HISTORY OF SOIL FERTILITY RESEARCH CONDUCTED BY SOIL SCIENTISTS AT NORTH DAKOTA AGRICULTURAL EXPERIMENT STATION

J. C. Zubriski and J. T. Moraghan

Soil fertility research conducted by soil scientists at North Dakota Agricultural Experiment Station began in 1908 when Dr. R. C. Doneghue, agronomist of the station from 1908 to 1919, laid out long-time fertility plots at Fargo. The plan of these experiments reflected the philosophy of Dr. C. G. Hopkins from the University of Illinois. Hopkins believed that the key to maintenance and improvement of soil fertility, and hence permanent agriculture, lay in maintaining organic matter levels through use of legumes, manure and crop residues. The legumes were to supply the necessary nitrogen, and commercial fertilizers were to be added to restore phosphorus and potassium removed by crops. Ground limestone was to be added to correct soil acidity and to provide favorable conditions for maximum nitrogen fixation by the legumes and for mineralization of organic matter to promote release of soluble forms of phosphorus and potassium. Dr. H. L. Walster was in charge of these experiments from 1919 to 1934. T. E. Stoa (agronomist) assisted in the management of these experiments after 1920 and was in charge of these experiments from 1934 until 1954.

Dr. R. A. Young superimposed new fertility treatments perpendicular to the initial treatments in 1954 and was in charge of these plots until 1963. From 1963 until termination in 1965, the plots were managed by Dr. J. C. Zubriski. The results from these experiments were published by Walster (44), Volkerding and Stoa (43), Young, Zubriski and Norum (46) and by Stoa and Zubriski (42). Some conclusions from this research were: (a) lime was not needed on the Fargo clay soil; (b) crop residues alone were not as effective as manure in maintaining yields; (c) supplemental P fertilizer increased yields under both residue and manure treated plots (d) soil organic carbon and N declined 27 percent in check plots and 20 percent in crop residue or manure plots after 40 years of cropping; (e) extractable P declined appreciably in check plots, less in crop residue and manure plots and increased in P-treated plots; (f) physical measurements did not reveal any important differences in structural properties; (g) additional N and P over that supplied by initial treatments were required for maximizing wheat yields; (h) oats and barley grown on fallow responded to additional P but not to additional N; (i) wheat yields following alfalfa were greater than wheat yields following non-legumes; and (j) where both commercial N and P were applied, wheat yields following non-legumes were increased considerably but were not as great as yields from comparable plots following the legume.

Zubriski and Moraghan are professors, Department of Soil Science.

Soil fertility research during the 1920s and the 1930s (12) centered around applications of superphosphate or ammonium phosphates on fallow land for increasing yields of small grains. These results showed that P deficiencies were widespread (12).

Fertility research from the late 1940s to the mid-1950s was mainly on use of phosphates on fallow land for small grain production and on development of a soil test that could be useful for predicting the need for supplemental P fertilizers. Results from these field tests also showed that many soils in North Dakota were deficient in P for optimum crop production (40). Laboratory tests and greenhouse experiments (54) revealed that the Olsen sodium bicarbonate test for phosphorus (41) correlated best with crop response to added phosphate fertilizer. The soil testing laboratory was established at NDSU in 1953.

Research was also begun in the 1950s to determine the effect of fertilizers on soil moisture utilization by small grain crops. The first publication showing that fertilizers increased grain yields but did not cause a greater withdrawal of soil moisture was in 1955 (53). Since that time, several more articles have been published on the effect of commercial fertilizer on grain yields and on water use (2, 3, 4, 6, 7, 8, 9, 10, 38). In general, commercial fertilizers have caused greater yields per unit of water used (increased water use efficiency). Water use efficiencies reported were about 2.0 bushels grain per acre per inch of water used for unfertilized grain and about 2.5-3.0 bushels grain per acre per inch of water used for fertilzied grain (7, 8, 38). These results have encouraged farmers to use optimum fertilizer rates so as to make the best use of the limited supplies of moisture in North Dakota.

Research in the 1950s showed further that crops such as corn (5, 11, 34, 47), potatoes (39) and flax (48, 49, 50) also respond to commercial fertilizers. With adequate fertility and moisture, corn produced larger yields at 16,000 plants per acre than at 12,000 plants (34, 37). On non-fallow fields, potatoes required both N and P to produce maximum yields (39). When commercial fertilizers for flax were placed in the row with the seed at planting time, germination injury occurred and erratic responses to applied fertilizers were obtained. However, if commercial fertilizers for flax were banded to the side and below the seed or broadcast, excellent responses to fertilizer were obtained, particularly to added N on non-fallow soils (48, 49, 50).

