Spring Rainfall Dictates Success of Nitrogen Applied to Corn in Fall or Winter

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Abstract

Nitrogen fertilizer applied to corn (*Zea mays* L.) well before plant uptake is susceptible to losses from certain weather conditions, especially spring rainfall. Our objectives were to determine how spring rainfall and the N application time interact to result in grain yield loss, and to develop functions to predict and correct these yield losses with supplemental N. Variable application times were achieved by fertilizing at monthly intervals with a constant N rate (134 kg N ha^{-1}), and then determining grain yield loss from a fall (Oct/Nov) or winter (Dec/Jan/Feb) application compared to the spring (Mar/Apr). The same N treatments were applied at 10 site-years in central and northern Illinois between 1997 and 1999 and weather data were collected at each site. The responsiveness to N was assessed by including an unfertilized treatment at all sites, and seven sites had an N titration (five rates from 67 to 201 kg ha^{-1} in 34 kg increments) applied in April. All but one site exhibited yield increases from N application, and only three sites did not have a fall or winter application that yielded less than spring. Plateau-linear functions best described the relationship between spring (Mar, April, and May) rainfall and yield reductions from fall or winter applied N, and indicated the precipitation threshold above which these yield losses accentuated (270 mm and 325 mm for fall and winter applied N, respectively). We used these relationships and historic rainfall data to predict the probability for a given yield loss from fall or winter applied N, and we developed equations to determine the amount of supplemental N needed to correct for this loss.

Introduction

The best time for N application to corn must balance a number of contentious issues including: the propensity for N to be lost, the biology of the crop in using N, the unpredictability of the weather, the availability of equipment and manpower, and the economics of fertilizer cost and grain value. A number of N fertilizer recommendation systems have been developed for different geographic regions that attempt to accommodate these variables, but in many cases the success of N fertilization is largely dependent on the weather. This is obviously because of the major impacts that temperature and precipitation have on the microbial and physical processes associated with N loss. Clearly, from the standpoints of N loss and crop biology, the best time to apply N should be just prior to the period of rapid crop uptake. The risk of adverse weather, however, plays a large role in the reluctance of growers to widely adapt this practice and necessitates other times for N application. These times are also dictated by the impact that weather has on soil moisture, which determines when equipment for N application can be used. Despite its major impact on N fertilization, weather considerations are generally secondary to economic ones, especially since fertilizer cost and grain prices both exhibit large and independent fluctuations.

The major distinction in timing of N application is between fall and spring, and an abundance of research shows that applying N in the spring is usually superior to the fall (Bundy, 1986; Miller et al., 1975; Randall et al., 2003; Randall and Vetsch, 2005; Stevenson and Baldwin, 1969). The degree of yield reduction from fall fertilization is often associated with spring rainfall (Malzer and Randall, 1985; Randall and Vetsch, 2005; Vetsch and Randall, 2004). Guidelines for fall N fertilization, however, do not include any means of predicting the degree to which spring rainfall causes yield loss, or any recourse for supplemental N application if yield loss has occurred. Our objectives were to address this issue by: (i) determining the degree of yield loss associated with spring rainfall and N application time, and (ii) developing functions to predict when yield loss has occurred and the amount of supplemental N needed to correct this loss.

Materials and Methods

Nitrogen was applied at monthly intervals from October through April at 10 site-years in Central and Northern Illinois, and grain yield was measured along with weather data. Field and cultural characteristics at each site are given in **Table 1**. There were three sites in 1997 and 1998, and four in 1999. Each site-year is abbreviated by three letters, followed by two numbers representing the

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Abbreviations: N = nitrogen;

Table 1. Characteristics of the 10 Illinois site-years where fertilizer N was applied from October through April.

		Site-year Characteristics							
Site-year	Nearest town	Soil Bray P1	Soil Exch. K	O.M., %	pH	Soil series, Texture	Slope, %	Prev. Crop	Tillage
		- - - - - mg/kg - - - - -							
Gif 98	Gifford	13	190	3.7	7.3	Swygert, SiCl	2-5	Corn	Plow
Man 99	Manlius	19	108	3.5	6.9	Joy, Sil	0-2	Corn	Strip
Ran 98	Rantoul	47	207	5.2	4.7	Raub, Sil	0-2	Soybean	Mulch
Mor 98	Morris	30	163	3.4	5.5	Darroch, Sil	2-5	Soybean	Zero
Dek 99	Shabbona	37	175	4.1	6.0	Elpaso, SiCl	0-2	Soybean	Mulch
Lex 97	Lexington	50	192	2.9	6.2	Elpaso, SiCl	2-5	Soybean	Strip
Urb 97	Urbana	63	202	2.5	4.7	Drummer, SiCl	0-2	Corn	Zero
Tow 97	Towanda	52	209	3.8	6.2	Sabina, Sil	0-2	Corn	Strip
Ran 99	Rantoul	26	174	2.5	5.5	Dana, Sil	2-5	Soybean	Mulch
Fla 99	Flanagan	40	292	3.4	5.9	Chenoa, SiCl	2-5	Soybean	Strip

