The Effects of Nitrogen Fertilizer On Soil

Department of Agronomy

Nitrogen (N) fertilizer use increased greatly through the 1970's and remained relatively constant through the 1980's. In Kansas, the tonnage of actual nitrogen applied in 1984 was 9.5 times that applied in 1958. For the period July 1987 through June 1988, 59 percent of the total commercial nitrogen applied in Kansas was anhydrous ammonia, 18 percent was urea-ammonium nitrate solution, 11 percent was urea, and 3 percent was ammonium nitrate. In 1960, only 18 percent of the nitrogen applied as commercial fertilizer was anhydrous ammonia. This marked increase in nitrogen use has generated many questions about possible negative effects of nitrogen fertilizer on soil chemical and physical properties. Long-term use of anhydrous ammonia often raises additional concerns.

Nitrogen source comparisons have been made in many short-term experiments with the majority of studies showing little or no difference among sources when properly applied. Few long-term nitrogen studies exist for comparing nitrogen source effect on soil physical and chemical properties, but such studies have been conducted in Kansas. During a 20-year period (1969 through 1988), four nitrogen fertilizer sources (anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate solution [UAN]) were applied annually to field plots at three Kansas locations (Manhattan, Ottawa, and Powhattan [two field sites]). The soil types are Smolan silty clay loam, Woodson silt loam, and Grundy silty clay loam at Manhattan, Ottawa, and Powhattan, respectively.

During this study, corn was grown on one Powhattan site and grain sorghum was grown on the other Powhattan site and at Ottawa. At Manhattan, the crop grown varied from grain sorghum to winter wheat to soybeans during the 20 years. The four nitrogen sources were applied in the spring, starting in 1969 at an annual rate of 200 lbs N/acre. Starting in 1973, the rate at Powhattan changed to 150 lbs N/acre. At Ottawa, the rate changed to 100 lbs N/acre starting in 1980. In addition, from 1969 through 1978 at Powhattan, totals of 94 lbs N/acre, 113 lbs phosphorus/acre, and 17 lbs potassium/acre were applied as starter fertilizer on the corn site; totals of 67 lbs N/acre, 89 lbs phosphorus/acre, and 35 lbs potassium/acre were applied as starter fertilizer on the sorghum site. At Ottawa, 21 lbs phosphorus/acre were applied on all plots in 1980. A no-nitrogen check plot was included at each field location. Except for the starter fertilizer at Powhattan, and the phosphorus application at Ottawa, the check treatments were not fertilized. Nitrogen source applications continued annually through the spring of 1988.

These field plots have provided test sites for evaluating the influence of nitrogen fertilizers on soil physical and chemical properties. In the fall of 1978, physical and chemical properties of soil samples from these plots were evaluated and showed primarily a lower pH on the nitrogen fertilized compared to the no-nitrogen check. (The evaluation of soil properties after 10 years of nitrogen source treatments was the subject of Extension fact sheet C-625 by L.R. Stone, R. Ellis, Jr., and D.A. Whitney, Kansas Cooperative Extension Service.) In October of 1988 we sampled the field plots again and determined the status of selected soil physical and chemical properties after 20 years of nitrogen source treatments. (The detailed chemical and physical evaluation was the subject of an M.S. thesis by Darusman [Soil properties after 20 years of different nitrogen sources, 1990, Kansas State University]). We sampled two soil layers, the 2.5- to

5.5-inch and the 8.5- to 11.5-inch layers. Results of our analysis follow.

Soil Chemical Properties

Table 1 shows chemical analyses for the two soil layers sampled for all treatments. Statistical contrasts show no significant difference (0.05 probability level) in chemical properties of either soil layer among the four nitrogen sources. In the upper soil layer, nitrogen-fertilized plots compared with the no-nitrogen check had reduced pH, available phosphorus, and exchangeable calcium (Ca), magnesium (Mg), and sodium (Na); and increased nitrate-nitrogen, ammonium-nitrogen, and DTPA-extractable iron (Fe), copper (Cu), and manganese (Mn). In the lower soil layer, nitrogen-fertilized plots compared with the no-nitrogen check had reduced pH and exchangeable sodium, and increased nitrate–nitrogen.

Treatments receiving nitrogen had a significantly lower pH than the no-nitrogen check. Fertilizers that either contain ammonium (NH_4^+) or convert to ammonium have an acid-forming nature because of the release of hydrogen (H^+) during the nitrification of NH_4^+ to nitrate (NO_3^-). All four nitrogen sources reduced pH (more acid) compared with the no-nitrogen check and there was no significant difference in pH among the four nitrogen sources. Liming will correct acid conditions produced by continued use of acid-forming fertilizers, as these four are. The increase in concentration of DTPA-extractable micronutrients iron, copper, and manganese associated with a decrease in pH is consistent with expected trends. We found no significant difference in zinc concentration. With soil acidification, we expected the concentrations of exchangeable calcium, magnesium, and sodium to decrease. Exchangeable potassium was not significantly influenced by treatment.

