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No-Till Corn Response to Nitrogen Rate and Timing in the Middle Atlantic Coastal Plain

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Improved N use efficiency for no-till corn (*Zea mays* L.) production on sandy soils may be enhanced with split applications of N fertilizer immediately prior to periods of highest N uptake. A field study was conducted in 1988 and 1989 at the Eastern Shore Agricultural Experiment Station in Painter, VA, on a Bojac loamy sand (coarse-loamy, mixed, thermic Typic Hapludult) to investigate split N applications near silking. Nitrogen treatments (as 30% N-urea ammonium nitrate solution) of 0, 36, 72, 108, and 144 lb N/acre at the 5-leaf growth stage (*ENR*) were factorially arranged with 0, 25, 50, 75, and 100 lb N/acre applied at the 16-leaf stage (*LNR*) in a randomized complete block design with three replications. Corn cultivar Pioneer Brand 3320 was planted no-till into a killed winter rye (*Secale cereale* L.) cover crop onto the same site each spring. At the 14-leaf stage, samples of the leaf immediately below the whorl were collected from each plot and analyzed for N, P, K, Ca and Mg. Yield response was attributed less to timing of N applications than to the total N rate; however, at least 36 lb N/acre were required at the 5-leaf stage to prevent N deprivation and reduction of yield potential. While *LNR* treatments increased yield at all *ENR* treatments, the greatest yield response to late N application was obtained between 36 and 72 lb N/acre applied early. At equal N rates, N use efficiency was not significantly affected when fertilizer N applications were split between the 5-leaf and 16-leaf growth stages. Under the high rainfall conditions which increased yield and nitrate leaching potentials, recommended 16-leaf stage N rates for 14-leaf N concentrations of 1.7 to 2.0% ranged from 85 to 92 lb/acre. Calibration of 16-leaf stage fertilizer N requirements with 14-leaf stage critical N values were not successfully developed for leaf N concentrations greater than 2% because yields were not maximized despite total N applications considerably higher than routinely recommended. Diagnosis and Recommendation Integrated System (DRIS) norms developed in Georgia did not accurately diagnose corn N status in Virginia; hence, local calibration of DRIS norms is necessary.

Split N fertilizer application increases N use efficiency (NUE) of field crops produced on sandy soils if the nutrient can be made available prior to the periods of high N uptake. Corn possesses great potential for increased NUE through optimization of application rate and timing because of the crop's high N requirement and wide period of N uptake. Increasing NUE for corn is extremely important in the Atlantic Coastal Plain, where the coarse-textured soils are especially prone to N leaching losses (Gilliam and Boswell, 1984).

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For corn grown without legume cover crops or organic N additions, i.e., manure or sewage sludge, state soil testing laboratories in Virginia, Maryland, and Delaware have recommended approximately 150 lb N/acre, or about 1.0 to 1.3 lb N/bu grain (Bandel and Fox, 1984). The recommended practice has been to apply 50% of the N at planting and 50% as a sidedress application when the corn is between 6 and 18 in. in height. In contrast, Evanylo (1990) and Bandel (personal communication, 1987) have demonstrated that delaying the initial N application as late as 4 wk after planting (5- to 6-leaf-growth stage) increased corn yields.

Nitrogen uptake curves for corn indicate that rapid N uptake begins at about 6 wk after planting and continues until 10 to 12 wk after planting (Olson and Kurtz, 1982). These periods correspond to the 6- to 8-leaf-growth stage and early grainfill, respectively, for corn grown in eastern Virginia. Application of a portion of the crop's N requirement at the 5-leaf-growth stage reduces the potential for early season nitrate leaching loss during the germination, emergence and initial growth, while assuring that early season deprivation does not limit yield potential (Evanylo, 1990). Because most studies indicate that maximum N uptake rates by corn occur near silking (Bigeriego et al., 1979; Mengel and Barber, 1974; Russelle et al., 1983), an N application made at approximately the 15- to 16-leaf stage should increase NUE, provided the crop responds to N applied immediately prior to silking.

Plant tissue calibration has been proposed as a method of estimating crop fertilizer N requirements (Baethgen and Alley, 1989). Elwali and Gascho (1988) tested the capabilities of DRIS and critical N levels (CNL) for making correct supplemental fertilizer recommendations for corn grown on Georgia Coastal Plain coarse soils. The advantage of DRIS is its ability to make correct nutrient diagnoses in spite of variable growth stage; however, the capability for development of N rate calibration of DRIS norms or N concentrations for corn leaves has not been proven.

