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Nitrogen Fertilizer Requirements in an Annual Dryland Cropping System

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ABSTRACT

Reduced tillage systems in the Central Great Plains have improved precipitation storage efficiency and increased the potential to crop more intensively than with the traditional crop–fallow system. More intensive cropping will require additional N input to maintain economical yields. Nitrogen fertility requirements for optimum crop yields in a dryland, annual cropping system were studied. Six N fertilizer rates (0, 22, 45, 67, 90, and 134 kg N ha^{-1}) were applied to the same plots for 8 crops on a Weld silt loam (montmorillonitic, mesic Aridic Paleustoll). Spring barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and winter wheat (*Triticum aestivum* L.) were grown in rotation from 1984 through 1991. Although grain yields varied with crop and year, average annual grain production was 2108, 2683, 3162, 3459, 3382, and 3411 kg ha^{-1} for the above N rates, respectively. This included 1 yr of zero yield, when a corn crop was lost due to hail, and 1 yr of low barley yields due to heat and water stress at anthesis. This compares with annualized winter wheat yields of 1381 kg ha^{-1} yr^{-1} produced in an adjacent crop–fallow system with adequate applied N. Application of 67 kg N ha^{-1} each crop year or, based on regression analysis, an average available N (soil plus fertilizer) supply of 170 kg N ha^{-1} was sufficient to optimize (95% of maximum) grain yields over the 8-yr period. These results indicate a high potential for adopting more intensive dryland cropping systems in the Central Great Plains to increase water use efficiency and better maintain soil quality.

UNDER RAINFED (DRYLAND) AGRICULTURE, plant available water is limited and highly variable in the semiarid central Great Plains (Greb, 1979; Greb et al., 1974, 1979). No-till and reduced tillage systems have improved soil water storage efficiencies during summer fallow periods (Smika and Unger, 1986; Greb et al., 1974, 1979). Increases in winter wheat yields have been observed with implementation of these water conservation practices (Greb, 1979, 1983; Greb et al., 1979). The traditional winter wheat–fallow system of farming, using conventional tillage practices, has utilized plant available water supplies very inefficiently and contributed to development of saline seeps in the Great Plains (Halvorson, 1990a; Berg et al., 1991). Thus, if no-till and/or reduced tillage practices are adopted, the potential for accelerated saline seep development is increased unless the water is used by crops. More intensive cropping systems than the traditional crop–fallow system are therefore needed to make more efficient use of water supplies under dryland conditions in the Great Plains (Black et al., 1981; Halvorson, 1988).

The need for N fertilization in the 1950s and 1960s in the Central Great Plains was small, because of the inherently high level of available mineralizable N generated from soils during the summer fallow period (Greb et al., 1974). Studies conducted since the 1970s indicate that N responses by winter wheat grown on summer-fallowed land can be expected (Goos et al., 1982; Halvorson, 1990b; Westfall and Peterson, 1990; Nielsen and Halvorson, 1991). Nitrogen mineralization capacity of soils in this region have declined with time and yields have increased; thus, responses to N fertilization occur on almost all soils.

Utilization of reduced tillage systems to conserve more water for crop production makes it feasible to crop more frequently than with a conventional crop–fallow system in the Central Great Plains area (Anderson et al., 1986; Halvorson, 1990b; Peterson et al., 1990; Shanahan et al., 1988). With an increase in cropping frequency plus the lower N mineralization capacity of soils, additional N will be needed in the Central Great Plains to maintain sustainable yield levels. Nitrogen management information on crops grown within more intensive dryland cropping systems is limited for the Central Great Plains area. The study objective was to determine the N fertility requirements for optimum barley, corn, and winter wheat grain yields under dryland, annual cropping conditions of the Central Great Plains.

