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Effect of Nitrogen-Fertilized Wheat on Water Loss From Soils of the Barnes Catena

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Differences in yield of spring wheat grown on different soils of a catena in the same field are commonly observed in semiarid and subhumid regions. Many factors can contribute to these differences, but two of the most likely are water supply and available nutrient level. Water supply can differ among soils receiving the same amount of precipitation because runoff may occur from some and runon to others. Water supply can differ because soils may not have the same drainage characteristics or available water capacity. The effect of water supply on wheat yields has been shown in numerous studies (Bauer, 1972). In general, these are positively correlated. But increase in yield with increase in water supply is greater with adequate soil fertility level than if there is a nutrient deficiency (Bauer and Young, 1966).

Organic matter is a primary indigenous source of nutrients for plants. The rate of decomposition of organic matter and the rate of transformation of nutrients from unavailable to forms available to plants is affected by soil chemical and physical properties. These properties may differ enough among soils in a catena to effect a difference in available nutrient supply. Soil properties also affect the rate of transformation of available nutrients, as applied in fertilizers, to unavailable forms.

Organic matter content differs among soils of the grasslands. The thickness of the mollic epipedon is a key diagnostic criterion in classification of soils in which organic matter accumulation is a dominant pedogenic process (Buol, Hole, and McCracken, 1973). The concentration of organic matter of the A_1 horizon, however, may not necessarily differ among these soils.

Water for growing crops often is of limited supply in North Dakota. Soils, too, often are deficient in available nitrogen, especially following a non-leguminous crop. A better understanding of soil factors contributing to crop yield differences among soils is important from the standpoint of optimizing fertilization and cultural practices. The trials reported here were conducted to determine if the influence of topographic position caused variations in wheat yields because of differences in available nitrogen and/or water regime.

LITERATURE REVIEW

Rennie and Clayton (1960) showed the degree to which wheat yields and yield responses to phosphorus fertilization occurred within the catenary groups of the Weyburn and Oxbow soil associations. Wheat grain yields were closely related to pedogenic characteristics used to classify these soils. They concluded that any inference drawn from data obtained from an experiment, applied in most instances only to the soil type on which it was conducted.

Wheat yields and wheat yield responses to a given phosphorus fertilization rate averaged more on fallowed Chernozem (Udic Borolls) or Chernozem-like (Udorthentic Borolls) soils than on Chestnut (Typic Borolls) soils in North Dakota, even though phosphorus soil test levels were identical (Bauer et al., 1966). Within each great soil group, plant responses to fertilization were less on soils with thick A_1 horizons (>12 inches) than on soils with thin A_1 horizons even though soil test ratings were identical. Responses were also less on coarse and moderately coarse textured soils than on medium textured soils.

In a literature review, Ferguson and Gorby (1967) categorized factors influencing responses of wheat to phosphorus fertilization to include weather, inherent soil fertility, geographic variation, soluble salts, and soil morphology. From a study conducted on Black Chernozemic soils occurring in catenary sequence, Ferguson and Gorby (1967) attributed differences in wheat yield response to phosphorus fertilization; to microclimatic factors such as shape, size, and aspect of the drainage area; to seasonal and yearly fluctuations in meteorologic factors; and, in part, to the effect of the microclimatic and meteorologic factors on competitive ability of weeds. For maximum profit, the soil in the lowest topographic position of the Miniota association (Gleyed-Calcareous Black) required about twice as much phosphorus fertilizer as soil in the better drained (Orthic-Black) positions. Similar results were obtained in the Carroll soil association. Within the Waskada association, an interaction between plant response to phosphorus fertilization and topographic position was obtained only one year in four.

Spratt and McIver (1972) conducted 15 experiments on summer fallow on 8 to 12 per cent slopes on an association of Black Chernozemic and Gleysolic soils developed on calcareous glacial till. Fertilizer phosphorus increased wheat grain yields 20 to 30 per cent on the crown, upper slopes, and midslopes. The increase was less than 10 per cent on the lower slopes and depressions. Yields were increased by the 9-pound per acre phosphorus (P) rate, with no additional increase with 17 pounds P per acre. They concluded that basic pedologic differences in soils of the catena and microclimatologic factors affected yields more than fertility.

In a closed drainage system of the Barnes catena, Malo and Worcester (1974) obtained differences among soils in sunflower emergence percentage, height, and yield. Yields were lowest on the lowest landscape position.

