Nitrogen Management and Interseeding Effects on Irrigated Corn and Sorghum and on Soil Strength[1]

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ABSTRACT

A 15-yr experiment on Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudolls) investigated N management effects on corn (*Zea mays* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] grown side by side, under identical furrow-irrigated conditions. Included were comparisons of anhydrous ammonia (AA) and N solution (UAN) as N sources, planting time (UAN-PL) vs. summer sidedressing (UAN-SD) application of the N, and rates of 90, 180, and 270 kg N ha⁻¹. Additionally, interseeding of rye (*Secale cereale* L.) into high N plots and alfalfa (*Medicago sativa* L.) into check plots of corn was accomplished at the time of ridging for furrow irrigation. The objectives were to evaluate the long term effects of varied management of the two N carriers and the interseedings on grain yields and N utilization, and the relative effects of these treatments on soil strength. Grain sorghum was the more productive crop under conditions of low N availability while corn responded to higher N rates, becoming the more economic crop with yields approaching 10 Mg ha⁻¹ when N was plentiful. Yield increases averaged 5% greater for UAN-SD over UAN-PL, and AA was slightly more effective than UAN-SD for both crops. Interseeded alfalfa and rye green manures provided average corn yield increases of 880 and 585 kg ha⁻¹, respectively, explainable in part by improved N economy. No significant differences in penetrometer or vane shear tests were found between soils from AA and UAN-SD plots, although there was a tendency toward lower soil-strength values with both N carriers, relative to check plots.

Additional index words: N use efficiency, Allelotrophy, Green manure, N carrier, ***Zea mays*** **L.,** ***Sorghum bicolor*** **(L.) Moench.**

FERTILIZER N has contributed more toward increasing yields of grain crops in the U.S. and the world in the past 30 years, than any other single factor. At the same time N has become the foremost input in relation to cost and energy requirement in advanced agricultural production systems. The national growth in its use to the current approximate 11 million tons annual N consumption, far exceeding N inputs prior to the Chemical Age in agriculture, has added the further dimensions of excessive N for crops and of groundwater pollution with nitrate (5,7,14,25). Accordingly, it is in the best interests of the farmer, fertilizer dealer, and manufacturer that fertilizer N be used in the most efficient way possible for minimizing costs of crop production, conserving energy, and preserving environmental integrity.

Many short-term studies have demonstrated the need for adjusting N rate to the yield obtainable, and even more importantly, to the amount of residual mineral N in the soil rooting zone at planting and the soil's nitrification capacity (10,16,17,22). Irrigation, where practiced, is recognized as a primary vehicle for carrying NO_3^- to groundwater, therewith necessitating the integration of water and N management practices for the protection of groundwater quality (18,19,21,22).

A limited number of long term experiments for evaluating the effects of time, rate, and kind of N fertilizer on irrigated crop yields and soil properties have been conducted. The literature reveals little evidence of the impact that interseeding a green manure crop will have on yields and soil properties in irrigated monoculture. Interseeding in irrigated culture has been practiced extensively in China during recent times with a claimed average increase of 30 percent in total production of the two crops, over that with solid stand of the dominant crop (13). However, the rows of interseeded crops are clean tilled in the Chinese system and are grown to maturity and harvested in the year of seeding without a specific green manuring objective.

It has often been claimed that anhydrous ammonia (AA) is damaging to a soil's physical properties, making the soil hard. The application of AA does involve a tillage operation of sorts and results in a very high concentration of ammonium ion, an effective soil dispersant, in a limited volume of soil. A 10-yr Kansas study at four locations found no measurable differences on soil structure and compactibility among four N sources including AA (9), but contentions against ammonia persist.

Accordingly, the objectives of this work were to investigate the long term effects of urea-ammonium nitrate solution (UAN) and AA applied at different times and rates on grain yields, the yield effects of interseeding green manures in an irrigated monoculture corn system, and the relative effects of these measures on soil strength.

MATERIALS AND METHODS

The experiment was conducted from 1969 to 1983 with irrigated corn and grain sorghum on Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudolls), at the Nebraska Agricultural Experiment Station Field Laboratory near Mead, NE. Recommended high yielding hybrids of the two crops were planted in 12-row plots of 20 m length and 760 mm row spacing, with approximate populations of 62 000 and 185 000 corn and grain sorghum plants per hectare, respectively. Planting date varied with the season but averaged around 6 May for corn and 20 May for sorghum.