The objectives of this research were to evaluate the effects of split N applications on corn yields and to investigate the potential for fertilizer calibrations based on leaf critical N levels and established DRIS norms.

Abbreviations: ENR, early N rate; LNR, late N rate; DRIS, Diagnosis and Recommendation Integrated System; NUE, N use efficiency; CNL, critical N levels; NUYE, N use yield efficiency.

MATERIALS AND METHODS

Field studies were conducted in 1988 and 1989 at the Eastern Shore Agricultural Experiment Station, Painter, VA, on a Bojac fine loamy sand (coarse-loamy, mixed, thermic Typic Hapludult). Early N rate consisted of 0, 36, 72, 108, and 144 lb N/acre at the 5-leaf-growth stage. The 5-leaf-growth stage, as defined by Hanway (1971), is when five leaf collars are visible on the stem. Late N rate consisted of 0, 25, 50, 75, and 100 lb N/acre at the 16-leaf-growth stage (Growth Stage 4; Hanway, 1963), which occurred 9 and 7 d prior to silk emergence in 1988 and 1989, respectively. The *ENR* and *LNR* treatments were factorially arranged and completely randomized within each of three replications. Treatments were situated on identical plots each year.

Corn was planted no till each April into a winter rye (*Secale cereale* L. cultivar Abruzzi) cover crop to give a population of 23 000 plants per acre at a row spacing of 30 in. Individual plots measured 10 ft (width) by 24 ft (length). Paraquat was employed as a "burndown" practice approximately 10 d prior to planting each year. Further weed control was achieved with a tank mix of metolachlor, acifluorfen, and atrazine applied following planting. Permethrin plus piperonyl butoxide and methomyl were sprayed in May 1988 and 1989, respectively, to control early infestations of cutworm [*Euxoa excellens* (Grote)] and armyworm [*Pseudaletia unipuncta* (Haworth)].

Following soil testing laboratory recommendations (Donohue and Hawkins, 1979a), dolomitic limestone was broadcast and incorporated prior to rye seeding in fall 1987 at 1.0 ton/acre and KCl was broadcast prior to corn planting in spring 1989 at 60 lb K_2O/acre. The *ENR* treatments were applied 30 d and 20 d after 90% emergence in 1988 and 1989, respectively. In each year the *LNR* treatments were applied 30 d after *ENR*. All N applications were made by streaming urea ammonium nitrate solution 6 in. to each side of all treated rows employing backpack sprayers. Excessive soil moisture delayed planting in 1989 and the resulting warmer soil temperatures shortened the duration between 90% emergence and the 5-leaf-growth stage (*ENR*). Daily temperature, solar radiation and rainfall data were collected at the Eastern Shore Agricultural Experiment Station.

Immediately following planting each spring, twenty-five soil cores 0.75 in. in diameter were sampled to a depth of 12 in. in 6-in. increments from the entire study site and composited. Soil was air dried and passed through a 0.08-in. sieve in preparation for chemical analysis. Soil samples to a depth of 6 in. were subjected to Virginia Soil Testing and Plant Analysis Laboratory methodologies (Donohue and Friedericks, 1984) for Mehlich I-extractable P, K, Ca and Mg and soil pH. Organic carbon (Walkley, 1947) and the NH_4Cl/KNO_3 cation exchange capacity of Grove et al. (1982) were determined on 0- to 12-in. soil cores.

Twenty-five days after *ENR*, at the 14-leaf stage (Growth Stage 4; Hanway, 1963), 15 samples of the leaf immediately below the whorl were randomly collected from each plot. These sampling periods corresponded to 14 and 12 d prior to silk emergence in 1988 and 1989, respectively. The leaves were dried in a forced-air oven at 150 °F and ground to pass a 0.025-in. sieve for nutrient analysis. Following dry ashing in a muffle oven at 900 °F and digestion in HCl and HNO_3, P was determined colorimetrically (Kitson and Mellon, 1944), Ca and Mg by atomic absorption and K by atomic emission. Total Kjeldahl N was determined by acid titration following digestion of tissue in H_2SO_4 and alkaline distillation of ammonia into a boric acid indicator solution (Bremner and Mulvaney, 1982). Corn was hand picked each September and grain yields (15.5% moisture basis) were estimated from the entire length of the two middle rows of each plot.