Field phytometers were used by Radomski, Madany, and Nozynski (1977) from 1967 to 1973 to determine the relationships between microclimate and wheat and barley yields. The phytometers, 1.5 meters deep (about 5 feet) were all filled with the same soil material and buried at the crest, mid-slope, and the foot of a 28 per cent southern aspect slope. Grain yield differences due to slope positions were negatively correlated with minimal air temperature at 50 cm height (20 inches), positively correlated with temperature amplitude at the 50 cm height, and soil water in the phytometers. (Presumably, there were differences in soil water content during the experiment due to differences in water evaporation rate associated with topographic position.) Production at the foot of the slope position was larger than at mid-slope, which in turn was larger than at the crest. Yield differences were larger in "arid years" than in "moist years." The lower yields at the crest position were attributed to lower average soil water content in the phytometers over the period of active vegetative growth.

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Numerous soil fertility trials with wheat have been conducted on soils of the Barnes catena in North Dakota. However, no direct yield response comparisons were made among these soils in any one year within a field or at a single site. Soils of the Barnes catena occupy the major portion of the till plain. The till plain comprises about 80 per cent of the Drift Prairie physiographic area of 25,000 square miles (Omodt et al., 1968).

MATERIALS AND METHODS

Four soils of the Barnes catena were located in one field on the Howard Hanson farm near Lisbon, ND. These were Buse (Udorthentic Haploboroll), Barnes (Udic Haploboroll), Svea (Pachic Udic Haploboroll) and Hamerly (Aeric Calciaquoll). The landscape position in which these soils occur is depicted in Figure 1. Waldron hard red spring wheat (*Triticum aestivum* L.) was grown on contiguous Buse, Barnes, and Svea loam in 1970 and 1972 and on contiguous Barnes, Svea and Hamerly loam in 1971.

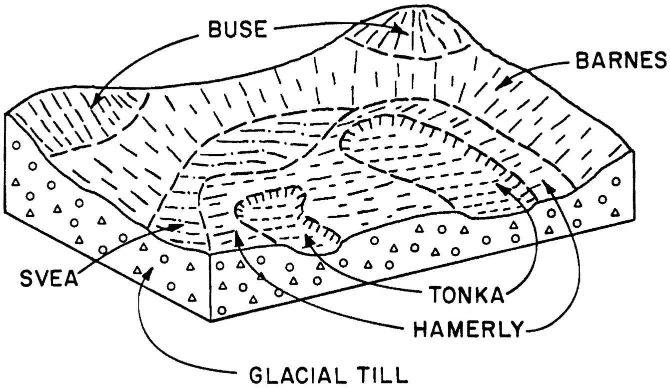

Figure 1. Position on the landscape of soils of the Barnes catena.

Relief, or difference in elevation of the site, was about 15 feet. Buse occupied the highest landscape position on the convex crest of a low knoll. Barnes was immediately below Buse on a plane and slightly convex backslope with a 5 per cent gradient. Svea was immediately below Barnes on a gently concave footslope of 1 to 3 per cent. Hamerly, adjoined by Svea, was on gentle convex slopes of about 2 per cent near a drainageway and a shallow depression. Elevation decreased from south to north.

The preceding year's crop, all years, was spring wheat. Soils were moldboard plowed in the fall and field cultivated shortly before spring seeding. Ammonium nitrate fertilizer (34-0-0) was broadcast after planting at four rates, each rate replicated four times. Nitrogen rates applied varied with soil type in 1970, and with years (see tables in text). Each year about 22 pounds phosphorus (P) per acre and 22 pounds potassium (K) per acre were applied by drill attachment in the row with the seed. The wheat was seeded with a double disk drill in 7-inch spaced rows at a rate of about one million viable seeds per acre. Each subplot was 35 to 40 feet long and 6.5 feet wide. Seeding dates were May 2, 1970, April 23, 1971, and April 28, 1972.

Steel electrical-conduit tubes were installed to 7 feet to permit access of a neutron source to monitor soil water (Stone, Kirkham and Read, 1955). These access tubes were placed in each of two N treatments, no fertilizer N and the third highest rate. In 1970 and 1971, one tube was placed in each of the two N treatments in each of three replications of each soil, a total of 18 tubes each year. In 1972, two tubes were placed in each of the two N treatments in each of two replications of each soil, a total of 24 tubes. Soil water was monitored to 6 feet on five dates in 1970, three dates in 1971, and eight dates in 1972 (see tables in text). Precipitation data reported are those recorded by the Environmental Sciences Service Administration weather station at the city of Lisbon, 4 miles south of the site (ESSA, 1970, 1971, 1972).

In 1970 and 1971, soil temperatures were sensed with copper-constantan thermocouples placed in one replication of each soil treated with the third largest fertilizer N rate (three thermocouples). Temperatures were recorded on the same day as soil water was monitored.