Soil Physical Properties

Table 2 summarizes results from the analysis of soil physical properties at all locations. As with the chemical properties of Table 1, statistical contrasts show no significant difference among the four nitrogen sources in the physical properties of either soil layer (Table 2).

If nitrogen source influences soil compaction, then different compaction levels in treated plots would be indicated by differences in clod density. Clod density values presented in Table 2 show no effect from treatments on either soil layer.

The clod density method usually gives larger density values than other bulk density methods. A primary reason is that the clod method does not take the interclod air spaces into account. But the clod density values enable a comparison of compaction levels among treatments. In that comparison we found no evidence of different compaction levels among treatments.

The size distribution of water-stable aggregates can be expressed as a single value by determining the geometric mean diameter (GMD) of the aggregates. The larger the GMD, the greater the proportion of large water-stable aggregates. Nitrogen-fertilized plots had significantly larger GMD values in the upper layer and significantly lower GMD values in the lower layer (Table 2). We have no evidence to explain this seemingly contradictory finding for the two soil layers. There were, however, no differences among nitrogen sources for either layer.

If chemical dispersion of clay and clay migration occur from nitrogen source application, then nitrogen source should influence soil physical properties such as clay content, water content at low soil water potentials, and soil compactibility. An analysis of particle-size distribution showed no significant difference in clay content of either soil layer due to nitrogen source. Soil water content at low water potentials is directly related to particle surface area. (The –1.5 MPa soil water potential value is normally considered to be the potential corresponding to the permanent wilting point condition.) If dispersion of clay and clay migration had occurred in treated plots, one would expect the water content at –1.5 MPa of water potential to be different. Our results show no significant difference in water content among the four nitrogen sources or between nitrogen treated and the no-nitrogen check.

Even though the clod density data of Table 2 indicates no real difference in density due to treatment, it is possible that differences in potential for compaction existed but were not evident due to proper soil and tillage management. If dispersion of clay and clay migration are influenced by nitrogen source, then nitrogen sources should exhibit different potentials for soil compaction.

To evaluate the potential for compaction, we determined soil compactibility with a standard, constant-load technique (Figure 1). As soil water content increases from air–dry, water films provide lubrication between soil particles, allowing the particles to slip and form a closer packing (increased density) when a load is applied. As water is added to soil, the amount of water occupying soil pore space increases, and the pore spaces occupied by water are unable to receive soil particles during load application.

The lubrication and pore-filling influences of water are present at all levels of water content; lubrication, however, is of greater importance when the soil is relatively dry and pore-filling of greater importance when the soil is relatively wet. When

Table 1. **Chemical properties, as influenced by nitrogen source, of disturbed soil samples taken from two layers in field plots.**

Nitrogen source	pH	Organic matter	CEC	Avail. P	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	DTPA-extractable Zn	DTPA-extractable Fe	DTPA-extractable Cu	DTPA-extractable Mn	NO_3^--N	NH_4^+-N
		g kg^{-1}	$cmol_c kg^{-1}$						mg kg^{-1}					
2.5- to 5.5-inch soil layer														
1. Check (no N)	6.2	20.4	23.3	38	220	2,949	548	25	1.23	52.8	1.63	14.8	4.0	5.0
2. Anhydrous ammonia	5.2	18.4	22.7	27	217	2,601	459	15	1.20	75.9	1.99	39.8	26.6	8.7
3. Ammonium nitrate	5.2	22.7	21.7	26	220	2,443	432	14	1.11	70.4	2.14	44.3	20.9	11.2
4. Urea	5.1	22.8	22.7	24	210	2,566	478	15	1.07	75.7	2.12	51.2	30.8	11.5
5. UAN solution	5.2	20.4	22.2	28	204	2,494	425	15	1.02	77.8	1.89	38.0	20.2	8.4
Contrasts[a]														
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	**	NS	NS	**	NS	**	**	**	NS	**	**	**	**	**
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8.5- to 11.5-inch soil layer														
1. Check (no N)	6.4	15.2	32.6	8	210	3,893	822	71	0.48	44.7	1.94	8.9	1.4	4.7
2. Anhydrous ammonia	6.0	12.8	31.6	6	199	3,823	733	40	0.36	49.4	1.90	10.4	13.0	4.8
3. Ammonium nitrate	6.2	14.9	34.0	6	208	4,060	815	41	0.42	43.1	1.93	7.4	9.3	5.1
4. Urea	6.0	15.4	32.6	6	212	3,666	719	42	0.38	45.4	1.99	15.6	10.1	5.9
5. UAN solution	6.2	14.1	31.0	5	209	3,949	808	40	0.33	39.0	1.80	7.1	9.0	4.8
Contrasts[a]														
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	*	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	**	NS
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Orthogonal contrasts were not different at the 0.05 probability level (NS), were different at the 0.05 probability level (*), or were different at the 0.01 probability level (**).

