Fertilizing corn adequately with less nitrogen

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ABSTRACT—Farmers can improve the efficiency of nitrogen (N) fertilizer use in corn production on slowly permeable claypan soils in the Midwest by modifying fertilizer application practices so more N is available when corn needs it. These modifications involve the timing, rate, and placement of N. About 25 percent of the recommended annual N should be banded into the soil at corn planting. The remaining N should be banded into the soil at sidedress. This practice applies to both conventional tillage and no-till systems.

USE of chemical fertilizers in corn production has increased steadily nationwide the past 25 to 30 years. The crop's response to fertilizer is particularly great in the relatively infertil claypan soils of the Midwest. Good crop management, plus moderate fertilization of claypan soils, produces corn yields equal to those on better Missouri soils (*9*).

Many researchers report losses of nitrogen (N) in runoff from agricultural and forested areas (*2, 7, 8, 12, 13*). Generally, the N losses are greater in runoff from fertilized farmlands than from forested areas. However, nitrate nitrogen (NO_3-N) levels in runoff from fertilized cropland usually are well below 10 parts per million (ppm), the concentration considered hazardous to infant health.

Management practices greatly influence N losses from fertilized cropland. N losses are greater when fertilizer is applied to the soil surface than when it is mixed into the soil (*13*). Soil cover and seasonal periods also influence N losses (*2*). The efficiency of applied N is highest when most fertilizer is applied just before or during the period of greatest crop growth (*11*). Also, split applications, timed to meet crop needs, reduce N loss from the rooting zone.

Present fertilizer application practices do not conform to these spoonfeeding concepts. Usually, the time and method of fertilization depend more on seasonal fertilizer cost, availability of application equipment, and farm labor. Many corn producers apply all N before or at corn planting in liquid form or as anhydrous ammonia. As a result, fertilizer often is applied several weeks or months ahead of when the crop really needs it. The energy crisis, which has increased N fertilizer costs and reduced supplies, requires more efficient application practices. Emphasis on water quality also mandates that N fertilizer in runoff be minimized.

With these considerations in mind, we sought to provide information on the possibilities for increasing the efficiency of N fertilizer used in corn production.

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Experimental Site and Procedures

We conducted our research at the Midwest Claypan Experiment Station near Kingdom City (McCredie) in central Missouri. The slowly permeable soil, Mexico silt loam (Udollic Albaqualf), is representative of about 10 million acres of cropland extending from eastern Kansas across Missouri and Illinois.

Claypans are problem soils in most years. A clay subsoil, beginning at a depth of 7 to 18 inches, restricts air and water movement and greatly retards plant root development during wet periods. Crop management practices that provide soil cover are needed to control erosion throughout the year and minimize evaporation during droughty seasons.

Our study included no-till planting of corn through previous crop residue (without prior tillage), which provided soil cover throughout the year. We also used conventional tillage, including fall or spring plowing and disking prior to planting. These tillage treatments provide data for extreme soil cover conditions. Although the water storage capacity in the top 4 feet of soil was 18 inches, only 6.3 inches were available to plants (*5*).

We obtained data, including runoff, soil loss, and N loss, for each runoff event on 15 plots in continuous corn. Ion electrodes were used to determine nitrate and ammonium concentrations in runoff water. We determined total N in sediment on acidified samples (taken to dryness) by the standard Kjeldahl method, excluding nitrates. We also obtained corn yield data.

The plots, each 10.5 × 90 feet (0.02 acre), were on a 3 percent slope. All were farmed parallel to the slope (no-till and conventional tillage) using conventional field equipment. A detailed description of the plots, the claypan soil, and previous research results were published in 1968 (*4*).

We planted corn to obtain a final stand of 20,000 to 22,000 plants per acre in 30-inch rows. Herbicides were used to control weeds in no-till corn. In conventionally tilled corn we used cultivation along with herbicides.

