hay is safe for cattle feed. This value is the price premium a nitrate-testing bermudagrass hay producer needs to break even with the producer who does not test nitrate levels.

Methods

A linear response plateau function was used to estimate bermudagrass yield response to N fertilizer. The linear response plateau function assumes yield responds linearly to additional N until a yield plateau is reached. At the plateau, N is no longer a limiting factor in maximizing yield; thus, additional N does not increase yield. The yield response function is illustrated in Figure 2, and it was estimated using the NLIN procedure in SAS 9.2 (SAS Institute Inc., 2004). Given the linearity of the response function, the profit-maximizing N rate is a corner solution at the N rate required to reach the plateau if the marginal value product of N is greater than the marginal factor cost of N below the plateau (Tembo et al., 2008). Conversely, if the marginal value product of N is less than the marginal factor cost of N, a profit-maximizing producer would not apply N (Tembo et al., 2008). In other words, if the benefit of a unit of N is greater than the cost of the unit of N then a producer would apply the N fertilizer rate at which the plateau yield is reached. If the cost of a unit of N is greater than the benefit of a unit of N then a producer would not apply N fertilizer.

Factors influencing nitrate accumulation in hay are commonly determined using an analysis of variance approach (Burns, Wagger, & Fisher, 2009; Evers, Redmon, & Provin, 2004; Osborne et al., 1999). The results from these models are limited to determining how discrete levels of N fertilizer influence nitrate accumulation. Since nitrate accumulation in bermudagrass is influenced by several environmental factors, going beyond testing discrete N rates to predict nitrate accumulation as a function of N fertilizer is difficult. To meet the objective, a logit model was used to predict the impact of N, rainfall, average daily maximum and minimum temperatures, irrigation, and harvest month on the likelihood of nitrate levels exceeding the threshold dangerous to cattle. This modeling approach is new to the nitrate-toxicity literature, and allows for N to be treated as a continuous variable instead of the fixed effects of discrete levels of N.

The dependent variable in the logit model equals one for nitrate levels greater than or equal to 5,000 ppm and equals zero for nitrate levels less than 5,000 ppm. The nitrate toxicity threshold is based on the literature (Connell et al., 2011; MacKown & Weik, 2004; Strickland et al., 1996; Undersander et al., 1999). The explanatory variables N, rainfall, average maximum and average minimum daily temperatures for the harvest period are continuous variables while irrigation and harvest month are indicator variables. A positive (negative) parameter estimate for a variable indicates that an increase (decrease) in a continuous variable, or the presence of an indicator variable, increases (decreases) the probability of nitrates exceeding the toxic threshold. The logit model was estimated using the LOGISTIC procedure in SAS 9.2 (SAS Institute Inc., 2004). Parameter estimates from the logit and yield response models were used to calculate the probability of exceeding the nitrate threshold at profit-maximizing N levels by harvest month. This was done by following the methods outlined in Toliver et al. (2012). Parameter estimates from the yield response function and the logit model were used to determine the profit-maximizing N fertilizer rates for each harvest month with and without considering the probability of nitrate toxicity.

Results and Discussion

Parameter estimates from the linear response plateau model were significant at the 0.05 level (Table 2). The intercept represents the expected yield if no N was applied and the plateau estimate represents the expected yield when N was no longer a limiting input. The expected plateau was the highest in July and August and lowest in September. Bermudagrass is a warm-season grass so yields were expected to be highest in the warmest months. The slope parameter estimate represents the yield response in ton/acre to an increase of one lb./acre applied. Yield response to N was fairly similar for June, July and August but decreased in September. The yield-maximizing N fertilizer rate was highest for the July and August harvests and lowest for the June harvest (Table 2). The variation in yield-maximizing N fertilizer rates demonstrates that application of a uniform rate across all harvest months would result in over or under application of N fertilizer in some months.

The coefficients for N fertilizer rate, rainfall, and average maximum daily harvest-month temperature were positive and significant at the 0.05 level (Table 3). The results show that an increase in N fertilizer application increases the probability of nitrates exceeding the toxic threshold. Previous research found that higher N fertilizer rates result in higher nitrate levels in bermudagrass (Osborne et al., 1999; Westerman et al., 1983), but, in contrast to their results, our results are expressed as the probability of nitrates exceeding the toxic threshold.