year in which the experiment was conducted. None of the sites were repeated and eight were conducted on-farm. Soil fertility levels were generally within accepted levels, and except for the N treatments other management practices were in accordance with the grower's standard practices that used local recommendations for high yield. Corn was planted between April 15th and May 11th, at seeding rates that ranged from 67 to 82 thousand seeds per hectare.

Nitrogen was applied between the 8th and 20th of each month at a rate of 135 kg ha^{-1}. This rate was selected based on preliminary trials conducted at four of the sites (Lexington, Morris, Towanda, Urbana) in 1996, and on the advice of the farmers and farm managers at each site. To assess the responsiveness to N, all sites had an unfertilized control. Seven sites (1998 and 1999) had a N titration of five rates ranging from 67 to 201 kg N ha^{-1} in 34 kg increments applied in April. The N source at all sites was granular ammonium sulfate which was broadcast on the soil surface. At all sites, N treatments were arranged in a randomized complete block design with four replications, with plot dimensions of 6.1 m wide and 30.5 m long.

Precipitation data were collected on-site using a tipping bucket and self-emptying style rain gauge with a 200 mm collection opening. Air temperature was measured 1.5 m above the soil surface and all data logged with WatchDog™ data loggers (Spectrum Technologies, Inc. 23839 W. Andrew Rd., Plainfield, IL 60544). Corn grain yield was measured by harvesting the center two rows of an experimental unit with plot combines or by hand harvest. When machine harvested, the entire 30.5 m length of plots was used, while 5.3 m in a row was used for hand harvested plots. Grain moisture was determined, and grain dry matter yields were adjusted to zero moisture.

Statistics were performed by ANOVA using the GLM procedures of SAS (SAS Institute, 2003). A LSD at α=0.10 was used for means separations. Corn yield loss for fall (October through November) and winter (December through February) N fertilization was calculated as the difference between corn yield for spring (March through April) fertilization and fall and winter applied N at each location, respectively.

Mean monthly temperature and total monthly precipitation, as well as cumulative precipitation and mean temperature for the periods fall, winter, and March through May were evaluated as independent variables to estimate yield loss. The effect of spring rainfall on fall and winter yield loss and on supplemental N needed was modeled with a plateau-linear function using the NLIN procedure of SAS (SAS Institute, 2003). Corn yield response to N fertilizer across all sites was modeled with the same procedure. Linear-plateau and quadratic-plateau models were tested and the linear-plateau model was chosen because it provided the best fit to the data. All parameters for yield loss, supplemental N, and yield response models were tested at α=0.1.

The cumulative probability of yield loss from fall and winter applications was calculated for Urbana (40°6'N, 88°12'W), Bloomington (40°28'N, 88°59'W), Paw Paw (41°41'N, 88°58'W), and Monmouth (40°54'N, 90°38'W), Illinois, based on the yield loss functions. These locations were selected to provide a range of environmental conditions within Northern and Central Illinois, the inference space for this research. Total spring (March through May) precipitation was calculated based on weather data obtained from the Illinois State Climatologist Office (http://www.sws.uiuc.edu/data/climatedb/). The weather data encompassed 106 records for Urbana and Monmouth, 86 for Paw Paw, and 56 for Bloomington.

Results

There was considerable variation among the sites in their responsiveness to N, and in the degree of yield loss from a fall or winter N application compared to spring (**Table 2**). At all sites, spring-applied N produced yields that were higher or similar to N applied in the fall or in the winter. The biggest difference was between fall and spring applications, with 5 of the 10 sites producing lower yield with fall applications ($p \leq 0.10$), and two sites producing lower yield with winter N applications, compared to spring application. At all but three sites there was at least one monthly N application that produced a grain yield less than spring.