MATERIALS AND METHODS

The experiment was conducted on a Weld silt loam soil (montmorillonitic, mesic Aridic Paleustoll) at the Central Great Plains Research Station, Akron, Colorado, with a pH of 7.2 and organic matter level of 12 g kg^{-1} (0- to 15-cm depth). The initial $NaHCO_3$-extractable soil P level (0- to 15-cm depth) was 22 mg P kg^{-1} soil, considered a high soil test P level in Colorado. A randomized, complete block design with four replications was used with N rates of 0, 22, 45, 67, 90, and 134 kg N ha^{-1}. The 134 kg N ha^{-1} rate was 179 kg N ha^{-1} the first two crop years of the study (1984 and 1985). This N rate was reduced because of a significant increase in residual soil NO_3–N. Nitrogen rates were reduced 50% in 1988 because of crop failure caused by hail resulted in no measurable N removal in 1987. Nitrogen, as NH_4NO_3, was broadcast with no mechanical incorporation at planting. Plot size was 6.1 by 12.2 m. A no-till system of farming was used with chemical control of weeds between crops and within the growing crop using appropriate contact and residual herbicides. The plot area was summer-fallowed in 1983 using stubble mulch tillage.

A spring barley–corn rotation was generally followed, except when climatic events (hail storm) allowed planting of winter wheat rather than spring barley. 'Otis' barley was seeded about 1 April at a seeding rate of 89 kg ha^{-1}. Corn (hybrid Pioneer 3732) was planted at a population of $\approx$30 000 seeds ha^{-1} about 1 May each year. 'Tam 107' winter wheat was planted in mid-September 1987, because the 1987 corn crop was destroyed by hail on 4 August. Table 1 summarizes the seeding, harvest, and other management factors for each year. Precipitation was monitored at an adjacent weather station.

Soil samples were collected before planting and after grain harvest to assess soil NO_3–N and gravimetric soil water levels. Samples were collected from the 0- to 15-cm, 15- to 30-cn, 30-to 60-cm, 60- to 90-cm, 90- to 120-cm, and 120- to 180-cm soil depths. Soil NO_3–N was determined by a cadmium reduction method with an autoanalyzer (Technicon, 1973). Gravimetric soil water content was calculated using an average soil bulk density of 1.34 g cm^{-3}. Table 2 summarizes the estimated evapotranspiration (ET), average soil water use over N rates (0- to 180-cm soil depth), growing season precipitation (planting to harvest), cropping system precipitation (harvest of previous crop

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Table 1. Summary of crop planted, planting date, seeding rate, drill type, harvest date, and area harvested each crop year.

Year	Crop	Planting date	Seeding rate	Drill†	Harvest date	Harvest area
						m^{-2}
1984	Barley	16 Apr. 1984	81 kg ha^{-1}	Noble, hoe	23 July 1984	3
1985	Corn	4 May 1985	32 276 seeds ha^{-1}	Buffalo	25 Sept. 1985	28
1986	Barley	25 Mar. 1986	84 kg ha^{-1}	Haybuster, hoe	9 July 1986	30
1987	Corn	28 Apr. 1987	28 272 seeds ha^{-1}	Buffalo	–‡	–
1988	Winter wheat	14 Sept. 1987	67 kg ha^{-1}	Haybuster, hoe	15 July 1988	30
1989	Corn	1 May 1989	29 760 seeds ha^{-1}	Buffalo	26 Oct. 1989	37
1990	Barley	27 Mar. 1990	89 kg ha^{-1}	Haybuster, disk	7 July 1990	18.5
1991	Corn	9 May 1991	36 000 seeds ha^{-1}	Buffalo	9 Oct. 1991	18.5

† Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or the USDA-ARS.

‡ The 1987 corn crop was lost to hail.

to harvest of current crop), and total annual precipitation (January to December). Estimated ET was the sum of soil water use by the crop and growing season precipitation.

All grain yields were determined by harvesting a minimum of a 1.5- by 12-m area from each plot with a plot combine, except for hand harvesting in 1984. Grain samples were cleaned before weighing for yield determination. All statistical comparisons are at the 0.05 probability level unless otherwise stated. Analyses of variance were performed using MSTAT-C computer program from Michigan State University (Freed et al., 1989). Regression analyses were used to evaluate N rate response data if the analysis of variance indicated a significant *F*-value at the 0.05 probability level.