Contrary to expectations, an increase in rainfall increased the probability of nitrates exceeding the toxic threshold. This result was unanticipated since drought is commonly found to explain high nitrate levels in the literature (Connell et al., 2011). However, some soil moisture must be available for the plant to take up and accumulate nitrates. Plants surviving drought are often higher in nitrates for several days following the first rain (Stoltenow & Lardy, 1998). Rainfall close to harvest can increase N uptake by bermudagrass and amplify nitrate accumulation. Depending on the timing of harvest after the first rain during drought stress, the plant may not have time to reduce nitrate levels by converting nitrates into proteins. Thus, the implication is that the timing of harvest after the first rain following a drought period might be integral to determining nitrate levels in bermudagrass hay. It is likely this result is a caveat of the three years of data, and more research on nitrate levels following rainfall is needed.

An increase in the average maximum daily temperature increased the probability of nitrate levels exceeding the toxic threshold while an increase in the average minimum daily temperature decreased the probability of nitrate levels exceeding the toxic threshold. Thus, when the daily high temperature gets warmer the probability of nitrate levels exceeding the toxic threshold increased, and when the daily low temperature gets warmer the probability of nitrate levels exceeding the toxic threshold decreased. The latter result can also be interpreted as the daily low temperature gets colder, the probability of nitrate levels exceeding the toxic threshold increased. Irrigation decreased the likelihood of nitrate levels exceeding the toxic threshold at the 0.10 level. Irrigation rates and timing were controlled in the experiment so the bermudagrass that received irrigation never was drought stressed and could continually convert nitrates to protein. Conversely, rain-fed bermudagrass would not necessarily be able to continually convert nitrates to proteins due to intermittent moisture availability. The probability of nitrate levels exceeding the toxic threshold was greater for the July harvest than the June, August and September harvests. We found no significant differences in nitrate accumulation in the plant tissue for the June, August and September harvests. The finding for July implies more N may have been taken up by the bermudagrass before the July harvest than was converted to protein, resulting in excessive nitrate accumulation.

The yield- and profit-maximizing N fertilizer rate for the hay producer who does not consider nitrate levels varied across harvest months from 64 lb./acre in June to 108 lb./acre in July (Table 4). The University of Tennessee Extension recommends producers to use a soil test to determine soil nitrogen needs, but commonly recommends an annual application of 400 lb./acre of N fertilizer for hybrid bermudagrass (Carter, 2011). Applying this uniform N fertilizer for the year would over apply N fertilizer and reduce the bermudagrass hay producer's net returns, relative to a variable-rate N fertilizer application across harvest months. Yields varied from 1.07 ton/acre in September to 2.40 ton/acre in July (Table 4). The probabilities of bermudagrass hay exceeding toxic nitrate levels for the June, August and September harvests at the profit-maximizing N fertilizer rates were low (3%, 1%, and 0%, respectively), but the probability of exceeding the nitrate threshold was 37 percent for the July harvest (Table 4). Expected net returns were highest for the July harvest and lowest for the September harvest (Figure 3). Given the estimated probabilities of nitrate levels exceeding the threshold, this producer likely would be selling hay that is toxic to cattle.

The yield- and profit-maximizing N fertilizer rates for the hay producer who considers nitrate levels were the same for the June, August, and September harvests, and were no different from the profit-maximizing rates of the producer who does not consider nitrate levels. However, the profit-maximizing N rate decreased by 56 lb./acre for the July harvest and the expected yield decreased by 0.72 ton/acre to 1.67 ton/acre (Table 4). With the decrease in the N fertilizer rate, the probability of producing hay exceeding the toxic nitrate threshold decreased from 37 percent to 11 percent (Table 4). Furthermore, expected net returns decreased for the June, July and August harvests because the producer did not sell the hay with nitrate levels exceeding the toxic threshold and because of nitrate testing costs (Figure 1). The largest decrease in expected net returns occurred for the July harvest, resulting from the reduced N fertilizer rate and subsequent reduction in expected yield. The total decrease in expected net returns for the producer who tests for nitrates was $59/acre/year. The total hay produced over the four harvests for the producer who considers nitrate levels was 6.46 ton/acre/year. Dividing the revenue loss by the total expected yield, gives a reduction in expected net returns, compared with the other producer, of $9.12/ton. This producer must receive a price premium of $9.12/ton for low-nitrate, cattle-safe hay to break even with the producer who disregards the potential for nitrate toxicity to cattle, and to financially justify continuing the testing and managing of nitrates in bermudagrass hay.

These results may also have economic implications which cannot be measured in this study, but would require further research to address. The hay producer unconcerned with nitrate levels may be risking damaging his or her reputation by selling hay with high nitrate levels. Hay buyers might avoid purchasing hay from this producer because of past experiences with purchasing high nitrate hay. On the other hand, the hay producer that does test for nitrates can market his or her hay as cattle-safe hay. Previous economic studies have found buyers' were willing-to-pay a premium for hay with higher levels of proteins, total digestible nutrients, acid detergent fiber, and neutral detergent fiber (Hooper et al., 2004; Ward, 1994). However, it is unknown what hay buyers are willing to pay for hay with a reduced risk of causing nitrate toxicity to cattle. The question for future research is whether hay buyers are willing to pay more for higher protein hay with higher risk of toxicity to cattle, or for lower protein hay that has a lower risk of being toxic when fed to cattle?