NOTE: To convert from SI units, perform these multiplications: g kg^{-1} × 0.1 = percent, $cmol_c kg^{-1}$ × 1 = milliequivalents per 100 grams, and mg kg^{-1} × 1 = parts per million.

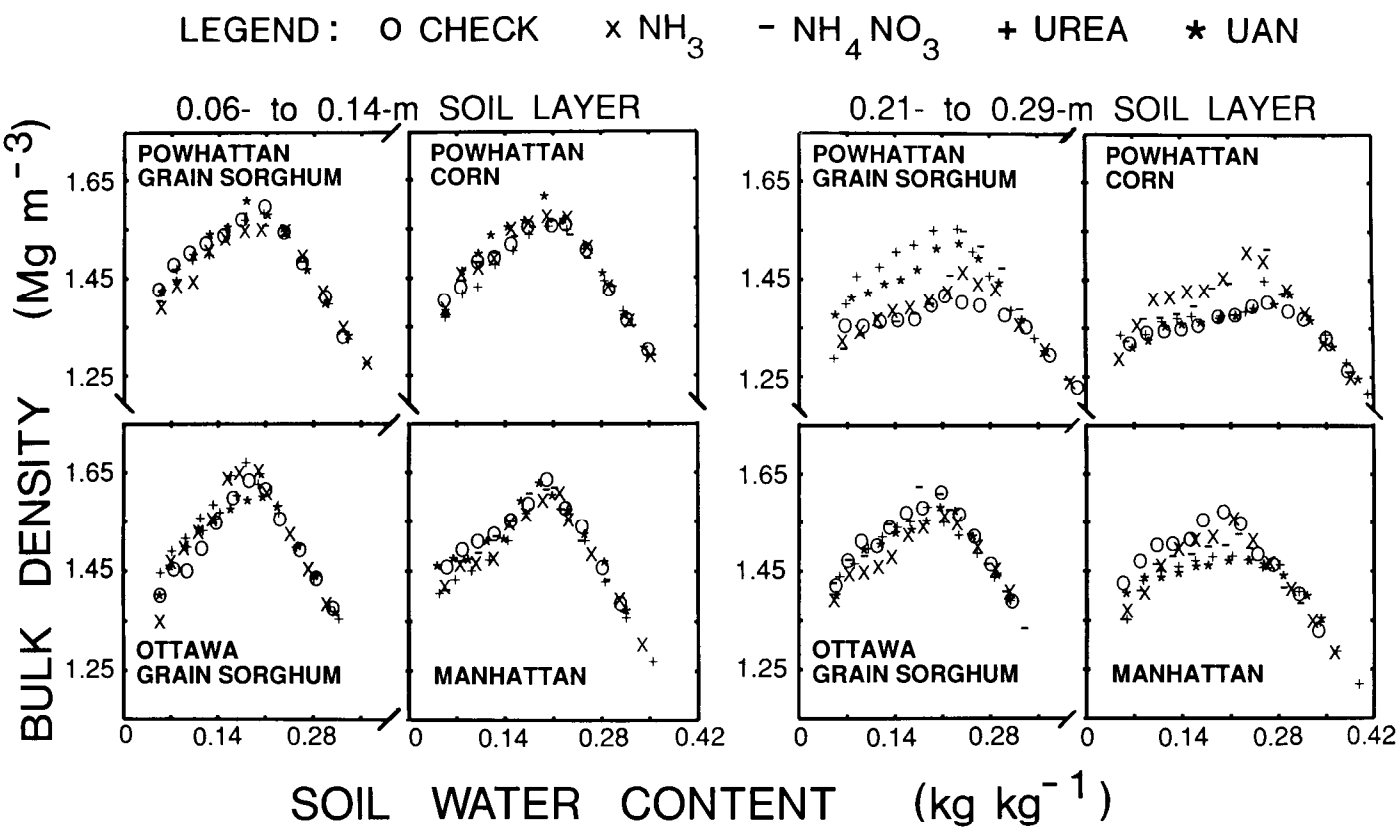
Table 2. **Physical properties, as influenced by nitrogen source, of disturbed soil samples taken from two layers in field plots.**