While no, or a small, yield response to N lessened the likelihood of an N-timing effect, a large N-induced yield increase did not always equate to a large difference in yield from fall or winter application. This occurred at Urb97 and Mor98, which exhibited large yield responses to N (193 and 116%), but negligible differences due to N timing (**Table 2**). Other sites (Gif98 and Man99) exhibited large differences due to the time of N application, but smaller magnitudes of yield response to N application (75 and 85%). The yield response to N for the seven sites where an N titration was conducted is shown in **Figure 1**. A greater range was observed among the sites for the yield of unfertilized plots, which narrowed with any rate of applied N. A linear-plateau function best fit the data ($R^2 = 0.42$), and indicated an average maximal yield of 8.81 Mg ha^{-1} with 126 kg ha^{-1} of N. The N rate that maximized yield turned out to be fairly similar to the N rate used to compare N application times (135 kg ha^{-1} N).

The magnitude of grain dry matter yield loss (in Mg ha^{-1}) from a fall or winter N application was calculated for each site by subtracting the season average yield from the yield obtained in the spring. This resulted in a range of yield losses of from 0 to 3.3 Mg ha^{-1} for fall N applications and from 0 to 1.8 Mg ha^{-1} for winter N applications. The only weather parameter related to the degree of this yield loss was spring rainfall (cumulative total for

Table 2. Influence of ammonium sulfate (AMS) application time on the grain dry matter yield of corn grown at 10 Illinois site-years (1997-1999). Ammonium sulfate was broadcast on the soil surface at the same rate (135 kg ha-1) for each application time.

Time of N application		Site-year										
Season	Month	Gif98	Man99	Ran98	Mor98	Dek99	Lex97[1]	Urb97	Tow97	Ran99	Fla99	Avg.
		Mg per ha										
No fertilizer N		4.91	3.71	7.04	3.82	6.55	8.13	4.36	6.27	8.95	5.35	5.91
Fall	Oct	5.24	4.69	8.78	7.47	8.95	8.67	——	——	8.95	7.97	7.59
	Nov	5.40	6.11	9.27	7.77	8.73	9.24	8.13	7.15	9.55	7.97	7.93
	Avg.	5.36	5.40	9.03	7.62	8.84	8.96	8.13	7.15	9.25	7.97	7.76
Winter	Dec	6.49	6.87	9.93	8.07	8.51	9.06	8.18	7.20	9.77	7.26	8.13
	Jan	6.55	6.38	9.71	7.97	9.06	9.11	8.18	6.22	9.33	7.42	7.99
	Feb	7.47	6.82	9.27	7.97	9.71	9.11	8.29	6.66	9.66	7.64	8.26
	Avg.	6.84	6.69	9.64	8.00	9.09	9.09	8.22	6.69	9.58	7.44	8.13
Spring	Mar	7.80	7.04	9.93	7.91	9.27	9.55	8.35	7.53	9.93	8.18	8.55
	Apr	9.44	6.66	10.04	8.57	9.44	9.55	8.57	7.58	9.27	7.31	8.64
	Avg.	8.62	6.85	9.98	8.24	9.36	9.55	8.46	7.56	9.60	7.75	8.60
LSD(0.10)[2]		1.10	0.68	0.65	0.54	0.52	0.54	0.77	0.73	ns	0.74	0.44

[1] 20 kg N ha^{-1} was applied to the No-N control. [2] The LSD applies to the means of No fertilizer N and to the means of each season.

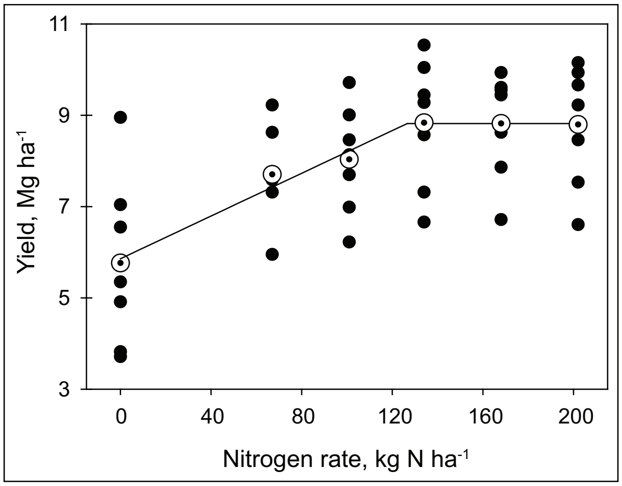

Figure 1. The grain dry matter yield response of corn to varying amounts of spring applied N for the seven sites where a complete N-rate titration was conducted. A linear-plateau function best fit the data ($R^2 = 0.42$) with model parameters $y = 5.86 + 0.0234x$ if $x < 126$, or $y = 8.81$ if $x > 126$.