Summary

The objective of this research was to determine the price premium a hay producer would need to receive for cattle-safe, low-nitrate hay to economically justify managing nitrate levels. The bermudagrass yield response to N fertilizer was estimated for four harvest months, and it was determined the profit-maximizing N fertilizer rate varies across harvest months. Applying the commonly recommended annual uniform N fertilizer rate to bermudagrass would over apply N and reduce the producers net returns. Profit-maximizing bermudagrass hay producers should apply N fertilizer at variable rates across harvest months. This finding could have important implications for farm managers who are applying uniform rates of N fertilizer annually.

The logit model indicated that N fertilizer, rainfall, average daily maximum and minimum temperatures, irrigation, and harvest month significantly affect nitrate accumulation in bermudagrass hay. The results from the estimated models show that both producers have the same profit-maximizing N fertilizer rates for the June, August, and September harvests because the probability of exceeding the toxic nitrate threshold is small for those harvests. In contrast, the profit-maximizing N rate for the producer who considers nitrate levels when choosing an N fertilizer rate decreased by 56 lb./acre for the July harvest. The total loss in revenue from the lower N rate required to guarantee safe hay for cattle consumption was $59/acre/year. A hay producer would need to receive a price premium of $9.12/ton for low-nitrate, cattle-safe hay to justify continued testing of bermudagrass hay for toxic nitrate levels.

This approach to analyzing nitrate accumulation in hay production has not previously appeared in the literature. Earlier economic research has examined quality and quantity issues, but no paper has presented the value of testing bermudagrass for toxic nitrate levels. This article provides a new economic framework to help hay producers choose optimal N fertilizer rates when nitrate toxicity to cattle is an issue. Although bermudagrass is not considered a high-risk forage for accumulating nitrate levels toxic to cattle, this approach to managing nitrate levels in bermudagrass can be adapted for any forage being produced for hay.

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Table 1. Average yield (ton/acre) by nitrogen rate and harvest month

	Month				
N (lb/acre)	June	July	August	September	Total
0	0.834	0.931	0.809	0.490	3.063
50	1.364	1.756	1.793	0.886	5.799
100	1.497	2.226	2.129	1.024	6.876
150	1.408	2.392	2.218	1.064	7.082
200	1.635	2.404	2.286	1.125	7.450

Table 2. Parameter estimates for the linear response plateau function (ton/acre)

	Month			
Parameter	June	July	Aug	Sept
Intercept	0.833**	0.989**	0.811**	0.489**
Slope	0.011**	0.013**	0.019**	0.008**
Plateau	1.514**	2.397**	2.210**	1.071**
Random error	0.313**	0.947**	0.554**	0.187**
Yield Max N Rate (lb/acre)	64.13	108.39	71.36	72.96

** Significant at the 0.05 level.

Table 3. Parameter estimates for the logit model

Variable	Parameter Estimate
Intercept	−16.176**
N	0.027***
Harvest-June†	0.119
Harvest-July†	3.699***
Harvest-August†	0.641
Irrigation	−0.605*
Rainfall	0.888***
Max Temperature	0.404***
Min Temperature	−0.459***

*, **, *** Significant at the 0.1, 0.05, and 0.01 level, respectively.
† Harvest month of September is dropped so significance is determined relative to the September harvest.

Table 4. Profit-maximizing N rates (lb./acre), profit-maximizing expected yields (ton/acre), and probability of exceeding nitrate levels toxic to cattle by harvest month

Result	June	July	August	September
	Not concerned with nitrate toxicity			
Optimal N rate (lb/acre)	64.13	108.36	71.36	72.96
Optimal yield (ton/acre)	1.51	2.40	2.21	1.07
Probability of exceeding toxic nitrate threshold	3.0%	37.0%	1.0%	0.0%
	Concerned with nitrate toxicity			
Optimal N rate (lb/acre)	64.13	52.28	71.36	72.96
Optimal yield (ton/acre)	1.51	1.67	2.21	1.07
Probability of exceeding toxic nitrate threshold	3.0%	11.0%	1.0%	0.0%

Figure 1. The probability of nitrate levels in bermudagrass for four harvest months