Soil samples were removed in 6-inch increments from the upper foot, and in 12-inch increments from the next 5 feet, in treatments where access tubes were installed. The samples were placed in plastic bags to prevent water loss while enroute to the laboratory. Measurements on these samples were bulk density, field-moist soil water content, water content at 15 atmospheres soil water tension, and nitrate concentration. Nitrate concentration was determined with a nitrate-specific electrode (Dahnke, 1971).

Available water capacity was calculated from bulk density and water content at 15 atmosphere soil water tension measured on samples from the trials, and water content at field capacity of these soils as determined by Cassel and Sweeney (1974).

Broadleaf weeds were controlled with herbicides applied with aerial applicators. The herbicides were applied at the same time that Mr. Hanson's wheat fields were sprayed.

Plant population was determined prior to tillering on three 6-foot-long rows seeded by the same drill opener in each subplot. The number of heads was counted at harvest on this same portion of row in 1971. Plant height, to top of the heads, was measured just before harvest in 1970 and 1972.

Plant samples from four 1-square-yard areas were cut with hand-wielded sickles for grain yield measurements in 1970 and threshed with a Vogel thresher. In 1971 and 1972, the plants were harvested from essentially the entire subplot area with a small plot combine. In 1972 the straw was caught in a box mounted to the combine to obtain straw yield information.

Nitrogen concentration in grain was measured by a Kjeldahl method (Bremner, 1965). The factor 5.7 was used to convert N concentration in grain to protein.

One thousand kernels were removed with an electronic counter from subsamples of the 1971 and 1972 grain and weighed.

The number of kernels per head in 1971 was calculated from data of number of heads per unit area at harvest, the grain yield, and 1000-kernel weight.

Data were analyzed as a split block (LeClerg, Leonard and Clark, 1962).

RESULTS AND DISCUSSION

The effect of soil or fertilizer N rate on the performance of Waldron wheat was not consistent from year to year (Table 1). Responses to fertilizer N rates occurred more often than responses to kind of soil. Except for a soil-by-fertilizer N interaction for grain yield in 1970 and grain protein in 1971, response of wheat to the fertilizer N rates was the same among soils in a given year.

Table 1. Summary of measurements and significance of variance sources for nitrogen fertilization trials conducted on a Barnes Catena, 1970 to 1972.

Year	Measurement	Variance source		
		Soil (S)	Nitrogen (N) rate	S x N
1970	Seedling no. (6/3)[4]	ns[1]	ns	ns
	Height (harvest)	ns	**[3]	ns
	Grain yield	ns	ns	**
	Test weight	ns	**	ns
1971	Seedling no. (5/19)[4]	ns	ns	ns
	Heads (harvest)	ns	**	ns
	Grain yield	ns	**	ns
	Test weight	**	**	ns
	Protein per cent	ns	**	*
	Kernel weight	**	ns	ns
	Kernels/head	*[2]	*	ns
1972	Seedling no. (5/26)[4]	*	ns	ns
	Height (harvest)	*	**	ns
	Grain yield	**	**	ns
	Straw yield	*	**	ns
	Test weight	ns	**	ns
	Protein per cent	**	**	ns
	Kernel weight	**	**	ns

[1] Not significant at the 5% probability level.
[2] Significant at the 5% probability level.
[3] Significant at the 1% probability level.
[4] Month/day

Seedling Population And Soil Water At Seeding

Plant population is an important factor affecting grain yield. From multiple regression analysis of data from a 4-year study on dryland and under irrigation (Bauer, unpublished data), the number of heads at harvest accounted for about 78 per cent of the difference in grain yield among yield components of spring wheat cultivars grown with several fertilizer N rates. The other two components of yield, kernels per head and kernel weight, accounted for the remainder. While tillering will compensate for low seedling population in some cases, not all tillers produce heads nor does a tiller-head produce as many kernels as the main-stem heads (Power and Alessi, 1978). Waldron wheat, grown in one dryland and two irrigated trials in 1971 (Bauer, unpublished data), averaged 2 to 2.5 tillers per plant. Of these tillers, average per cent that produced heads ranged from 55 to 68. Power and Alessi (1978) reported the first tiller-head contributed about 22 to 32 per cent to the final grain yield. Each head of the succeedingly-produced tiller contributed progressively less. The main-stem head contributed the largest amount, 32 to 66 per cent of the final grain yield, the percentage generally decreasing with an increase in fertilizer N rates producing yield increases.

Available soil water supply in the seed-placement and seedling rooting zone can affect seedling establishment. Lindstrom (1973) reported an 80 per cent emergence of two winter wheats at soil water potential down to about -10 atmospheres. Below this potential, emergence percentage was much less.

