On Non-Fallowed Soil

Stored Soil Moisture Best Guide to Nitrogen Needed

A. Bauer, E. H. Vasey, R. A. Young and J. L. Ozbun

Soil tests, past management practices, and observations of growing plants provide information helpful in evaluating fertility status of soils. Soil tests, to be useful, must be developed in the soil area and for the soil conditions they are intended to serve. A soil test is a projection of results obtained from soil fertility research conducted on a relatively small number of locations, to a large number of farm fields. Major objectives of testing are to predict the capacity of soil to supply a given nutrient and to provide information on nutrient application rate if the capacity is less than optimum to meet crop needs.

Less than optimum available nitrogen supply is present in non-fallow or continuously cropped soils for production of non-leguminous crops in North Dakota. This was indicated by yield response to nitrogen fertilizer obtained in trials over a period of several years (2, 10). Yield increases of as much as 16 bushels per acre of hard red spring wheat were obtained.

While yield increases to nitrogen fertilizer applied to non-leguminous crops grown on non-fallowed soils occurred frequently, there were numerous cases in which yield responses were not obtained even though soil and environmental conditions appeared similar at responding and non-responding sites. This suggested the need for a test to predict nitrogen fertilizer responses.

The study to develop a test for nitrogen was conducted in 1958, 1959 and 1960 and consisted of 66 rate-of-nitrogen trials on farm fields throughout the state. These trials provided (a) data of yield response to nitrogen fertilizer and (b) soil samples. The soil samples were used to evaluate the suitability of five laboratory methods to assess soil nitrogen content. The methods used were those utilized in other states and Canadian provinces to predict fertilizer nitrogen needs. These included determination of (a) total nitrogen (b) organic matter content, (c) available ammonium plus nitrate content together with stored available soil moisture at seeding (d) nitrate produced in 2 weeks incubation under optimum conditions and (e) nitrogen released through oxidation with alkaline permanganate.

Dr. Bauer is an associate professor and Dr. Vasey, assistant professor, Department of Soils; Drs. Young and Ozbun are former department members.

METHODS

Field

The test crop was wheat in 64 trials and barley in two trials. Seedbed preparation, weed spraying, and recording precipitation on a daily basis were done by the farmer cooperator. Identical rain gauges were supplied to all cooperators.

All sites were nearly level. Textures of soils represented were as follows: at five sites, fine-textured or moderately fine-textured throughout the 5-foot profile; at 13 sites, medium-textured throughout; at 44 sites, medium-textured at the surface but moderately fine-textured at varying depth; at two sites, medium-textured to 24 or 30 inches over gravel; and at two sites moderately coarse-textured throughout the 5-foot depth. Soil drainage class at 45 sites was well drained; at 13 sites moderately well drained; at seven sites, moderately well to somewhat poorly drained; and at one site, somewhat poorly drained.

Soil samples were taken at seeding in increments of 0 to 6, 6 to 12, 12 to 18, 18 to 24, 24 to 36, 36 to 48, and 48 to 60 inches with an auger from eight probings to a depth of 24 inches and three probings at a depth of 24 to 60 inches from each trial site.

The trials at 63 sites were seeded with a nursery drill equipped with six double disks at 7-inch spacing, press wheels, and endless belts to dispense fertilizer at desired rates. At the other three, a conventional 6-foot press drill equipped with two fertilizer attachments was used.

Nitrogen fertilizer was applied at rates supplying from 0 to 60 pounds of nitrogen (N) per acre in 1958 trials and 0 to 90 in the 1959 and 1960 trials; the number of nitrogen (N) treatments was never less than four and as many as seven at each site. Method of application of the nitrogen fertilizer varied with years but drill attachment applications were made every year. Broadcast application immediately after seeding also was tested. Source of nitrogen was ammonium nitrate (33.5-0-0). Phosphate was applied with all nitrogen rates at 35 to 40 pounds P_2O_5 per acre from 0-46-0 by drill attachment. Each fertilizer treatment was repeated six times at each site.

Laboratory

Soil samples removed from the trial sites were placed in plastic lined containers and sealed to prevent moisture loss during transit to the laboratory. Available soil moisture was determined by procedures set forth in USDA Handbook 60 (8) except that soil bulk densities were estimated from data obtained from identical or similar soils by Experiment Station and Soil Conservation Service personnel (5).