Nitrogen source	Compactibility analysis: Maximum bulk density	Compactibility analysis: Optimum water content for compaction	Clod density	Water content at -1.5 MPa potential 2	Particle-size distribution: Sand (0.05-2 mm)	Particle-size distribution: Coarse silt (0.02-0.05 mm)	Particle-size distribution: Fine silt (0.002-0.02 mm)	Particle-size distribution: Clay <0.002 mm	Geometric mean diameter
	Mg m^{-3}	kg kg^{-1}	Mg m^{-3}	kg kg^{-1}	g kg^{-1}				mm
2.5- to 5.5-inch soil layer									
1. Check (no N)	1.60	0.190	1.50	0.125	113	260	338	290	0.95
2. Anhydrous ammonia	1.59	0.193	1.45	0.126	95	213	398	295	1.48
3. Ammonium nitrate	1.59	0.189	1.46	0.127	85	253	368	295	1.50
4. Urea	1.58	0.196	1.46	0.125	103	215	395	288	1.75
5. UAN solution	1.60	0.190	1.49	0.127	108	255	343	295	1.57
Contrasts[a]									
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	NS	NS	NS	NS	NS	NS	NS	NS	**
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS
8.5- to 11.5-inch soil layer									
1. Check (no N)	1.49	0.220	1.67	0.188	75	180	330	415	1.35
2. Anhydrous ammonia	1.51	0.216	1.66	0.189	70	183	330	418	0.90
3. Ammonium nitrate	1.52	0.217	1.65	0.191	58	215	308	420	0.98
4. Urea	1.50	0.219	1.68	0.192	60	175	338	428	0.94
5. UAN solution	1.49	0.232	1.67	0.187	80	173	328	420	1.02
Contrasts[a]									
Check (no N) vs. fertilized (1 VS. 2, 3, 4, 5)	NS	NS	NS	NS	NS	NS	NS	NS	**
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Orthogonal contrasts were not different at the 0.05 probability level (NS), or were different at the 0.01 probability level (**).

NOTE: To convert from SI units, perform these multiplications: Mg m^{-3} × 62.4 = lbs per ft^3, MPa × 9.90 = atmospheres, kg × 2.20 = pounds, g kg^{-1} × 0.1 = percent, and mm × 0.0394 = inches.

Figure 1. **Bulk density versus water content during compaction of soil from the 2.5- to 5.5-inch (0.06- to 0.14-m) and the 8.5- to 11.5-inch (0.21- to 0.29-m) soil layers with five treatments and four locations.**



the "lubrication effect" increases more rapidly than the "pore-filling effect," there is an increase in dry bulk density with increased water content. When the "lubrication effect" increases slower than the "pore-filling effect," there is a decrease in dry bulk density with increased water content.

The change from an increasing to a decreasing dry bulk density pattern with increased water content often occurs near the "field capacity" water content value. In practice, farming operations occur to the left of the maximum bulk density value. At soil water contents where field operations are possible, the potential for compaction increases as water content increases.

In this study, if dispersion and migration of clay had occurred, the compatibility analysis would have shown an influence of treatment on maximum bulk density and optimum water content for compaction. The maximum bulk density and optimum water content for compaction values are calculated from the data from Figure 1 and are summarized in Table 2. No significant treatment effect was found on maximum bulk density and optimum water content for compaction.

Grain yields were taken at the Ottawa and Powhattan locations. During the years 1985 through 1988, plots receiving nitrogen fertilizer yielded significantly more grain (overall average of 77.6 bushels per acre) than the no-nitrogen check (average of 36.6 bushels per acre). There was no significant difference in grain yield among the four nitrogen sources.

Summary and Conclusions

Our results show no significant difference in the effect on soil from the four nitrogen sources (anhydrous ammonia, ammonium nitrate, urea, urea-ammonium nitrate solution). The primary influence of 20 years of nitrogen fertilization has been on soil acidification and the associated nutrient availability, and on increased concentrations in the soil of nitrate-nitrogen and ammonium-nitrogen.

Thus, nitrogen source selection should be based primarily on cost of the nitrogen applied, adaptability of the source to the producers' crop-tillage system and availability. All nitrogen sources are agronomically equal per pound of nitrogen when they are properly applied.

David A. Whitney
Extension Specialist
Soil Testing

Loyal R. Stone
Research Soil Physicist
Department of Agronomy

Keith A. Janssen
Agronomist-in-Charge
East Central Kansas Experiment Field

James H. Long
Agronomist-in-Charge
Cornbelt Experiment Field

KSU KANSAS STATE UNIVERSITY

Cooperative Extension Service, Kansas State University, Manhattan

Issued in furtherance of Cooperative Extension Work, acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and U.S. Department of Agriculture Cooperating, Richard D. Wootton, Associate Director. All educational programs and materials available without discrimination on the basis of race, color, national origin, sex, age, or disability.

Revised May 1991

File Code: Crops & Soils, 4-1; JH5-91—5M; 4-96—2M