In our experiments seedling population differed among soils in 1972 only. The amount of available water present in the uppermost foot of soil, when the first soil water content measurement was made 5 days after seeding in 1972 was 1.16, 1.42, and 2.18 inches respectively, for Buse, Barnes, and Svea. These 1972 quantities were larger by at least 0.37 inches than in any soil in 1970 and 1971, when the first water content measurements were made 23 days after seeding and on the day of seeding, respectively (Tables 2, 3, and 4). Seedling number per 18 feet of row was 184, 205, and 255 respectively on Buse, Barnes, and Svea in 1972. The seedling population in 1970 and 1971, average of all soils, was 154 and 180 per 18 feet of row, respectively (Appendix Tables 1, 2, and 3).

The available water content in the uppermost foot of soil affected seedling establishment in 1972, since the largest population was established on the soil with the largest available water content. The available water content of Buse was about 50 per cent of field capacity while in Svea it was near field capacity.

The average seedling population was 180 per 18 feet of row in 1971, approximately the same as the population of 184 on Buse in 1972, even though available water content was lower at the first measurement date in 1971 than in 1972. However, about an inch of rainfall was received within 5 days of seeding in 1971 (Appendix Table 5), which, presumably, increased the soil water supply in the upper foot of soil. About an inch of rainfall was received within 8 days after seeding in 1972 (Appendix Table 6), but this amount, even if all entered the soil, did not bring the available water content of Buse to that of Svea.

Average seedling population on Barnes and Svea in 1970 was 158 per 18 feet of row. The population on these two soils in 1971 was 185 on the same measured area, but the available water content was about 0.27 inches more in 1970. However, the first date of soil water measurement in 1970 was 23 days after seeding. This is considered to be too long a period after seeding to make meaningful comparisons to other years.

Soil Water Loss And Crop Performance

Soil water losses or gains to a depth of 6 feet are reported (a) as changes between two successive measurement dates during the growing season (Tables 5, 6, and 7), and (b) as the difference between the measurement made on, or closest to, seeding and harvest dates (Table 8). The water losses that occurred are attributed to direct evaporation from soil and removal by plant roots. However, loss by deep percolation may also have occurred.

1970

The amount of water loss or gain in each foot of soil between two successive periods of measurement and the soil depth to which loss occurred usually differed among soils and with fertilizer N rate. The net loss between May 25 and June 12 was only from the uppermost foot and ranged from 0.54 inch from Buse to 0.92 inch from N-fertilized Svea. Available water content was increased below the 2-foot depth from 3.2 inches rain which fell during the period (Appendix Table 4). But by June 30, about at wheat heading stage, Feeke's scale 10.1 (Large, 1954), net water loss was to the 6-, 4-, and 3-foot depth of Buse, Barnes and Svea, respectively where no fertilizer N was applied, amounting to 1.32, 0.81, and 0.74 inches, respectively. With N fertilization, net water loss was to the 6-foot depth from Buse and Barnes and to the 4-foot depth from Svea, amounting to 1.51, 1.54, and 0.67 inches, respectively.

From July 1 to July 15 net water loss was to the 6-foot depth on Buse and Barnes where no fertilizer N was applied, but only the 3-foot depth from Svea, amounting to 2.11, 1.30, and 1.10 inches, respectively. With N fertilization, loss was to the 5-foot depth of all soils, amounting to 1.86, 1.42, and 1.22 inches from Buse, Barnes and Svea, respectively. From July 16 to July 31, net water loss was 1.73 inches from Buse where no fertilizer N was applied, but loss from the same fertilization treatment was only 0.57 and 0.97 inches from Barnes and Svea, respectively. With N fertilization, net loss was 1.26

Table 2. Available soil water to 6 feet in three soils fertilized with two fertilizer nitrogen rates, on several dates in 1970.[1]