Soil nitrogen content was determined by procedures set forth by Saunder **et al.** (7) for the ammonium plus nitrate content at seeding and ammonium plus nitrate release during 2 weeks incubation, by Richard **et al.** (6) for the release of nitrogen by oxidation with alkaline permanganate, by Ma and Zuazaga (4) for total nitrogen and by Walkley (9) for organic matter. The soil increments analyzed for moisture and nitrogen are shown in table 1.

Statistical analyses were computed by standard procedures.

RESULTS

The amount of nitrogen removed from soil varied with the method of analysis and the depth from which the sample was taken. Data shown in table 2 are averages of amounts removed from soils at the 66 sites involved in the study.

The data show the wide variation in amount of nitrogen removed with various laboratory methods. Other than organic matter analysis, nitrogen removed

Table 1. Soil characteristics included in correlation studies between grain yield response to fertilizer nitrogen and soil and climatic variables.

Soil characteristic	Depths analyzed
	inches
Total nitrogen	0 to 6, 6 to 12, 12 to 18, 18 to 24
Organic matter	0 to 12, 6 to 12
Ammonium plus nitrate content at seeding[1]	0 to 6, 6 to 12, 12 to 18, 18 to 24
Stored available soil moisture at seeding	0 to 6, 6 to 12, 12 to 18, 18 to 24 24 to 36, 36 to 38, 48 to 60
Ammonium plus nitrate released during 2 weeks incubation[1]	0 to 6, 6 to 12 12 to 18, 18 to 24
Nitrogen released by alkaline permanganate	0 to 6, 6 to 12 12 to 18, 18 to 24

1/Determined on samples air-dried, field moist, and frozen after mixing. See Young et al. (12) for more details on this phase of the study.

Table 2. Average amounts of nitrogen (N) in soils as determined by various methods of analysis.

	Pounds nitrogen (N) per acre[1]				
		Soil depth in inches			
Method of analysis	**0 to 6**	**6 to 12**	**12 to 18**	**18 to 24**	**Total**
Total nitrogen	3948	2504	1873	1303	9628
Organic matter[2]	3200	1820	-	-	5020
Ammonium plus nitrate content at seeding[3]	18	15	11	10	54
Ammonium plus nitrate released in 2-weeks incubation[3]	71	38	21	14	114
Released by oxidation with alkaline permanganate	306	221	172	119	818

1/ Based on assumption that each 6-inch increment of soil weighs 2,000,000 pounds per acre.
2/ Based on assumption that 5 per cent of the organic matter is nitrogen (N).
3/ Determined on air-dried samples.

in proportion to total nitrogen was low. The ammonium and nitrate content at seeding, which represents available nitrogen, was slightly more than 0.5 per cent of the total nitrogen to a depth of two feet. After two weeks incubation under ideal conditions for microbial activity, the amount of available nitrogen released was more than double the amount which had been initially present. The sum to two feet of available nitrogen at seeding (54) and that released through incubation (114 pounds) represents less than two per cent of the average total quantity present in these soils to two feet.

The question that arises is "which of these methods, if any, can be used to predict nitrogen sufficiency or deficiency?" Determination of the nitrogen content in soil does not, in itself, constitute a soil test; the amount determined present, by whatever method of analysis, must be interpreted in the light of what it means in terms of sufficiency or deficiency for crop growth.

The potential usefulness of each of the methods of analysis and other measured soil and climatic characteristics in predicting fertilizer nitrogen needs was determined by using a statistical technique known as simple correlation. This technique determines the relationship between two measured variables. The value of the correlation coefficient "r" indicates the degree to which the two variables are related; the larger the "r" value the higher the degree of relationship. (An "r" value of 1.0 indicates a perfect relationship). Correlation coefficients and levels of statistical significance for grain yield responses to fertilizer nitrogen in relation to nitrogen removed by various methods from various soil increments, stored available soil moisture at seeding, and growing season rainfall and temperature are shown in table 3. For the correlation analyses, yield response to nitrogen fertilizer was the difference in yield between the highest yielding nitrogen-phosphate treatment and the phosphate treatment.

The data in table 3 show that both stored available soil moisture at seeding and growing season rainfall were positively correlated with yield response to fertilizer nitrogen; in both cases the relationship was of a higher degree than with any chemical method of soil nitrogen determination. (The positive relationship means that yield response to nitrogen fertilizer increased as moisture supply increased). Temperature was negatively correlated with yield response to the same degree as the nitrate content to a depth of 24 inches at seeding. (The negative relationship means that yield responses to fertilizer nitrogen decreased as temperature increased above a certain level, or as nitrate content increased). Total nitrogen and organic matter content also were significantly correlated

Table 3. Coefficients of correlation between maximum grain yield response to fertilizer nitrogen and soil nitrogen determined by various methods, stored available soil moisture, and climatic factors.