In the 1950s and 1960s, fertilizer experiments also tested rates of N and time and method of application for small grain production on non-fallow soils. Stored soil water, precipitation and nitrate nitrogen content of the soil were monitored at many sites throughout North Dakota. These investigations showed that yields and yield response to N fertilizers depended on several variables (3, 4, 45), including stored available water at seeding, growing season precipitation and amount of soil nitrate nitrogen in the top 2 feet of soil at seeding time. The contribution of an inch of water, either stored in the soil or derived from precipitation, was estimated by an interdisciplinary team as about 2.4 bushels of wheat per acre which approximates the water use efficiencies reported earlier (37). Results of field and laboratory investigations led to the adoption of the nitrate nitrogen test in 1968 for improving nitrogen fertilizer recommendations. Soil testing laboratories of Washington State University and the University of Manitoba adopted the nitrate nitrogen test before 1968. Since 1968 this test has been adopted by many other soil testing laboratories in the Great Plains area.

In the 1960s the causes of high protein content in malting barley were investigated. These investigations (55) revealed that either late seeding or amounts of N from either soil or fertilizer sources in excess of that required to maximize grain yields were mainly responsible for the high protein content of the grain. Potassium fertilizers were also tested in these trials. Even though, by most standards, amounts of available potassium are high in most North Dakota soils, yield responses and increased percentages of plump barley kernels were obtained in some cases. These observations plus previous observations that potassium produced small yield increases of corn and potatoes on some soils led to the adoption of a potash test by the soil testing laboratory in 1968. At the present time, however, it is not certain whether the small grain responses were due to the added potassium or due to the effects of chloride on reducing root diseases. Investigations are being conducted to evaluate these findings.

One of the principal changes in fertilizer practice which has occurred in North Dakota during the past decade is the replacement of ammonium nitrate (34-0-0) by anhydrous ammonia (82-0-0) as the leading commercial N fertilizer (21). Research with anhydrous ammonia, partly because of problems with calibration of equipment, is much more difficult than with solid fertilizers. Some of these problems were defined and rectified (23). Anhydrous ammonia studies with corn and small grains were subsequently started. Spring-applied anhydrous ammonia was more efficacious for irrigated corn production at Oakes than the fall-applied product; in addition, N-Serve increased the efficiency of anhydrous ammonia. N-Serve was found to decrease the buildup in nitrite under field conditions during the nutrification process.

The importance of soil fertility, particularly N availability, to the sugarbeet industry of the Red River Valley has been demonstrated in the late 1960s and 1970s (15, 16, 30, 35, 36). Sugarbeet producers as a group make greater use of soil-testing services than any other segment of the North Dakota farm community. Research has clearly shown that sugar yields in the Valley can be increased by advancing the date by which an effective leaf canopy is obtained. Adequate soil fertility is very important in this context.

Sugarbeet is a much deeper rooting crop than most other annual crops in North Dakota (33). This deep-rooting nature of sugar beets was shown to have important consequences for root quality of sugar beets (20, 28). Residual nitrate-N located deep in the soil profile becomes available late in the growing season; this results in smaller sugar percentages and increased accumulation of impurities in roots.

Plant analysis is helpful for the determination of the P status of sugar-beet plants (30). However, the critical value for plant phosphate extracted with 2 percent acetic acid was found, unlike in some earlier reports, to decrease during the growing season. A relatively simple method for determining plant-extractable phosphate was developed (13). Many soils used in sugarbeet production were shown to require no additional P fertilizer.

A lower leaf scorch which is sometimes observed in commercial sugar beet fields, particularly in seasons with limited precipitation, was found to be due to potassium deficiency (29). Sugar beet has a relatively high requirement for potassium; removal of 70 to 100 pounds per acre of potassium in sugarbeet roots is not uncommon in the Red River Valley.

Relatively little research has been done on the micronutrient status of North Dakota crops. Zinc deficiency symptoms on corn plants, growing on soils with low contents of DTPA-extractable Zn, are frequently seen early in the growing season. Corn responded to zinc fertilizer in one study (1).

