Fertilizer Nitrogen Applications to Wheat in Relation to Pollution

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Concern about the degradation of the environment resulting from activities of man is expressed daily through all public media. Hardly any segment of any industry has not been pointed to as a contributor to lowering the quality of waters. Usually the largest industry is designated as the "big polluter".

Agriculture is North Dakota's largest industry; it accounted for about 74% of the gross income produced in the state in 1969.[1] The inherent productive capacity of the state's soils in creating new wealth has been enhanced by using agricultural chemicals to correct soil nutrient deficiencies, control diseases and insects, and eliminate weeds. These same agricultural chemicals are pointed to as contributors to water pollution.

Evidence of nutrient deficiency in North Dakota soils for field crop production has been demonstrated for nitrogen, especially on soils cropped annually, phosphorus, potassium and zinc. Deficiencies of the latter two are much less extensive in terms of acreage, affected crops, and degree. Evidence that available nutrients are deficient in soils of the state—based on response to commercial fertilizer application—was provided as early as 1903 (9).

Trials conducted after 1946 showed the extent and degree of deficiency of available phosphorus (2). Deficiency of available forms of nitrogen for non-leguminous crops were shown to exist on extensive acreages by 1956 (1, 3, 10). Infrequent yield responses of wheat to potassium fertilizer were obtained prior to 1960 (2), but yield and quality responses of barley are since evident (14). By 1966, zinc fertilizer was shown to produce corn grain yield increases, especially if applied to corn grown on moderately coarse to coarse textured soils calcareous to the surface and under a management level that resulted in yields near 100 bushels per acre (4).

Fertilizers sold in North Dakota in 1951 reached 20,000 tons, and this increased to about 328,000 tons in 1969.[2] Nitrogen (N) accounted for about 38% of the fertilizer nutrients contained in the tonnage sold in 1969 and phosphorus (P_2O_5) for about 56%. Based on the 1964 United States Census, the latest data available, about 80% of the tonnage was applied to small grain cereals and flax.

Average pounds of nitrogen (N) applied **per fertilized acre** in 1964 was less than 11 pounds for any of these crops and the average rate of phosphorus (P_2O_5) **per fertilized acre** was less than 23 pounds (12). Fertilizer applied in 1964 amounted to 193,000 tons. While the average application rate per acre is likely to have increased from 1964 to 1969, especially of nitrogen, it is likely that the number of acres fertilized has also increased so that application rate per acre has not increased in proportion to increase in tonnage of fertilizer applied over the same time.

To pollute water supplies, transport agents must move the fertilizer nutrient from the soil to which it is applied to the water affected. The chief transporter is water itself. Nutrients, irrespective of source, can be moved by water when they are in solution and they can be moved when attached to soil particles that are moved by water. Wind and gravity are other transporting agents that can move soil particles. Nutrients that come from plants also can enter streams during spring runoff (8). In this

[1]Richard Crockett, Greater North Dakota Association, address at 22nd Annual Fertilizer Conference, Dec. 3-4, 1970, Fargo, North Dakota.

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case the nutrients are leached from plants because cells rupture over winter from freezing.

Nutrients applied in fertilizers are subject to several "restraints" imposed by soil properties that prevent or limit their movement. One of the restraints is the attraction of some nutrients to the colloidal materials, clay and humus. Clay and humus are negatively charged and adsorb positively charged particles such as NH_4+ (ammonium nitrogen) and K+ (potassium). A second restraint is the formation of chemical substances (compounds) of very low water solubility. Substances insoluble in water will not move in soil solution. A third restraint is the presence of microorganisms which have the same nutrient requirements as higher plants and which can incorporate, or immobilize, nutrients as new cells are synthesized. A fourth restraint is the capacity of soil to hold water so as to retard its movement and keep it within reach of plant roots. Soils vary in their capacity to hold water, ranging from about ½ inch per foot of soil of coarse textured to about 2½ inches per foot of medium and moderately fine textured soil.

To these four restraints provided by soil can be added a fifth factor, which involves soil indirectly, the growing plant. Fertilizers added to nutrient deficient soils effect increases in growth of plants, both in quantity and rate. Nutrients applied as fertilizers are incorporated into organic material to produce yield increases. Added restraints provided by fertilized crops are produced from stimulated growth which can result in more rapid depletion of soil water, thus providing more "space" in the soil to retain a larger quantity of the succeeding precipitation and also retaining more of it in the upper portion of the soil in the rooting zone. Also an increase in plant growth can reduce the runoff hazard on sloping areas by the physical barrier it imposes.

