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USING FERTILIZER Nitrogen Effectively on Grain Crops

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Using Fertilizer Nitrogen Effectively on Grain Crops

By R. A. Olson, A. F. Dreier, C. Thompson, K. Frank
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SUMMARY

Fertilizer nitrogen is necessary for the efficient production of grain crops throughout the midwest. Farmers have recognized this need by tremendous increases in nitrogen consumption during the past decade.

Fertilizer nitrogen where needed for optimum yield usually increases slightly the total water used by the crop. The water required in making this optimum yield, however, is used a good deal more efficiently than where nitrogen is omitted.

Nebraska studies on fertilizer economy have demonstrated nitrate leaching losses in some cases, especially serious on sandy soils of low water holding capacity and with irrigation. Strong circumstantial evidence also suggests denitrification of nitrate leached into the subsoil of some fine-textured subsoil types and resultant escape of elemental nitrogen gas.

In other cases, ammonia volatilization losses have proved serious, particularly with surface broadcasting of products containing or producing ammonium ion on neutral to alkaline soils. Magnitude of ammonia evolution is accentuated by drying conditions and by surface residue where nitrogen carriers are applied in solution form. Loss by volatilization is reduced greatly as the fertilizer is mixed immediately with the soil.

Summer sidedressing of fertilizer nitrogen for row crops, regardless of chemical form, has usually proved superior to fall or spring applications. This superiority has been especially apparent at the lower application rates. Not only has this been noticeable in the year of application, but the carryover nitrogen effect has been greater than with earlier application times. Thus, losses are minimized by delaying application to a time when crop roots are actively absorbing nitrogen from the soil.

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In getting the most out of fertilizer nitrogen in grain crops, soil incorporation of the fertilizer and delayed application time seem in order.

INTRODUCTION

Midwestern farmers have had excellent results from the use of nitrogen fertilizers on grain crops. The response of cereals to nitrogen has exceeded that obtained from any other single element with the majority of soils and cropping practices. Other elements are often needed in addition, but nitrogen supply is especially important for grain production.

Recognition of this fact has been responsible for a skyrocketing increase in fertilizer nitrogen consumption throughout the Corn Belt. In Nebraska, for example, there was an increase from about 10,000 tons fertilizer nitrogen used in 1950 to 300,000 tons in fiscal 1966, ranking the state high in the nation in use of fertilizer nitrogen.

Nitrogen is highly transitory in soil. It may change from a gaseous ammonia state to mineral ammonium, nitrite and nitrate compounds, or to combined organic nitrogen, depending on conditions of soil environment.

Furthermore, reactions can take place from any of the above states to gaseous nitrogen oxides, ammonia and even elemental nitrogen, depending again on soil environment and the activities of different soil microorganisms. Adding further complexity is the high solubility of nitrate compounds, which may leach from the soil. Thus, in deriving maximum returns from nitrogen fertilizer with grain crops it is essential that rate of application, timing and placement of the fertilizer promote maximum crop utilization of the nutrient while minimizing potential losses.

This bulletin summarizes results of the large number of fertilizer experiments conducted on grain crops in Nebraska involving nitrogen, and evaluates soil and fertilizer management practices as they influence fertilizer nitrogen efficiency.

EXPERIMENTAL METHODS

Field plots were established with equipment developed to effect the best placement of seed and fertilizer. In the case of small grains, individual plots were five feet wide in 10-inch spaced rows 50 to 100 feet long; corn and grain sorghum were planted in rows of 40-inch spacing, four or six rows wide and 50 feet long. A randomized block design was used in all cases, with 3, 4 or 5 replications. Appropriate samples were harvested at crop maturity for effecting yield determination. Total nitrogen content of the mature grain and corn stover was determined by Kjeldahl distillation. Nitrate nitrogen in soil was determined by phenoldisulfonic acid procedure after water extraction.

Fertilizer nitrogen was supplied as ammonium nitrate in most cases, otherwise as indicated in the data. The fertilizer was broadcast on the surface, incorporated into the soil by banding or plowing, or injected according to the specified treatment.

Soil moisture determinations were made with the aid of a neutron-scatter moisture gauge. Aluminum access tubes were placed in three replications of two treatments in 1960–1962 experiments. Treatments compared were the check and one which was considered beforehand to afford an optimum nitrogen supply. Moisture readings were taken for each foot to a depth of six feet on four occasions during the growing season. Differences between profile moisture supply at the beginning and end of the season, with addition of seasonal rainfall less ten percent for runoff, gave the consumptive use values expressed in the data charts. Seasonal rainfall was obtained either by rain gauge at the experimental location or by averaging precipitation measured by official weather stations, usually 3 to 5, in the county.

RESULTS AND DISCUSSION

Forecasting Need for Nitrogen

Considering the tremendous acceptance of fertilizer nitrogen and the large farmer investment involved, the necessity of a reliable soil test for nitrogen, prescribing where and how much is needed, is apparent. The need is especially obvious in western Nebraska where, under limited rainfall and dry farming practice, yield reductions from nitrogen application have been frequent.

Nitrogen testing of soils presents extraordinary problems because of the many interactions involved. Nonetheless, soil nitrate production rate of the surface soil has proved a reasonably reliable measure of nitrogen needs by corn, wheat and oats (Table 1).

Proper prescription of nitrogen need in accordance with established

Table 1. Correlations between soil nitrate production and yield response of grain crops to fertilizer N in Nebraska, 1952-1959.

Comparison: Soil nitrate production *vs.* yield response to N	No. expts.	Correlation coefficient	
		r	R
Wheat yield response to N			
Continuous cropping			
Topsoil only	59	–0.630**	
Topsoil + 'subsoil'	59		–0.637**
Fallow-wheat cropping			
Topsoil only	60	–0.463**	
Topsoil + 'subsoil'	60		–0.466**
Oats yield response to N			
Topsoil only	75	–0.677**	
Topsoil + 'subsoil'	75		–0.716**
Corn yield response to N			
Topsoil only	76	–0.604**	

Table 2. Calibration of soil nitrate production test with N needs of grain crops in Nebraska.

Nitrate production range and crop[a]		Locations with			Apply
		Increase to N	No effect of N	Decrease to N	
	ppm. NO_3–N	%	%	%	lbs. N/A.
Response assured					
Wheat, C	0–15	97	3	0	40–60
F	0–10	100	0	0	30–40
Oats	0–15	91	9	0	40–60
Corn	0–15	87	13	0	80–200
Response likely					
Wheat, C	15–20	75	25	0	30–40
F	10–14	50	22	28	20–30
Oats	15–21	80	20	0	30–40
Corn	15–21	67	33	0	40–80
Response possible					
Wheat, C	20–25	50	50	0	20–30
F	14–18	42	19	39	no>20
Oats	21–27	36	64	0	20–30
Corn	21–27	27	73	0	30–40
Response unlikely					
Wheat, C	>25	0	100	0	
F	>18	0	27	73	
Oats	>27	0	100	0	
Corn	>27	17	83	0	

[a] C = continuous, F = Fallow-cropping.

calibrations for corn, wheat and oats is reasonably certain (Table 2). Of particular interest is the possibility of yield depression with fallow wheat from nitrogen application, and the indication of this possibility by the soil test. Also noteworthy is the variation in calibration ranges for the different crops, corn and oats continuing to respond at higher nitrate production levels than wheat, and fallow wheat requiring much lower test values for the different response ranges than continuous wheat. The latter observation is probably related to the greater storage of nitrate during the period of fallow than occurs with continuous cropping. The smaller correlation coefficient with corn than with the other cereals is undoubtedly related to situations where legumes preceded the corn, in which case soil samples collected before legume incorporation do not fully reflect the legume nitrogen.

Soil nitrate production rate has specific shortcomings, including: (a) observed seasonal variations in nitrate production rate of field soils; (b) varied NH^+_4 accumulation in soils prior to incubation analysis, dependent on environment before and after soil sample collection, which ultimately influences nitrifying capacity; (c) unmeasured nitrate that has accumulated in the soil profile from fallow or nitrogen fertilizer application; and (d) inadequate reflection of nitrogen potential of soil samples collected in an existing legume field.

The unmeasured nitrate shortcoming is apparent in data from four 1962 experiments with irrigated corn and grain sorghum where fertilizer nitrogen failed to increase yields significantly (Table 3).

Table 3. Influence of residual nitrate-nitrogen on yields of irrigated corn and grain sorghum, 1962.

Location and crop	NO3-N in soil by foot depth, lbs./A							Grain yield, bu./A.	
	0–1′	1–2′	2–3′	3–4′	4–5′	5–6′	Total 0–6′	Check	120 N/A[a]
Corn									
Hamilton (3)	95	15	13	18	20	35	196	125	125
Hamilton (4)	113	32	10	5	7	11	178	143	165
Dawson	19	54	41	29	18	13	174	124	124
Grain sorghum									
Webster	25	12	25	14	35	34	145	106	112

[a] Yield differences were not significant (.05 level) in any of these experiments. Rate of nitrogen application was 60 pounds at the Webster location.

In these situations more than enough nitrate-nitrogen reserve existed from previous years' fertilization in the six-foot depth of soil to assure a maximum yield without further nitrogen application. This large profile nitrate supply was not evidenced in the nitrification rate values which were modest for the first two soils and relatively low for the last two.

Despite those limitations the nitrate production rate has exceeded all quick nitrogen tests investigated and is proving reasonably effective for prescribing the nitrogen needs of Nebraska grain crops.[2]

Moisture-Nitrogen Interdependence

Most midwestern farmers have at one time or another experienced an "overstimulation" of cereal crops following legume growth when rainfall was deficient. This led many to believe that nitrogen fertilizer use would be hazardous outside of humid climatic regions. Experience has demonstrated that the nitrogen fertilizer has not been responsible for excessively depleting the soil of moisture as did the legume, and that, on the contrary, fertilizer nitrogen use helped crops to make more efficient use of existing soil moisture.

Figure 1 indicates that effective use of fertilizer nitrogen enhances the efficiency of water use by grain crops. A small amount of additional water is used in the process. The 2.87 bushels of wheat returned per inch of water used with fertilized wheat represents an 8 percent increase in water use efficiency due to nitrogen for the 24 locations represented. Correspondingly, the oat crop was 28 percent more efficient in its consumption of water when fertilized with nitrogen, corn 47 percent more efficient, and grain sorghum 27 percent more efficient.

Looking more closely at situations of bare moisture sufficiency, however, in wheat experiments of 1960 and 1961 there were 5 locations which averaged 0.6 inch greater water use from fertilizer treat-

[2] Olson, R. A., Meyer, M. W., Lamke, W. E., Woltemath, A. V., and Weiss, R. E. Nitrate production rate as a soil test for estimating fertilizer nitrogen requirements of cereal crops. Trans. 7th Int. Cong. of Soil Science II: 463–470. 1960.

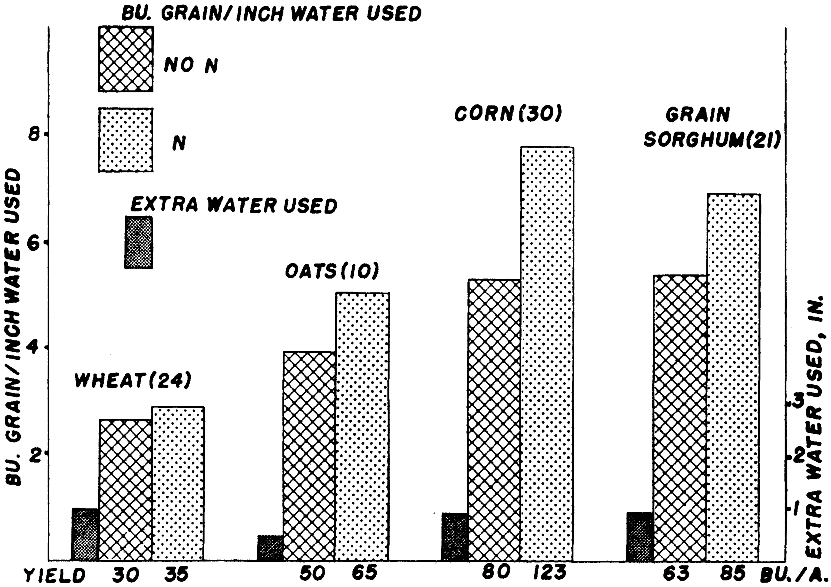

Figure 1. Water use efficiency by grain crops as influenced by nitrogen fertilizer, 1960-1962 (as a general rule, 40 pounds N/A. used with the small grains, 80 or 160 pounds with corn and grain sorghum; number of experiments in parentheses).

ment at harvest in July, which, combined with an average yield increase of 9.4 bushels at these locations, represents an increase of 17 percent in water use efficiency. In these situations, an average 3.77 bushels of wheat was produced per inch of water used with nitrogen treatment—a much more efficient water use than with locations of plentiful moisture supply. On the other hand, five of the 1961 experimental locations on fallow wheat, all with high nitrogen supplies and producing high yields without treatment, showed a decline from 3.38 to 2.91 bushels per inch of water used as nitrogen was applied, despite substantial available water in the lower part of the soil profile at season's end. In most cases studied in Nebraska, however, fertilizer nitrogen has notably increased water use efficiency by the crop while drawing a small amount of additional water from the soil.