Flax is the most susceptible to zinc deficiency of the major crops grown in North Dakota (18, 19, 25, 26, 27). Zinc deficiency, once described as "chlorotic dieback" (14), usually does not affect entire fields but rather is present within relatively small, irregularly shaped areas. Zinc deficiency is accentuated by low soil temperatures and is usually most obvious in fields in the early part of the growing season, especially if temperatures are below average. High levels of available P increase the likelihood of zinc deficiency in flax growing on soils marginal in available zinc. Application of phosphate fertilizers over a period of years will result in the availability of phosphorus to plants being increased. The incidence of zinc deficiency in fields which are marginal in available zinc is likely to increase with continued P fertilization. Application of the iron chelate FeEDDHA also increases the occurrence of zinc deficiency. The DTPA-extractable zinc level is, with certain qualifications, a useful guide for predicting the need for zinc fertilizer.

A necrotic spotting on intermediate and older leaves of flax was found to be due to manganese toxicity (31); the problem was eliminated by application of the iron chelate FeEDDHA. Above-ground parts, but not roots, of afflicted plants contained relatively high levels of manganese (24). Plant-mangagnese concentration was poorly related to manganese extracted from soils with DTPA, 1 N ammonium acetate (pH = 7) and 1 N ammonium acetate + 0.2% hydroquinone (pH = 7), but was significantly inversely related to DTPA-extractable iron (22). It was hypothesized that plant-iron satus influenced the ability of flax roots to utilize soil manganese, possibly through changes in pH or redox potential at or adjacent to roots. The problem is influenced by flax genotype (32).

Sunflower fertility trials have been conducted annually since 1971 on dryland and since 1977 on irrigated soils to evaluate the effects of soil fertility, moisture, and plant population on seed yield and quality of seed (51, 52, 56). Some recent data obtained from this research are presented in Tables 1 through 3.

Table 1. Effect of nitrogen supply on average seed yields of dryland and irrigated sunflower.

Soil plus fertilizer N[1]	Dryland	Irrigated
	lbs/A	
25	1540	2100
50	1810	2600
100	2340	3100
150	2350	3240
200	—	3275
Number of trials	32	4

[1]Soil nitrate N/A/2 foot depth plus fertilizer N at planting.

Table 2. Effect of nitrogen supply on oil percentage of sunflower seeds grown on dryland and irrigated plots in North Dakota.

Soil plus fertilizer N	Dryland	Irrigated
	percent	
25	46.3	50.7
50	45.8	50.6
100	45.0	49.9
150	44.2	49.0
200	—	48.2
Number of trials	32	4

Table 3. Effect of nitrogen fertilizers on water use efficiency of dryland and irrigated sunflower in North Dakota.

Fertilizer N	Dryland	Irrigated
lbs/A	lbs seed/A/inch of water used	
0	114	70
100-200	147	137
Total water used, inches	15.3	24
Number of trials	22	3

These data show that N fertilizers applied to nonfallow soils produced substantial seed yield increases, decreases in percentage of oil in seeds and increases in water use efficiencies by dryland and irrigated sunflowers. Additional data (52, 56) obtained from this study show that response of sunflower to applied P was poorly correlated with soil tests for phosphorus. Additional research is required to determine why sunflower does not always produce yield increases to applied phosphorus on soils testing low in phosphorus.

The Department of Soil Science began studies on fertilty and water management of irrigated soils in the 1950s. The early studies were furrow or flood irrigation and were discontinued by 1960. With the development of center pivot sprinkler irrigation systems and the proposed availability of water from the Garrison Diverison Project, research in this area was renewed in 1970. A 15-acre experimental site near Oakes was leased to conduct various kinds of crop and soil management experiments. These studies are being continued. One basic objective of this research is to measure yield potential of different crops grown under various cropping sequences and under varying water and fertilizer levels. Another objective is to measure plant uptake of fertilizer nutrients and movement of fertilizers and soluble salts in the soil profile as affected by fertilization, irrigation and management practices including kind of fertilizer, rate and time of application and amount of irrigation water applied. A third objective is to measure water use efficiency by crops grown under varying water and fertilizer treatments. Some recent data obtained from this project are presented in Tables 4 through 6.

Table 4. Effects of water level and nitrogen applied at planting on average grain yields during the past four years at Oakes, ND.

	Lbs N/A				
Water Level	0	50	100	200	Average
			Bu/A		
Dryland	24	33	32	25	28
Intermediate[1]	46	110	157	158	118
Near Optimum[2]	59	119	174	179	133

[1]Irrigated when about ½ of available soil water at 12 inch depth was depleted.

[2]Irrigated when about ¼-⅓ of available soil water at 12 inch depth was depleted.