The role of the plant in the disposition of fertilizer nitrogen is illustrated in data obtained at the Carrington Irrigation Branch Station in 1969. The study was conducted to test the effect of fertilizer nitrogen rates on yield and quality aspects of six spring wheat varieties grown on Heimdal silt loam, a moderately well drained soil. Details of the experimental procedures and some of the results have been published (6), but aspects of the experimental procedures pertinent to this report bear repeating. Ammonium nitrate (33.5-0-0) was broadcast after seeding at rates to supply 0, 50, 100, 150 and 200 pounds nitrogen (N) per acre. Plant and soil measurements included removal of aboveground tissue and the determination of nitrogen concentration in the leaves of the harvested tissue, harvest of grain and the determination of nitrogen concentration in the grain, soil sampling at seeding and at harvest to determine the position and concentration of available nitrogen in the upper 48 inches of soil, measurement of the amount of available soil water to a soil depth of 72 inches, and recordings of amounts and time distribution of water additions from precipitation and irrigation.

All measurements made on plants were limited to the varieties Waldron, World Seeds 1812, and Inia, hence data presented will be averages of these varieties. Also, only data from the plots receiving 0, 50, and 100 pounds of fertilizer nitrogen (N) will be presented.

Data in Table 1 show water inputs to the soil. The intervals correspond to dates on which measurements were made to determine the available soil water content.

Table 1. Water Inputs From Precipitation and Irrigation.

Interval	Water Source: Precipitation	Irrigation
	Inches	
5/6 to 6/6	2.17	2.5 (6/7)[1]
6/6 to 6/24	1.16	
6/25 to 7/8	5.10	
7/9 to 7/23	1.25	2.0 (7/15)
7/23 to 8/11	1.18	1.5 (7/29)

[1]Date of application ( ).

More than 10 inches of precipitation were received during the growing season; the irrigated plots received about six inches of water in addition.

The amount of available water present in the soil at several dates is shown in Table 2. Measurements were made with a neutron probe.

Table 2. Available Water In Soil At Several Depths and Dates On Dryland and Irrigation Sites.

Management	Date	6-12	12-24	24-36	36-48	48-60	60-72
		Soil Depth, Inches					
Dryland[1]		Inches					
	5/6	0.61	0.81	0.67	1.47	1.63	2.00
	6/5	0.32	0.75	0.63	1.00	1.27	1.45
	6/24	−0.05	0.16	0.52	0.92	1.18	1.35
	7/8	0.46	0.74	0.62	1.08	1.22	1.52
	7/23	0.12	0.24	0.28	0.85	1.18	1.56
	8/21	−0.18	−0.18	−0.02	0.72	1.07	1.57
Irrigated		Inches					
	5/6	0.93	1.55	1.80	1.65	1.25	1.69
	6/5	0.64	1.25	1.50	1.39	1.27	1.27
	6/24	0.78	1.44	1.53	1.60	1.24	1.27
	7/8	0.80	1.58	1.88	1.78	1.57	1.72
	7/23	0.85	1.56	1.76	1.80	1.56	1.77
	8/21	0.83	1.20	1.57	1.52	1.45	1.85

[1]Average of 6 tubes (sampling sites).

The available water supply was always larger in the irrigated plots than on the dryland. Because the supply of available water in dryland plots was less than the amount the soil could hold at the time of measurement, the data suggest that water obtained from precipitation did not move beyond the rooting zone of wheat in the dryland plots. But on the irrigated plots water may have moved beyond the rooting zone, especially in view of the increase in water content at the 60 to 72-inch depth after July 8. Roots of spring wheat extend to about 48 to 60 inches, depending upon environmental factors (5).

Data in Table 3 show the yield of above-ground vegetative parts several times during the season. Sample size was a three-foot portion of a row. Each value represents an average of four replications and of three wheat varieties.

Table 3. Above Ground Dry Matter of Spring Wheat Grown Under Irrigation at Various Dates as Influenced by Fertilizer Nitrogen (N) Rate.

	Fertilizer Nitrogen (N) Rate		
	0	50	100
Date	Pounds/acre oven-dry tissue		
6/11	406	571	439
6/27	2075	2575	2756
7/9	3096	3770	4054
7/23	4404	5765	6602
7/23[1]	2687	3576	4260

[1]Stems and leaves only.

Amount of above-ground tissue produced by June 11, about 36 days after planting, on plots receiving the 50-pound nitrogen (N) rate, was about 40% more than on check plots. More dry matter was produced on the 100-pound rate plots than on the others. Tissue samples taken July 23 were divided into components of stem, leaves and heads. The yield of stem plus leaves is taken as an estimate of straw yield at grain harvest.

Data of the nitrogen concentration in leaves are presented in Table 4. Each datum is an average of tissue from three varieties and four replications of each variety.