What is the source of the additional water used by crops as a result of fertilizer treatment? In the case of wheat, virtually all additional water came from the surface four feet of soil in 1960–1962 experiments (Figure 2). There was very little use of water from the fifth and sixth feet of depth irrespective of treatment. Essentially the same picture emerged from studies with oats. But with grain sorghum and corn there was evident moisture extraction throughout the six foot soil profile, and the additional water required as a result of nitrogen treatment was derived about equally from all depths

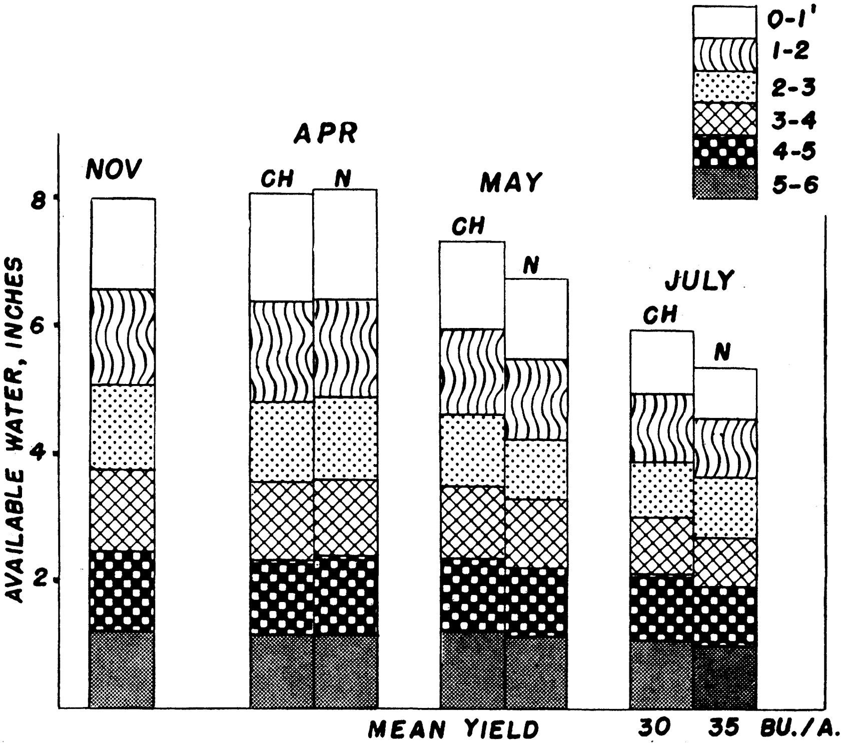

Figure 2. Available water in soil to a depth of six feet in wheat field experiments of 1960-1962 as influenced by time of season and applied fertilizer (experiments where yield response was due entirely to 40 lbs. N/A.).

(Figure 3). Thus, a substantially greater root activity is observed with these summer grain crops for extracting soil moisture to greater depth than is apparent with small grains, which capability is enhanced by nitrogen treatment.

Fertilizer nitrogen is no substitute for water, but plants will not grow efficiently if this element is low in supply even though moisture is plentiful. It is essential that nitrogen fertilization practices be adjusted to the available supply of soil moisture in deriving maximum efficiency from both of these plant growth components.

Nitrogen Topdressing for Wheat

Earlier Nebraska studies established the general need for supplemental nitrogen by wheat grown under continuous cropping conditions.[3] These experiments showed that 20 pounds of nitrogen usually was less than needed, while 40 pounds gave generally excellent results.

[3] Olson, R. A., and Rhoades, H. F. Commercial fertilizers for winter wheat in relation to the properties of Nebraska soils. Nebr. Agr. Exp. Sta. Bul. 172: 21–26. 1953.

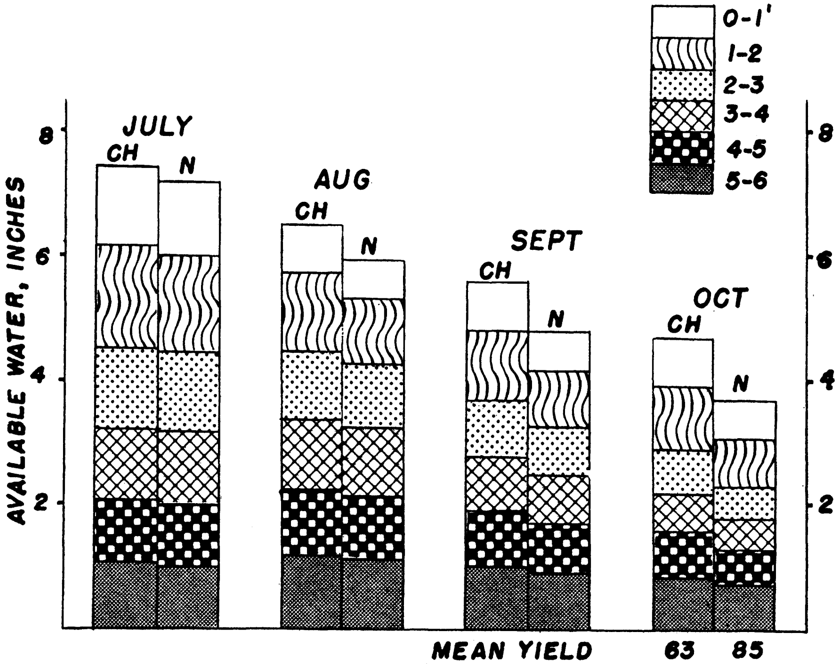

Figure 3. Available water in soil to a depth of six feet in grain sorghum field experiments of 1960-1962 as influenced by time of season and applied fertilizer nitrogen (80-160 pounds nitrogen/A.).

The current data of Figure 4 similarly show very good response to 40 pounds of nitrogen with slight benefit from the additional nitrogen increment up to 60 pounds per acre. The advantage of spring over fall application for greater protein is evident, as is the increasing protein level with increasing rate of nitrogen applied.

Further studies on time of application for a 40-pound rate of nitrogen show little difference in yield response between fall and spring application (Figure 5). Winter broadcasting of the nitrogen has provided minimal response, suggesting partial loss of nitrogen applied to a frozen soil surface. A split application of the nitrogen, with 10 pounds combined with the phosphorus applied at planting and 30 pounds topdressed in the spring, has afforded the maximum return in bushels. This is attributed to a benefit of the nitrogen in promoting phosphorus fertilizer utilization rather than to nitrogen response *per se*. Although yield increase in bushels was similar with fall and spring treatment, greater efficiency of fertilizer use was apparent from spring treatment in higher protein content of the grain. There was strong evidence that the 40-pound standard by which these data were compared was higher than needed for optimum yield in many cases, and that a somewhat lower rate would have shown a larger disparity in favor of spring application.

In the semiarid western half of Nebraska, wheat is commonly produced on fallowed land. There both positive and negative responses to applied nitrogen have been common, the level of soil nitrogen and the availability of soil moisture largely explaining the differences. The result is that average response to nitrogen has been small (Figure 6). When the positive, negative and no response situations are considered separately, however, it is clear that the need for fertilizer

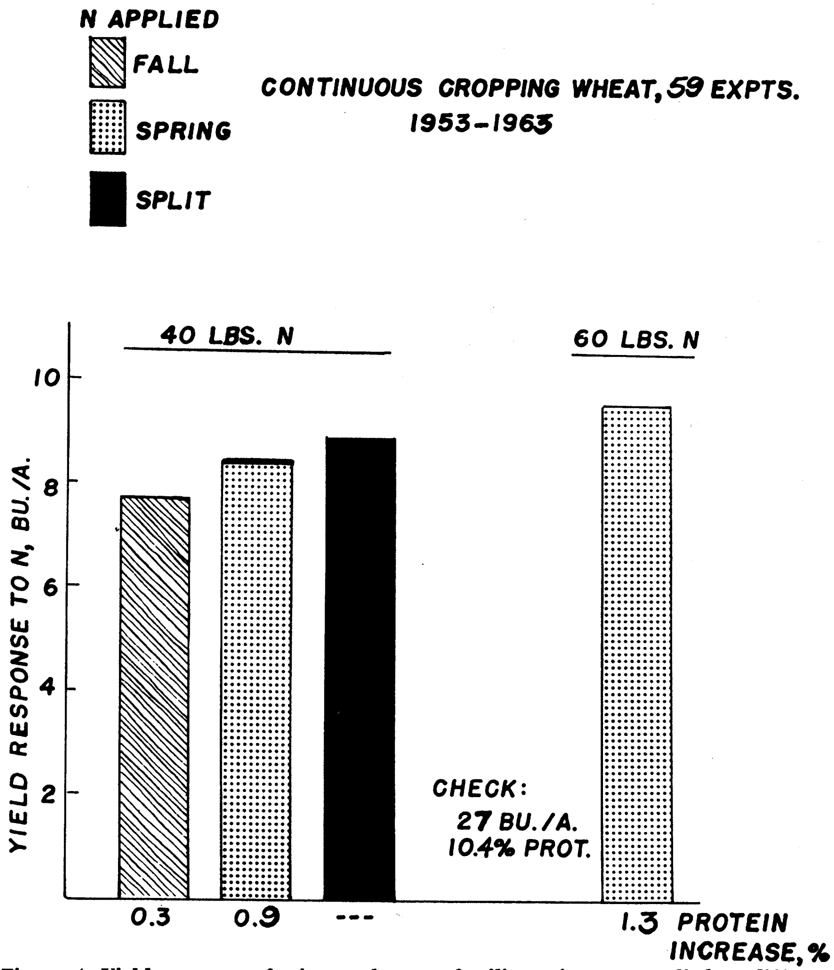

Figure 4. Yield response of winter wheat to fertilizer nitrogen applied at different times and rates. Ammonium nitrate was the nitrogen carrier; all treatments surface broadcast except for 10 pounds N in the split application which was placed in the row. (These data exclude 1956 when drought prevented yield response and other individual experiments without response to fertilizer.)

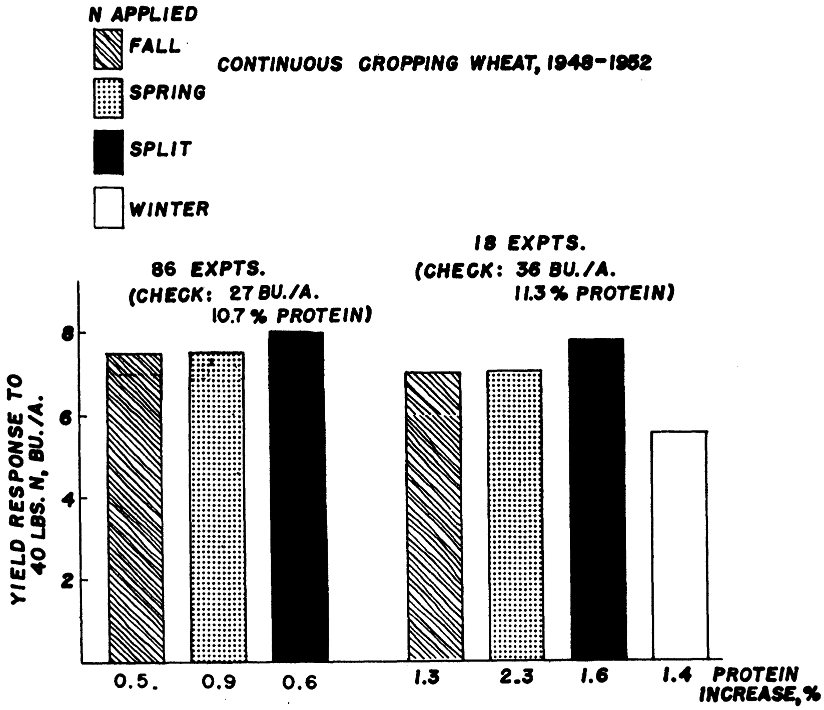

Figure 5. Yield response of winter wheat under continuous cropping to 40 pounds nitrogen per acre applied at different times. Ammonium nitrate was the nitrogen carrier; all treatments surface broadcast except for 10 pounds of the split application which was placed in the row.

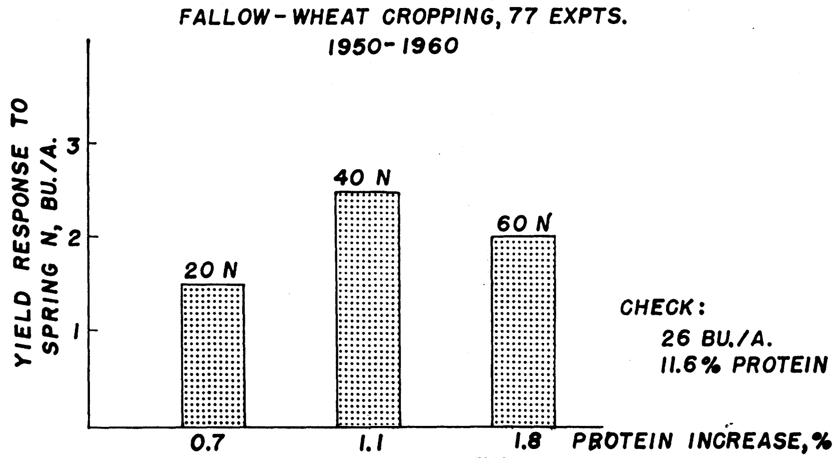

Figure 6. Yield response of winter wheat to different rates of fertilizer nitrogen applied in the spring under fallow-wheat cropping. Ammonium nitrate was the nitrogen carrier, surface broadcast in all cases.