Annual precipitation during the study (1970-1975) was 47.6, 27.3, 30.6, 47.7, 38.0, and 40.7 inches, respectively. The long-term average for the area is 37.8 inches. In all years except 1973 the soil was too wet or too dry during parts of the growing season for optimum corn development.

To help evaluate treatment effects, we applied additional water each year by sprinkler irrigation, either to insure runoff from all treatments in given crop growth periods or to supplement rainfall during drought for more normal plant development. During the first 4 years, we applied about 5.5 inches of water annually; in 1974 we applied 0.8 inch and in 1975, 1.45 inches. The water was applied in six increments in 1970, five in 1971, three in 1972, one each in 1973 and 1974, and two in 1975. Water applied in 1974 and 1975 was not sufficient for normal corn production.

Annual runoff and soluble N losses increased 4 percent and 10 percent, respectively, as a result of the additional water applied from 1970 through 1973. That applied in 1974 and 1975 had no apparent effect on runoff or nutrient losses.

Reprinted from the Journal of Soil and Water Conservation
January-February 1978, Volume 33, Number 1
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We applied five rates of N ranging from 13 to 325 pounds per acre each year using ammonium nitrate. Precipitation contributed an additional 11 pounds per year. Table 1 and figures 1 through 4 provide details on the time, rate, and placement of fertilizer and tillage methods. Some changes in fertilizer application methods occurred during the study. We selected data from comparable years for our analysis.

From 1970 through 1972 we broadcast the N on the soil surface immediately before planting no-till corn and sidedressed when the corn was about 10 inches tall. On conventionally tilled corn we plowed down most N 5 or 6 weeks before planting and mixed the sidedress application into the soil during one of the crop cultivations. We banded starter fertilizer, containing 13 pounds N per acre, near the row at planting on each treatment.

Begining in 1973 we banded the N on no-till corn (formerly surface applied) 4 to 5 inches deep near the row and in the row middles at planting and sidedressing. We made this change because individual storm data (1970 through 1972) showed that applying N on the soil surface was a poor management practice. Most annual N losses occurred during the first two or three runoff events after the surface applications. However, to evaluate the effects of the deeper placement, we added two treatments on which part of the N was surface-applied at planting.

Fertilizer application methods on conventionally tilled corn remained the same throughout the experiment.

The N application rate of 150 pounds per acre, once considered optimum for economic corn production, was increased to 175 pounds per acre in 1973. Yields from no-till corn fertilized at the 150-pound rate prior to 1973 were lower than those from conventionally tilled corn fertilized at the same rate. We felt the additional 25 pounds per acre on no-till treatments were needed to compensate for N temporarily tied up by decaying crop residues (Figure 1).

To further determine the effect of fertilizer application time on soluble N losses in runoff, we changed (fall of 1973) the time of the major N application on the fall-plowed seedbed. We plowed down the N application (108 pounds per acre) in November instead of disking it in immediately before planting. The same amount was plowed down in April on spring-plowed plots. On no-till corn we applied 120 pounds N per acre at planting. All fertilizer applied, including 68 pounds N per acre applied as a sidedressing (on all three treatments), was banded 4 to 5 inches deep.

Experimental Results

Time of Application

N requirement and nutrient uptake capacity of corn are low until 5 or 6 weeks after planting. N applied before or at planting thus is vulnerable to high losses in runoff. The probability of runoff during this period also is high in most years because soil water is usually near field capacity. In fact, wet soils frequently delay planting.

A study of runoff and N losses from individual storms showed that N losses could be reduced significantly if major applications of N were made after the corn root system developed adequately for rapid N uptake and after soil water levels declined, providing greater soil water storage during rainstorms. Starter fertilizer banded near the row contained adequate N for plant use until the major application was made.