Table 4. Nitrogen (N) Concentration in Green Leaves of Spring Wheat at Various Dates as Influenced by Fertilizer Nitrogen (N) Rate.[1]

	Fertilizer Nitrogen (N) Rate		
	0	50	100
Date	% Nitrogen (N)		
6/11	4.72	5.06	5.30
6/27	3.68	4.37	4.47
7/9	3.10	3.87	3.81
7/23	2.47	3.45	3.30

[1]Analyses by Wisconsin Alumni Research Foundation Laboratory.

Nitrogen (N) concentration in the green leaves was always greater on plots receiving fertilizer nitrogen. Nitrogen concentration decreased in the green leaves as the season advanced.

The product of yield and nitrogen (N) concentration is a measure of the uptake of nitrogen by plants from the soil (disregarding the amount in the germinating seed). The data in Tables 3 and 4 show that fertilizer nitrogen was removed from the soil throughout the growing season, increasing both tissue yield and nitrogen concentration in these tissues.

Data of average grain yields produced on dryland and under irrigation are presented in Table 5.

Table 5. Average Grain Yield of Three Wheat Varieties Grown on Dryland and Under Irrigation as Affected by Fertilizer Nitrogen (N) Rate.

Nitrogen (N) Rate	Management	
	Dryland	Irrigated
Pounds/Acre	Pounds/Acre	
0	2142	2200
50	2736	3385
100	3012	3331

Yield response to 50 pounds of fertilizer nitrogen (N) ranged from about 10 to 19 bushels per acre on dryland and irrigation, respectively; application of 100 pounds of nitrogen (N) tended to further increase yield on dryland but not under irrigation. Based on soil samples taken at random to a depth of 24 inches prior to seeding, the recommended fertilizer nitrogen (N) rate based on standards of the Soil Testing Laboratory at NDSU would have been about 50 pounds nitrogen (N) per acre under conditions of favorable soil moisture conditions.

Data of nitrogen (N) concentration in the grain are presented in Table 6.

Table 6. Average Nitrogen (N) Concentration In Grain of Three Wheat Varieties Grown on Dryland and Under Irrigation as Affected by Fertilizer Nitrogen (N) Rate.

Nitrogen (N) Rate	Management	
	Dryland	Irrigated
Pounds/Acre	% Nitrogen (N)	
0	2.33	2.21
50	2.42	2.35
100	2.47	2.35

Nitrogen (N) concentration in the grain was greater where fertilizer nitrogen (N) was applied; the concentration in grain grown at a given fertilizer nitrogen (N) level was greater on dryland plots than the irrigated.

Table 7. Average Nitrogen Uptake in Straw and Grain of Three Wheat Varieties as Affected by Fertilizer Nitrogen (N) Rate.

Nitrogen (N) Rate	Dryland			Irrigated		
	Straw[1]	Grain	Total	Straw[1]	Grain	Total
	Pounds per Acre					
0	8	48	56	8	48	56
50	12	66	78	11	79	90
100	19	74	93	17	78	95

[1]Estimated nitrogen (N) concentration in straw was 0.30%, 0.40%, and 0.50% for the 0, 50, and 100-pound fertilizer nitrogen (N) rate under both managements.

In Table 7 are data which show the nitrogen uptake in straw and grain. Yield of straw on dryland was estimated from yields obtained under irrigation, on the same straw/grain ratio basis. Nitrogen concentration in the straw was estimated from data by Bauer and Young (7).

Uptake of nitrogen (N) increased with increase in fertilizer nitrogen (N) application rate. Nitrogen uptake from plots supplied with the 50-pound fertilizer nitrogen rate was 22 and 34 pounds nitrogen (N) more than from check plots on dryland and under irrigation, respectively, and 37 and 39 pounds more respectively, on plots supplied with 100 pounds of fertilizer nitrogen (N).

No estimate was made of the root yields or the amount of chaff produced. The weight of roots left in the soil is about one-eighth the weight of the crop above ground (11). On this basis, about 100 and 250 pounds more roots per acre were produced on the 50-pound fertilizer nitrogen (N) plots than on check plots on dryland and irrigated, respectively, and about 260 and 340 pounds more on the 100-pound rate plots. While no estimates of nitrogen (N) concentration in wheat roots are available to the author's knowledge, it is likely that some of the fertilizer nitrogen was removed from the soil by the larger quantity of roots produced.

The amount of available nitrogen (N) present in the soil to a depth of 48 inches at seeding and at harvest in the dryland and irrigated plots is indicated in Table 8. The amount present at seeding and harvest has been corrected for bulk density.

Table 8. Amount of Available Nitrogen (N), Nitrate Plus Ammonium, in Soil to 48 Inches at Seeding and Harvest as Affected by Management and Fertilizer Nitrogen (N) Rate.

Nitrogen (N) Rate	Dryland			Irrigated		
	Seeding	Harvest	Disposed[1]	Seeding	Harvest	Disposed[1]
	Pounds per Acre					
0	124	81	43	138	101	37
50	124	118	56	138	108	80
100	124	99	125	138	104	134

[1]Amount at seeding plus fertilizer nitrogen (N) added minus amount at harvest.