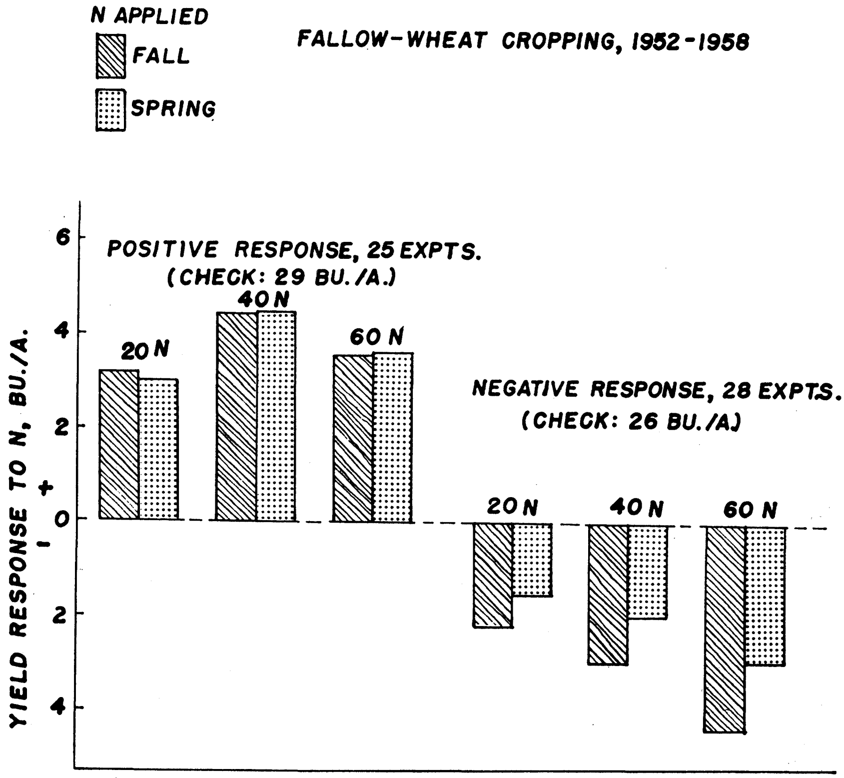

Figure 7. Yield response of winter wheat to fertilizer nitrogen applied in the fall and spring under fallow-wheat cropping. Ammonium nitrate was the nitrogen carrier; all treatments were surface broadcast.

nitrogen in this dry farming region is widespread, but the fertilizer must be used cautiously (Figure 7). Sixty pounds of nitrogen per acre almost invariably has been too much, with excessive vegetative growth at the expense of yield. If nitrogen is required, a rate in the range of 20–40 pounds per acre is generally enough since considerable nitrate has been accumulated during fallow. Application in fall or spring has given equally good results, considering yield alone. Where there are negative responses, yield decreases have been larger with increasing rate of nitrogen applied. Yield decrease has been further enlarged by fall application of the nitrogen, presumably because of extra moisture use from the associated greater fall and early spring vegetative growth.

The extra protein expected from supplemental nitrogen, especially when spring-applied, can be a most important factor in wheat quality for flour, provided the wheat meets other requirements, such as gluten quality, satisfactorily. Substantial premiums have been paid for high protein when needed by the millers, more recently for high sedimentation rate. This benefit may be counteracted completely by a reduced price for low test weight where the wheat matures too rapidly under severe moisture stress, a common occurrence in dry farming regions. This probability is increased with nitrogen application.

Spring, therefore, would seem to be a favored time for topdressing nitrogen on wheat. This time also allows a relatively late season evaluation of soil moisture availability. On the other hand, equitable distribution of the farmer's available working time may determine optimum application time, especially in the general cropping, subhumid east.

There is no certainty that spring topdressing of nitrogen represents the last word on its efficient use with the winter wheat crop. Whereas the data reported in Figures 5–7 involved ammonium nitrate as the carrier, and even though it has proved equal or superior to other carriers similarly topdressed, we cannot say that ammonia volatilization was not a factor in many cases. Certainly the average response of 8 bushels from 40 pounds nitrogen per acre is profitable, but this represents only about 30 percent utilization even accounting for protein increase. It is probable that topdressing does not lend itself to maximum efficiency with most nitrogen carriers.

Comparisons between nitrogen carriers have shown good, and essentially similar, responses of wheat to spring topdressings of ammonium nitrate, urea, ammonium sulfate, nonpressure nitrogen solutions, and fall injections of anhydrous ammonia and nitrogen solutions of high vapor pressure. On occasion the urea and nitrogen solutions have been strikingly better when spring applied than when topdressed in the fall, and also when injected into the soil rather than surface broadcast.

Time of Nitrogen Application for Corn

During the 1946–1956 interval thirty-three field experiments were conducted in Nebraska comparing times of application of fertilizer nitrogen for corn. These studies were divided between irrigated and non-irrigated lands. There was a decided advantage in summer sidedressing of the nitrogen for both moisture situations in the 31 cases of significant response (Figure 8). In some cases spring application was made by a planter attachment; in other cases the nitrogen was plowed down. In those situations using both methods of spring application there was no consistent difference in results. To the extent experimental treatments allowed, an optimum rate of nitrogen was selected in preparing Figure 8. Sometimes this was as low as 40 pounds per acre; other times it was over 100 pounds.

Nine non-irrigated and irrigated experiments included in Figure 9 indicate large and similar responses to nitrogen sidedressed at 18 and 36-inch growth stages, with a small advantage for the latter. In certain

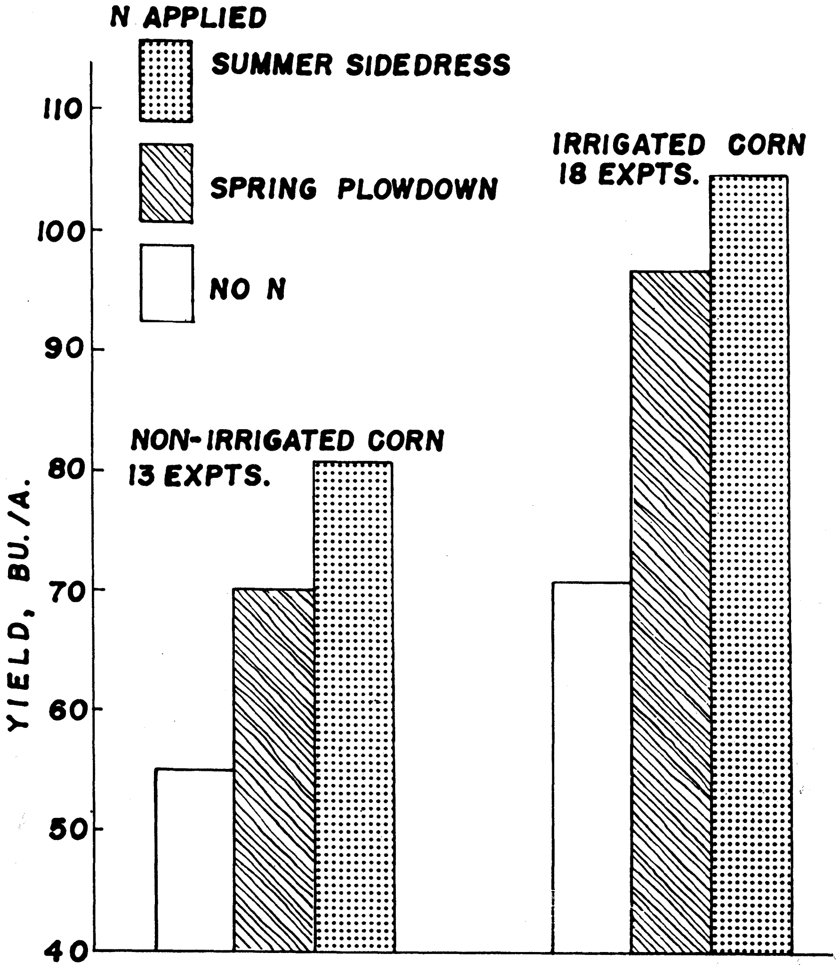

Figure 8. Yield response of corn to fertilizer nitrogen applied in the spring and summer in experiments of 1946-1956. Spring nitrogen broadcast and plowed under or banded at planting; summer sidedressing accomplished at second or third cultivation. Ammonium nitrate or anhydrous ammonia was the nitrogen carrier; rate ranged from 40 to 100 pounds nitrogen per acre.

other earlier Nebraska experiments, nitrogen was sidedressed by hand when the corn was 5 feet tall with optimum results.[4] Excellent results were also obtained in certain individual experiments where the nitrogen was applied in irrigation water as late as August 8, when the corn was well into the tasseling stage of development. These very late treatment times present little possibility for widespread practical application, especially where the crop is dependent on rainfall. Should dry weather persist following application, the response of corn to nitrogen

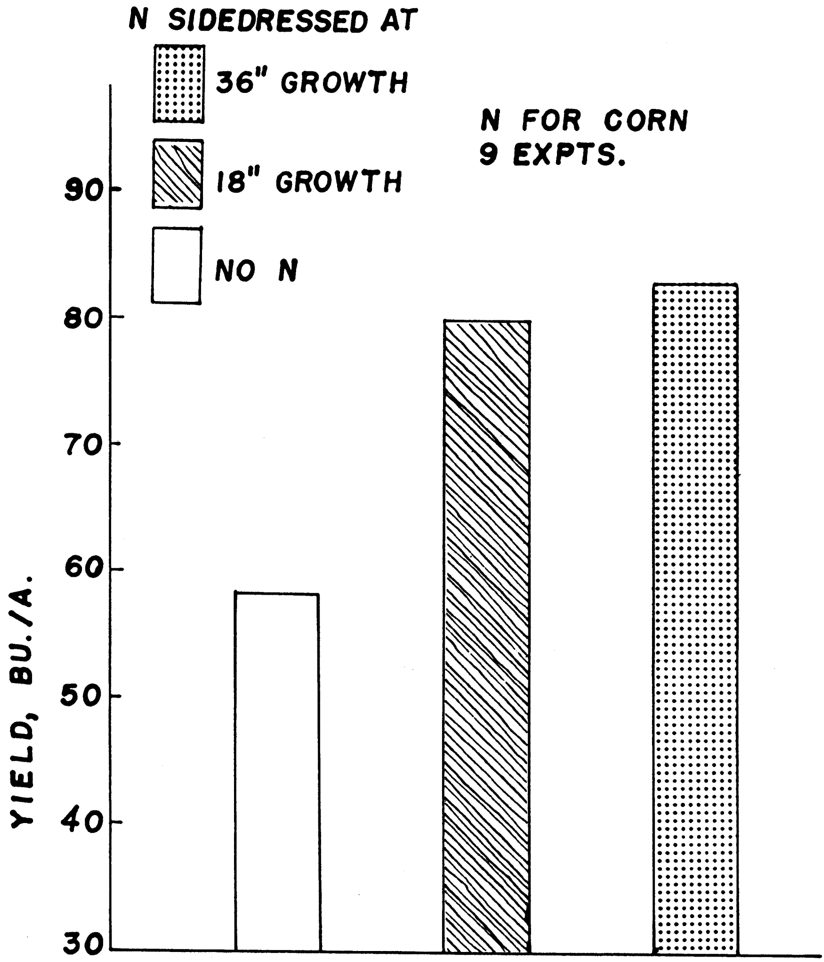

Figure 9. Yield response of corn to fertilizer nitrogen sidedressed at two different growth stages in 5 irrigated and 4 non-irrigated experiments.

fertilizer is certain to be poor. When applied at a 12–24 inch growth stage, however, a fair amount of rain prior to shoot formation is reasonably assured throughout most of the corn belt. If there is no rain during this period, the yield potential is likely to be low anyway.

It is obvious that some incorporation of the fertilizer nitrogen with soil is required for effecting maximum yield response in corn (Figure 10). Although broadcasting between the rows caused a substantial yield response to the nitrogen, this was only 61 percent as effective

[4] Fitts, J. W., McHenry, J. R., and Allaway, W. H. Soils studies for 1945. Nebr. Agr. Exp. Sta. Bul. 382. 1946.

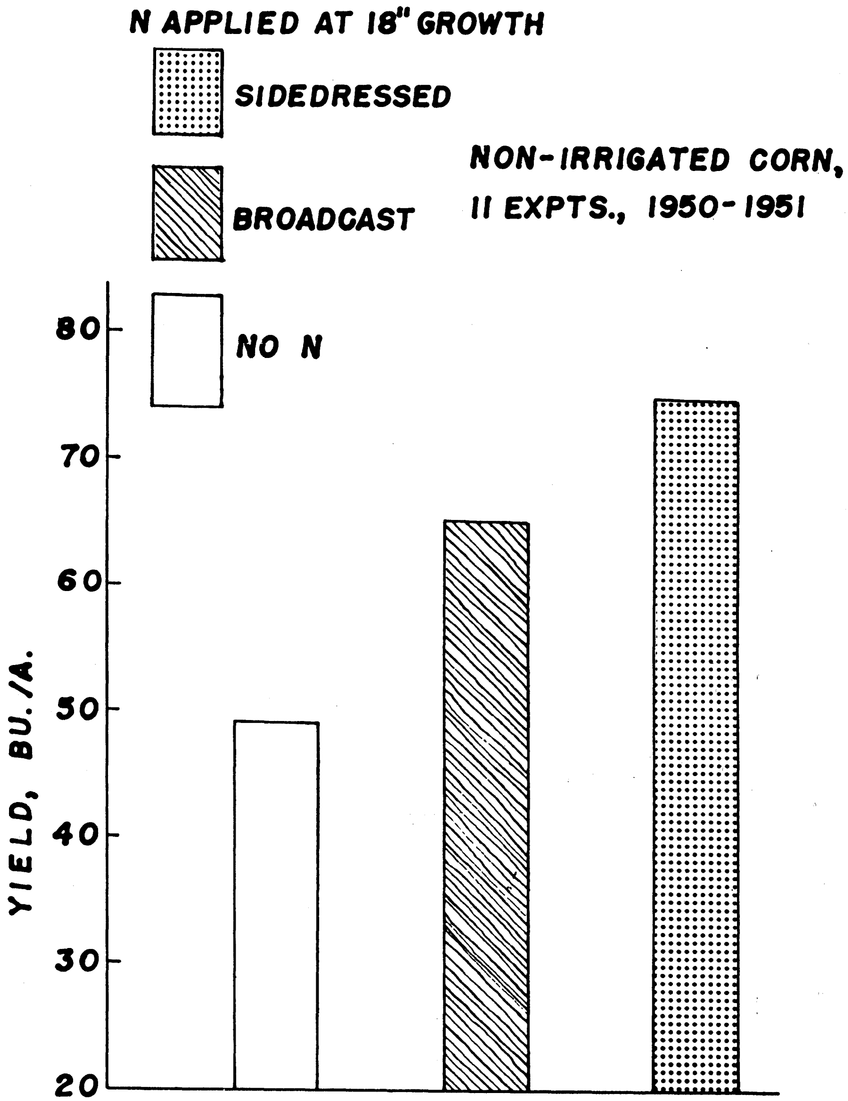

Figure 10. Yield response of corn to fertilizer nitrogen applied by broadcasting between the rows and by sidedressing at an 18″ growth stage, 1950-1951. Ammonium nitrate was the nitrogen carrier and rate of application was 40 to 80 pounds nitrogen per acre. (Only those experiments with statistically significant yield response to fertilizer were included in the summation.)

as where the nitrogen had been incorporated. Apparently there are losses of applied nitrogen with surface application. This observation was made using a carrier containing only half its nitrogen in the ammonium form. If it is assumed that the reduced effectiveness is a result of ammonia volatilization, it then seems probable the surface application would have been even less effectual had the carrier been one in which all nitrogen passed through the ammonium form. Positional availability may have been a contributing but minor factor in these experiments.