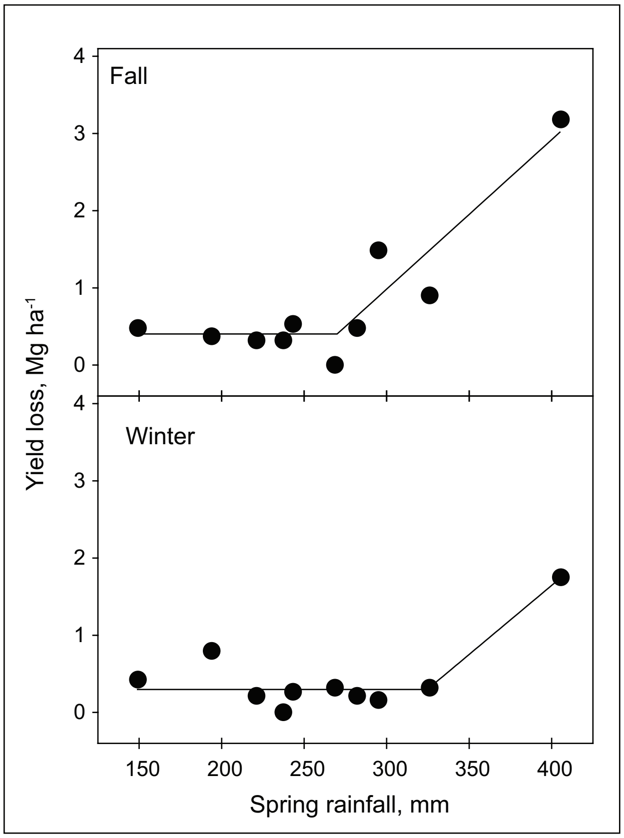

Figure 2. The relationship between cumulative spring rainfall (March, April, May) and the amount of grain dry matter yield loss associated with a fall (top) or a winter (bottom) application of N compared to spring. Data are from 10 sites in central and northern Illinois over a 3-year period. The degree of yield loss associated with spring rainfall can be explained by the models: $y = 0.40 + (\text{rain} – 270) \times 0.01936$, if $x > 270$ ($R^2 = 0.82$) for fall, and $y = 0.30 + (\text{rain} – 325) \times 0.01788$, if $x > 325$ (R2 = 0.83) for winter.

March, April, and May). These relationships were best described by plateau-linear models, which also indicated the precipitation threshold above which yield loss occurred (**Figure 2**). For fall applications, yield losses greater than 0.40 Mg ha^{-1} occurred when spring rainfall was more than 270 mm, while winter N application required more than 325 mm of spring rain for yield losses greater than 0.30 Mg ha^{-1}. The rate of yield loss (Mg ha^{-1} mm^{-1}) above the critical level was similar between both application times.

These functions along with historic spring rainfall data from four regions in Central and Northern Illinois were used to predict the cumulative probability for a given yield loss (**Figure 3**). This analysis indicated a higher probability of yield loss for fall than winter N applications in all regions, and a region specific difference in the likelihood of these yield losses to occur. For example, yield losses from fall applications will be greater than 1.25 Mg ha^{-1} in 40% of years in Urbana, while this level of yield loss is expected to occur only 20% of the years in Paw Paw (**Figure 3**). Alternatively, in one out of five years a yield loss greater than 2.5 Mg ha^{-1} is expected to occur in Urbana when N