RESULTS AND DISCUSSION

Grain yields were significantly increased each year by N application (Fig. 1). A significant year × N interaction occurred because of changing crops and climatic conditions each year. Therefore, yield responses to N application are shown individually for each year. Spring barley yields were optimized (≈95% of maximum) with the application of 67 kg N ha^{-1} in 1984 and 1990, whereas 90 kg N ha^{-1} was required in 1986. Winter wheat yields were optimized by the application of 45 kg N ha^{-1} in 1988. Corn yields were optimized at 90 kg N ha^{-1} in 1985 and 1989, and at 67 kg N ha^{-1} in 1991.

Regression equations expressing yearly yield response to N application rate are shown in Table 3. Average annual grain yields from all crops over the 8 yr of this study, including 1987 when the corn was hailed out (zero yield), were 2108, 2683, 3162, 3459, 3382, and 3411 kg ha^{-1} for the 0, 22, 45, 67, 90, and 134 kg N ha^{-1} treatments, respectively. This compares with an annualized winter wheat yield of 1381 kg ha^{-1} yr^{-1} produced from 1984 to 1992 in an adjacent no-till crop-fallow system receiving 56 kg N ha^{-1}.

Annual residual soil NO_3-N (0- to 180-cm depth) levels at planting and before N application as a function of N fertilizer rate are shown in Fig. 2. Residual soil NO_3-N levels did not tend to increase until N rates exceeded 90 kg N ha^{-1}. At the highest N rate, residual soil NO_3-N in the 0- to 180-cm soil depth exceeded 350 kg N ha^{-1} in 1988, 1990, and 1991. The distribution of the residual soil NO_3-N in the root zone for 19 Mar. 1990 is shown in Fig. 3. At the 22 kg N ha^{-1} rate, the residual soil NO_3-N was essentially the same as the zero N rate. As N rate increased, the residual soil NO_3-N increased in the 15- to 90-cm soil depth. The highest N rate had a significant accumulation of residual NO_3-N in the 30- to 90-cm soil depth. Only at the highest N rate were there indications of potential leaching of NO_3-N below the root zone of the crops grown.

Residual soil NO_3-N varied each crop year depending on N rate and N use by previous crop (Fig. 2). This is clearly demonstrated by the high level of root zone NO_3-N at planting of the 1988 winter wheat crop in the fall of 1987 following the loss of the 1987 corn crop to hail in August. Therefore, to be realistic, grain yields need to be expressed as a function of soil plus fertilizer N (Fig. 4). Grain yields were near maximum most years when soil plus fertilizer N levels were in the range of 175 to 200 kg N ha^{-1}. Regression equations expressing the yearly grain yield response of each crop to soil plus fertilizer N level are reported in Table 3.

Because yields varied in relation to yearly climatic differ-

Table 2. Estimated evapotranspiration (ET), average soil water use, and growing season precipitation, cropping system precipitation (harvest of previous crop to harvest of current crop), and total annual precipitation (Jan.-Dec.).

Year	Crop	ET	Soil water use†	Precipitation‡ Growing season	Precipitation‡ Cropping system	Precipitation‡ Total annual
		cm				
1984	Barley	38.5	3.1	35.4	89.6	47.2
1985	Corn	43.7	12.9	30.8	59.0	45.5
1986	Barley	29.8	8.3	21.5	31.3	33.6
1987	Corn	–§	–	–	41.4	50.1
1988	Winter wheat	36.8	11.8	25.0	49.1	41.3
1989	Corn	34.0	4.5	29.5	43.8	34.4
1990	Barley	27.1	6.0	21.1	27.8	53.0
1991	Corn	44.9	17.1	27.8	58.1	38.8

† Average soil water use over N rate, 0- to 180-cm soil depth.

‡ Average long-term (83 yr) precipitation = 42.0 cm.

§ Not determined.