Experiments involving time of nitrogen application were con-

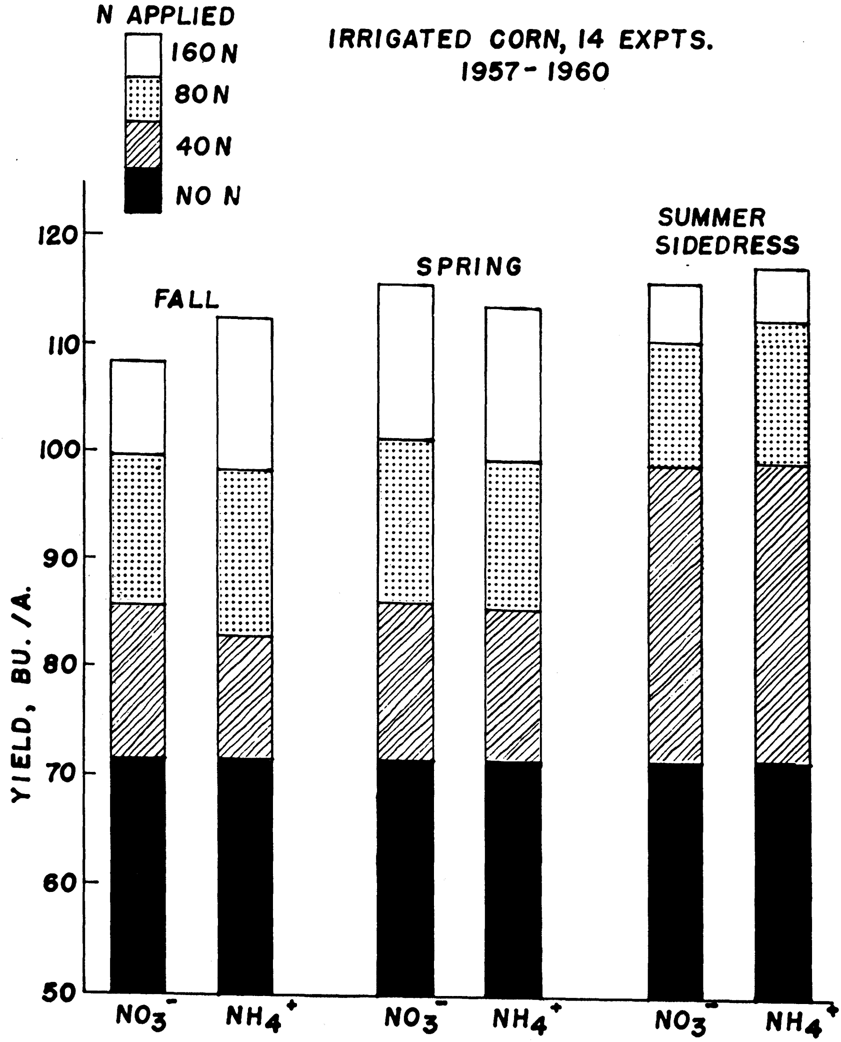

Figure 11. Corn yields for 14 irrigated experiments as influenced by kind and rate of nitrogen fertilizer and time of application, 1957-1960. Average stand of 15,000 plants per acre; nitrate supplied by calcium nitrate and ammonium by ammonium sulfate; largely medium to fine textured soils of the Crete, Hastings and Hall Series.

ducted on irrigated Nebraska soils during the 1957–1960 interval. These experiments included rates of 40, 80 and 160 pounds of nitrogen per acre and compared nitrate and ammonium forms. This was part of a North Central Region project studying fertilizer nitrogen economy.[5] In yield alone, 40 pounds of nitrogen per acre sidedressed was approximately equivalent to 80 pounds fall or spring applied, and 80 pounds sidedressed gave results equal to 160 pounds applied at the earlier dates (Figure 11). The most profitable treatment was 80 pounds of nitrogen per acre by summer sidedressing.

The maximum net return for fall and spring applications came at 160 pounds of nitrogen per acre, but this return was substantially less than that with 80 pounds sidedressed. There was little difference in results between the two chemical forms.

Figure 12 shows a large increase in total vegetative yield for the previously noted irrigated corn experiments with sidedressing at the low rates of nitrogen compared with fall or spring application. Virtually all of this increase was in yield of grain. There was little difference in total vegetative yield in the case of a heavy rate among the three times of application, however. Total nitrogen yield was notably greater with summer sidedressing, especially at the two lower rates of nitrogen application, and grain-stover ratio was even more strikingly increased by delayed application. Thus, it is apparent that one of the reasons for more efficient response of corn to sidedressed nitrogen is an increase in grain yield without a corresponding increase in vegetative growth. Efficiency of use in grain production relative to stover is not all that is involved, since it is clear that efficiency in this case may be partially a result of reduced losses.

Stover yield and nitrogen percentage of the stover and grain permitted an estimate of fertilizer nitrogen utilization when total nitrogen yield of the check was subtracted from total nitrogen yield of any

Table 4. Percentages of utilization of applied nitrogen at varying times and rates.

Time and rate of nitrogen	Utilization of applied nitrogen, %
40 lbs. N/A.	
Fall	25
Spring	28
Summer sidedress	58
80 lbs. N/A.	
Fall	31
Spring	34
Summer sidedress	51
160 lbs. N/A.	
Fall	31
Spring	35
Summer sidedress	39

[5] Cooperative experiments under NC-16 technical committee of the North Central Region, supported in part by Regional Research Funds.

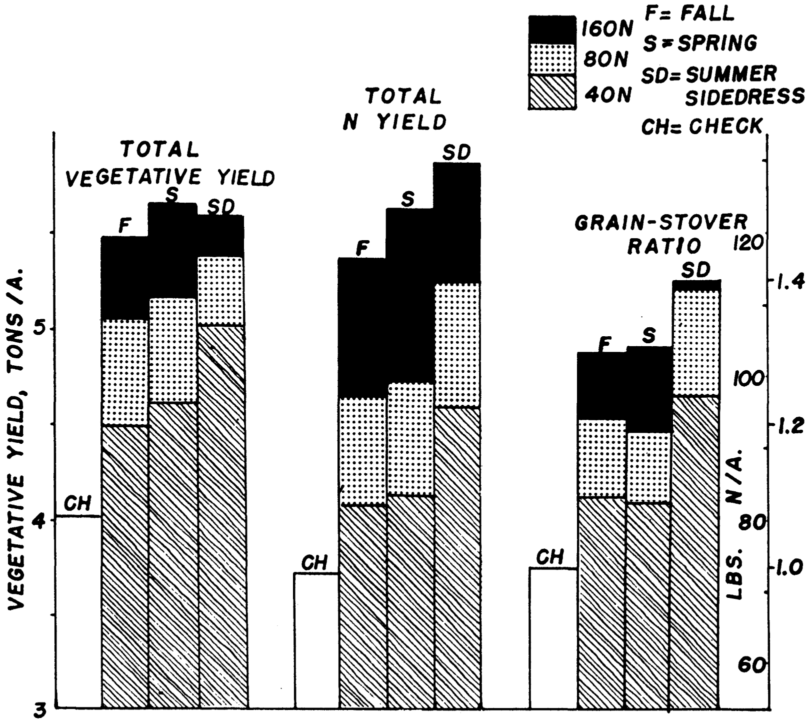

Figure 12. Total vegetative and nitrogen yield and grain-stover ratio for 14 irrigated corn experiments as influenced by time and rate of nitrogen application, 1957-1960.

specified treatment. This approach gave percentages of utilization (Table 4) of applied nitrogen in experiments reported in Figures 11 and 12, as a mean for the two carriers. These data also demonstrate greater utilization of applied nitrogen with delayed time of application. The benefit of delay is decreasingly noticeable with increasing rate of application. The data show that later application is essential for highest utilization if minimal application rates are used.

It may be contended that the above observations on utilization efficiency are incomplete, that the residual effects in succeeding years balance out the differences in the year of application. Nebraska data do not support this contention. Researchers at the Scottsbluff Experiment Station in experiments of 1950–1952 noted greater residual effects from sidedressing than from planting time fertilizer nitrogen in the second year.[6] Similarly, recent experiments on irrigated land of central Nebraska show greater two-year yield response from sidedressed nitrogen than from other times of application (Figure 13).

[6] Pumphrey, F. V. and Harris, Lionel. Nitrogen fertilizer for corn production on an irrigated Chestnut soil. Agron. Jour. 48: 207–212. 1956.

There was little yield response to nitrogen increments above forty pounds per acre in the year of application at these locations because of a rather high soil nitrogen supply initially. But there was a sub-

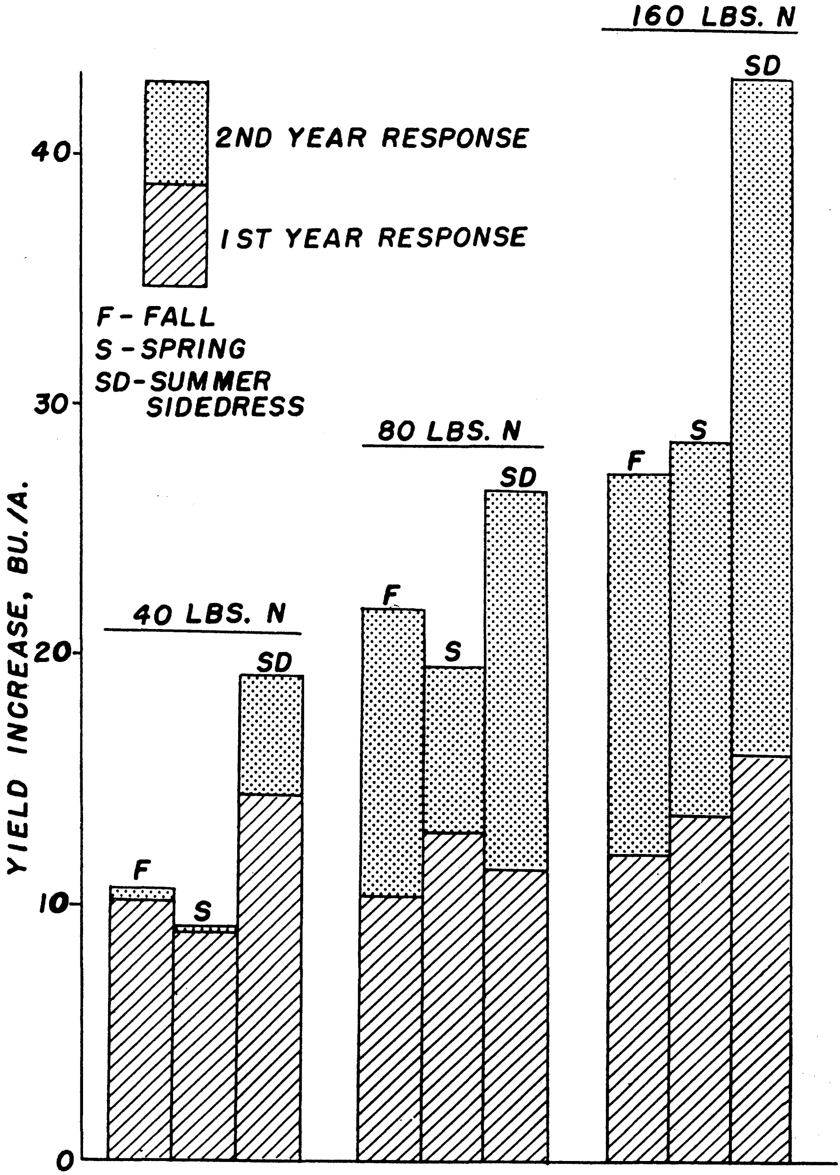

Figure 13. Two-year response of corn to one application of fertilizer nitrogen. Mean for two irrigated experiments in Phelps and Nance Counties on medium textured soils, 1957-1960.