			Soil depth (feet)					
Date	Soil	N rate	0-1	1-2	2-3	3-4	4-5	5-6
mo/day		lbs/ac			inches water			
May 25[2]	Buse	0	0.36	0.81	1.21	1.59	1.81	2.49
		70	0.32	0.76	0.36	0.98	1.52	1.38
	Barnes	0	0.64	0.96	1.98	2.80	2.79	3.14
		60	0.67	1.24	1.69	1.99	2.93	2.78
	Svea	0	0.84	0.84	1.58	2.04	2.68	2.75
		40	0.74	1.20	2.17	2.36	3.40	2.27
June 12	Buse	0	-0.20[3]	0.82	1.52	2.08	2.07	2.99
		70	-0.22	0.78	0.81	1.31	1.83	1.79
	Barnes	0	-0.07	1.19	2.27	3.19	3.24	3.62
		60	0.07	1.66	1.91	2.57	3.30	3.16
	Svea	0	0.25	1.24	2.37	2.50	3.07	3.07
		40	-0.18	1.23	2.59	2.72	3.68	2.65
June 30	Buse	0	-0.33	0.56	1.19	1.73	2.02	2.79
		70	-0.51	0.49	0.28	1.16	1.76	1.68
	Barnes	0	-0.35	0.78	2.20	3.04	3.20	3.76
		60	-0.30	1.18	1.74	2.37	3.18	2.99
	Svea	0	-0.08	1.04	2.30	2.36	3.13	3.24
		40	-0.47	0.93	2.51	2.73	3.84	1.96
July 15	Buse	0	-0.57	-0.06	0.71	1.41	1.81	2.55
		70	-0.70	-0.15	-0.28	0.86	1.59	1.80
	Barnes	0	-0.63	0.34	1.96	2.84	3.19	3.63
		60	-0.47	0.71	1.31	2.17	3.03	2.94
	Svea	0	-0.56	0.51	2.21	2.36	3.13	3.20
		40	-0.82	0.55	2.50	2.65	3.44	2.74
July 31	Buse	0	-0.72	-0.24	0.29	0.63	1.61	2.95
		70	-0.77	-0.09	-0.43	0.22	1.41	1.52
	Barnes	0	-0.55	0.39	1.79	2.60	3.00	3.43
		60	-0.50	0.46	1.03	1.88	2.83	2.71
	Svea	0	-0.53	0.29	2.02	2.22	2.93	2.95
		40	-0.67	0.60	2.23	2.55	3.32	2.64

[1] Average of three holes per treatment per soil.

[2] Soil water measurement began 23 days after seeding.

[3] The minus sign (-) means that soil water content, in the amount indicated, was depleted to less than the content at the permanent wilting point.

Table 3. Available soil water to 6 feet in three soils fertilized with two fertilizer nitrogen rates, on three dates in 1971.[1]

			Soil depth (feet)					
Date	Soil	N rate	0-1	1-2	2-3	3-4	4-5	5-6
mo/day		lbs/ac			inches water			
April 23[2]	Barnes	0	0.33	1.36	3.12	2.62	3.25	3.43
		40	0.55	2.14	3.43	2.61	2.88	2.84
	Svea	0	0.29	1.36	1.55	2.03	1.70	1.82
		40	0.64	1.77	2.18	2.30	1.89	2.29
	Hamerly	0	-0.60[3]	0.36	0.60	1.25	1.97	2.05
		40	-0.21	0.67	1.45	1.52	2.10	1.98
June 16	Barnes	0	0.01	1.42	2.76	2.44	3.60	3.79
		40	0.15	1.98	2.59	2.62	3.18	3.14
	Svea	0	-0.12	1.49	1.48	1.78	1.81	1.82
		40	0.13	2.02	1.57	2.08	2.27	2.87
	Hamerly	0	-0.56	0.67	0.61	1.26	2.15	2.21
		40	-0.38	0.77	1.57	1.75	2.38	2.17
August 5	Barnes	0	-0.43	1.48	3.35	3.29	4.55	5.34
		40	-0.62	2.20	3.23	3.48	4.14	4.70
	Svea	0	-0.55	1.63	1.96	1.86	2.59	2.53
		40	-0.29	2.60	2.20	2.80	2.75	3.88
	Hamerly	0	-1.32	0.60	0.81	1.82	2.81	2.96
		40	-0.93	0.79	1.75	2.35	3.16	3.05

[1] Average of three holes per treatment per soil.

[2] Soil water measurement on same day as seeding.

[3] The minus sign (-) means that soil water content, in the amount indicated, was depleted to less than the content at the permanent wilting point.

Table 4. Available soil water to 6 feet in three soils fertilized with two fertilizer nitrogen rates, on several dates in 1972.[1]