Method of analysis	Soil depth or period	r
Total nitrogen	0 to 6 inches	0.30*[1]
	0 to 12 inches	0.32**
	0 to 18 inches	0.31*
	0 to 24 inches	0.30*
Organic matter	0 to 6 inches	0.32**
	0 to 12 inches	0.35**
Ammonium plus nitrate content at seeding[2]	0 to 12 inches	-0.31*
	0 to 24 inches	-0.36**
Ammonium plus nitrate released by incubation[2]	0 to 6 inches	0.16
	0 to 12 inches	0.18
	0 to 18 inches	0.12
	0 to 24 inches	0.05
Nitrogen released by alkaline permanganate	0 to 6 inches	0.08
	0 to 12 inches	0.15
	0 to 18 inches	0.14
	0 to 24 inches	0.14
Stored available soil moisture at seeding	0 to 48 inches or dry zone	0.57**
Rainfall	Seeding to 5 days before harvest	0.41**
Temperature (degree days above 70° F)[3]	5 to 70 days before harvest	-0.36**

1/ The asterisks mean that the r value is statistically significant. The odds are at least 95 out of 100 (*) or 99 out of 100 (**) that the observed correlation could not have arisen by random sampling.

2/ Air-dried samples.

3/ Degree day above 70° F was calculated by subtracting 70 from each maximum daily temperature that exceeded 70° F.

with yield response to fertilizer nitrogen but the coefficient of correlation was a lower value than with nitrate content to 24 inches at seeding. Nitrate released by incubation or nitrogen released by alkaline permanganate was not related to yield response.

Because stored available soil moisture showed the best relationship to yield response at the 66 field experimental sites and because it can be estimated before seeding, it is more useful in predicting yield response to fertilizer nitrogen than any other soil characteristic investigated. Although growing season rainfall and

Table 4. Average grain yield responses to fertilizer in relation to stored available soil moisture at seeding on non-fallowed soils.[1]

Stored available soil moisture[4]	No. of trials	Yield of check	Yield increase over check			
			P[2]	20N[3]+P	40N+P	60N+P
inches		Bushels per acre				
Less than 2	26	16.0	2.1	3.3	3.2	2.9
2 to 4	20	22.0	2.2	4.7	6.3	5.6
4 to 6	10	25.9	-0.5	7.5	10.9	11.2
More than 6	10	23.5	3.9	7.9	13.0	15.3

1/ Barley yield based on 60-pound bushel.
2/ 35 to 40 pounds P_2O_5 per acre.
3/ Refers to nitrogen (N).
4/ To four feet or dry zone.

temperature also showed a relationship with yield response, they are of little value for prediction of fertilizer nitrogen needs because they are not known at seeding, except that the nitrogen-need prediction can be based upon average growing season rainfall and temperature.

Data in table 4 show average grain yields of the check (no fertilizer) treatment and average yield increases from fertilizer rates common to all 66 trials as affected by stored available soil moisture at seeding.

When less than two inches of stored available soil moisture was present at seeding the average yield response to fertilizer nitrogen did not exceed 1.2 bushels irrespective of the rate applied (presuming a uniform 2.1 bushel increase from phosphorus). As the amount of stored available soil moisture increased, yield response to fertilizer nitrogen increased. In addition, with increase in moisture the rate of fertilizer nitrogen required to produce the greatest response increased also.

Stored available soil moisture at seeding serves not only as a useful guide for predicting the need for supplemental nitrogen, but also for determining the rate of fertilizer nitrogen which will correct the deficiency. This aspect in development of a soil test is termed calibration; that is, development of information useful in predicting the rate of fertilizer nutrient required to correct a deficiency, based upon the soil characteristic useful in describing deficiency or sufficiency.

The effect of growing season rainfall on yield response to fertilizer nitrogen is presented in table 5. Average rainfall from April 15 through July 31 ranges from about 8 inches in western North Dakota to about 9 inches in eastern North Dakota (3).