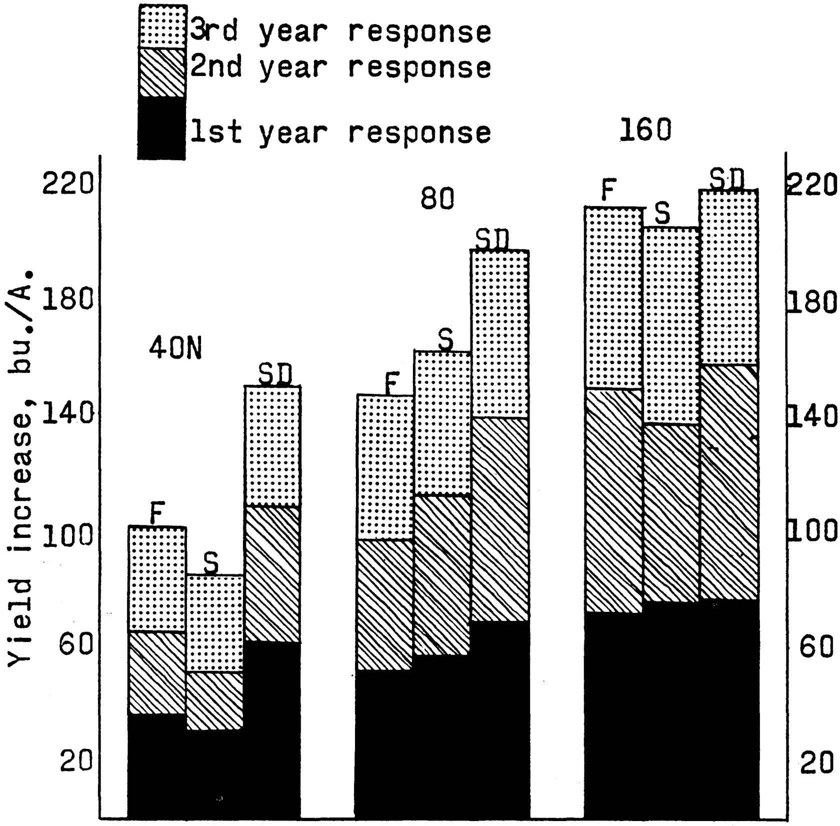

Figure 14. Yield increases of irrigated corn through a 3-year period during which nitrogen was applied each year at three different rates and times. (Mean values for NO_3^- and NH_4^+ sources of nitrogen on Crete silty clay loam, 1960-1962; F = Fall, S = Spring, SD = Sidedress.)

stantial residual effect from the higher nitrogen rates in the second year, especially where the nitrogen was sidedressed. Considering total nitrogen yield of grain and stover, fertilizer nitrogen was used far more efficiently with the late application. At the 40-pound nitrogen rate, utilization efficiencies over the two years were 20, 20 and 54 percent for fall, spring and summer applications, respectively. At the 80-pound rate corresponding recoveries were 34, 37 and 50 percent; and at the 160-pound rate recoveries were 23, 24 and 41 percent. Certainly any leftover fertilizer nitrogen in the year of treatment would have equal opportunity for stable combination in soil by the year after application, whether the initial treatment was in the fall, spring or summer. Thus, it seems safe to conclude that these differences in residual effectiveness of applied nitrogen reflect losses that have occurred.

Another residual study evaluated the buildup of nitrogen in soil from the annual application of different rates at different times through three years of cropping to corn (Figure 14). These data were accumulated on irrigated Crete silty clay loam of very low initial nitrogen availablity (mean check yield of 54 bushels per acre) in Fillmore County.

The three-year response values show that 80 pounds of nitrogen sidedressed gave nearly optimum returns, while this amount was inadequate when fall or spring applied. Forty pounds of nitrogen sidedressed was equivalent to 80 pounds fall or spring applied, but was inadequate with early application. Desirability of delaying nitrogen application until shortly before the period of peak crop need to derive greatest nitrogen efficiency was clearly apparent at this location.

Time of Nitrogen Application for Grain Sorghum

Although there have been fewer investigations on grain sorghum than corn, fertilizer nitrogen management results are similar. As with corn, most efficient utilization has come from delayed nitrogen application, again presumably because of minimized nitrogen loss (Table 5).

One experiment in Platte County in 1960 indicated that sorghum can get adequate nitrogen from soil which is inadequate for corn. With both crops growing on the same soil, a highly significant increase of 23 bushels of corn resulted from 80 pounds of nitrogen per acre, whereas grain sorghum yielded more and showed no significant effect

Table 5. Grain sorghum yields as influenced by time of nitrogen application and kind of nitrogen carrier.[a]

	Grain yield, bu./A.				
Treatment	York Co. 1958 I.	Phelps Co. 1961	Webster Co. 1961 I.	Hamilton Co. 1962 I.	Hamilton Co. 1963 I.
Check	66	68	53	107	45
Ammonium nitrate					
Fall	99	78	86	....	..
Spring	105	80	....	127	72
Planting time	....	....	....	122	83
Sidedress	111	88	101	136	81
Late sidedress	...	....	....	137	85
Anhydrous ammonia					
Fall	102	77	....		
Spring	103	90	....		
Sidedress	103	90	....		
Urea					
Fall	101	83	74		
Spring	95	84	....		
Sidedress	107	94	96		
N solution					
Fall	....	....	87		
Sidedress	104	....	95		

[a] This summary includes only those locations with significant response to fertilizer. Values given are mean of all rates of nitrogen applied; locations designated by I. were irrigated. Sidedress nitrogen applied at about 12-inch growth, late sidedress at about 20 inches.

from nitrogen application. It is postulated that the sorghum root system is more capable of extracting soil nitrogen than the corn root system, perhaps because of a longer period during which nitrogen can be extracted for maximum yield under the existing environment.

Nitrogen Losses from Applied Fertilizer

The above data imply greater nitrogen losses with fall or spring application than with early summer sidedressing for corn and grain sorghum. One reason would be that the nitrogen applied remains a relatively free agent in the cool soil during the fall, winter and early spring. There is limited microbial activity for incorporating it into a semi-stable organic combination; there is no active crop root to absorb it into a plant system. It remains largely as soluble nitrate to move with any water movement, and as ammonium ion which can be changed to a gaseous state under certain conditions. Drying and freezing especially promote ammonia volatilization. It may also escape as nitrogen oxides in acid soils, a loss which is probably accentuated by environmental conditions that limit nitrification. The likelihood of all of these potential losses is logically reduced if the nitrogen is applied at a time when crop roots will actively absorb it.

The time for sidedressing is a busy time for farmers. Many may be inclined to sacrifice some efficiency for a less rushed application time. The fertilizer industry also couldn't possibly supply all the fertilizer nitrogen required by the corn belt during a short sidedressing period.

Although there was no large difference in effectiveness of nitrate and ammonium carriers on medium to fine textured Nebraska soils, there has been a marked superiority of the ammonium source on sandy soils, especially noticeable with fall application. Here, too, summer sidedressing of the nitrogen was most effective. The apparent

Table 6. Yield of irrigated corn as influenced by carrier and time of application. Mean of eight experiments on medium textured soils, 1957-1962.[a]

Nitrogen carrier	Time of applying N fertilizer: Fall	Spring	Summer sidedress
	bu./A.	bu./A.	bu./A.
	80 lbs. N per acre		
Ammonium nitrate	98	103	112
Anhydrous ammonia	108	102	112
Urea	90	96	109
Mean	99	100	111
	160 lbs. N per acre		
Ammonium nitrate	112	118	118
Anhydrous ammonia	118	113	118
Urea	106	115	119
Mean	112	115	118

[a] Average check yield was 69 bushels/acre.

conclusion is that leaching is a major factor in sandy soils, and this loss is reduced by use of an ammonium rather than nitrate carrier and by delayed application.

Other field experiments since 1957 have compared ammonium nitrate, anhydrous ammonia and urea applied in the fall, spring and summer. Again, spring application has produced slightly better results than fall application, and summer sidedressing was distinctly superior to the other times (Table 6). These observations apply to all carriers studied. They are especially evident at the smaller 80 pound per acre rate of application, but are still noticeable at the 160 pound rate. Fall applied urea produced especially poor results in some of these experiments. Evidently, losses associated with early application are accentuated when this carrier is employed.

Because of the solution and gaseous phases through which applied nitrogen may pass while in the soil, it is difficult to measure what happens to an applied increment, especially under field conditions. Nonetheless, sampling of soil after treatment will sometimes intercept nitrate leached to different depths in accordance with treatments.

Leaching

Measurements of residual nitrate-nitrogen in a 1958 Phelps County experiment showed more nitrogen in the fourth foot of soil where the nitrogen was fall-applied than where summer sidedressed. An experiment in Polk County during 1959 located 31 pounds of nitrate-nitrogen at harvest time in the 4–6 foot soil depth following application of 160 pounds of nitrogen as calcium nitrate the previous fall. A similar treatment with ammonium sulfate as the carrier resulted in only 5 pounds of nitrate-nitrogen in the 4–6 foot zone. How much additional nitrate leached on through with the nitrate carrier is conjectural, but there was an approximate yield difference of 10 bushels favoring the ammonium carrier.

Figure 15 shows nitrate-nitrogen values at various depths in the soil from a nitrogen residual experiment of 1960 and 1961 on irrigated Belfore silty clay loam. In this case, 160 pounds of nitrogen was applied as calcium nitrate and as ammonium sulfate in the fall, spring and summer for the 1959 corn crop. Soil samples were collected in the spring to a depth of six feet before planting the 1960 crop and again prior to the 1961 crop. It was evident that substantial nitrate had moved on through the 6-foot soil section with fall application of the two carriers during the first year of the experiment. A moderate amount had moved out of the 6-foot soil section from spring application compared with summer sidedressing. Residual value in yield of the 1959-applied nitrogen in the 1960 corn increased with delay in time of application. This obvious saving of nitrogen from loss during the year of application was still evident in the 1961 corn. It seems likely that much of the saving in nitrogen for greater residual value in this experiment resulted from minimized leaching loss with delayed application.

Leaching loss of nitrate is controlled by the movement of water through the solum of soil. Where rain or irrigation moisture does not penetrate beyond the crop rooting depth there is little or no leaching hazard. Even with uniform soil, however, it is possible to have differential leaching within a field, from insignificant to serious, because of small variations in surface microrelief. Thus, with runoff from the slightly elevated points and accumulation in the low spots, moisture penetration may be alternately slight and excessive. This is demonstrated by the data of Figure 16, representing an irrigated site on Crete silty clay loam. Here moisture has penetrated excessively in replication No. 5 of the experiment with consequent magnified leaching loss of nitrogen. Replication No. 2 was slightly higher than the

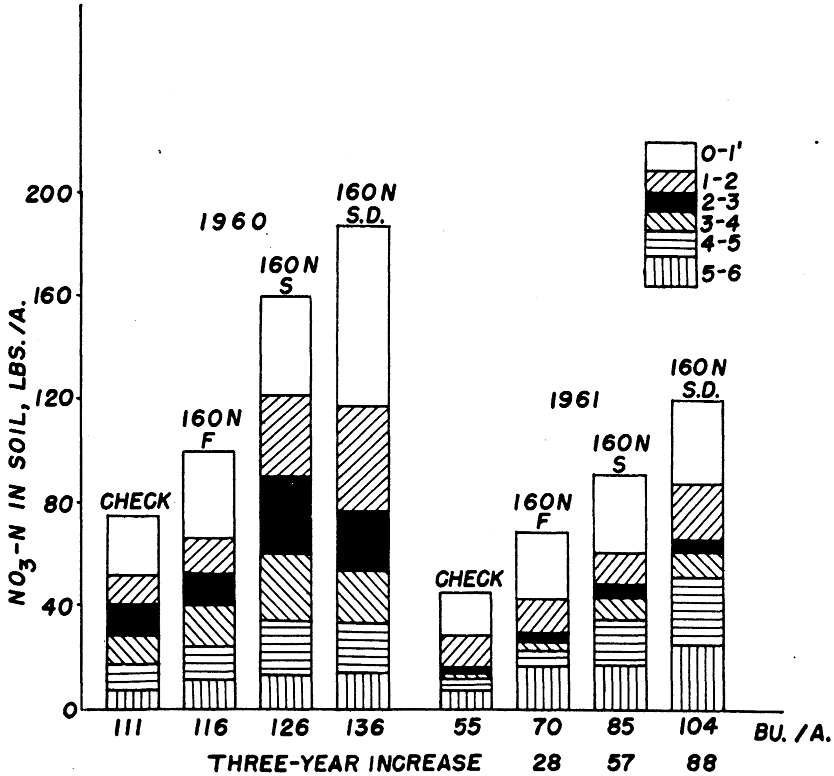

Figure 15. Residual nitrate supply and yield of irrigated corn for three years following a single application of 160 pounds nitrogen per acre at different times in 1959. Mean for calcium nitrate and ammonium sulfate nitrogen sources on Belfore silty clay loam. Yields in 1959 were: check, 94 bu.; fall nitrogen, 102 bu.; spring nitrogen, 106 bu.; summer sidedress nitrogen, 108 bu./A.

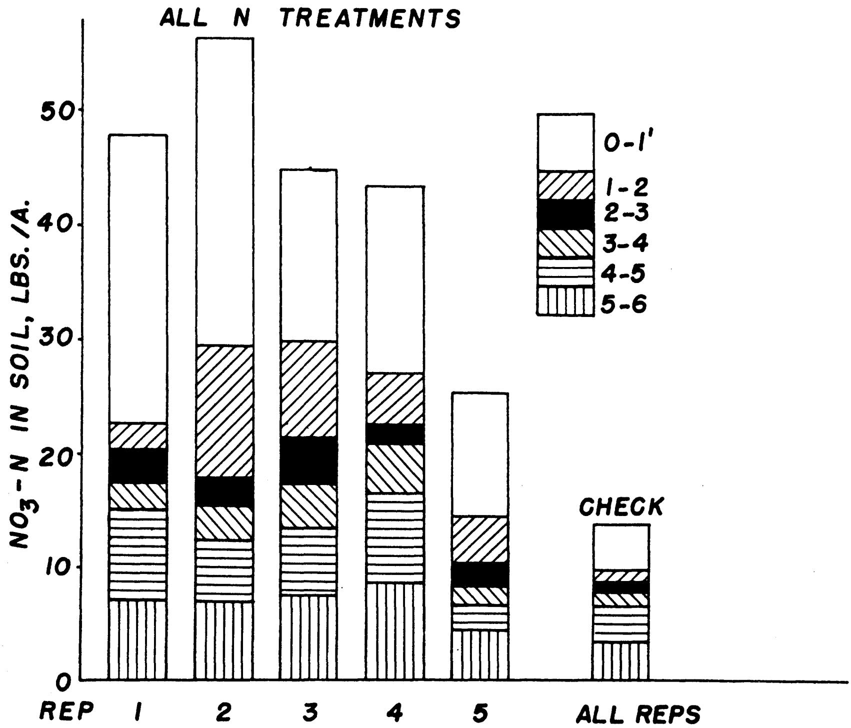

Figure 16. Variability in nitrate storage and leaching at the end of the cropping season in accordance with land surface conformity. Irrigated field experiment on Crete silty clay loam with rep 2 slightly higher and rep 5 lower than the remainder of the experimental area.

rest of the experimental area and showed maximal residual nitrate at season's end. The surface topography variations at this site were minute, not evident to the naked eye until irrigation water was running in the irrigation furrows.