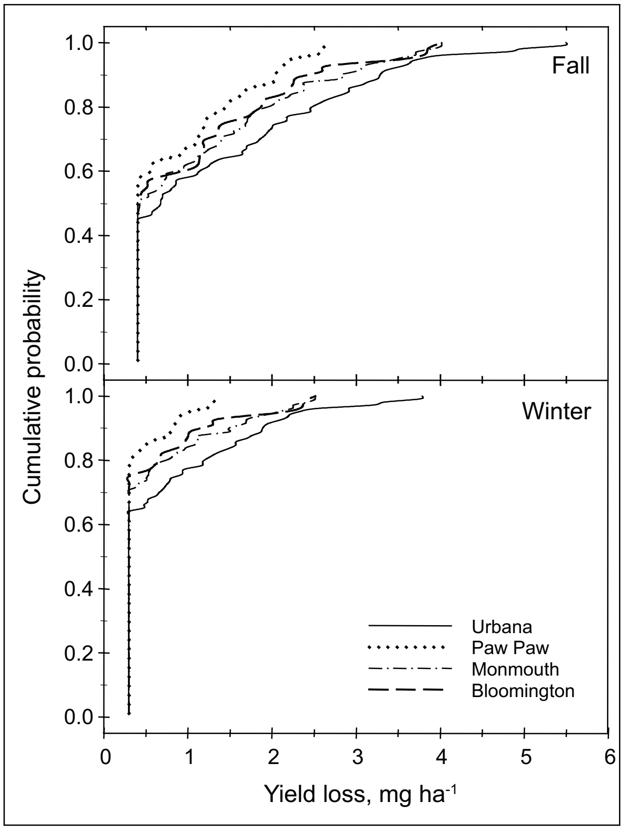

Figure 3. The cumulative probability of predicted corn grain dry matter yield loss for fall (top) or winter (bottom) applications of fertilizer N compared to spring for four locations in central and northern Illinois. Locations include Urbana (40°6’N, 88°12’W), Bloomington (40°28’N, 88°59’W), Monmouth (40°54’N, 90°38’W), and Paw Paw (41°41’N, 88°58’W).

is applied in the fall compared to 1.4 Mg ha^{-1} yield loss in Paw Paw.

Based on the yield loss functions from fall or winter N and spring rainfall (**Figure 2**), and the overall yield response function to N (**Figure 1**), we predicted the amount of supplemental N needed to produce yields like spring applied-N, based on the time of N application and the spring rainfall (**Figure 4**). These plateau-linear functions indicate that fall and winter applied fertilizer rates should be increased by 20 kg N ha^{-1} and 13 kg N ha^{-1} with respect to spring application even when spring precipitation is low. For fall applications, the supplemental N required increases linearly when spring rainfall exceeds 267 mm, whereas for winter N application this threshold was 320 mm. For both application times, the supplemental N required per mm of spring rainfall in excess of the threshold was very similar.

Discussion

Weather and the availability of N are usually the two factors exerting the greatest impact on corn yields. They can act independently, or be closely linked, and their effects can be to either increase or decrease crop growth and yields. Considerable variation in yield at the same site is generally attributed to weather, usually the amount and distribution of preseason and seasonal precipitation (Anderson et al., 2001; Magrin et al., 2005; Thompson, 1986). Nitrogen supply is also of major importance in crop productivity because it impacts all phases of plant growth and yield determination (Below, 2002).

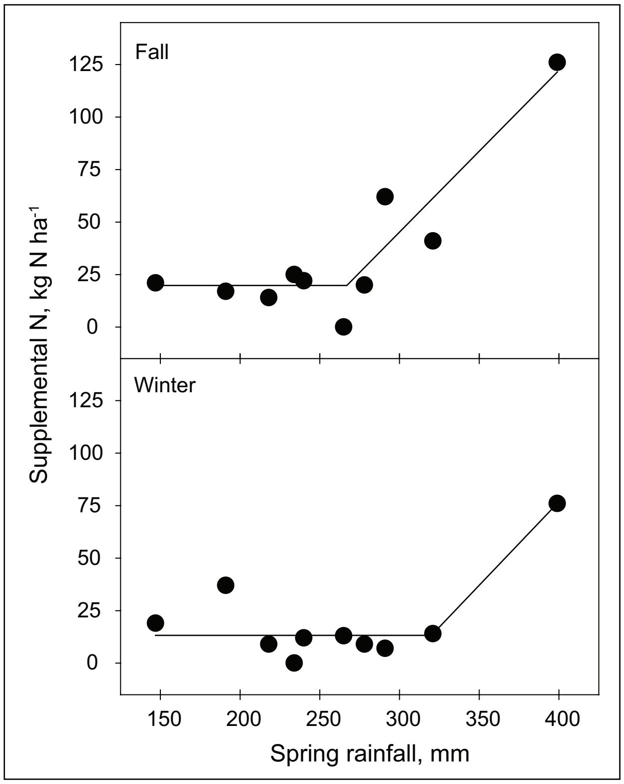

Figure 4. The predicted supplemental N needed to obtain yields similar to spring-applied N as a function of spring rainfall (March, April, May) when N is applied in the fall (top) or in the winter (bottom). Data are from 10 sites in central and northern Illinois over a 3-year period. The supplemental N needed can be explained by the models: y = 20 + (rain – 267) x 0.77, if x > 267 (R^2 = 0.88) for fall, and y = 13 + (rain – 320) x 0.79, if x > 320 (R^2 = 0.81) for winter.