A split-block factorial design repeated over time was employed, with two whole blocks (corn and grain sorghum with identical treatments, side by side), each with four randomized blocks. Treatments consisted of a factorial arrangement of three N rates (90, 180, and 270 kg ha⁻¹) and three N methods: (i) UAN (32% N) band applied at planting (PL), 760 mm spacing, 80 mm depth; (ii) UAN band applied sidedress (SD), 11 to 12 leaf stage, 760 mm spacing, 80 mm depth; and (iii) AA injected sidedress, 11 to 12 leaf stage, 760 mm spacing, 150 mm depth. Two check plots outside of the factorial were included in each replication. Blocks were split in half whereby P rates of 0 and 22 kg ha⁻¹ were randomly allocated to each side. In keeping with the split-block nature, 11 treatments were randomly allocated to 11 experimental units in each complete block. The ANOVA model used in Table 4 assumes that years were fixed effects and

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that the error terms associated with year interactions are equal. Treatments were applied to the same plots each year, thus ANOVA was split *in time*. Tests for differences in *residual error minus rep by year error* vs. *rep by year error* were not significant for any of the variables discussed. Corn and sorghum experiments were analyzed separately. Due to confounding of sources within methods, analysis was performed on both factorial effects and separate treatment combinations.

Preemergence applications of appropriate pesticides were made for control of weeds and rootworm (*Diabrotica* sp.). Irrigation water was applied as needed to both crops through furrows created by ridging after final cultivation. Beginning in 1977, alfalfa (*Medicago sativa* L.) was interseeded after ditching into half of the two P-treated check sub-blocks, and beginning in 1974, rye (*Secale cereale* L.) was interseeded into half of the P-treated UAN-PL and UAN-SD, 270 kg N ha^{-1} sub-blocks. The delayed interseeding is necessary to allow degradation to the point of nonphytotoxicity of herbicides applied at the time of planting the corn. Analyses of these replicated treatments were performed separately as split-plot experiments, the split in the alfalfa interseeded experiment being the two check plots in each block, and the two methods being the split in the rye-interseeded experiment. In most years spring tillage before planting involved plowing followed by disking, but in some years till-planting was done into existing residues and green manure crop after stalk shredding.

Initially, grain yields were determined by hand harvesting 12 and 6 m lengths of two center rows of corn and grain sorghum, respectively. Since 1980, however, harvesting of the two center rows has been done by two-row plot combine. Grain samples were analyzed for total N by standard Kjeldahl procedure. Grain N utilization efficiency (Gw/GN) was determined by the method of Moll et al. (12), where Gw = grain weight and GN = product of yield and percent N in the grain.

Soil strength was evaluated on check plots (alfalfa-interseeded and no interseeding), AA plots, and UAN-SD plots (rye-interseeded and no interseeding), at the 270 kg N ha^{-1} rate, using two measuring instruments; (i) a pocket vane shear tester (1), and (ii) a cone penetrometer (6). A flat surface was cleared with a spade to allow two penetrometer readings on either side of the vane shear measurement. All three measurements were on a straight line parallel to the row and within 50 mm of the original surface. A sample for soil moisture was also collected directly below the location where the vane shear measurement was obtained. Each plot was sampled four times between rows where wheels have never run, while four samples were also collected between rows showing clear evidence of wheel tracks. Thus, each plot yielded eight penetrometer and four vane shear measurements, in either wheel-track or nonwheel-track rows.

Soil properties for the experimental site at the beginning of the study are presented in Table 1.

RESULTS AND DISCUSSION

Comparative N Fertilizer Responses

Table 2 reveals the comparative response of corn and grain sorghum to rate and method of N applied. These are not outstanding average yields for irrigated conditions, but do reflect the hazards in production experienced by farmers, of hail and wind damage in some years, disease and pest attacks in others [southern corn leaf blight (*Helminthosporium maydis* Nisik.) in one year]. The data show grain sorghum to be the better yielder under low N-availability conditions (the control plots of each crop), but corn responds to higher levels of applied N with a result of substantially higher yield potential. A yield-potential shortcoming of sorghum hybrids currently available is the notably shorter period available for carbohydrate production to form and fill grain heads compared to that for corn. Optimum N rate for grain sorghum under the soil and

Table 1. Chemical characteristics of the soil at the experimental site at initiation of the study in 1969.