The responses of leaf N concentration and corn grain yield to N fertilizer were studied utilizing analysis of variance by partitioning the treatment sums of squares into orthogonal contrasts to detect linear and/or quadratic response trends (Gomez and Gomez, 1984). Response curves of leaf N concentration and grain yield to N fertilizer were fitted using regression analysis (Gomez and Gomez, 1984). Cumulative NUE, as it refers to the relationship between yield and N rate, was calculated as described by Bock (1984) and employed to compare N treatments using polynomial and orthogonal contrasts. Corn DRIS norms established by Elwali et al. (1985) were employed to calculate nutrient indices. All analyses were conducted using a statistical analysis package (SAS Institute, Inc., 1982).

RESULTS AND DISCUSSION

The chemical properties of the Bojac series were characteristic of mid-Atlantic Coastal Plain soils employed in corn production (Table 1). Values of soil test P, K, Ca, and Mg corresponded to qualitative ratings of very high, high, medium, and high, respectively. None of the soil test nutrients nor soil pH was considered to be yield limiting.

Rainfall amounts and patterns were markedly different between the 2 yr (Table 2). Despite the early season soil moisture excess in 1989 which delayed planting, the 14-leaf stage was attained by corn crops in both years on approximately the same date (17 June 1988, 16 June 1989). Mean monthly temperatures were not significantly different between years except in June. Mean daily solar radiation differences be-

Table 1. Selected chemical properties of Bojac loamy sand used in experiments.

		Mehlich I extractable					
Year	pH	P	K	Ca	Mg	Organic C	CEC
		ppm				%	meq/100 g
1988	6.3	>90	132	578	95	0.5	1.4
1989	6.2	>90	117	554	75	–	–

Table 2. Climate data for Eastern Shore Agricultural Experiment Station during corn growing seasons.

Year	March	April	May	June	July	August	Total
			precipitation, in.				
1988	2.68	3.27	3.15	6.26	6.10	5.08	26.54
1989	5.71	4.29	2.76	5.51	7.28	8.86	34.41
48-yr avg.	4.09	3.07	3.35	3.43	4.21	4.06	22.20
			mean temperature, °F				
1988	47.7	54.7	63.7	72.7	78.6	78.6	
1989	48.0	54.3	64.0	77.0	77.7	76.5	
			mean daily solar radiation, cal/sq. ft./day				
1988	–	458.2	515.2	595.1	494.5	510.4	
1989	–	429.4	512.7	537.4	514.1	374.0	

tween years were significant for June and August as 1989 produced many overcast days.

The response of corn to *ENR* as evaluated by 14-leaf N concentration was similar each year (Fig. 1). The range of leaf N concentrations was not as wide in 1989 as in 1988, probably due to less favorable environmental variables, i.e., excess rainfall, lower solar radiation, which minimized the integration of N uptake and dry matter accumulations. Sufficient N for plant requirement is considered to be that amount which results in a CNL of 3.0% for corn at silking (Donohue and Hawkins, 1979b; Melsted et al., 1969; Plank, 1989). A mean rate of fertilizer at the 5-leaf stage of 72 lb N/acre was calculated (by solving the quadratic equations which described the leaf N responses to *ENR*) to achieve such a CNL.

Yield responses to split N applications were nearly identical each year (Fig. 2, 3). With no early N, yield responses to *LNR* were best described by quadratic equations (Table 3) and were maximized (by solving the equations) with 85 and 92 lb N/acre in 1988 and 1989, respectively. At all other early rates, yields were increased linearly by *LNR* up to the highest rate of 100 lb N/acre. The observed yield responses to N rates as high as 244 lb N/acre were unexpected, as standard recommendations for corn in this region range from 125 to 150 lb N/acre (Donohue and Hawkins, 1979a). The unusual climate conditions, i.e., above average rainfall during the months of June through August, apparently increased yield and nitrate-leaching potentials. Typical nonirrigated corn yields on Bojac and associated soils are approximately 100 bu/acre (T. Simpson, personal communication, 1990). By ameliorating the characteristic yield-limiting summer moisture stress, yield potential was increased, thereby accentuating the N limitations probably exacerbated by leaching losses.