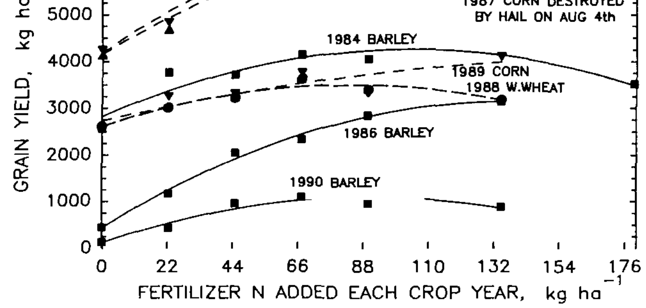

Fig. 1. Grain yields for each crop from 1984 through 1991 as a function of N rate under dryland, annual cropping at Akron, CO.

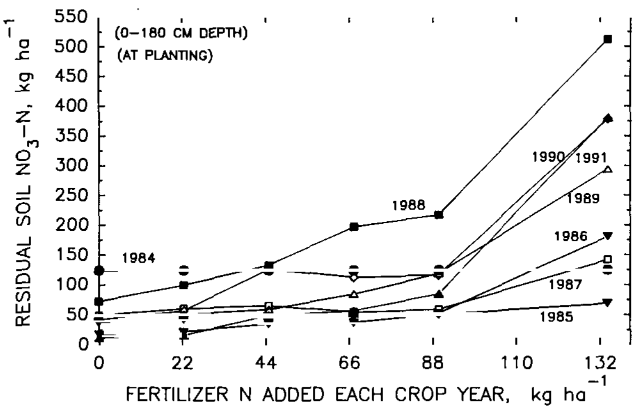

Fig. 2. Residual soil NO_3-N (0- to 180-cm soil depth) level by year at planting as a function of N fertilizer rate from 1984 through 1991.

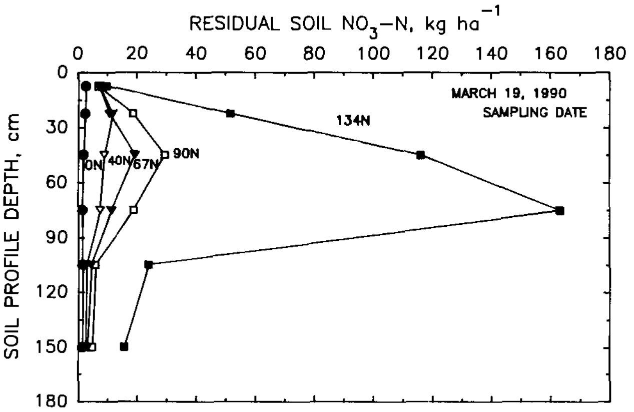

Fig. 3. Residual soil NO_3-N profiles in the spring of 1990 as a function of annual N application rate.

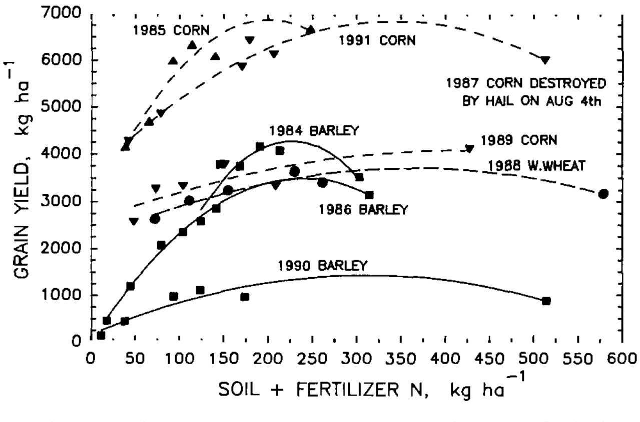

Fig. 4. Grain yields from 1984 through 1991 as a function of soil (0- to 180-cm depth) plus fertilizer N applied under dryland, annual cropping at Akron, CO.

Table 3. Summary of regression analyses of grain yield vs. N fertilizer added and grain yield vs. soil NO_3-N (0- to 180-cm depth) plus fertilizer N added for each crop year.