Table 5. Average grain yield response to fertilizer in relation to growing season rainfall on non-fallowed soils.[1]

Rainfall[2]	No. of trials	Yield of check	Yield increase over check			
			P[3]	20N[4]+P	40N+P	60N+P
inches		Bushels per acre				
Less than 4	4	12.7	1.0	1.4	0.4	0.5
4 to 6	12	17.9	3.2	4.3	5.3	3.6
6 to 8	21	19.4	1.0	4.2	5.6	6.6
8 to 10	19	23.5	2.0	5.7	8.2	7.5
More than 10	10	25.0	2.4	7.6	11.6	12.2

1/ Barley yields based on 60-pound bushel.
2/ Seeding to five days before harvest.
3/ 35 to 40 pounds P_2O_5 per acre.
4/ Refers to nitrogen (N).

Less than six inches rainfall during the growing season resulted in yield responses to fertilizer nitrogen of about two bushels or less per acre, but as rainfall increased average yield response increased. Data in table 5 also show that as growing season rainfall increased, higher rates of fertilizer nitrogen were required to produce the largest yield increases.

Data showing the inter-relation of moisture supply on average grain yield responses are presented in table 6.

Average yield response to fertilizer nitrogen under conditions of less than two inches stored available soil moisture at seeding did not exceed two bushels per acre unless growing season rainfall exceeded 10 inches. When the stored available soil moisture at seeding was two to four inches, average yield response exceeded five bushels per acre from 40 pounds of fertilizer nitrogen with growing season rainfall of six to eight inches; yield increases were larger with larger amounts of rainfall. With more than four inches of stored available soil moisture at seeding, increases to fertilizer nitrogen were obtained even when growing season rainfall was less than six inches. The data in table 6 also show that with increase in moisture supply, larger amounts of fertilizer nitrogen were needed to produce the largest yield increases.

Because **total** moisture supply influences the amount of nitrogen required to meet crop needs, both stored available soil moisture at seeding and growing sea-

Table 6. Inter-relation of stored available soil moisture at seeding and growing season rainfall on average grain yield response to fertilizer on non-fallowed soils.[1]

Rainfall[5]	No. of trials	Yield of check	P[3]	20N[4]+P	40N+P	60N+P
		Available soil moisture,[2] less than 2 inches				
inches		Bushels per acre				
Less than 4	1	7.4	1.6	2.0	2.2	2.9
4 to 6	4	10.0	2.6	2.3	1.9	2.8
6 to 8	11	16.5	0.8	2.5	1.8	1.5
8 to 10	8	21.0	3.7	4.6	5.4	3.9
More than 10	2	16.8	2.3	5.5	5.9	7.3
			Available soil moisture, 2 to 4 inches			
Less than 4	3	14.5	0.8	1.2	-0.2	-0.3
4 to 6	6	21.1	3.8	5.4	5.6	4.3
6 to 8	5	21.5	3.0	5.6	8.1	9.2
8 to 10	4	21.7	-0.8	3.3	6.2	3.4
More than 10	2	40.0	1.3	6.7	11.9	11.9
			Available soil moisture, 4 to 6 inches			
4 to 6	1	30.0	-0.8	4.1	1.6	0
6 to 8	3	20.2	-0.2	10.1	13.8	16.9
8 to 10	4	29.4	-0.2	6.6	11.1	11.0
More than 10	2	25.4	-1.5	7.0	10.7	8.6
		Available soil moisture, more than 6 inches				
4 to 6	1	18.0	6.0	6.3	9.9	6.8
6 to 8	2	28.6	0	1.6	8.4	13.2
8 to 10	3	25.0	4.2	10.5	14.4	17.6
More than 10	4	21.3	5.0	9.5	14.9	16.8

1/ Barley yields based on 60-pound bushel.
2/ To four feet or dry zone.
3/ 35 to 40 pounds P_2O_5 per acre.
4/ Refers to nitrogen (N).
5/ From seeding to five days before harvest.

Table 7. Average grain yield response to fertilizer nitrogen as influenced by soil nitrate content at seeding.

Nitrate content[1]	No. of trials	Yield response to fertilizer nitrogen
Pounds N per acre[2]		Bushels per acre
Less than 40	18	7.4
40 to 80	41	6.4
More than 80	7	2.7

1/ Air-dried soil samples.
2/ To 2 feet.

son rainfall should be considered in estimating the nitrogen fertilizer rate to apply. However, a precise means for predicting the growing season rainfall is not available at the time a decision is made to apply nitrogen, so the amount must be estimated. "Average" rainfall is the best available estimate at this time.

The nitrate content of the soil at seeding also was correlated with yield response (table 3). The influence of soil nitrate content at seeding on response is shown in table 7.