Largest leaching losses of nitrogen would be expected in the more humid part of the corn belt and where irrigation is practiced. Greatest losses also would be expected with highly permeable sandy soils of limited water holding capacity. Implications here reach beyond the economics of efficient response to applied nitrogen.

Denitrification

An additional mechanism for nitrogen loss is indicated from values in the soil horizons of Figure 15. Almost without exception in both 1960 and 1961 the minimum accumulation of nitrate-nitrogen was in the third foot of soil, the zone of maximum clay accumulation and compaction at this site. Because the moisture holding capacity of this layer is greatest, there should have been substantially more nitrogen here than was found, unless gaseous loss had occurred. The circumstantial evidence here is that nitrogen was lost in a volatile form as N_2 or N_2O through denitrification in the rather dense, fine-textured subsoil of this location, and also in the 2–3 foot zone of Figure 16 and in nineteen similar soils presented in Table 7. If this observation is valid, additional loss of nitrate-nitrogen which is leached to and stops temporarily in claypan and similarly dense subsoil types can be expected because of anaerobic denitrification in such a medium. Perhaps such loss also can be expected from the soil immediately above the claypan which is kept saturated for periods of time because of the slow permeability rate of the claypan layer.

Ammonia Volatilization

Previously cited evidence has suggested ammonia volatilization loss from surface application of fertilizer nitrogen. The data of Figure 17 give further indication of ammonia evolution from surface applied materials. Other laboratory and greenhouse studies at the University of Nebraska have confirmed the serious aspects of ammonia evolution from certain materials broadcast on the soil surface (Figure 18).[7] It

Table 7. Occurrence of NO_3–N at different depths in several Nebraska soils in field experiments of 1960-63.

Location and soil		NO_3–N according to soil depth, lbs./A.					
		0–1′	1–2′	2–3′	3–4′	4–5′	5–6′
		Fine textured types with dense subsoil					
Ex. 1	Crete sicl	16.0	4.5	8.9	15.7	15.7	17.0
Ex. 2	Belfore sicl	35.2	18.9	3.8	4.5	9.9	13.1
613	Belfore sicl	23.0	9.9	4.5	9.9	17.9	14.1
659	Hastings sicl	5.8	3.5	3.5	9.0	9.9	12.5
663	Crete sicl	43.8	15.0	3.8	2.9	1.6	2.9
666	Crete sicl	31.7	10.2	2.6	1.0	1.6	1.6
712	Hastings sicl	31.0	6.7	2.2	3.8	1.9	4.2
713	Crete sicl	23.7	6.7	3.8	5.4	4.2	16.3
716	Crete sicl	20.2	4.2	3.2	4.8	6.1	3.8
719	Crete sicl	8.3	3.5	2.2	1.9	3.2	3.2
755	Belfore sicl	36.5	19.8	7.0	10.6	17.9	19.5
756	Crete sicl	15.0	4.8	1.9	2.6	5.1	6.1
782	Wymore sicl	29.8	4.2	2.9	3.5	2.6	1.6
785	Butler sicl	7.4	1.0	1.0	3.5	1.0	0.6
807	Crete sil	54.4	6.4	9.6	3.2	6.4	12.8
809	Crete sicl	28.8	19.2	6.4	6.4	9.6	38.4
818	Crete sicl	23.4	3.2	1.3	1.3	1.6	2.6
822	Wymore sicl	17.6	7.0	1.3	0.6	0.6	1.6
824	Crete sicl	42.6	9.6	3.2	1.6	1.0	4.5
	Mean	26.0	8.3	3.8	4.9	6.2	9.3
		Mean for 125 friable subsoil types					
		39.4	22.4	12.2	9.9	8.3	9.9

[7] Meyer, R. D., Olson, R. A., and Rhoades, H. F. Ammonia losses from fertilized Nebraska soils. Agron. Jour. 53: 241–244. 1961.

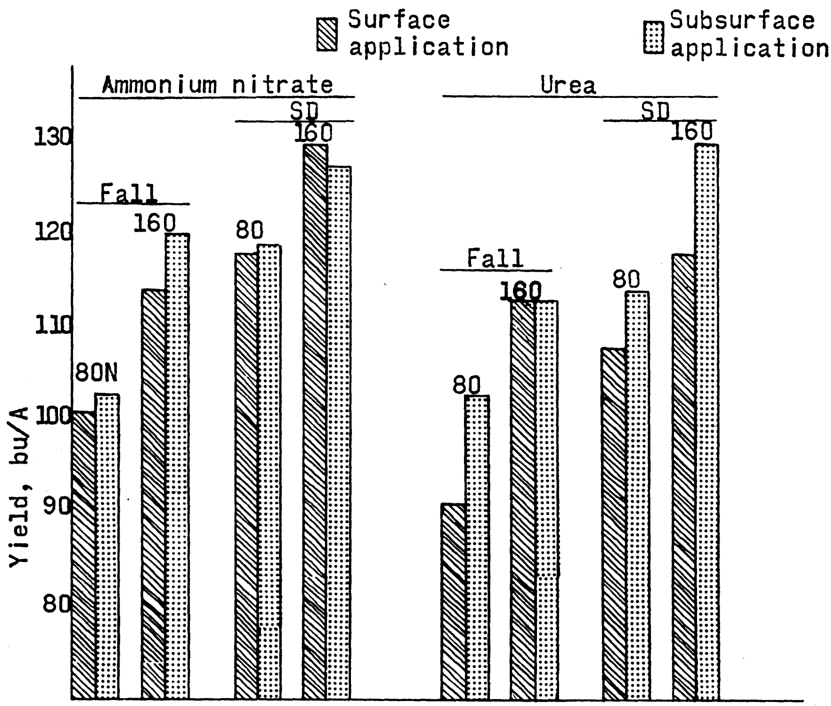

Figure 17. Influence of kind, time, rate and method of fertilizer nitrogen application on yield of irrigated corn. (Mean of 4 experiments conducted during 1960-1961 with average check yield of 74 bu./A.)

was established among the carriers studied that ammonia losses were greatest with urea-containing products, especially when applied on neutral to alkaline soils (Figure 19).

The data also showed ammonia loss to be greatest with limited rainfall and to be magnified greatly, in the case of solution products, by the presence of crop residue covering the soil surface. With surface residue present, losses of solution nitrogen on acid soils approached those on alkaline soils.

Mixing of fertilizer with soil in all cases greatly reduced ammonia volatilization losses, as did simulated rain immediately after surface broadcasting of all carriers. Most of the ammonia evolution recorded above took place during the first day or two after application.

Presumably ammonia volatilization loss from surface application of nitrogen products containing or producing ammonium ion is the greatest in dry climatic regions with low air humidity and with long intervals between rains. Such climatic areas also possess base-saturated soils, neutral to alkaline in reaction, where attraction for ammonia by the soil exchange complex is minimal. But volatilization losses are possible during dry periods even in humid climatic regions where acid soils predominate, especially where solution products are broadcast on existing crop residues.

Excessive Use of Fertilizer Nitrogen

There is mounting evidence that many farmers are using more fertilizer nitrogen than necessary for best economic return. This must become a further concern because excess nitrate accumulating in forage or ground-water constitutes a hazard to animal and human welfare. Data in Table 8 show that the majority of sites with high residual nitrate from previous years' treatments did not respond significantly to applied nitrogen. If yield increase did result from fertili-

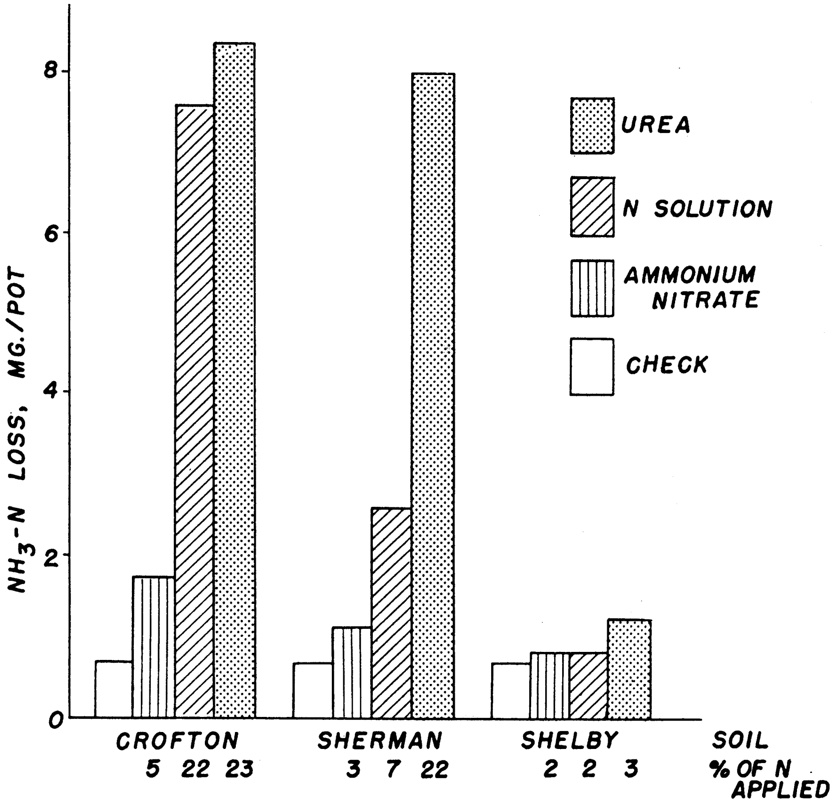

Figure 18. Ammonia evolution in one month from different soils treated with three nitrogen carriers in the laboratory. (Crofton is a high pH calcareous soil of northeastern Nebraska, Sherman a neutral soil of western Nebraska, and Shelby an acid soil of the southeast; nitrogen carriers broadcast on the soil surface. 36 mg. fertilizer N added to each pot; incubation carried out with soil at field capacity wetness and 75° F.)

zer nitrogen, it was restricted to the first small increment of nitrogen added in most cases. In the few experiments in this group in which nitrate in stover was determined, the high soil nitrate level did not portend high stover nitrate. However, as appreciable fertilizer nitrogen was added for the current crop, stover nitrate was notably increased. The highest level measured (0.66% Nance County) is not considered critical, but there would probably be long-term bad effects on animals if all of the farm's forage was at this level.

It was also apparent in many cases that nitrate was moving through the soil profile beyond the reach of roots. This deduction came from those sites where large amounts of nitrate were measured in the fifth and sixth foot of soil. Further leaching of these nitrates can be expected to deposit them in the groundwater below, with consequent potential danger to animal and man. So it behooves the farmer and those who advise him to keep nitrogen application rates within the bounds where yield response is obtained.

It is also important that farmers keep in mind the acidifying action of nitrogen compounds when using large amounts of fertilizer

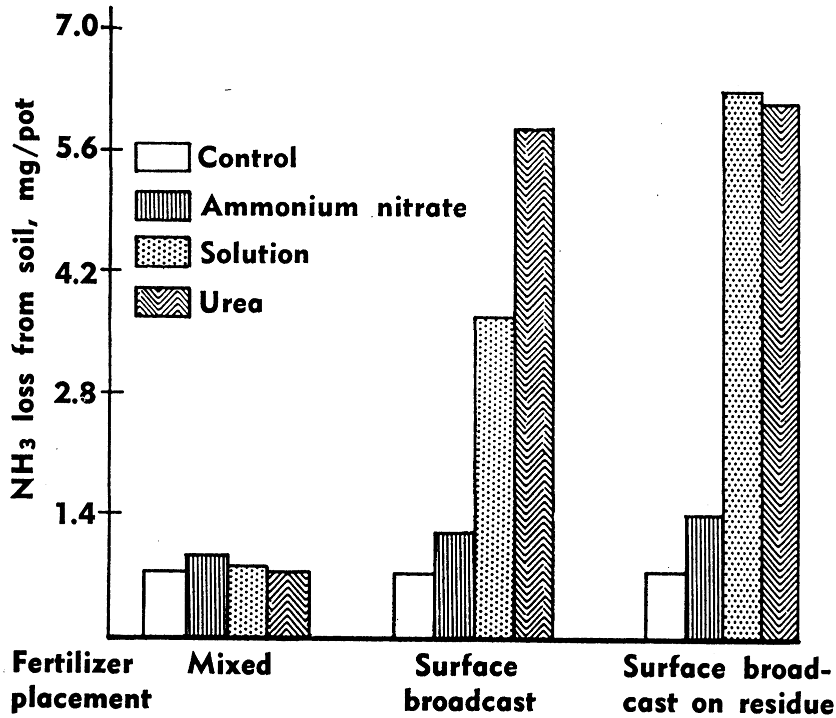

Figure 19. Ammonia evolution during one month from soil to which different nitrogen carriers were applied in various ways. (Mean values for three soils of Figure 18.)