			Soil depth (feet)					
Date	N rate	Soil	0-1	1-2	2-3	3-4	4-5	5-6
mo/day	lbs/ac				inches water			
May 2[2]	0	Buse	1.20	1.78	3.19	3.24	3.47	2.12
	100	Buse	1.12	1.24	2.47	2.24	2.62	2.51
	0	Barnes	1.50	1.68	3.47	2.62	2.68	3.29
	100	Barnes	1.34	1.20	3.09	3.11	2.73	3.13
	0	Svea	2.98	1.47	2.17	2.39	2.30	2.65
	100	Svea	2.78	1.56	2.03	2.38	3.10	3.05
May 18	0	Buse	1.61	2.06	3.69	3.66	4.03	2.99
	100	Buse	1.33	1.73	2.82	3.16	3.20	2.88
	0	Barnes	1.94	1.92	3.37	3.80	3.82	3.84
	100	Barnes	1.78	1.60	2.88	3.83	3.45	3.53
	0	Svea	3.79	2.29	2.50	2.88	2.83	2.96
	100	Svea	3.45	2.17	2.59	3.22	3.35	3.34
June 2	0	Buse	1.32	2.04	3.44	3.88	4.14	3.47
	100	Buse	1.15	1.45	2.61	3.16	3.53	3.44
	0	Barnes	1.66	1.78	2.97	3.68	3.98	3.32
	100	Barnes	1.43	1.33	2.46	3.69	3.43	3.70
	0	Svea	3.64	2.29	2.96	3.38	3.11	2.83
	100	Svea	3.34	2.34	3.32	3.45	3.41	3.33
June 15	0	Buse	0.47	1.34	2.83	3.46	3.83	3.22
	100	Buse	-0.02[3]	0.68	1.86	2.70	3.33	3.06
	0	Barnes	0.26	1.08	2.62	3.33	3.66	3.78
	100	Barnes	-0.05	0.69	2.11	2.87	3.42	3.33
	0	Svea	1.53	1.75	2.53	3.06	2.90	2.82
	100	Svea	0.50	1.63	2.59	3.01	3.26	3.30
June 30	0	Buse	0.19	0.97	2.58	3.38	3.99	3.14
	100	Buse	-0.09	0.32	1.52	2.41	3.45	2.98
	0	Barnes	0.12	0.59	2.31	3.22	3.61	3.76
	100	Barnes	-0.10	0.34	1.61	2.88	3.31	3.40
	0	Svea	0.55	1.09	2.56	2.70	2.82	2.69
	100	Svea	0.16	1.03	2.28	2.70	3.28	3.08
July 14	0	Buse	-0.09	0.59	1.91	3.02	3.73	2.72
	100	Buse	-0.16	0.11	1.05	2.60	3.07	2.72
	0	Barnes	-0.13	0.17	1.78	2.64	3.38	3.59
	100	Barnes	-0.18	0.11	1.01	2.35	3.03	3.19
	0	Svea	0.07	0.59	1.83	2.48	2.42	2.74
	100	Svea	-0.01	0.39	1.48	2.26	3.02	3.24
July 25	0	Buse	0.31	0.64	2.00	2.96	3.84	2.38
	100	Buse	0.58	0.18	1.00	2.00	3.04	2.79
	0	Barnes	0.32	0.22	1.69	2.59	3.10	3.47
	100	Barnes	0.67	0.19	1.09	2.21	2.94	3.15
	0	Svea	0.21	0.61	1.87	2.36	2.30	2.74
	100	Svea	-0.02	0.38	1.49	2.25	3.02	3.04
August 9	0	Buse	0.17	0.70	1.99	2.84	3.59	2.47
	100	Buse	0.05	0.18	1.03	2.06	2.99	2.67
	0	Barnes	0.02	0.33	1.73	2.60	3.00	3.31
	100	Barnes	0.16	0.31	1.12	2.23	3.01	3.22
	0	Svea	0.22	0.74	1.90	2.34	2.15	2.87
	100	Svea	-0.03	0.51	1.62	2.44	3.04	2.93

[1] Average of four holes per treatment per soil except three holes in Svea at 0 N rate for all dates and three holes in Barnes at 100 pound N rate on May 2, May 18, and June 2.

[2] Soil water measurement five days after seeding.

[3] The minus sign (-) means that soil water content, in the amount indicated, was depleted to less than the content at the permanent wilting point.

inches from Buse, essentially the same amount from Barnes as Buse, but only 0.39 inches from Svea. The July 16 to July 31 period was the only one in which water losses occurred to the 6-foot depth of Svea.

The net soil water loss, obtained by differences between two successive measurement dates and summed over the four periods, was 5.72, 3.39, and 3.40 inches from Buse, Barnes, and Svea, respectively, where no fertilizer N was applied, and 5.17, 4.84, and 3.20 inches, respectively, with N fertilization.

The net soil water loss determined by difference in soil water content to 6 feet between the first and last measurement dates was 3.75, 2.41, and 0.85 inches from Buse, Barnes, and Svea, respectively, where no fertilizer N was applied, and to 3.46, 2.89, and 1.55 inches, respectively with N fertilization. The reason a larger net water loss was measured from summation of losses over four periods than by difference between the first and last soil water

Table 5. Cumulative soil water loss between periods from spring wheat grown on three soils fertilized with two nitrogen rates, 1970.