The average annual loss of soluble N from January 1, 1970, to November 7, 1973, was 21 pounds per acre when we plowed down 100 pounds N per acre 25 days before corn planting. When we disked N in immediately before planting on a fall-plowed seedbed and broadcast N on the soil surface immediately before planting on no-till corn, soluble N loss in runoff was 15 pounds per acre. This difference in N loss (6 pounds per acre) was small because runoff during the period from N application (spring plowing) to planting was low except in 1970.

Observation of early corn growth showed improved crop response to N applied at planting compared with earlier applications. This suggests that delaying N application for even short periods — to more nearly that time when corn can use N—is advantage-

Table 1. Effects of time and method of N application on N losses in runoff from fall- and spring-plowed seedbeds and from no-till plots, by seasonal periods, from November 1973-November 1975.

	N Applications (lbs/a)		
	Conventional Tillage		
Fertilizer Application	*Fall Plowing*	*Spring Plowing*	*No-till (N banded 4"-5" deep)*
Plowed down	108	108	—
At planting	13	13	121
Sidedressing	68	68	68
Annual total	189	189	189

	Soluble N (NO_3—N and NH_4—N) in Runoff (lbs/a)					
	Fall Plowing		*Spring Plowing*		*No-till*	
Seasonal Periods (Avg. date of field operation)	*First Year*	*Second Year*	*First Year*	*Second Year*	*First Year*	*Second Year*
Fall plow (11-7) to spring plow (4-2)	20.6	5.7	2.5	2.1	3.2	2.2
Spring plow (4-3) to plant (5-29)	3.7	1.6	2.6	6.7	.5	.5
Plant (5-30) to sidedress (6-25)	1.7	.1	3.2	.1	9.2	0
Sidedress (6-26) to fall plow (11-6)	0	4.0	0	11.8	0	12.7
Total	26.0	11.4	8.3	20.7	12.9	15.4
Annual average	18.7		14.7		14.2	
Average corn yield (bu/a)	106		103		97	

ous. More N is available in the surface soil for corn plants. Rapid early corn growth with greater nutrient uptake resulted in consistently lower N losses for each cropping period of the year. We believe that with adequate N in the starter fertilizer (applied at planting) for rapid early corn growth, together with delaying the major application until 5 or 6 weeks after planting, would increase the crop-use efficiency of N. Average corn yields during the 4 study years (1970-1973) were 132 bushels per acre when we plowed down 100 pounds of N per acre a month before planting, 158 bushels per acre when we disked N in immediately before planting (fall-plowed seedbed), and 136 bushels per acre when we broadcast N on the soil surface immediately before no-till planting.

Table 1 shows the effect of fall versus spring application of N on soluble N loss in runoff. Because of moisture and temperature stress on corn after sidedressing (1974 and 1975), yield differences among treatments were relatively small.

Observations of corn growth from plant emergence to sidedressing suggested that N losses, in addition to those measured, occurred on areas where N was plowed down in November (1973). Where 108 pounds of N per acre were plowed down in the fall, corn was about 12 inches shorter at the time of sidedressing (1974) than corn in areas where N was applied in the spring. This height difference probably resulted from N losses due to denitrification. Conditions conducive to denitrification — poor aeration resulting from saturated soil, along with high temperatures — were prevalent early in the 1974 cropping season.

An N budget assessment for continuous corn on these plots showed that unaccounted N was a substantial portion of the 153 pounds applied (*6*). The budget, based on 5 years of data (1970-1974), considered corn grain use, N in runoff, and accumulation of N in the subsoil. Unaccounted N was 11 and 20 percent, respectively, for conventionally tilled and no-till corn.