	Soil depth, m					
Soil property	0–0.3	0.3–0.6	0.6–0.9	0.9–1.2	1.2–1.5	1.5–1.8
pH	6.5	6.3	6.4	6.6	6.7	6.9
Total N† ($mg \cdot kg^{-1} \times 10^3$)	1.5	1.1	0.6	0.4	0.3	0.3
Mineral N‡ (kg ha^{-1})	34	21	17	12	12	12
Available P§ (mg kg^{-1})	14	7	21	32	29	23
Exchangeable K¶ (mg kg^{-1})	285	225	240	265	270	265

† Bremner (3). ‡ Bremner (4). § Bray & Kurtz P-1.
¶ 1 *M* NH_4OAc extraction, using a flame photometer with propane gas.

Table 2. Average grain yield, grain N yield, and grain utilization efficiency for irrigated corn and grain sorghum, 1969–1983.†

	Corn			Grain sorghum		
N Rate	AA-SD	UAN-PL	UAN-SD	AA-SD	UAN-PL	UAN-SD
kg ha^{-1}			Grain yield (Gw), Mg ha^{-1}			
0		5.64			6.09	
90	8.78	7.82	8.39	8.14	7.76	8.03
180	9.08	8.63	9.09	7.97	7.89	8.11
270	9.28	8.74	8.85	8.03	7.81	7.84
			Grain N yield (GN), kg ha^{-1}			
0		61.1			65.9	
90	104.6	91.2	98.3	105.2	94.1	99.5
180	111.5	106.2	112.2	107.6	105.4	109.8
270	116.5	111.8	111.9	114.8	108.4	109.3
			Gw/GN			
0		92.3			92.4	
90	84.4	86.3	85.7	78.9	95.5	83.0
180	81.6	81.7	81.2	75.7	76.7	75.0
270	80.3	78.5	79.2	73.1	73.0	73.6

† Gw/GN = grain utilization efficiency; corn grain yield at 15.5% moisture, grain sorghum 14%. UAN = urea ammonium nitrate. AA = anhydrous ammonia. SD = N sidedressed at 11-12 leaf stage. PL = N applied at planting. See Table 4 for statistical treatment.

Table 3. Economic fertilization optimums derived from regression equations of yield vs. N rate, on means over years.†

Treatment		*r*	CV
AA-SD	Grain yield = 5.748 + 37.27(RT) − 91.40(RT)²‡ RT_f = 0.1871 Mg ha^{-1} Grain yield = 9.522 Mg ha^{-1}	0.72**	18.0
UAN-SD	Grain yield = 5.667 + 36.70(RT) − 93.01(RT)² RT_f = 0.1715 Mg ha^{-1} Grain yield = 9.225 Mg ha^{-1}	0.66**	20.2
UAN-PL	Grain yield = 5.644 + 28.80(RT) − 64.67(RT)² RT_f = 0.1856 Mg ha^{-1} Grain yield = 8.762 Mg ha^{-1}	0.62**	21.1

** *r* significant at 0.01 probability level with 57 df error.

† Price ratio $= \frac{\$302/\text{Mg N}}{\$98/\text{Mg grain}} = 3.069$ for AA

$= \frac{\$472/\text{Mg N}}{\$98/\text{Mg grain}} = 4.796$ for UAN

‡ RT = rate of N, Mg ha^{-1}.

§ RT_f = economic fertilizer rate when the slope of the quadratic yield function equals the price ratio.

environmental conditions of this study was 90 kg ha^{-1} or less, whereas economic rate optimums for corn × method interactions were in the order of 180 kg ha^{-1} (Table 3). Quadratic response equations for sorghum were not used since mathematical peaks exceeded 90 kg ha^{-1}, which the data in Table 2 show to be unrealistic. These calculations show that under the existing conditions, it is economic to apply more N via AA-SD while at the same time obtaining greater increases in yield compared with UAN-PL and UAN-SD.

Corn and sorghum crops achieved an approximate 5% yield advantage for UAN-SD over UAN-PL at the optimum N rate for yield. The explanation lies in the fact that a fairly comprehensive root system exists for N uptake by the crop at the 30 to 45 cm above-ground growth stage for rapid absorption of the N with less opportunity for loss than with the root-free system at planting. An even later application time would likely have been beneficial if field equipment were available for operation in taller corn (21). Such enhanced efficiency in N fertilizer utilization has been a common observation under irrigated and humid climatic conditions (11,16,20,26), but less so in drier environments where moisture penetration is not sufficient to move the applied N into the rooting zone.