Table 8. Experiments on corn and grain sorghum where residual nitrate-nitrogen in the soil was high at planting.

Year, location and crop[a]	Previous N history	NO_3–N in soil at planting to 6 feet, lbs./A.	Check yield, bu./A.	Yield response to nitrogen, bu./A.						Nitrate in stover, % K NO_3 for	
				40N	60N	80N	120N	160N	LSD (.05) for expt.	Check	Highest N treatment
1962 Hamilton (3) C*	140N yearly	196	125	–2	....	0	0	–3	n.s.	0.33	0.48
Hamilton (4) C*	100N + yearly	178	143	13	....	15	23	22	n.s.		
Dawson C*	Alfalfa + N	174	124	....	....	....	0	...	n.s.		
Webster GS*	Unknown	145	106	....	6	....	....	....	n.s.		
1963 Gosper C*	Alfalfa + N	162	111	....	....	....	–3	...	n.s.		
Jefferson GS	Fallow + 40–60N yearly	66	80	....	....	1	....	.	n.s.	.11	.22
1961 Franklin C*	120N yearly	168	111	....	....	9	....	7	n.s.		
Hamilton (3) C*	135N yearly	126	75	25	....	28	36	35	7	.03	.38
Lancaster C	60–80N yearly	166	76	....	....	....	4	....	n.s.		
Dundy C*	125N yearly	119	86	....	....	....	12	....	9		
Phelps GS	50N yearly	102	68	16	....	18	....	....	10		
Morrill GS	Safflower	154	40	....	2	....	....	.	n.s.		
1960 Adams (3) C*	80–100N yearly	133	74	....	....	11	....	18	12		
Platte GS	60N yearly	88	96	1	....	13	....	....	n.s.		
Lancaster C	Old lot 60–80N yearly	336	94	....	....	5	....	....	11		
Hamilton GS*	80–120N yearly	110	120	....	....	....	17	....	n.s.		
Dixon GS	Unknown	102	69	....	....	16	....	....	12		
Dundy GS	Fallow	63	26	–1	1	–1	....	....	n.s.		
Nance C*	90N yearly 160N in 1959	190	136	....	....	....	....	2	16	.10	.66
Nuckolls C*	40–100N yearly	100	116	....	....	33	....	32	31	.10	.39

[a] C = corn, GS = grain sorghum, * = irrigated. Locations selected where profile NO_3–N exceeded 60 pounds per acre if non-irrigated, 100 pounds if irrigated.

Table 9. pH values from soil samples taken at the end of the corn growing season in 1962.

Treatment	Soil pH at harvest time											
	Hamilton Co.											
	No. 1		No. 2		No. 3		No. 4		No.5		York Co.	
	0–6″	6–12″	0–6″	6–12″	0–6″	6–12″	0–6″	6–12″	0–6″	6–12″	0–6″	6–12″
Check	6.2	6.0	6.0	6.0	6.3	6.7	6.1	6.3	6.0	6.0	6.2	6.2
40N	6.1	6.0	6.0	6.0	6.1	6.4	6.2	6.3	6.0	5.8	6.1	6.1
80N	5.8	5.8	5.8	5.6	6.2	6.4	6.0	6.2	6.0	5.8	5.8	6.0
120N	5.6	5.9	5.4	6.0	6.0	6.4	6.1	6.6	5.9	5.7	6.0	6.2
160N	6.0	5.8	5.6	5.6	5.8	6.6	5.8	6.0	5.6	5.7	6.0	5.8
200N	5.5	5.4	5.4	5.6	5.1	5.8	5.4	6.0	5.8	5.8	5.6	5.9

nitrogen for grain production. Table 9 with pH data from soil samples taken at the end of the corn growing season in 1962 shows evidence of the magnitude of this problem.

These data are all the more striking considering that the soils involved were irrigated with groundwater containing an appreciable amount of 'hard water' salts. In that particular year, however, irrigation was limited because of high summer rainfall. The lowest pH values in all cases were associated with large amounts of nitrate-nitrogen in the soil. The pH can be expected to increase as the nitrate disappears, particularly under the irrigation regime where calcium and magnesium are being continuously replenished by the water. Where all moisture is in the form of rain water, however, other compensation must be made eventually for this acidifying action. There is very little difference among the major fertilizer nitrogen carriers used in Nebraska in this respect.

Appendix Table 1. Soil properties of the surface six inches and some specific yield response data for the winter wheat experiments portrayed in the various charts and tables.

Year and location[a]	Soil type	pH	Bray P, ppm.	Nitrif. rate, ppm.	Exch. K, ppm.	Treatments 0+30+0	40+30+0 Fall N	40+30+0 Spring N	40+30+0 Split N	40+30+0 Winter N	60+30+0	LSD (05)
Figures 4, 5 (See also Bul. 172, Nebr. Agr. Exp. Sta. 1953)												
1948 Dodge	Sharpsburg si.c.l.	....	....	....	....	24	36	43	39	35	....	4
Seward	Crete si.l.	....	....	....	....	43	48	45	49	49	....	n.s.
York	Crete si.l.	....	....	....	....	26	35	35	34	36	....	7
Hamilton (1)	Hastings si.l.	....	....	....	....	19	33	30	31	26	....	3
Hamilton (2)	Hastings si.l.	....	....	....	....	24	42	47	42	41	....	4
Adams (1)	Hastings si.l.	....	....	....	....	33	39	37	37	36	....	n.s.
Adams (2)	Hastings si.l.	....	....	....	....	26	42	38	43	37	....	6
Kearney	Hastings si.l.	....	....	....	....	31	52	52	51	45	....	6
Furnas	Holdrege si.l.	....	....	....	....	50	55	57	58	55	....	5
Frontier	Holdrege si.l.	....	....	....	....	50	51	53	52	54	....	n.s.
Hayes	Keith si.l.	....	....	....	....	39	51	51	50	48	....	7
Hitchcock	Keith si.l.	....	....	....	....	35	37	30	40	32	....	8
Dundy	Keith si.l.	....	....	....	....	61	61	62	60	60	....	n.s.
Chase	Keith si.l.	....	....	....	....	42	44	42	41	39	....	n.s.
Perkins	Dunlap l.	....	....	....	....	26	18	18	22	20	....	n.s.
Cheyenne	Rosebud l.	....	....	....	....	39	40	41	44	39	....	n.s.
Box Butte	Rosebud l.	....	....	....	....	32	40	40	40	40	....	n.s.
Sheridan	Keith si.l.	....	....	....	....	49	54	56	56	56	....	4
1953 Johnson	Shelby si.c.l.	5.6	1	21	....	32	52	46	49	....	46	5
Pawnee	Shelby c.l.	5.7	11	26	....	15	26	25	28	....	28	6
Colfax	Wann f.s.l.	8.2	15	13	....	35	40	41	40	....	....	3
Saline	Crete si.l.	5.6	10	13	....	36	44	47	46	....	44	5
Nance	Belfore si.l.	5.3	8	12	....	31	43	43	47	....	43	5
Kearney	Holdrege si.l.	6.0	24	15	....	12	28	26	26	....	27	4
1954 Pawnee	Sharpsburg si.c.l.	5.6	12	22	375	23	33	39	39	....	41	4
Nance	Ortello l.f.s.	6.0	3	14	225	32	38	38	37	....	37	3
Colfax	Wann f.s.l.	8.2	4	10	313	26	34	31	32	....	32	5
Dodge	Lamoure s.c.l.	8.1	1	18	250	21	30	30	29	....	30	3
Adams	Hastings si.l.	6.1	37	15	600	15	24	22	26	....	25	4
Fillmore	Crete si.c.l.	5.7	13	17	350	16	30	25	27	....	28	3
Polk	Hastings si.l.	5.8	14	15	375	15	23	21	20	....	21	3

Table 1.—(Continued)

Year and location[a]	Soil type	pH	Bray P, ppm.	Nitrif. rate, ppm.	Exch. K, ppm.	Treatments 0+30+0	Treatments 40+30+0 Fall N	Treatments 40+30+0 Spring N	Treatments 40+30+0 Split N	Treatments 40+30+0 Winter N	Treatments 60+30+0	LSD (05)
1955 Nemaha	Shelby si.c.l.	5.5	17	19	>150	40	46	48	44	....	42	4
Dodge	Lamoure si.c.l.	7.5	38	21	>150	43	52	58	56	....	64	6
Saline	Hastings si.l.	5.4	27	11	>150	38	47	49	56	....	51	7
Jefferson	Crete si.c.l.	5.6	30	14	>150	52	61	64	63	....	68	6
Thayer	Crete si.c.l.	5.6	31	14	>150	21	24	32	33	....	33	9
1957 Lancaster	Sharpsburg si.c.l.	5.6	14	15	345	34	41	41	39	....	43	6
Cass	Sharpsburg si.c.l.	5.5	23	15	338	26	38	38	36	....	40	4
Dodge	Sharpsburg si.c.l	6.0	27	21	665	37	34	38	41	....	39	n.s.
Saline	Crete si.c.l.	5.5	18	15	376	22	35	36	36	....	37	2
1958 Otoe	Crete si.c.l.	5.7	25	24	295	44	48	47	50	....	61	4
Richardson	Crete si.c.l.	5.8	23	20	313	34	40	41	39	....	41	5
Seward	Hastings si.c.l.	5.7	25	16	298	32	38	41	42	....	44	5
Merrick	Cass s.l.	5.9	10	13	163	43	47	50	49	....	49	4
Adams	Hastings si.l.	6.0	19	12	305	26	36	36	39	....	41	5
1959 Nemaha	Sharpsburg si.c.l.	6.1	21	18	275	18	28	27	26	....	24	3
Johnson	Shelby si.c.l.	6.1	11	19	363	24	28	27	26	....	28	4
Jefferson	Shelby si.c.l.	6.0	21	22	215	20	30	26	29	....	26	4
1960 Otoe	Sharpsburg si.c.l.	6.6	14	14	300	35	42	38	42	....	40	6
Colfax	Lamoure si.l.	8.1	<1	28	205	37	42	40	40	....	40	6
Polk	Hastings si.l.	6.1	16	16	495	25	28	27	28	....	31	4
Nuckolls	Crete si.c.l.	5.7	32	10	500	34	38	38	41	....	39	3
1961 Dodge	Lamoure si.c.	7.6	9	16	190	34	34	31	30	....	34	5
Pawnee	Wymore si.c.l.	6.7	4	17	200	41	42	43	46	....	47	5
Thayer	Hastings si.c.l.	6.1	7	9	378	24	39	42	35	....	47	5
Jefferson	Crete si.c.l.	6.2	11	9	345	18	28	38	38	....	42	6
Webster	Crete si.l.	6.5	27	13	495	18	30	36	40	....	44	7
1962 Gage	Wymore si.c.l.	7.2	50	20	413	42	48	52	52	....	54	4
Otoe	Shelby c.l.	6.4	12	20	343	27	42	40	41	....	39	5
Colfax	Lamoure si.c.l.	8.6	4	35	280	20	22	20	22	....	20	4
Nuckolls	Hastings si.c.l.	5.8	28	22	533	25	27	28	28	....	30	5
Adams	Hastings si.l.	6.3	20	18	463	11	14	14	12	....	13	3

Table 1.—(Continued)

Year and location[a]	Soil type	pH	Bray P, ppm.	Nitrif. rate, ppm.	Exch. K, ppm.	Treatments 0+30+0	40+30+0 Fall N	40+30+0 Spring N	40+30+0 Split N	40+30+0 Winter N	60+30+0	LSD (05)
Buffalo	Holdrege si.l.	6.6	10	14	550	12	19	15	18	....	13	5
Frontier	Holdrege si.l.	6.9	31	14	620	22	23	22	23	....	24	4
Deuel	Keith si.l.	6.9	25	10	578	37	41	41	41	....	40	4
Cheyenne	Keith si.l.	6.7	40	16	1249	26	27	27	27	....	28	5
Box Butte	Parshall f.s.l.	7.0	27	11	408	18	22	24	26	....	27	2
1963 Pawnee	Wymore si.c.l.	6.3	9	11	200	19	30	32	33	....	37	3
Cass	Sharpsburg si.c.l.	6.2	14	10	304	26	32	38	36	....	44	5
Dodge	Belfore si.c.l.	5.8	15	16	437	46	48	50	49	....	49	3
Nance	Belfore si.c.l.	5.7	39	16	558	28	36	40	36	....	39	5
Fillmore	Crete si.c.l.	5.9	46	16	625	17	23	23	25	....	26	2
Webster	Hastings si.l.	6.0	28	13	612	24	29	28	29	....	30	4
Harlan	Holdrege si.l.	6.6	33	17	487	24	29	40	39	....	46	4
Red Willow	Holdrege si.l.	7.0	17	11	537	21	34	42	40	....	45	6
Kimball	Keith l.	8.4	7	11	300	18	27	28	24	....	27	6
Dawes	Keith si.l.	6.8	25	15	583	26	40	45	43	....	49	4

[a] Yield response data for 1956 omitted due to extreme drought effects during that year; certain other individual locations also omitted where drought, hail or other calamities prevented response to fertilizer. All N supplied as NH_4NO_3.

Appendix Table 2. Soil properties of the surface six inches and yield response of summer fallow wheat to fertilizer nitrogen as NH_4NO_3 applied at different times and rates (Figure 7 in text).