As indicated in table 7, average yield response to fertilizer nitrogen decreased as nitrate content at seeding increased.

The effect of stored available moisture at different levels of nitrate content at seeding on average grain yield response to fertilizer nitrogen is shown in table 8.

Yield response to fertilizer nitrogen decreased as the soil nitrate content increased at some levels of available soil moisture. The greatest change occurred at sites with more than four inches stored available soil moisture at seeding.

The data (table 8) indicate that both the soil moisture and nitrate content at seeding have an effect on yield response to fertilizer nitrogen. Hence, an estimate of both would be beneficial in determining fertilizer nitrogen needs. Knowing the nitrate content would make the greatest contribution to determination of fertilizer needs when stored available soil moisture exceeds four inches.

The variables which were correlated with grain yield response to fertilizer nitrogen were subjected to multiple correlation. Multiple correlation analysis determines the proportion of existing variation in yield response that can be attributed to the variables tested. The coefficient of multiple correlation is R. R^2 for multiple correlation and r^2 for simple correlation, termed the coefficient of the determination, indicate the proportion of variation that can be attributed to the variables or variable included in the correlation analysis. Results of simple and multiple correlation of grain yield response with fertilizer nitrogen and soil and climatic variables are shown in table 9.

Table 8. Average grain yield response to fertilizer nitrogen as influenced by stored available soil moisture and soil nitrate content at seeding.

	Yield response to fertilizer nitrogen		
	Nitrate (Pounds N per acre)[1]		
Available soil moisture	40	40 to 80	80
inches	Bushels per acre		
0 to 2	4.5	1.8	2.5
2 to 4	3.6	6.2	-
More than 4	12.4	11.9	3.4

1/ To 2 feet.

Table 9. Coefficients of simple and multiple correlation and coefficients of determination of grain yield response to fertilizer nitrogen and soil and climatic variables.

Variables	r or R	r^2 or R^2
Stored available soil moisture at seeding (SM)	0.57	0.32
Rainfall, seeding to 5 days before harvest (Pr)	0.41	0.17
Temperature, degree days above 70° F. (T)	-0.36	0.13
Ammonium plus nitrate content at seeding to 2 feet (I)	-0.36	0.13
SM + Pr	0.65	0.42
SM + Pr + T	0.66	0.43
SM + Pr + T + I	0.70	0.50

Stored available soil moisture at seeding accounted for about 32 per cent (r^2 of 0.32) of the explainable variation in grain yield response to fertilizer nitrogen. Inclusion of growing season rainfall with stored available soil moisture in multiple correlation increased the explainable variation to 42 per cent (R^2 of 0.42). An improvement, statistically significant, was obtained by inclusion of soil nitrate content in the multiple correlation (R^2 of 0.50). Inclusion of any other nitrogen fraction in a multiple correlation analysis with stored available soil moisture at seeding, growing season rainfall and temperature, and nitrate content at seeding did not improve the explainable variation (12); however, when all measured variables were included in the multiple correlation, R^2 increased to 0.83.

DISCUSSION

The four facets of investigation in development of a soil test are: (a) to conduct trials in the field and/or the greenhouse to obtain yield response data to the nutrient element for which a test is sought, (b) to determine the amount of the nutrient in question that can be removed from the soil taken from the trial sites and to characterize other soil properties that may aid to explain response, (c) to determine the relationship by correlation analysis between yield response data and laboratory data characterizing various soil properties, and (d) to calibrate the test, that is, to determine the rate of nutrient to apply to the soil to correct the deficiency. All predictions of sufficiency or deficiency of nutrients in samples submitted by farmers are based upon the results obtained from such investigations. A soil test compares a characteristic or characteristics of the farmer's soil sample to those of the soils at the experimental sites at which yield response data were obtained. If the soil characteristic(s) descriptive of the sufficiency of the nutrient, is the same or similar in the farmer's soil sample to that of soils at experimental sites at which yields were increased, the prediction is that there is a deficiency of the nutrient. If the characteristic(s) is the same or similar as that of soils at sites where yields were not increased, then the prediction is that a deficiency of the nutrient does not exist. Thus, the key to development of a soil test is to find a soil characteristic, or several characteristics, relating crop yield response to the nutrient applied as a fertilizer. If there is no relationship between the yield response and a specific soil characteristic, this soil characteristic is of no value in predicting sufficiency or deficiency of the nutrient.