Laboratory, greenhouse, and lysimeter studies indicate that appreciable amounts of applied N might be lost in gaseous forms to the atmosphere and

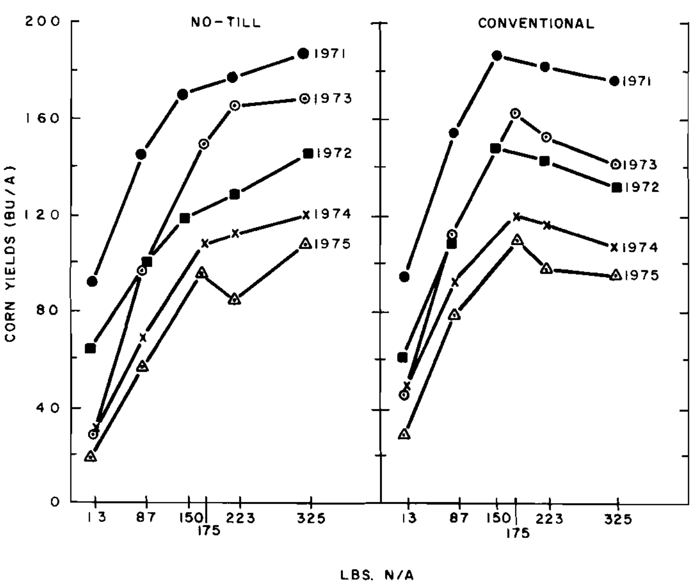


Figure 1. Effects of N application rate on corn yields, 1971-1975.

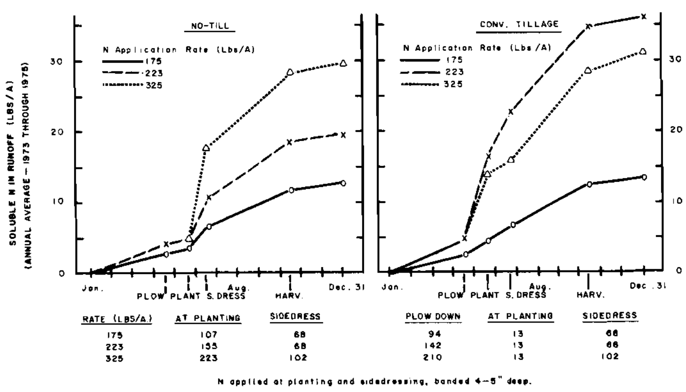
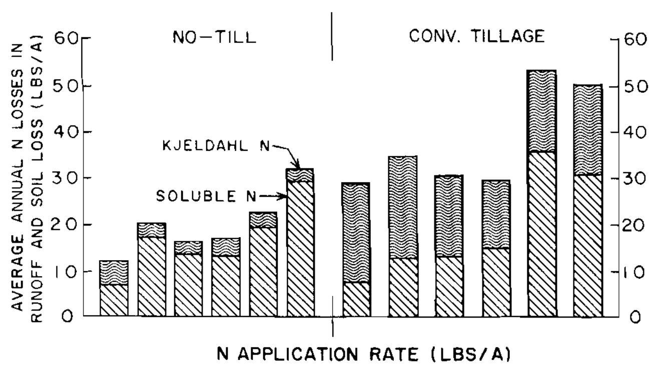


Figure 2. Soluble N (NO_3—N and NH_4—N) losses in runoff from continuous corn, by cropping periods, as affected by rate and placement of N fertilizer.



PLOW DOWN (SP.)	—	—	—	—	—	—	—	40	94	108	142	210
AT PLANTING	13	53	107	121	155	223	13	13	13	13	13	13
SIDE DRESS	—	34	68	68	68	102	—	34	68	68	68	102
ANNUAL TOTAL	13	87	175	189	223	325	13	87	175	189	223	325

Figure 3. Soluble N (NO_3—N and NH_4—N) and Kjeldahl N losses as influenced by tillage on runoff and soil loss from corn (1973-1975).