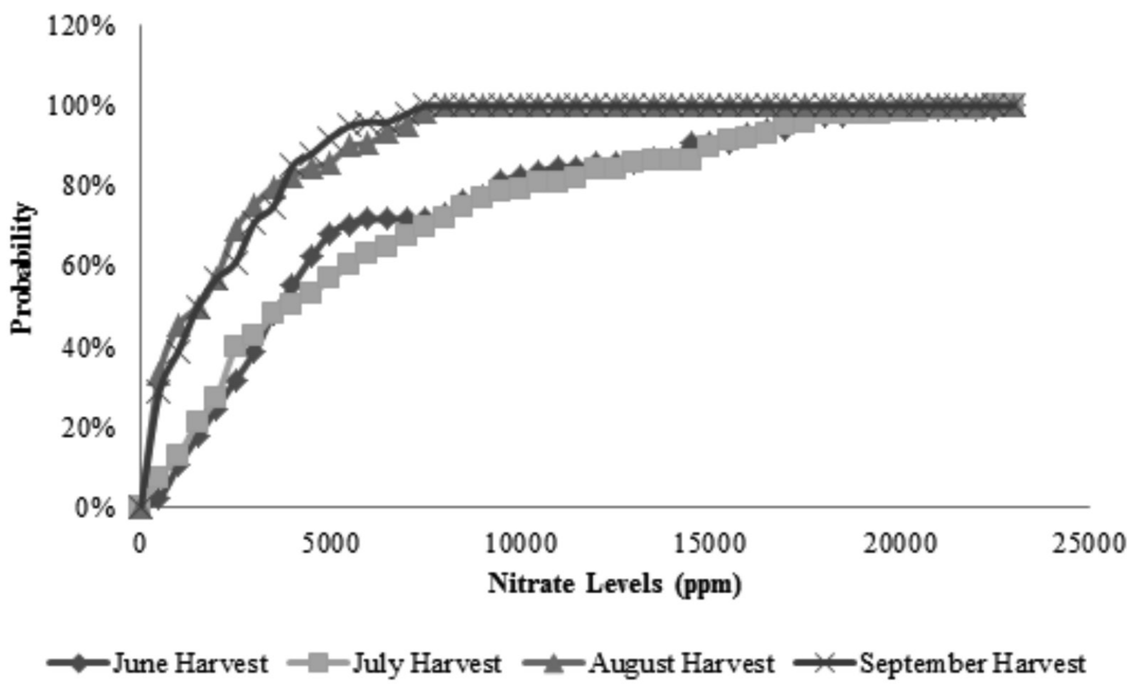

Figure 2. Illustration of a linear response plateau function for bermudagrass yield (ton/acre) response to N

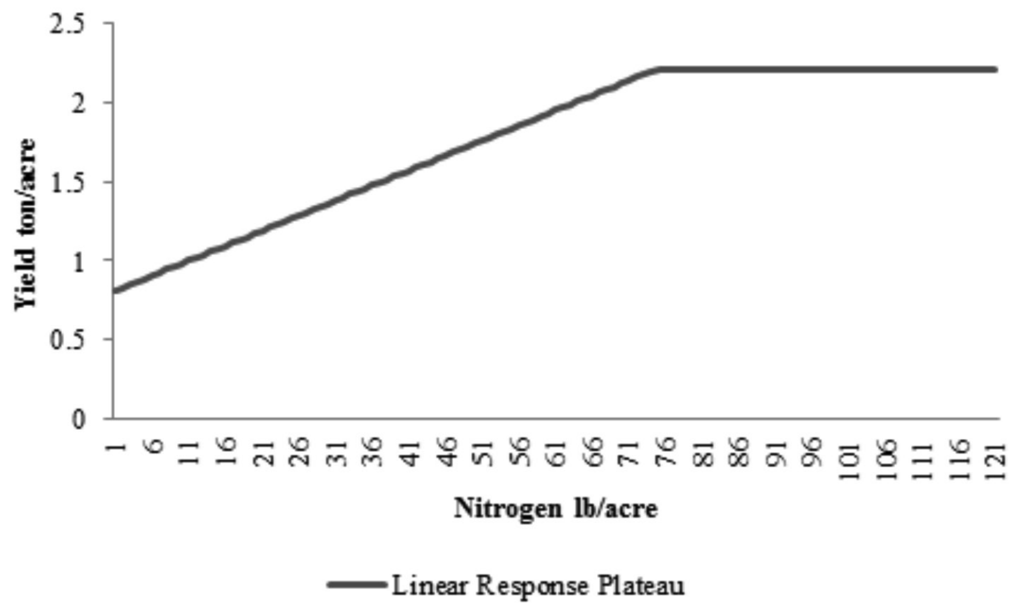

Figure 3. Expected net returns per acre by harvest month for a producer who considers nitrates when selecting an N fertilizer rate and a producer who does not consider nitrates when selecting an N fertilizer rate