Year and location	Soil type	pH	Bray P, ppm.	Nitrif. rate, ppm. N	Exch. K, ppm.	Treatments: Check	20 N: F	20 N: S	40 N: F	40 N: S	60 N: F	60 N: S	LSD (05)
1952 Custer	....	5.9	25	13	....	31	31	32	33	34	24	30	3
Harlan	....	6.2	13	13	....	26	29	26	28	28	27	26	2
Frontier	....	7.6	31	17	....	26	27	26	30	25	28	22	1
Hitchcock	....	6.5	18	17	....	16	14	10	12	10	12	9	4
Dundy	....	7.2	55	12	....	33	38	37	36	34	35	30	3
Cheyenne (1)	....	6.3	27	20	....	22	20	16	19	17	18	17	3
Box Butte (1)	....	6.8	29	18	....	17	16	14	15	12	14	12	3
Box Butte (3)	....	7.1	14	17	....	21	19	22	21	21	20	21	2
Perkins	....	5.8	29	12	....	12	12	11	12	10	11	10	n.s.
Box Butte (2)	....	6.7	15	21	....	16	14	13	16	15	15	13	n.s.
1953 Phelps	Holdrege si.l.	5.6	34	8	....	37	38	36	38	39	35	40	3
Red Willow	Holdrege l.	6.7	53	17	....	39	37	38	35	42	34	40	4
Chase	Keith f.s.l.	6.8	59	....	....	34	39	39	47	42	39	43	6
Cheyenne	....	6.4	13	15	....	26	29	31	30	31	26	29	5
Garden	Sherman si.l.	5.8	44	....	....	25	22	23	25	25	19	24	4
Box Butte (1)	Rosebud si.l.	7.1	13	13	....	30	27	25	27	28	24	26	4
Box Butte (2)	Springer f.s.l.	6.8	18	15	....	33	32	33	31	32	28	32	3
Sheridan	Rosebud si.l.	7.8	6	18	....	21	18	20	18	18	19	19	3
Hayes	Keith si.l.	6.4	24	....	....	27	25	25	26	27	23	26	n.s.
Box Butte (3)	Rosebud si.l.	7.4	9	10	....	23	23	22	23	23	24	23	n.s.
1954 Harlan	Holdrege si.l.	6.3	30	12	728	30	36	36	39	40	45	41	3
Gosper	Holdrege si.l.	6.5	12	12	462	22	20	23	18	21	19	20	3
Chase	Keith l.	6.9	21	17	521	20	19	18	17	18	16	16	4
Keith	Keith l.	6.3	20	7	388	22	17	20	17	20	16	21	3
Deuel	Sherman si.l.	6.5	18	12	583	24	23	23	23	24	19	25	3
Hitchcock	Keith si.l.	7.1	11	11	604	10	11	11	9	9	8	9	n.s.
Box Butte	Keith si.l.	6.9	27	10	>500	17	20	20	18	18	16	16	n.s.

Table 2.—(Continued)

Year and location	Soil type	pH	Bray P, ppm.	Nitrif. rate, ppm. N	Exch. K, ppm.	Check	Treatments 20 N		40 N		60 N		LSD (05)
							F	S	F	S	F	S	
1955 Red Willow	Holdrege si.l.	6.9	5	9	>150	13	13	13	13	15	12	11	2
Cheyenne	Keith l.	7.3	15	10	>500	36	42	42	43	43	44	45	4
Dawes	Rosebud si.l.	6.0	11	13	>500	27	27	28	26	25	25	28	5
Phelps	Holdrege si.l.	5.6	59	18	>150	16	16	19	14	18	14	18	n.s.
1956 Harlan	Holdrege si.l.	6.0	43	12	525	18	16	18	16	16	15	15	n.s.
Hitchcock	Keith si.l.	7.7	4	17	642	8	8	7	7	7	8	8	2
Lincoln	Holdrege v.f.s.l.	6.6	12	18	512	20	22	21	22	23	22	21	n.s.
Box Butte	Springer f.s.l.	7.2	19	6	372	25	25	24	23	24	23	22	2
Chase	Sherman l.	6.8	45	18	590	12	11	11	10	11	11	12	n.s.
Perkins	Sherman s.l.	6.5	22	15	500	20	18	18	19	18	17	18	n.s.
Sheridan	Keota c.l.	7.6	17	16	900	23	27	22	22	24	24	23	4
Deuel	Keith si.l.	6.8	32	8	625	30	30	32	28	32	31	31	n.s.
1957 Furnas	Holdrege si.l.	6.5	20	15	349	36	42	41	43	41	41	43	2
Phelps	Holdrege si.l.	5.9	45	14	615	35	33	35	29	32	27	27	4
Frontier	......	6.6	7	10	441	22	25	29	28	27	32	28	6
Franklin	Hastings si.l.	6.1	65	15	740	28	24	29	22	27	21	24	6
Dawes	Keith l.	7.1	10	14	495	37	40	39	45	44	45	45	6
Kimball	....	7.9	12	24	378	40	37	34	40	38	35	37	n.s.
Chase	Keith si.l.	6.5	31	9	325	25	34	28	39	35	40	38	2
1958 Kearney	Hastings si.l.	6.0	34	14	360	40	39	40	38	39	38	37	n.s.
Harlan	Holdrege si.l.	6.3	31	17	460	47	42	42	41	44	43	39	n.s.
Red Willow	Holdrege si.l.	6.5	39	13	500	42	38	40	37	41	31	37	n.s.
Perkins	Dunlap v.f.s.l.	5.7	52	13	>500	30	28	27	28	28	23	22	n.s.
Deuel	Keith si.l.	6.3	29	13	>500	53	59	58	62	61	59	59	5
Cheyenne	Keith si.l.	6.8	22	13	>500	42	45	49	48	49	49	50	4
Box Butte	Dunlap v.f.s.l.	6.4	32	13	>500	31	33	36	33	36	34	32	3

Appendix Table 3. Soil properties of the surface six inches and some specific yield response data for the corn experiments portrayed in the various charts and tables.

Year and location	Soil type	pH	Bray P, ppm.[a]	Nitrif. rate, ppm.	Exch. K, ppm.	Treatments						LSD (05)
							40 or 80 N					
						Check	Plow down	Sideband planting	18″ side-dressing	36″ side-dressing	18″ broad-cast	
						Figures 8, 9 and 10 (irrigated corn)						
1946 Hall	....	....	....	....	....	41	76	75	....	85	....	6
Nance	....	....	....	....	....	64	96	90	....	94	....	12
Phelps	....	....	....	....	....	65	86	82	....	91	....	9
1948 Hamilton	Hastings si.l.	....	....	....	....	40	82	69	85	100	....	11
1945 Dawson	Hall si.l.	....	....	....	....	41	....	55	....	60	....	7
Phelps	Holdrege si.l.	....	....	....	....	54	....	64	60	76	....	9
Hall	Hall si.l.	....	....	....	....	52	....	61	....	80	....	7
Phelps (2)	Holdrege si.l.	....	....	....	....	124	....	133	....	142	....	....
1951 Merrick	Cass f.s.l.	5.8	15	16	....	71	95	....	103	....	....	11
1952 Merrick	Cass f.s.l.	5.3	9	....	....	50	80	....	83	....	....	12
Nuckolls	Hall si.l.	5.5	27	....	....	37	97	....	105	....	....	14
1953 Nuckolls	Hall si.l.	6.0	17	....	610	111	125	....	134	....	....	17
1954 Adams	Crete si.l.	6.2	24	....	500	61	95	....	102	....	....	17
Nuckolls	Waukesha si.l.	6.0	30	....	500	81	101	....	102	....	....	12
1956 Hamilton	Hastings si.l.	6.0	30	....	500	62	....	130	....	132	....	5
Adams	Hastings si.l.	6.2	30	....	500	135	....	150	....	150	....	11
1955 Adams	Hastings si.l.	6.4	27	....	480	116	....	126	....	133	....	9

Table 3.—(Continued)

Year and location	Soil type	pH	Bray P, ppm.[a]	Nitrif. rate, ppm.	Exch. K, ppm.	Treatments						(05) LSD
							40 or 80 N					
						Check	Plow down	Sideband planting	18″ side-dressing	36″ side-dressing	18″ broad-cast	
						(non-irrigated corn)						
1949 Wayne	Moody si.l.	....	....	....	....	83	....	86	91	97	....	12
Cuming	Marshall si.l.	....	....	....	....	40	....	68	72	62	....	5
Sarpy	Marshall si.l.	....	....	....	....	80	94	93	104	102	....	16
Otoe	Sharpsburg si.c.l.	....	....	....	....	52	56	65	70	72	....	13
Clay	Crete si.c.l.	....	....	....	....	47	63	70	....	77	....	9
Clay	Butler si.c.l.	....	....	....	....	44	55	44	....	61	....	9
1950 Otoe	Sharpsburg si.c.l.	....	....	....	....	32	73	.....	94	....	75	12
Sarpy	Sharpsburg si.c.l.	....	....	....	....	72	87	....	93	98	76	13
Cuming	Marshall si.l	....	....	....	....	56	61	....	87	....	75	13
Wayne	Marshall si.l.	....	....	....	....	69	72	....	83	....	78	10
Pierce	Thurman l.f.s.	....	....	....	....	58	....	....	82	72	66	8
Holt	Thurman f.s.l.	....	....	....	....	47	....	....	64	66	58	6
Clay	Crete si.c.l.	....	....	....	....	55	83	....	91	....	72	12
Clay	Butler si.c.l.	....	....	....	....	48	67	....	71	....	64	10
1951 Fillmore	Crete si.c.l.	5.8	17	22	....	36	51	....	61	....	....	6
Colfax	Marshall si.c.l.	6.0	13	20	....	35	....	....	45	....	46	7
Thurston	Moody si.c.l.	6.5	11	17	....	54	....	....	63	....	62	5
Pierce	Thurman l.f.s.	6.2	13	4	....	18	....	....	45	....	43	5

[a] Values prior to 1954 obtained by a different extraction procedure. These have been converted to the approximate equivalent from Bray extractant. All N supplied as $NH_4 NO_3$.

Appendix Table 4. Soil properties of the surface six inches and some specific yield response data for the corn experiments portrayed in tables and figures of the text.

Year and location	Soil type	pH	Bray P, ppm.	Ni-trif. rate, ppm.	Exch. K, ppm.	Nitrogen treatments: Check	NH_4NO_3 80F	NH_4NO_3 80S	NH_4NO_3 80SD	NH_4NO_3 160SD	NH_3 80F	NH_3 80S	NH_3 80SD	$CO(NH_2)_2$ 80F	$CO(NH_2)_2$ 80S	$CO(NH_2)_2$ 80SD	LSD (05)
Table 6 (irrigated corn)																	
1957 Adams	Hastings si.l.	6.4	26	....	430	83	120	126	131	137	126	115	134	106	116	132	10
Hamilton	Hastings si.l.	6.4	16	....	446	76	111	103	114	111	108	103	117	94	105	113	14
1958 York	Crete si.l.	6.0	24	22	420	58	70	91	100	101	91	78	109	55	80	76	18
1959 Thayer	Crete si.l.	6.2	29	14	500	83	103	120	128	131	115	104	130	108	112	126	18
Saline	Crete si.l.	5.6	10	13	263	80	100	94	120	123	117	122	119	102	113	117	16
1960 Hamilton	Hastings si.l.	6.9	16	8	370	63	98	104	111	129	128	110	110	100	92	113	15
Adams	Colby si.l.	6.6	13	20	385	74	89	87	89	92	80	80	81	87	84	86	12
1961 Kearney	Holdrege si.l.	6.7	9	12	305	35	97	102	107	122	97	101	99	65	69	112	11

Year and location	Soil type	pH	Bray P, ppm.	Ni-trif. rate, ppm.	Exch. K, ppm.	Check	80F	80S	80SD	40SD	160SD	LSD (05)
Figures 11, 12, and 15 (irrigated corn)—Mean for $Ca(NO_3)_2$ and $(NH_4)_2SO_4$												
1957 Dawson	Hall si.l.	7.4	10	....	360	75	100	105	132	109	144	19
Hamilton	Hastings si.l.	6.6	9	....	360	77	89	91	96	88	105	12
1958 Merrick	Ortello s.l.	5.8	16	11	180	45	79	80	101	85	103	12
Fillmore	Crete si.l.	5.9	19	18	323	119	117	114	117	116	112	5
Kearney	Hastings si.l.	6.5	20	20	388	100	127	132	144	123	138	13
1959 Webster	Crete si.l.	6.5	12	12	375	24	78	72	93	64	119	20
Polk	Hastings si.l	6.3	18	21	500	63	103	111	121	111	126	13
Hall	....	6.6	15	13	200	105	114	111	121	115	126	21
Nance	Belfore si.l.	6.8	53	18	>500	94	99	106	103	113	108	n.s.
Buffalo	Holdrege si.l.	6.8	20	17	440	37	74	74	101	71	98	15
Scottsbluff (1)	Tripp f.s.l.	8.3	10	....	>500	41	69	73	75	66	80	14
Scottsbluff (2)	Parshall l.f.s.	7.2	19	....	356	42	69	69	76	66	83	8
1960 Fillmore	Crete si.c.l.	5.5	38	15	395	67	118	124	135	128	144	20
Nuckolls	Hall si.l.	6.6	20	13	290	116	148	141	148	134	148	31

Table 4.—(Continued)

Year and location	Soil type	pH	Bray P, ppm.	Ni-trif. rate, ppm.	Exch. K, ppm.	Nitrogen treatments as NH_4NO_3 Check	160F	160S	160SD	40SD	80SD	LSD (05)
						Figures 14 and 15 (irrigated corn)						
1959 Nance	Belfore si.l.	6.8	53	18	>500	94	102	106	108	113	103	n.s.
1960 Nance	Belfore si.l.	Residual response				111	116	126	137	111	137	16
1961 Nance	Belfore si.l.	Residual response				55	70	85	104	59	81	15
1960 Fillmore	Crete si.c.l.	5.5	38	15	395	67	118	123	135	128	143	20
1961 Fillmore	Crete si.c.l.					37	83	93	108	84	119	14
1962 Fillmore	Crete si.c.l.					57	107	107	116	99	118	18