			Soil depth (feet)					
Period	Soil	N rate	0-1	0-2	0-3	0-4	0-5	0-6
mo/day		lbs/ac			inches water			
5/25-6/12	Buse	0	-0.56[1]	-0.55	-0.24	0.25	0.51	1.01
		70	-0.54	-0.52	-0.07	0.26	0.57	0.98
	Barnes	0	-0.71	-0.48	-0.19	0.20	0.65	1.13
		60	-0.60	-0.18	0.04	0.62	0.99	1.37
	Svea	0	-0.59	-0.19	0.60	1.04	1.43	1.75
		40	-0.92	-0.88	-0.46	-0.11	0.17	0.55
6/13-6/30	Buse	0	-0.13	-0.39	-0.72	-1.07	-1.12	-1.32
		70	-0.29	-0.58	-1.11	-1.26	-1.33	-1.54
	Barnes	0	-0.28	-0.59	-0.66	-0.81	-0.85	-0.71
		60	-0.37	-0.85	-1.02	-1.22	-1.34	-1.51
	Svea	0	-0.33	-0.53	-0.60	-0.74	-0.68	-0.51
		40	-0.29	-0.59	-0.67	-0.66	-0.55	—
7/01-7/15	Buse	0	-0.24	-0.86	-1.34	-1.66	-1.87	-2.11
		70	-0.19	-0.83	-1.39	-1.69	-1.86	-1.74
	Barnes	0	-0.28	-0.72	-0.96	-1.16	-1.17	-1.30
		60	-0.17	-0.64	-1.07	-1.27	-1.42	-1.47
	Svea	0	-0.48	-1.01	-1.10	-1.10	-1.10	-1.14
		40	-0.35	-0.73	-0.74	-0.82	-1.22	—
7/16-7/31	Buse	0	-0.15	-0.33	-0.75	-1.53	-1.73	-1.33
		70	-0.07	-0.01	-0.16	-0.80	-0.98	-1.26
	Barnes	0	0.18	0.23	0.06	-0.18	-0.37	-0.57
		60	-0.03	-0.28	-0.56	-0.85	-1.05	-1.28
	Svea	0	0.03	-0.19	-0.38	-0.52	-0.72	-0.97
		40	0.15	0.20	-0.07	-0.17	-0.29	-0.39

[1] A minus sign (-) indicates a net loss of water, and a positive number as a water gain.

Table 6. Cumulative soil water loss between periods from spring wheat grown on three soils fertilized with two nitrogen rates, 1971.

			Soil depth (feet)					
Period	Soil	N rate	0-1	0-2	0-3	0-4	0-5	0-6
mo/day		lbs/ac			inches water			
4/23-6/16	Barnes	0	-0.32[1]	-0.26	-0.62	-0.80	-0.45	-0.09
		40	-0.40	-0.56	-1.40	-1.39	-1.09	-0.79
	Svea	0	-0.41	-0.28	-0.35	-0.60	-0.49	-0.49
		40	-0.51	-0.26	-0.87	-1.09	-0.72	-0.14
	Hamerly	0	0.04	0.35	0.36	0.37	0.55	0.71
		40	-0.17	-0.07	0.05	0.28	0.56	0.75
6/16-8/05	Barnes	0	-0.44	-0.38	0.21	1.06	2.01	3.56
		40	-0.77	-0.55	0.10	0.96	1.92	3.48
	Svea	0	-0.43	-0.29	0.19	0.27	1.05	1.76
		40	-0.42	0.16	0.79	1.51	1.99	3.00
	Hamerly	0	-0.76	-0.83	-0.63	-0.07	0.59	1.34
		40	-0.55	-0.53	-0.34	0.26	1.04	1.92

[1] A minus (-) sign indicates a net loss of water, and a positive number as a water gain.

content measurement dates was because water from rainfall, which periodically recharged the soil during the growing season, was measured as part of the soil water loss.

Although there was a difference among soils in amount of water loss, wheat plant height, grain yield, and grain test weight were not significantly different at the 5 per cent probability level (Table 1, Appendix Table 1).

One reason for the apparent greater water loss from Buse than from the other soils may have been due to runoff occurring during the growing season. This runoff, flowing on and over the adjacent lower-lying Barnes and Svea soils, could have contributed to their water supply so as to reflect lower net losses than actually occurred through evapotranspiration. To evaluate the contribution of rainfall and of runon to soil water supply would require monitoring after each rainfall event.

Another pathway of water loss from Buse conceivably contributing to Barnes and Svea water supply is by subsurface intra-profile lateral movement. However, *in situ* hydraulic conductivity measurements of glacial till-derived soils (Matzdorf et al., 1975) suggest that the seasonal amount of water movement by this pathway would likely be small.

A third reason for differences in water loss among soils could be related to differences in humidity and wind turbulence within the canopies of the wheat grown on these soils. Humidity usually is higher in the plant canopies on north-facing slopes than in canopies on the crest of the slope because the lower angle of incident light on a north-facing slope can result in lower canopy temperature. Wind turbulence is greater at the highest landscape position because the wind profile at that landscape position has a steeper velocity gradient, i.e., rate of change

Table 7. Cumulative soil water loss between periods from spring wheat grown on three soils fertilized with two nitrogen rates, 1972.