The long term comparison of the N carriers, both injected into the soil, shows AA-SD to have been 5% more efficient than UAN-SD across all rates of application for corn, but little difference existed between the two for sorghum. The disparity here in favor of AA undoubtedly relates to the urea component of the UAN, which may allow both leaching loss and NH_3 volatilization in the high pH medium of the concentrated application band. Alternatively, NO_2^- accumulation in the periphery of the UAN band, due to the high pH and high NH_4^+ concentration, inhibits activity of *Nitrobacter* sp. that would oxidize NO_2^- to NO_3^-. The NO_2^- diffusing from the alkaline band into surrounding acid soil is converted to HNO_2 which either self decomposes with the evolution of NO and NO_2, or reacts with soil organic matter releasing N_2 (15). A further possible explanation for the superiority of AA may be in the enhanced N utilization efficiency and reduced disease incidence from the extended NH_4^+ nutrition occurring with the AA source (8).

Analyses of the P treatment component in this experiment provided no evidence of response to applied P to date on this soil, which has a low-medium soil test P in its surface. Lack of response can be attributed to the high subsoil P level that is characteristic of the Sharpsburg soil in this area (Table 1).

Method × year and N-rate × year interactions (Table 4) were expected because methods responded the same in dry years, while N-rate responses were present but varied in magnitude over time. A N-rate × P-rate interaction, present in the corn and sorghum experiments, indicated that at high N rates (180 kg N ha^{-1} corn, 270 kg N ha^{-1} sorghum) P fertilization depressed yields. Whether this is due to suppression of another nutrient's uptake or to some other reason cannot be established from the data at hand. Grain utilization efficiencies (Gw/GN) (Table 2) followed yield and GN data of both corn and sorghum. A smaller ratio of Gw/GN (Sorghum AA-SD-90 vs. UAN-SD-90 and UAN-PL-90) indicates increased protein content with no real

Table 4. Analyses of variance and associated contrasts for over-year analysis of corn and grain sorghum experiment.

	Corn				Grain sorghum			
Source	df	Grain yield	Grain N	Gw/GN	df	Grain yield	Grain N	Gw/GN
Total	1079				1079			
Rep	3	*	*	*	3	*	*	*
Method	2	**	**	NS	2	NS	**	*
N-rate	2	**	**	NS	2	NS	**	**
Method × N-rate	4	NS	***	**	4	NS	NS	*
Error (a)	24				24			
P-rate	1	NS	NS	NS	1	NS	NS	NS
Error (b)	3				3			
Method × P-rate	2	NS	NS	NS	2	NS	NS	*
N-rate × P-rate	2	*	NS	NS	2	NS	***	NS
Method × N-rate × P-rate	4	NS	NS	NS	4	NS	NS	NS
Error (c)	24				24			
Yr	14	**	**	**	14	**	**	**
Method × Yr	28	**	**	**	28	**	**	NS
N-rate × Yr	28	*	**	**	28	*	**	**
P-rate × Yr	14	NS	NS	*	14	**	*	NS
Method × N-rate × Yr	56	NS	NS	**	56	NS	NS	*
Method × P-rate × Yr	28	NS	**	**	28	NS	NS	*
N-rate × P-rate × Yr	28	NS	***	*	28	NS	*	NS
Method × N-rate × P-rate × Yr	56	NS	NS	NS	56	NS	**	NS
Residual	756				756			
CV		11.7	11.6	4.73		9.8	17.3	9.5
Contrast†								
AA-SD vs. UAN-PL		**	**	NS		*	**	**
AA-SD vs. UAN-SD		*	*	NS		NS	*	***
UAN-SD vs. UAN-PL		**	*	NS		NS	*	NS
N-rate Lin		**	**	**		NS	**	**
N-rate quad		**	**	**		NS	NS	*
90 vs. 180 × P-rate		*	***	NS		NS	NS	NS
90 vs. 270 × P-rate		NS	NS	NS		NS	*	NS

*,**,*** Significant at 0.05, 0.01, and 0.10 probability levels, respectively; NS = nonsignificant.

† AA-SD = anhydrous ammonia sidedressed, 11-12 leaf stage, UAN-SD = Urea ammonium nitrate sidedressed. 11-12 leaf stage, UAN-PL = Urea ammonium nitrate applied at planting.

difference in yield. A method × N-rate interaction for Gw/GN reflects larger decreases in grain utilization efficiencies with increasing rates for UAN-SD and UAN-PL vs. AA-SD.