Soil characteristics of greatest value in predicting sufficiency or deficiency of available nitrogen in North Dakota soils are the amount of stored nitrate ... depth of two feet and stored available soil water at seeding. These two soil characteristics showed the highest degree of relationship of yield response to nitrogen fertilizer in the 66 trials. Total nitrogen and organic matter content also were related to yield response, but to a slightly lesser degree. Nitrates released in two weeks incubation and nitrogen released by alkaline permanganate did not show a relationship and hence are considered to be of little value for predicting nitrogen fertilizer needs on North Dakota soils. Thus, the soil characteristic that serves as the major "test" in determining prospects of obtaining yield response to nitrogen fertilizer on non-fallowed soil in North Dakota, that of estimating stored available soil moisture at seeding, must be made in the field — "on the spot" as it were. This "test" can be improved by determining stored soil nitrates in a laboratory test in samples taken a few days before seeding.

To estimate the amount of stored available soil moisture requires knowledge of soil texture, observation and recognition of physical properties that give clues to soil moisture content, and depth of wetting. Estimates of the amount of available soil moisture present in soil of a given texture wetted to a given depth are provided (10), but this information can have application only if holes are dug and the soil from various depths examined. Estimates also can be made by several other procedures, but all require special laboratory equipment.

The importance of growing season rainfall and temperature to crop yield response to nitrogen fertilizers points up some reasons why predictions, at times, can fail. This is not only the case with respect to nitrogen fertilizer, but also to phosphorus (1).

Major drawbacks in use of nitrate content as a supplement to predicting nitrogen fertilizer needs on non-fallowed soils are the depth to which samples must be taken, handling of the sample, and time and frequency of sampling. In North Dakota, samples to two-foot depths would be required, with each sample divided into at least two depths, 0 to 6 inches and either 6 to 12 and 12 to 24 or 6 to 24 inches. The purpose of the two or three depth-increments is to eliminate the necessity of taking a separate sample of 0 to 6 inches for laboratory tests which determine soil characteristics useful in predicting phosphorus needs. The samples must be air-dried **immediately;** delay in drying could result in a considerable increase in nitrate content, especially if stored in a warm room, because moist, warm conditions favor rapid conversion of organic nitrogen to mineral (ammonium and nitrate) forms. The time and frequency of sampling would depend upon crop sequence. Under a continuous cropping system samples taken annually would be most desirable, as nitrate content of North Dakota soils can change rapidly. Changes occur because of the nature of environmental conditions after harvest, a legume in the cropping sequence, application of barnyard manure, carryover of nitrogen fertilizer from a previous application and immobilization of nitrogen by weeds.

Environmental factors play a major role in determining the mineral nitrogen content of North Dakota soils. The potential for an adequate supply of mineral nitrogen is great, because of the high soil organic matter and total nitrogen content of the most soils. Conversion of the nitrogen in organic matter to mineral forms available to plants is brought about by soil micro-organisms whose activities are affected by environmental factors, including moisture supply and temperature. These two factors limit accumulation of mineral nitrogen on non-fallowed soils as the soil after harvest usually is dry. (Excess water on poorly drained soils can restrict mineralization of nitrogen because of restricted aeration). As the season advances into late autumn and winter, temperatures become too cold for efficient microbiological activity and thus limit nitrogen mineralization; this limitation can extend into the early part of the following growing season. In general, by the time weather conditions are favorable for rapid mineralization of organic nitrogen, the nitrogen needs of rapidly growing crops, such as the small grains, cannot be met solely with mineral nitrogen originating from native sources without a reduction in potential yield.

Growing season precipitation is a major factor affecting the application rate of nitrogen, especially when there is more than 4 inches stored available soil moisture and low to medium soil nitrate content at seeding. Here the potential for yield response to nitrogen fertilizer is great and the magnitude of response depends on the rate of nitrogen fertilizer applied. Under conditions of less than two inches stored available soil moisture or high nitrates, a lower rate of fertilizer nitrogen produces the maximum yield response.

SUMMARY

Stored available soil moisture at seeding is the best guide to use in North Dakota to determine and recommend nitrogen fertilizer needs for small grains seeded on non-fallowed soil; determination of soil nitrate content to a depth of two feet at seeding provides additional aid, especially when the stored available soil moisture content at seeding is greater than four inches.

Response to fertilizer nitrogen and the fertilizer nitrogen rate required for maximum yield at a given soil nitrate content, increase as either stored available soil moisture or growing season rainfall increases.

As the amount of stored available soil moisture at seeding increases, less growing season rainfall is needed to produce a yield response to fertilizer nitrogen.

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