Available nitrogen (N) remained in the soil profile at harvest in plots not receiving fertilizer nitrogen as well as those that did; but larger amounts remained in nitrogen fertilized plots, especially on dryland.

The data in Table 7 show that the nitrogen (N) removed in the grain and straw harvested from the check plots was 56 pounds per acre on both dryland and irrigation. Because this value, 56 pounds, is a larger quantity than the difference between the amount at seeding and harvest in 48 inches of soil (Table 8) suggests that nitrogen was made available from soil organic matter during the growing season and that the amount of release was about 13 and 19 pounds nitrogen (N) per acre from dryland and irrigated, respectively. That the same amount was made available in all plots under a given management, irrespective of fertilizer nitrogen (N) rate applied, would appear to be a reasonable assumption.

A "balance sheet" showing the available nitrogen (N) sources and removals in grain and straw is presented as Table 9.

Table 9. Source and Quantity of Available Nitrogen Removed by Wheat Grain and Straw.

Management	Available Nitrogen (N) Source			
	Fertilizer	Soil	Total	Uptake[1]
	Pounds per Acre			
Dryland	0	56	56	56
	50	19	69	78
	100	38	138	93
Irrigated	0	56	56	56
	50	49	99	90
	100	53	153	95

[1]In grain and straw.

Considering the uptake in the grain and straw and the amounts of available nitrogen (N) from soil and fertilizer sources at or near seeding and harvest, all of the fertilizer nitrogen applied at the 50-pound rate, the rate that produced the maximum yield response, on dryland could be accounted for and at least 80 per cent of it on irrigated plots. Fertilizer nitrogen (N) applied in excess of the amount needed for maximum yield could not be accounted for, either in uptake or as remaining in the soil.

Fate of the fertilizer nitrogen (N) that could not be accounted for is unknown. One possible pathway from the irrigated plots is leaching, especially in view of the increase in available water below the five-foot depth toward the end of the growing season (Table 2). But on the dryland plots this was an unlikely pathway because the available water supply decreased, or was relatively low in the root zone, during much of the season (Table 2).

Another pathway of available nitrogen removal is denitrification; that is, conversion of available nitrogen in the mineral form to gaseous nitrogen. Nitrogen balance studies conducted in lysimeter and greenhouse pot experiments usually indicate losses of nitrogen from the system that have been attributed to denitrification. Losses of 20 per cent or more of the applied nitrogen have been reported as lost by this pathway (13).

Conversion of the mineral nitrogen to organic forms during synthesis of microbial cells is still another possibility. Microbial activity can be expected to be stimulated by addition of available nitrogen, and with the presence of organic substances surrounding the roots as a source of energy, immobilization is likely to occur. With the addition of an easily assimilable nitrogen source, competition between the higher plant and the microorganisms is probably decreased, and hence synthesis of microbial cells may be able to proceed to a greater extent.

Discussion

The largest quantities of fertilizer nitrogen are required to alleviate nutrient deficiency on soils cropped the previous year; the quantity recommended on fallow seldom exceeds 10 pounds nitrogen (N) per acre. Rates recommended for nonleguminous crops grown on soils cropped the previous year seldom exceed 60 pounds nitrogen (N) per acre in North Dakota.

Application methods of fertilizer nitrogen (N) utilized in North Dakota include fall or spring broadcast to the surface with or without incorporation, drill attachment application at seeding, and spring or fall application in bands below the surface. Differences in efficiency in effecting yield responses are small, if they exist at all, irrespective of application method provided no losses are incurred between time of application and planting.

From the standpoint of a potential pollutant, application at or near planting time may be most desirable because it provides the least opportunity for the fertilizer to be subjected to transporting agents before the crop is established. The probability of receiving precipitation during the nongrowing season of the magnitude that will cause nitrate-nitrogen to leach is low, and further, leaching cannot occur when soils are frozen and precipitation is in the form of snow. However, surface-applied nitrogen, especially if it is not incorporated into the soil, can be moved by runoff water, together with soil particles.

Summary

An increase in wheat grain and straw yield together with an increase in nitrogen concentration of the grain accounted for most of the fertilizer nitrogen applied at the recommended rate. On dryland, fertilizer nitrogen not removed by the crop remained within the upper 48 inches of soil at harvest. Under irrigation, fertilizer nitrogen taken up by the plant and remaining in the upper 48 inches of soil at harvest accounted for more than 80 per cent of the applied recommended rate.

Fertilizer nitrogen (N) applied at 50 pounds more than the recommended rate could not be entirely accounted for, either on dryland or irrigation.

Available nitrogen remained in the upper 48 inches of soil at harvest on plots not receiving fertilizer nitrogen as well as those that did.

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