Response to Green Manure Interseeding

Alfalfa interseeded into check plots at ditching for irrigation effected an average yield increase of 880 kg ha^{-1} from the limited growth realized in the monoculture corn system (Table 5). Stand establishment was accomplished when soil remained reasonably moist in the furrows, maintained by rain and irrigation, but very little growth occurred under the heavy shading of the growing corn. In the absence of early frost and with normal autumnal rain, a modest amount of growth was achieved before freezeup. Given these conditions, a fairly heavy growth was realized in the spring with a crop of alfalfa green manure standing 0.20 to 0.45 m tall in early May. The highly proteinaceous crop incorporated at that time had mobilized a significant amount of rapidly released N for the following corn to use.

Less readily explained is the benefit derived from interseeding rye into high N treatment plots (Table 6). The average 585 kg ha^{-1} grain-yield increase recorded could be, in part, a N factor from N absorbed in the rye and held against leaching or denitrification losses or both. What is likely to be of greater impact, however, are allelochemical effects from an altered deleterious microbial population that builds up in monoculture. This, in turn, could have been impacted by another group of organisms accompanying the secondary crop, a benefit recognized from crop rotation (2).

Allelotrophy, improved soil structure, and reduced disease and insect attack may all be involved with both interseedings, in addition to the N benefit registered.

Table 5. Influence of interseeded alfalfa into check plots (no N) on irrigated corn yields and total grain N.

	Grain yield			Grain N		
Year	Alfalfa	No alfalfa		Alfalfa	No alfalfa	
	—— Mg ha^{-1} ——			—— kg ha^{-1} ——		
1977	5.40	5.36	NS	70.2	70.7	NS
1978	9.19	9.56	NS	112.3	115.1	NS
1979	9.04	6.02	**	104.6	66.4	**
1980	4.39	3.71	*	47.4	42.3	NS
1981	7.61	6.86	***	86.9	82.4	NS
1982	5.80	4.49	**	62.0	46.9	**
1983	4.05	3.32	*	50.3	41.3	***
Avg sum	6.52	5.62	**	76.3	66.4	**
Mineralizable + exchangeable NH_4^+ in 1983 ($\mu g\ g^{-1}$, 0–300 mm)	67.1	63.9	*			

Analysis of variance on sum variables over years

	df	Grain yield	Grain N	Min + exch.† NH_4^+
Total	15			
Rep	3	NS	NS	NS
Check plot	1	NS	NS	NS
Error (a)	3			
Trt	1	**	*	*
Trt × check plot	1	NS	NS	NS
Residual	6			
CV		6.8	8.5	3.8

*,**,*** Significant at 0.05, 0.01, and 0.10 probability levels, respectively; NS = nonsignificant.

† Mineralizable + exchangeable NH_4^+ of surface soil on samples taken following harvest in 1983 only; NH_4^+ determined by steam distillation, mineralizable by autoclaving.

Table 6. Influence of interseeded rye on irrigated corn yields and total grain N of high N-treated plots.

	270 N Planting						270 N sidedressed					
	Grain yield			Grain N			Grain Yield			Grain N		
Year	Rye	No rye		Rye	No rye		Rye	No rye		Rye	No rye	
	—— Mg ha^{-1} ——			—— kg ha^{-1} ——			—— Mg ha^{-1} ——			—— kg ha^{-1} ——		
1974	5.08	6.18	*	89.3	110.3	**	5.82	6.10	NS	103.5	112.0	***
1975	8.75	8.37	NS	143.9	140.4	NS	7.45	7.86	NS	116.6	135.5	*
1976	8.56	7.40	NS	136.1	121.9	NS	8.06	6.96	NS	123.9	115.8	NS
1977	7.31	6.57	*	111.0	104.2	***	6.59	7.06	NS	101.6	110.9	*
1978	10.62	11.29	NS	149.9	162.1	NS	10.13	10.99	NS	141.5	148.7	NS
1980	7.80	7.67	NS	100.4	95.4	NS	8.28	7.98	NS	101.8	103.4	NS
1981	11.48	8.97	**	168.1	132.3	**	9.99	8.78	*	148.3	130.5	*
1982	11.75	9.25	**	149.1	119.6	*	10.98	9.46	*	141.9	121.6	***
1983	8.89	7.40	***	127.6	101.4	*	9.12	7.58	*	130.7	105.5	**
Avg sum	8.91	8.12	**	130.6	120.8	*	8.46	8.08	***	123.3	120.4	NS
Mineralizable + exchangeable NH_4^+ in 1983 ($\mu g\ g^{-1}$, 0–300 mm)	80	72	NS				107	75	***			

Analysis of variance on sum variables over years

	df	Grain yield	Grain N	Min + exch. NH_4^+
Total	15			
Rep	3	*	NS	*
Method	1	NS	NS	NS
Error (a)	3			
Trt	1	**	*	NS
Error	6			
CV		3.3	4.4	26.7
Contrast				
No rye vs. rye in planting		**	*	NS
No rye vs. rye in sidegress		***	NS	***

*,**,*** Significant at 0.05, 0.01, and 0.10 probability levels, respectively; NS = nonsignificant.