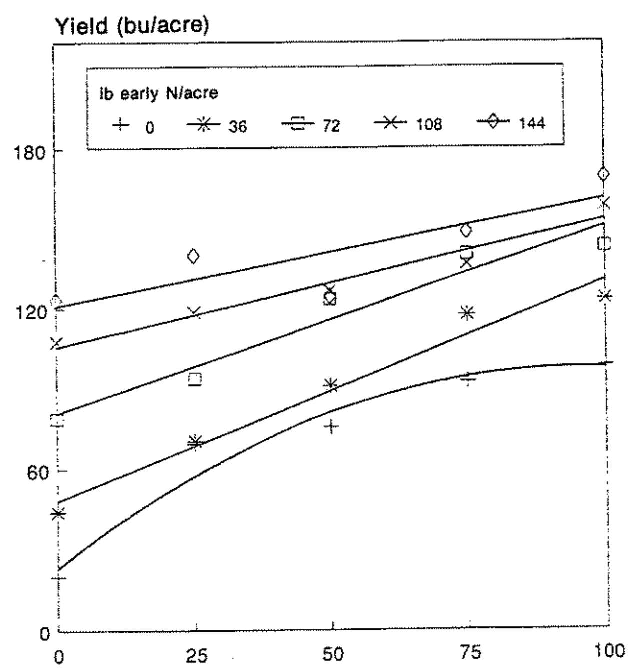

Fig. 1. Influence of N rate at 5-leaf-growth stage (*ENR*) on 1988 ($LN = 1.77 + 0.023\ ENR - 0.000059\ ENR^2$, $R^2 = 0.998$**) and 1989 ($LN = 1.97 + 0.019\ ENR - 0.000067\ ENR^2$, $R^2 = 0.983$*) 14-leaf-stage-N concentration (LN). *,** Models significant at 0.05 and 0.01 probability levels, respectively.

When no fertilizer N was applied at the 5-leaf stage, yield potential was reduced by early N deprivation that could not be overcome by N applications at the 14-leaf growth stage. This becomes evident when comparing yields achieved with the *LNR* of 100 lb/acre to those attained with the *ENR* of 108 lb/acre. Yield increases with *LNR* were maximized when *ENR* ranged from 36 lb/acre (1989) to 72 lb/acre (1988) as noted by the highest linear coefficients for the equations describing the yield responses (Table 3). As *ENR* was

Table 3. Regression equations describing the relationships between yields (*Y*) and 16-leaf-stage-N rates (*N*) for each 5-leaf N rate (*ENR*).

ENR (lb/acre)	Regression equation, $n = 3$	r^2
	1988	
0	$Y = 30.8 + 1.108\ N - 0.0065\ N^2$	0.981*
36	$Y = 47.0 + 0.670\ N$	0.991**
72	$Y = 68.6 + 0.739\ N$	0.977**
108	$Y = 104.4 + 0.416\ N$	0.914*
144	$Y = 116.9 + 0.356\ N$	0.609
	1989	
0	$Y = 24.4 + 1.594\ N - 0.0087\ N^2$	0.953*
36	$Y = 48.2 + 0.821\ N$	0.969**
72	$Y = 81.0 + 0.698\ N$	0.940**
108	$Y = 105.8 + 0.476\ N$	0.958**
144	$Y = 121.1 + 0.401\ N$	0.699

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

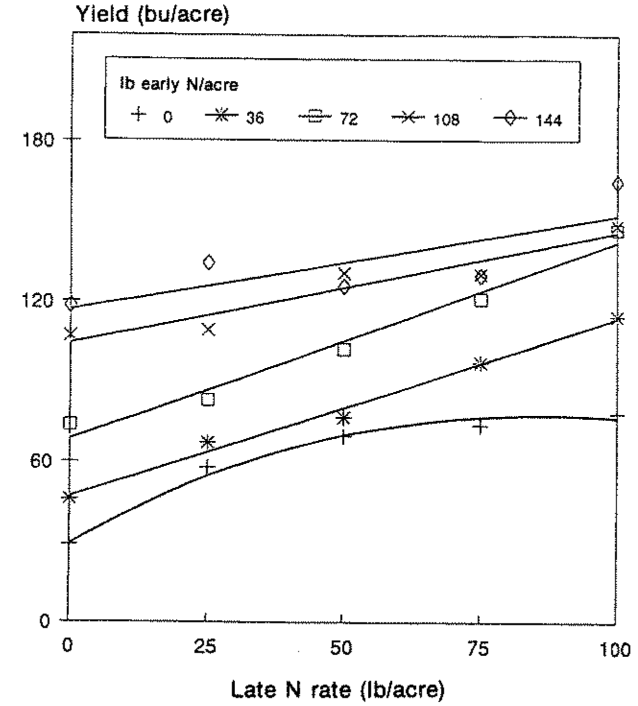

Fig. 2. Effects of split N treatments on 1988 corn yields. Yields predicted employing regression equations, Table 3.