Understanding how to best manage N fertilization to account for potential weather influence is clearly an important consideration in corn production, and has been the subject of numerous scientific studies and extension recommendations (Bundy, 1986; Hoeft and Peck, 2000; Malzer and Randall, 1985; Rehm et al., 1994). Obviously, when N is applied many months prior to crop uptake, it is even more subject to the vagaries of the weather, which is clearly demonstrated from our data. Similar to other published reports (Malzer and Randall, 1985; Randall and Vetsch, 2005; Vetsch and Randall, 2004), we noted a clear relationship between spring rainfall and yield when N was applied in the fall, and also showed a similar, although more tempered, relationship for N applied in the winter. Spring rainfall was the only weather parameter related to these application-induced losses in yield. Multiple regression models that included temperature, winter precipitation, and the responsiveness to N did not improve the relationship (data not shown).

Although considerable variation existed between sites, and for application times within sites, as a general rule the closer the N was applied to spring the better (**Table 2**). We also noted a fairly distinct difference in corn yield between fall and winter N applications, compared to spring applications, so we developed our predictive functions accordingly. These functions predicted a certain degree of yield loss from fall (0.40 Mg ha^{-1}) and winter N applications (0.30 Mg ha^{-1}) over a fairly wide range of spring precipitation, and the rainfall threshold at which these losses accentuated. This threshold was obviously lower for fall than winter applications (270 and 325 mm, respectively). These results indicate that irrespective of spring rainfall, a certain amount of N will become unavailable between N fertilization and corn uptake, resulting in corn yield loss. Sanchez and Blackmer (1988) found that 50 to 65% of fall applied N was not taken up by the plant and/or was lost from the soil, and our results suggest this effect is more pronounced for fall than winter applied N.

The potential loss of N increases with the length of time between N application and crop uptake

(Dinnes et al., 2002; Karlen et al., 1998). The higher temperatures prevalent in Northern and Central Illinois during fall compared to winter probably caused more nitrification of the fertilizer ammonium the earlier it was applied. Consequently, the higher concentration and the longer residence time of fertilizer-derived nitrate-N in the soil increases the likelihood of fall applied N to become unavailable for corn roots compared to winter and spring applied N, and explains the higher yield losses found with the earliest application time.

The relatively similar slopes of the yield losses and supplemental N requirements for fall and winter applied N indicate that the loss mechanisms driven by spring rainfall are similar for both application times, and consequently both application times would require the same management to minimize these losses.

Knowing the expected yield loss of a fall or winter N application in advance, and the precipitation threshold to exceed these losses gives growers a tool to help manage the interaction between the weather and N supply. In order to make informed management decisions, it is important to have an estimate of the likelihood of yield loss, which will depend on the frequency of spring rainfall exceeding the precipitation threshold for each application time at each location. This likelihood of a given yield loss for fall and winter applied N can be easily quantified with **Figure 3**. We selected four representative locations in north central Illinois that encompass a N-S transect (Urbana, Bloomington, and Paw Paw), and an E-W transect (Paw Paw and Monmouth). These figures indicate that the highest likelihood of yield loss is expected at the southernmost location (Urbana), and the lowest at the northernmost location (Paw Paw). In the latter location, the likelihood of a yield loss exceeding 0.3 Mg ha^{-1} is 1 in 5 years (20%) with winter fertilization, and 3 in 5 years (60%) for a yield loss higher than 0.4 Mg ha^{-1} for fall fertilization. At Urbana, these yield losses are expected to occur in slightly more than 5 out of 10 years (50%) and 3 out of 5 years, for fall and winter N applications, respectively. Clearly, fall N application has an extremely high risk of producing a yield loss in Urbana, but not so high a risk in Paw Paw.

Producers and nutrient management specialists could use these yield loss probability curves to assess the likelihood of a given yield loss from fall- or winter-applied N and evaluate if spring fertilization is required to eliminate or reduce it; or to decide if fall fertilizer application should be avoided in the first place. Alternatively, these figures could also be used as a management tool to evaluate if sidedress application of N is required to compensate fall or winter applied fertilizer N loss. At the sidedress time, in early to mid June, the total spring rainfall (March through May) is already known, allowing the estimation of the expected yield loss and the rate of N fertilizer that would be required to eliminate or reduce it, based on the yield loss and supplemental N functions.

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