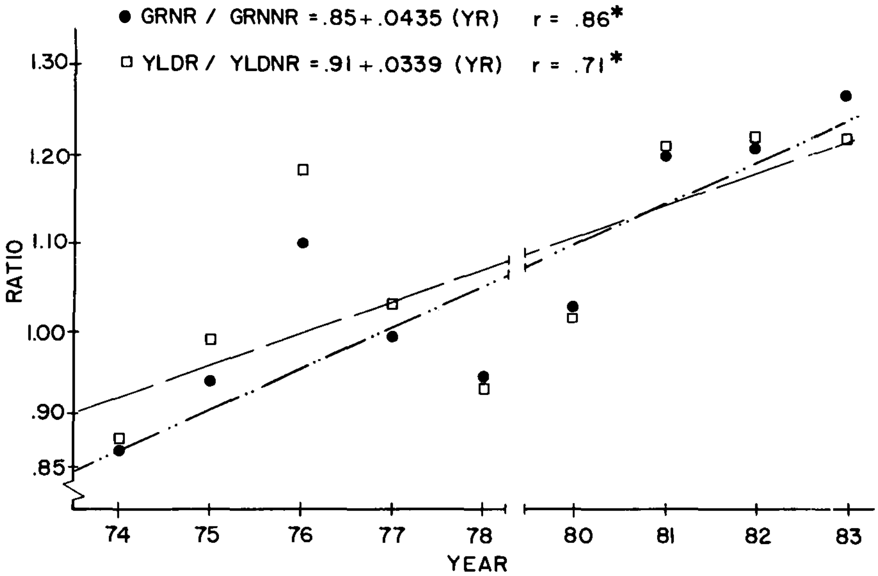

Fig. 1. Linear relationships of yield and grain N for ratios of rye interseeded/no interseeding vs. time. GRNR = grain nitrogen, rye interseeded; GRNNR = grain nitrogen, no rye interseeding; YLDR = yield, rye interseeded; YLDNR = yield, no rye interseeding. Yields of interseeded rye plots not measured in 1979.

No consistent benefit from the interseedings appeared in the first 3 or 4 yr. Time was needed to set the biological transformations that would benefit yield in motion. A positive linear relationship of the ratios (rye interseeded/no rye interseeding), for both yield and grain N vs. time (Fig. 1), supports this hypothesis. Some of the delay could certainly be attributed to problems in obtaining stands of the interseeded crops in years of a very dry summer and fall (despite furrow irrigation), and to early heavy frost resulting in lost stands. It seems very likely that stands would more readily be assured with center pivot irrigation, where surface soil wetting is more frequent and where a ridge that rapidly dries out does not exist.

Table 7. Influence of N treatments and interseeding on physical parameters measured.

Analysis of variance for cone penetrometer measurements

Treatment	Means†		
Check	4.60	Overall CV = 29%	
UAN-SD	3.47		
AA-SD	3.40	Overall	Means†
UAN-SD-rye interseeded	4.14	Wheel track	6.76
Check-alfalfa	3.94	Nonwheel track	1.05

Test of hypothesis	F value	Pr > F
Effect of treatment	0.84	0.464 NS
Check vs. other	0.95	0.355 NS
UAN-SD vs. AA-SD	1.06	0.331 NS
Check vs. Check-alfalfa	0.06	0.808 NS
UAN-SD vs. UAN-SD-rye interseeded	1.90	0.302 NS

Analysis of variance for vane shear measurements

Treatment	Means‡		
Check	2.19	Overall CV = 33%	
UAN-SD	1.84		
AA-SD	1.70	Overall	Means‡
UAN-SD-rye interseeded	2.02	Wheel track	3.31
Check-alfalfa	1.67	Nonwheel track	0.45

Test of hypothesis	F value	Pr > F
Effect of treatment	0.77	0.490 NS
Check vs. other	0.00	0.9996 NS
UAN-SD vs. AA-SD	1.48	0.254 NS
Check vs. check-alfalfa	1.08	0.339 NS
UAN-SD vs. UAN-SD-rye interseeded	0.71	0.487 NS

† Cone penetrometer expressed as Mg m^{-2}. Average gravimetric moisture content was 0.262 g g^{-1} for the wheel-track areas and 0.277 g g^{-1} for the nonwheel-track areas.
‡ Vane shear expressed as Mg m^{-2}.