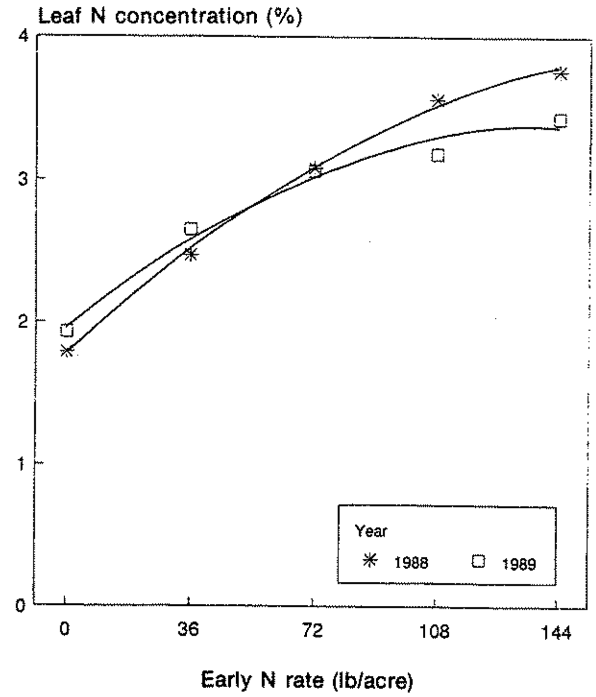

Fig. 3. Effects of split N treatments on 1989 corn yields. Yields predicted employing regression equations, Table 3.

increased to 108 and 144 lb/acre, linear coefficients and yield response to *LNR* declined.

The efficiency of N treatments in eliciting a crop response may be evaluated by comparing NUE of different treatments which employ equal total amounts of fertilizer N. One NUE relationship, yield efficiency, can be defined as the average yield increase per unit of applied N for a specified portion of the yield curve (Bock, 1984). Cumulative yield efficiency may be represented by the equation, $NUYE = (Y_i - Y_0)/N_i$, where $NUYE$ = N use yield efficiency, Y_i = yield at the i^{th} level of N, Y_0 = yield at N_0, and N_i = N rate at the i^{th} level of N. The *NUYE* is expressed in units of pounds grain/pound N.

Statistical analysis of *NUYE* values for corn (Table 4) indicated that N treatment significantly influenced yield efficiency in both years. The significant *ENR* by *LNR* interaction in 1988 ($P < 0.05$) and 1989 ($P <$

Table 4. Effect of early (*ENR*) and late (*LNR*) N rates on N use yield efficiency (*NUYE*).

	LNR (lb N/acre)					
ENR (lb N/acre)	0	25	50	75	100	Mean
	1988 *NUYE* (lb grain/lb N)					
0	–	65.0	45.7	33.6	27.7	43.0
36	26.5	35.1	31.2	34.5	35.3	32.5
72	34.7	31.3	33.6	35.1	38.5	34.7
108	40.5	33.9	36.0	31.0	32.2	34.7
144	34.7	34.9	27.9	25.8	31.2	30.9
Mean	34.1	40.0	34.9	32.0	33.0	
	1989 *NUYE* (lb grain/lb N)					
0	–	110.4	62.4	54.1	43.9	67.7
36	37.3	46.2	46.2	49.2	42.4	44.3
72	45.7	42.5	47.5	45.7	40.0	44.3
108	45.4	41.5	37.8	35.6	37.2	39.5
144	40.2	39.7	30.1	32.8	34.2	35.4
Mean	42.1	56.1	44.8	43.5	39.5	
F test	1988	1989				
ENR						
linear	*	**				
quadratic	NS	NS				
LNR						
linear	NS	**				
quadratic	NS	NS				
ENR × *LNR*	*	**				

*,**,NS Significant at the 0.05 and 0.01 probability levels, or not significant, respectively.

Table 5. Corn 14-leaf stage leaf nutrient concentration and DRIS index responses to N rate at 5-leaf-growth stage.