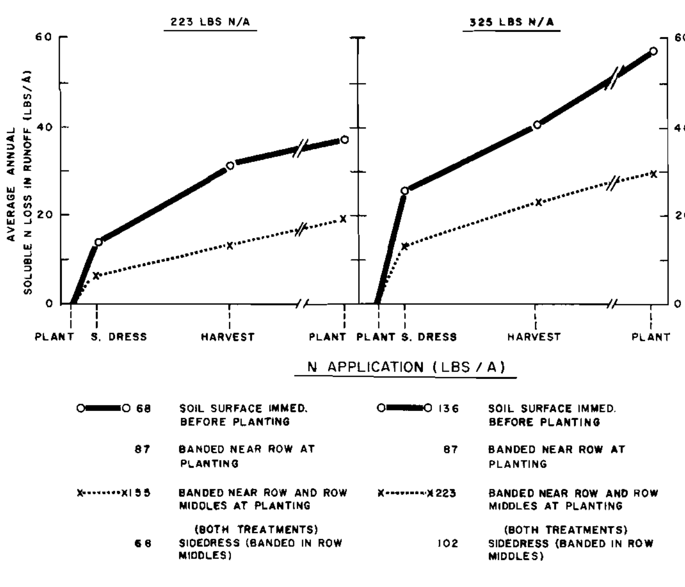


Figure 4. Soluble N (NO_3—N and NH_4—N) losses in runoff from continuous no-till corn as affected by placement of N fertilizer (1973-1975) for two N levels.

that field losses of 30 percent are believed common in Illinois (*11*).

Rate of Application

Our corn yield and N loss data showed the importance of applying N at an optimum rate for efficient use in corn production. About 175 pounds N per acre produced the maximum yield (based on present application method) under conventional tillage (Figure 1).

Applying more than 175 pounds N per acre on no-till corn greatly increased N losses in runoff on the claypan soil (Figure 2). Corn yields increased only moderately (Figure 1). Average yield (1971-1975) from no-till corn increased 4 bushels per acre when the application rose from 163 to 223 pounds per acre and 17 bushels per acre when 325 pounds N per acre were applied. At current prices for corn and fertilizer, the increased yield due to high N rates might cover the cost of additional N and its application. But we do not recommend the highest rate because soluble N losses in runoff from the no-till and conventionally tilled corn plots averaged 20 pounds per acre more than those from the plots with 163 pounds per acre.

In 1970, yields from conventionally tilled corn fertilized with 223 and 325 pounds N per acre were slightly higher than from corn receiving 175 pounds per acre. During each of the next 5 years, however, yields were lower from conventionally tilled corn receiving N at rates in excess of 150 or 175 pounds per acre. The yield declines ranged from 10 to 20 bushels per acre. Although climatic conditions caused annual yield variations, the effect of N applications were consistent from year to year (Figure 1). Initiation of our study required treatment changes on some plots, therefore, we omitted yields for 1970.

We made linear and curvilinear regression analyses (*10*) of the corn yield data shown in figure 1 for two periods, 1971 through 1972 and 1973 through 1975. This was necessary because of the changes in N rates and application methods in 1973 we described earlier. The linear regression analysis showed yield differences between conventionally tilled and no-till corn to be statistically significant at the 5 percent level in both cases. The curvilinear effect was significant at the 0.25 percent level for 1971 and 1972. Because of variations in 1973 data, however, the curvilinear analysis showed yield differences to be insignificant for the latter period.

Average yields from no-till and conventionally tilled corn grown on plots adjacent to those used in our study were nearly equal from 1970 through 1973 with an N application rate of 189 pounds per acre (*3*). Yields were 136 bushels per acre for no-till corn and 132 bushels per acre for conventionally tilled corn.

Figure 2 shows the effect on N loss in runoff when we applied more N than corn plants needed. N loss in runoff from no-till corn increased progressively as the N application rate increased from 175 pounds per acre to 223 and 325 pounds per acre. The increase in N losses from corn receiving the higher rates of N was 12 to 15 percent of the additional N applied beyond the 175-pound-per-acre level.