Effects on the Physical Properties of Soil

Measurements of soil strength by penetrometer and vane shear tests on plots with certain of the treatments in the experiment revealed the primary source of error in the measurements to be from the effects of soil moisture and wheel-track vs. non wheel-track rows (Table 7). The cone penetrometer and vane shear measurements represent two distinct characteristics of soil strength. The cone penetrometer senses soil strength as reflected primarily in compressibility. The vane shear device senses soil strength as reflected in the cohesive properties of soil and soil failure upon experiencing a shearing load. Thus, the two measurements provide complementary information about different aspects of soil strength. The effect of soil moisture on vane shear is well known (24). Similarly, cone penetrometer readings depend on soil moisture and soil bulk density (23).

These effects suggest that studies of soil strength may be biased if they do not consider soil moisture or wheel-track effects. This bias may occur due to insufficient sampling of both wheel-track and non wheel-track rows. Bias may also occur due to unrecognized systematic variations in soil moisture across a field. The present study indicates that when these factors are considered, no differences are detectable between UAN-SD or AA-SD treatments and the check plots.

It is interesting to note that there is a tendency in the results toward lower values of soil strength in the UAN-SD or AA-SD treated plots, relative to the check plots. Thus, it is unlikely that either UAN-SD or AA-SD treatments contribute to hardening of the soil, or that there are distinct differences caused by the N sources. More likely is the effect of fertilization to in-

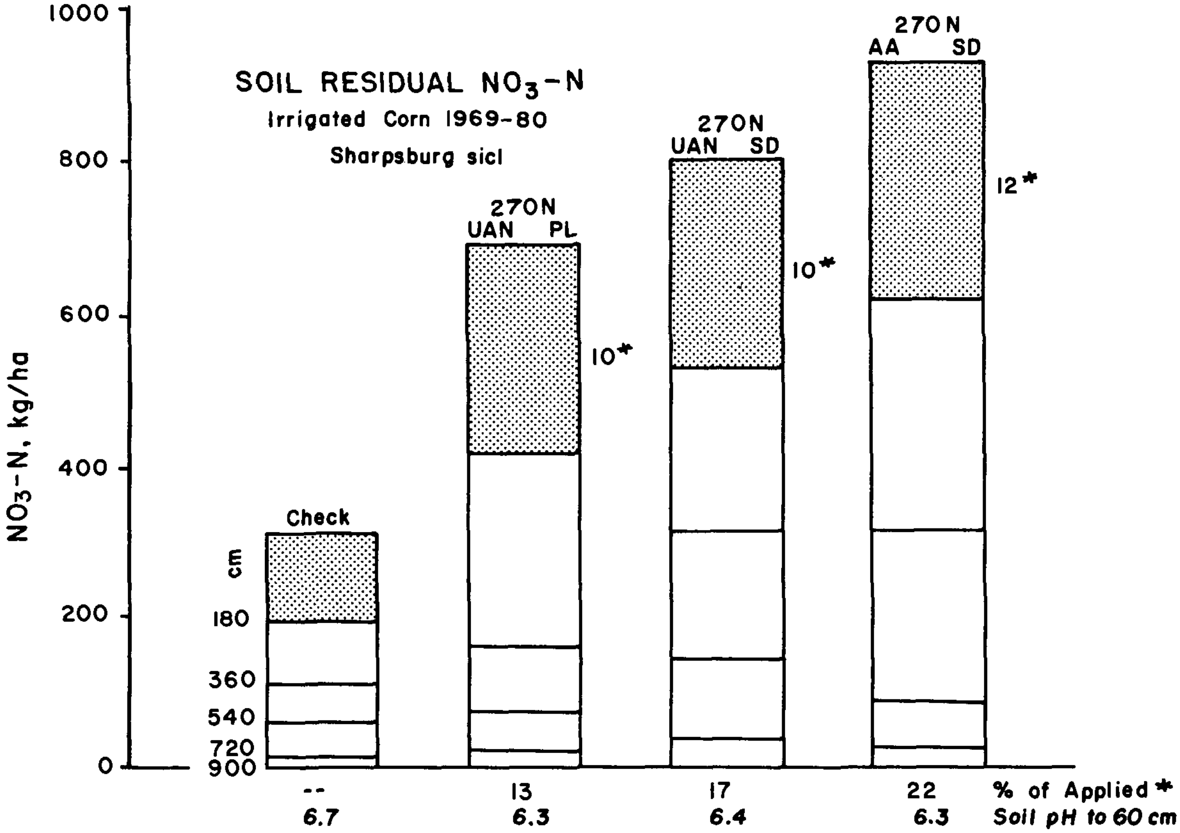

Fig. 2. Residual NO_3-N in control and high N plots after 12 years' treatments. Soils sampled from surface to the water table and reported by 1.8-m increments; each bar represents eight drillings.

crease soil organic matter, improving soil structure and reducing soil strength. Any observed 'hardening' of soil by AA is probably the result of its application into soil that is too wet for tillage and this is not the fault of the fertilizer.