Table 5. Eight year average total water use by corn fertilized with 100 or 200 lbs N/A at Oakes, ND.

Water	Water Source			
Level	Precipitation	Soil	Irrigation	Total
	Inches			
Dryland	9.06	1.77	0	10.8
Intermediate	9.06	1.35	9.81	20.2
Near Optimum	9.06	1.28	15.91	26.3

Table 6. Effect of N rate and water level on three year average soil nitrate-N at harvest in the top five feet of soil at Oakes, ND.

	Nitrate-N for N Rate			
Water Level	0	50	100	200
	lbs N/A/5 foot depth			
Dryland	46	57	93	190
Intermediate	28	31	38	83
Near Optimum	29	30	40	63

These data show that corn grain yields of 180 to about 200 bushels per acre on a Maddock fine sandy loam soil at Oakes are possible and such yields require from 100 to 200 pounds per acre of supplemental nitrogen and about 16 inches of supplemental water. The average water use efficiency values for the last four years were 3.1, 7.8 and 6.8 bushels per acre per inch of water used by dryland, intermediate and near optimum irrigated corn, respectively. For each N rate the largest amounts of soil nitrate-N were found in dryland plots and the lowest amounts in most cases in near optimum irrigated plots.

Titles of current projects being conducted by soil scientists at the North Dakota Agricultural Experiment Station include the following: (a) effects of management on sugarbeet production; (b) fate of nutrients in the environment as affected by soil and crop management; (c) effects of fertilizers and plant populations upon yield and quality of sunflowers; (d) intensive soil and water management for versatile cropping; (e) fertilizer and water management of irrigated crops; (f) soil test correlation and calibration; (g) micronutrients and plant growth; and (h) fertilizer soil testing.

Additional soil fertility research has been conducted by other departments of the North Dakota Agricultural Experiment Station, by North Dakota Branch Experiment Stations, by the Land Reclamation Research Center and by soil scientists stationed at the Northern Great Plains Resarch Center located at Mandan. The results of this research can be found in relevant annual reports and in other publications.

Increases in numbers of soil samples tested and in amounts of commercial fertilizers used together with increasing crop yields attest, at least in part, to the efficacy of soil fertility research conducted by soil scientists of other organizations and of the North Dakota Agricultural Experiment Station. The limited resources in both funds and the number of soil scientists at North Dakota Agricultural Experiment Station have been used well during the period following the establishment of the long-time fertility plots at Fargo.

Future goals of soil fertility research deal with principles, practices, techniques and methods of supplying essential plant nutrients to crops from soil, legume, crop residue, agricultural wastes and fertilizer sources. Genetic potential for solving problems of soil mineral stress needs study. The main goals of soil fertility management are to provide plant nutrients in sufficient quantities without incurring either phytotoxicity, poor crop quality, or pollution of the environment and to profitably increase crop yields to those more nearly approaching the genetic limit of the crop. Optimizing crop yields requires precision in all phases of crop production. The best possible combinations of climate, plant densities, irrigation, fertilization, crop varieties and other growth conditions and economic factors are not known perfectly and vary with site and time. For these reasons, soil fertility research remains a continuing need.

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12 percent in eastern North Dakota and about 18 percent in the west. Department of Agricultural Economics personnel are now evaluating the economic benefits.

Table 2. Average number of days with selected amounts of daily precipitation, 1931-1980 (after Enz et al., 1982).

Daily Precip.	Dickinson	Mandan	Pettibone	Fargo
	Days in June, July, and August with indicated precipitation			
	number of days			
0.01-0.10	16.1	13.5	11.5	15.5
0.11-0.50	11.1	9.7	9.7	10.3
0.51-1.00	3.3	3.3	3.2	3.3
1.00	1.3	1.4	1.7	1.8
Total days	31.8	27.9	26.1	31.0

CLIMATOLOGY OF HAIL IN NORTH DAKOTA

In an effort to quantify hailfall throughout North Dakota, we have identified all the National Weather Service hail occurrences and stored this information on computer tape. Unfortunately, many cooperative observers have apparently ignored hail events so an evaluation of these data is most difficult. A scheme is being developed to identify the poorer records. When this is completed, these data will be analyzed in order to determine the frequency of hail.

Additional detailed hail data collected by cooperative observers for the North Dakota Weather Modification Board will also be analyzed. Since these data include hail amounts, times of occurrence, and severity in addition to dates, they will improve the hail information. Eventually the economic impact of hail will be investigated in cooperation with the Department of Agricultural Economics.

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