N losses in runoff from no-till and conventionally tilled corn receiving 175 pounds N per acre were about equal (Figure 2). The annual soluble N losses were more than 30 pounds per acre from conventionally tilled corn fertilized at rates of 223 and 325 pounds N per acre. The ratio of increased N losses in runoff (by crop periods) to application rate was less consistent on the conventionally tilled plots than on the no-till plots. Differences in runoff after plowing probably caused this variation. Runoff from no-till plots was largely surface flow, whereas porespace in the loosened soil of the plow layer (conventional tillage) had to be filled before runoff occurred. Runoff then consisted of surface flow and return flow of excess water in the plow layer. The concentration of NO_3-N in this flow was usually higher than for no-till plots.

Figure 3 shows the soluble N loss in runoff and the N loss in sediment (Kjeldahl) for a range of application rates under both no-till and conventional tillage systems (1973 through 1975). Soluble N losses from corn with low and moderate N application rates were similar from no-till and conventionally tilled corn. However, higher soil losses from the conventionally tilled corn substantially increased total N loss.

Average annual soil loss from conventionaly tilled corn for the 6 years was 4.3 tons per acre. This compared with 0.3 ton per acre from no-till corn. Runoff from precipitation and applied water during the 6 years was 8.1 inches per year from conventionally tilled corn and 9.3 inches from no-till corn.

The soil loss from conventionally tilled corn during a wet year (1970) was 14.0 tons per acre compared with 0.4 ton from no-till corn. Runoff was about 15.0 inches from both treatments. Soluble N losses were 12, 21, 25, 45, and 35 pounds per acre from no-till corn receiving annual rates of 13, 87, 150, 223, and 325 pounds N per acre, respectively. Soluble N losses from conventionally tilled corn with the same N application rates were 8, 16, 31, 32, and 41 pounds N per acre, respectively. Average Kjeldahl N loss in 1970 was 2.9 pounds per acre from no-till corn and 42.0 pounds per acre from conventionally tilled corn.

Placement of N

Placement of N fertilizer affected N losses in runoff. When we broadcast 30 percent of the annual N application (223 pounds per acre) on the soil surface, annual N losses (1973 through 1975) were about twice those from corn on which all N was banded 4 to 5 inches deep (Figure 4). Similar results occurred when we applied about 40 percent of N at the 325-pound-per-acre rate on the soil surface. Figure 4 provides details on the time, amounts, and method of N application.

Corn yields reflected these differences in N losses during 1973, a season when soil moisture was adequate during silking, but not in 1974 and 1975, when dry, hot weather prevented normal corn development. Corn yield was 166 bushels per acre in 1973 when we banded 223 pounds N per acre into the soil on the no-till treatment, and only 17 pounds of N per acre were lost in runoff. In comparison, the corn yield was 150 bushels per acre when we broadcast 30 percent of the N application on the soil surface, and 26 pounds N per acre were lost in runoff. Yield response to soluble N losses in runoff was similar in 1973 on corn receiving 325 pounds of N per acre—168 and 149 bushels per acre, respectively. Soluble N losses in runoff were 28 and 44 pounds per acre, respectively.

Conclusions

The efficiency of N fertilizer use in corn production on slowly permeable claypan soils in the Midwest can be increased. Yields can be maintained with less N than is presently used by modifying fertilizer application practices so that more N is available for uptake by corn when the plants need it. The modification should entail delaying the major N application until N requirements and uptake capacity of corn are sufficient for rapid nutrient use—5 to 6 weeks after planting.

Applying more than 150 to 175 pounds N per acre greatly increased N losses in runoff, but only moderately affected corn yields.

When N was banded 4 to 5 inches deep at planting, N losses were less than when N was applied on the soil surface at planting or plowed down 5 to 6 weeks before planting.

We believe that applying 25 percent of N fertilizer in bands at corn planting and 75 percent in bands at sidedressing will reduce N losses in runoff and increase N use efficiency. Similar corn yields can be obtained with 25 percent less N than the present rate of 150 to 175 pounds per acre with either no-till or conventional tillage.

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