	Nutrient conc. (%)					DRIS indices				
Early N rate	N	P	K	Ca	Mg	N	P	K	Ca	Mg
lb/acre	1988									
0	1.79	0.28	1.02	0.15	0.09	6	22	−10	−17	−2
36	2.47	0.31	1.22	0.18	0.12	13	13	−9	−18	0
72	3.08	0.34	1.34	0.19	0.12	21	13	−9	−20	−4
108	3.56	0.35	1.51	0.20	0.14	28	14	−19	−23	0
144	3.76	0.36	1.84	0.24	0.14	21	9	−5	−21	−3
	1989									
0	1.93	0.29	1.32	0.14	0.08	5	21	6	−26	−6
36	2.65	0.32	1.46	0.17	0.10	16	11	5	−27	−5
72	3.06	0.32	1.39	0.19	0.11	21	11	−7	−19	−6
108	3.18	0.33	1.39	0.19	0.12	22	12	−8	−20	−5
144	3.44	0.32	1.35	0.19	0.13	26	12	−9	−25	−3

0.01) was explained by the reduction in *NUYE* with increasing *LNR* only when *ENR* was 0 lb N/acre. At all other *ENR* rates, no decline in *NUYE* occurred with increasing N rates at the 16-leaf-growth stage (*LNR*). Under favorable climatic conditions N applications made near silk emergence can apparently be efficiently converted into yield.

In order to evaluate the importance of N timing on yield efficiency, orthogonal contrasts were employed to compare *NUYE* between several treatments in which total N rate was approximately equal, but was achieved using different combinations of *ENR* and *LNR*. The following comparisons were evaluated in each year:

Comparison number	Early N *ENR*	*LNR*	Total	Late N *ENR*	*LNR*	Total
	pounds/acre					
1	72	0	72	0	75	75
2	72	25	97	0	100	100
3	108	0	108	36	75	111
4	108	25	133	36	100	136
5	144	0	144	72	75	147
6	144	25	169	72	100	172

In no case was the difference in *NUYE* between the compared treatments significant ($P < 0.05$). Under the favorable soil moisture conditions which predominated during the 2 yr of the study, splitting the fertilizer N application in any proportion between the 5-leaf- and 16-leaf-growth stages did not significantly alter *NUYE* at total rates between 72 and 172 lb N/acre.

Calibration of N fertilizer rates based on leaf N concentrations were not successfully developed because yields were not maximized by *LNR*, except when no early N was applied. For 14-leaf-N concentrations between 1.7 and 2.0% (that range obtained when no early fertilizer N was applied; Fig. 1), a sidedress rate of 85 to 92 lb N/acre by the 16-leaf stage (Fig. 2, 3) appeared appropriate. Corn benefited from late (16-leaf stage) N fertilizer applications even when 14-leaf-N concentration was at or above the early silking CNL of 3.0%.

The DRIS N indices increased each year with increasing *ENR*; however, even at the lowest N rate, the indices never diagnosed N as a limiting nutrient (Table 5). Despite adequate pH, Ca, and K levels as assessed by soil testing criteria (Donohue and Hawkins, 1979a), Ca or Ca and K were diagnosed as the most limiting nutrients. The DRIS corn norms established by Elwali et al. (1985) were not applicable to eastern Virginia corn production.

INTERPRETIVE SUMMARY

When fertilizer N applications were split between the 5-leaf- and 16-leaf-growth stages (the periods immediately prior to greatest N uptake by corn), yields exhibited greater dependence upon total N applied than upon application timing. Within a range which encompasses commonly recommended N rates (72–172 lb/acre), *NUYE*'s were not significantly affected by various combinations of early and late applied rates. If N sidedressing near silk emergence is practiced, at least 72 lb N/acre should be applied by the 5-leaf-growth stage to prevent loss of yield potential without risking highly inefficient N use under adverse environmental conditions. This rate resulted in presilking leaf N concentrations comparable to established critical N levels of 3.0% (Donohue and Hawkins, 1979b; Melsted et al., 1969; Plank, 1989).

The advantage of splitting fertilizer N between the 5-leaf- and 16-leaf-growth stage may be greatest under less than optimum environmental conditions. Some N applied at the 5-leaf stage will prevent reduced yield potential due to early season N deprivation while minimizing N lost from the system prior to silking via denitrification and leaching. Additional fertilizer N applied prior to silking will be largely available to the crop during the period of highest N uptake. Late N requirements may be more accurately estimated because the effects of other yield-influencing variables, e.g., soil moisture, pest infestations, etc., can be predicted with greater accuracy. Maximum N rate just prior to silk emergence may be modified depending on environmental factors which influence crop growth, available soil residual N levels at silking, and yield potential. The required N fertilizer rate may be modified by leaf N norms which respond to the aforementioned environmental factors. Local calibration is required for leaf N concentrations and DRIS norms.

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