Crop	Year	Regression equation	r^2
Y = grain yield, kg ha^{-1}; X = fertilizer N added, kg ha^{-1}			
Barley	1984	$Y = 2817 + 28.1X - 0.14X^2$	0.84
Corn	1985	$Y = 4158 + 38.1X - 0.14X^2$	0.91
Barley	1986	$Y = 435 + 39.8X - 0.15X^2$	0.99
Corn	1987	–†	–
Winter wheat	1988	$Y = 2611 + 21.5X - 0.13X^2$	0.93
Corn	1989	$Y = 2732 + 14.8X - 0.04X^2$	0.78
Barley	1990	$Y = 120 + 21.8X - 0.12X^2$	0.93
Corn	1991	$Y = 4175 + 46.0X - 0.24X^2$	0.95
Y = grain yield, kg ha^{-1}; X = soil N plus fertilizer N added, kg ha^{-1}			
Barley	1984	$Y = -2757 + 61.9X - 0.14X^2$	0.84
Corn	1985	$Y = 2695 + 41.4X - 0.10X^2$	0.92
Barley	1986	$Y = 0.27 + 29.2X - 0.06X^2$	0.99
Corn	1987	–	–
Winter wheat	1988	$Y = 2156 + 8.5X - 0.01X^2$	0.89
Corn	1989	$Y = 2550 + 7.4X - 0.01X^2$	0.71
Barley	1990	$Y = 148 + 8.2X - 0.01X^2$	0.84
Corn	1991	$Y = 3496 + 19.5X - 0.03X^2$	0.95

† The 1987 corn crop was lost to hail.

ences and crop type, data for each crop year were expressed on a relative yield (RY) basis (i.e., all yields expressed as a percentage of the N treatment with the highest yield in a given year) to normalize the response to N fertilization. The relative yield potentials for spring barley, corn, and winter wheat as a function of soil plus fertilizer N level are shown in Fig. 5, 6, and 7, respectively. The relative yield data for soil plus fertilizer N levels greater than that needed to achieve maximum yield (100%) are not shown. Regressions were then used to express the response of each crop (grain yield) over years to soil plus fertilizer N level. Thus, a soil plus fertilizer N level of ≈150 kg N ha^{-1} was needed to achieve a 95% yield potential for spring barley under the conditions of this study (Fig. 5). The soil plus fertilizer N level needed to achieve 95% yield potential for corn and winter wheat was ≈190 kg N ha^{-1} (Fig. 6 and 7). Plotting the relative yield level of all crops over all years as a function of soil plus fertilizer N level shows that a total estimated N requirement of 170 kg N ha^{-1} was needed to optimize (95% of maximum) yield potentials at this dryland site (Fig. 8). Estimated total N required per unit of grain yield at the 95% yield level averaged 40 g N kg^{-1} grain for barley (excludes 1990), 34 g N kg^{-1} for corn, and 56 g N kg^{-1} for winter wheat.

SUMMARY

This study demonstrates the potential for obtaining acceptable grain yields within an annual, no-till dryland cropping system in the Central Great Plains when fertilized with adequate N. Addition of 67 kg N ha^{-1} to each crop resulted in the maximum average grain production over the 8-yr period. Application of >90 kg N ha^{-1} resulted in a significant increase in residual soil NO_3-N within the

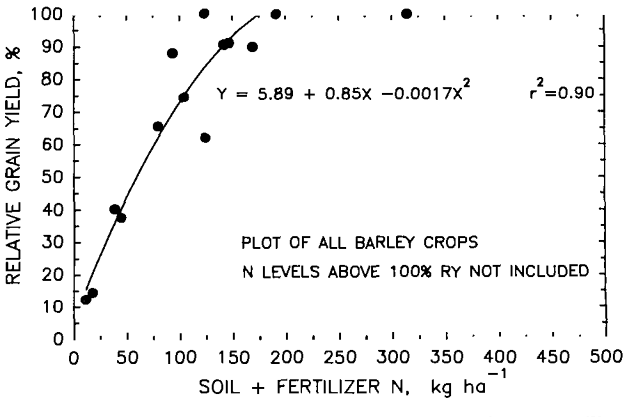

Fig. 5. Relative barley grain yield as a function of soil plus fertilizer N for the years 1984, 1986, and 1990 (RY = relative yield).