Profile Residual NO_3-N

Deep profile drillings were made to the water table in 1980 in all control and high N treatment plots of corn with two holes per plot and soil sampling by 0.6 m increments. The 270 kg N ha^{-1} rate was obviously excessive for yield (Table 2), interest being to determine what proportion of the amount applied could be measured in transit to the groundwater. Figure 2 shows that large quantities of NO_3-N in excess of that in check plots were indeed found, and in all 1.8 m increments of depth to the water table. From 10 to 12% of all the N applied during the 12-yr period was found in the surface 1.8 m, still potentially recoverable by a corn crop if no further N were applied. From 13 to 22% of all applied N was found in the full profile of soil. Less residual NO_3-N in the deep profile was found with UAN applied at planting than with UAN as a summer sidedressing, and most was accounted for with the AA source sidedressed. Of further interest in this figure is the fact that soil pH in the surface 0.6 m was dropped 0.4 unit by the N treatments.

From these residual profile values and the N uptake values through 1980, the following nitrogen balance can be made with respect to the 3240 kg N applied:

	UAN at planting	UAN sidedress	AA sidedress
N in grain	42%	43%	44%
Residual NO_3-N in profile	13%	17%	22%
N unaccounted for	45%	40%	34%

The larger amounts of residual NO_3-N in the lower 1.8 m segments of all N-treated profiles, compared with the check, make it evident that leaching into the groundwater is responsible for some portion of the unaccounted for N.

CONCLUSIONS

It can be concluded from this investigation that grain sorghum under irrigation exceeded corn as a scavenger for N under limited soil N supply among hybrids currently available, but corn had substantially greater yield potential with plentiful N. Delayed summer sidedressing of N fertilizer for both crops was superior to planting-time N, accounted for by a reduction in N losses when a partially established crop root system is in place for absorbing N as the fertilizer is applied. The greater effectiveness of AA-SD over UAN-SD for corn is explained by the added channels of loss to which the urea component is subject. Lack of P response throughout this long term study, despite a medium-low surface soil test, can be attributed to the high subsoil reserve of available P in the Sharpsburg soil.

The deep profile residual NO_3-N found gives evidence of substantial N leaching even with carefully controlled irrigation practice. Unpredictable rainfall amounts in this subhumid region contribute to the difficulty of effecting a water balance that is optimum for the crop with limited percolation loss. Clearly, the potential for substantial groundwater contamination by NO_3-N exists with an overly optimistic N rate applied at planting time for irrigated corn, upwards of 120 kg N ha^{-1} with the 270 kg ha^{-1} rate in this study.

Interseeding of alfalfa into established monoculture corn receiving no N fertilizer, at a 0.45 to 0.60 m growth stage, gives promise as an economic practice. Much of the benefit can be ascribed to the N accumulated and rapidly released by the incorporated green manure crop, although factors of soil structure and allelotrophy may have contributed. It is likely that biennial clover [e.g., *Melilotus officinalis* (L.) Pall. or *Trifolium pratense* L.] seedings at lower cost than alfalfa would be equally effective. The nearly equivalent benefit derived from interseeded rye into plots receiving more than enough N fertilizer can harrdly be explained as a predominant N effect. The greater influence is more likely an allelochemical effect from an altered microbial population that had built up with monoculture of corn. In essence, a crop rotation benefit was realized without the loss of high value crop that normally accompanies rotation. Success from interseeding obviously requires irrigation or a humid climatic regime to accommodate the extra moisture consumed by either green manure crop.

The soil strength portion of the investigations demonstrates the extreme importance of recognizing soil moisture and wheel-track effects as interpretation is made of penetrometer and vane shear tests. Highly relevant to this long-term study of fertilizer-N impact is the fact that neither UAN nor AA had any deleterious impact on soil structure but rather demonstrated a tendency to improve the physical quality of treated plots compared to plots with no N applied.

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