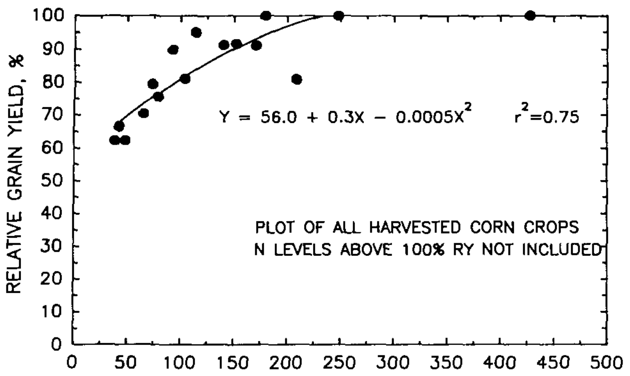

Fig. 6. Relative corn grain yield as a function of soil plus fertilizer N for the years 1985, 1989, and 1991 (RY = relative yield).

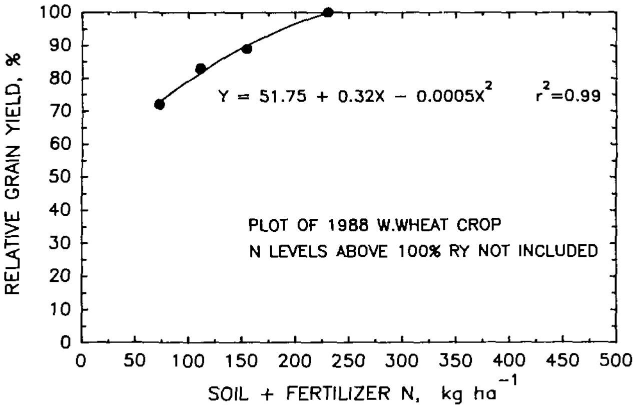

Fig. 7. Relative winter wheat grain yield as a function of soil plus fertilizer N for 1988 (RY = relative yield).

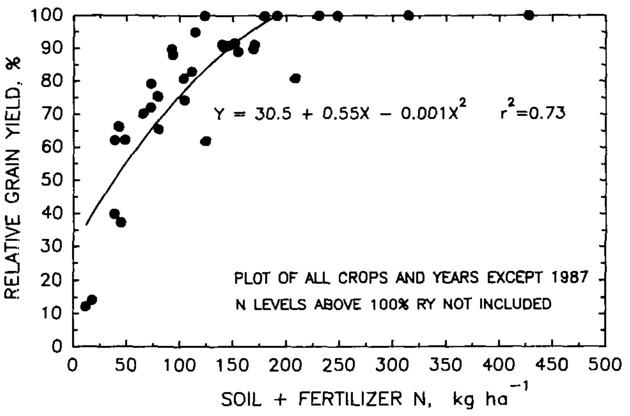

Fig. 8. Relative grain yield of all crops grown over all years as a function of soil plus fertilizer N (RY = relative yield).

root zone. The total available N requirements of spring barley, winter wheat, and corn were estimated to be 150, 190, and 190 kg N ha^{-1} for optimum yield (95% relative yield), respectively. Thus, fertilizer N needs can be estimated by testing the soil profile for residual soil NO_3-N before N application. The value of soil testing is demonstrated by the detection of the large increase in residual root zone NO_3-N in the fall of 1987 following the loss of the 1987 corn crop to hail. Thus, reducing the N application rate 50% for the 1988 winter wheat crop helped prevent or reduce further buildup of NO_3-N in the root zone. Application of only that amount of N needed to optimize yield will reduce the buildup of residual soil NO_3-N in the root zone and decrease the risk of groundwater contamination. This is demonstrated by the distribution of soil NO_3-N in the root zone on 19 Mar. 1990 (Fig. 3). As the annual rate of N fertilizer application increased, the level of residual soil NO_3-N in the 0- to 120-cm profile increased with a maximum accumulation (peak) in the 30- to 90-cm depth.

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