			Soil depth (feet)					
Period	Soil	N rate	0-1	0-2	0-3	0-4	0-5	0-6
mo/day		lbs/ac			inches water			
5/02-5/18	Buse	0	0.41[1]	0.69	1.19	1.61	2.17	3.04
		100	0.21	0.70	1.05	1.97	2.55	2.92
	Barnes	0	0.44	0.68	0.58	1.76	2.90	3.45
		100	0.44	0.84	0.63	1.35	2.07	2.47
	Svea	0	0.81	1.63	1.96	2.45	2.98	3.29
		100	0.67	1.28	1.84	2.68	2.93	3.22
5/19-6/02	Buse	0	-0.29	-0.31	-0.56	-0.34	-0.23	0.25
		100	-0.18	-0.46	-0.67	-0.67	-0.34	0.22
	Barnes	0	-0.28	-0.42	-0.82	-0.94	-0.78	-0.26
		100	-0.35	-0.62	-1.04	-1.18	-1.20	-1.03
	Svea	0	-0.15	-0.15	0.31	0.81	1.09	0.96
		100	-0.11	0.06	0.79	1.02	1.08	1.07
6/03-6/15	Buse	0	-0.85	-1.55	-1.96	-2.38	-2.69	-2.94
		100	-1.17	-1.94	-2.69	-3.15	-3.35	-3.63
	Barnes	0	-1.40	-2.10	-2.45	-2.80	-3.12	-2.66
		100	-1.48	-2.12	-2.47	-3.29	-3.30	-3.67
	Svea	0	-2.11	-2.65	-3.08	-3.40	-3.61	-3.62
		100	-2.84	-3.55	-4.28	-4.72	-4.87	-4.90
6/16-6/30	Buse	0	-0.28	-0.65	-0.90	-0.96	-0.80	-0.88
		100	-0.07	-0.43	-0.77	-1.06	-0.98	-1.06
	Barnes	0	-0.14	-0.63	-0.94	-1.05	-1.10	-1.12
		100	-0.08	-0.43	-0.93	-0.92	-1.03	-0.95
	Svea	0	-0.98	-1.64	-1.61	-2.00	-2.11	-2.24
		100	-0.34	-0.94	-1.25	-1.56	-1.54	-1.76
7/01-7/14	Buse	0	-0.28	-0.66	-1.33	-1.69	-1.95	-2.37
		100	-0.07	-0.28	-0.75	-0.56	-0.94	-1.20
	Barnes	0	-0.25	-0.67	-1.20	-1.78	-2.01	-2.18
		100	-0.08	-0.31	-0.91	-1.44	-1.72	-1.93
	Svea	0	-0.48	-0.98	-1.51	-1.70	-2.07	-2.02
		100	-0.17	-0.81	-1.61	-2.05	-2.31	-2.47
7/15-7/25	Buse	0	0.40	0.45	0.54	0.48	0.59	0.25
		100	0.74	0.81	0.76	0.16	0.13	0.20
	Barnes	0	0.45	0.50	0.41	0.35	0.07	-0.05
		100	0.85	0.93	1.01	0.87	0.78	0.74
	Svea	0	0.14	0.16	0.20	0.08	-0.04	-0.04
		100	-0.01	-0.02	-0.01	-0.02	-0.02	-0.22
7/26-8/09	Buse	0	-0.14	-0.08	-0.09	-0.21	-0.46	-0.37
		100	-0.53	-0.53	-0.50	-0.44	-0.49	-0.61
	Barnes	0	-0.30	-0.19	-0.15	-0.14	-0.24	-0.40
		100	-0.51	-0.39	-0.36	-0.34	-0.27	-0.20
	Svea	0	0.01	0.14	0.17	0.15	0.00	0.13
		100	-0.01	0.12	0.25	0.44	0.46	0.35

[1] A minus (-) sign indicates a net water loss of water, and a positive number of a water gain.

with height above the aerodynamic surface (Doughty et al., 1949). Since Buse occupied the highest topographic position and Barnes and Svea the north-facing slope, evapotranspiration can be greater from the canopy of Buse-grown wheat than from Barnes or Svea because it occurs at a faster rate.

Fertilizer N increased grain yield of wheat grown on Barnes but not on Buse or Svea soils (Appendix Table 1). Available N content, as nitrate (NO_3), to 2 feet was 91, 86, and 152 pounds per acre in Buse, Barnes, and Svea, respectively (Table 9). About 95 pounds available N in the upper 2 feet of soil is adequate for a 35 bushel per acre yield goal of wheat, based on recommendations of the North Dakota State University Soil Testing Laboratory (Wagner, Dahnke and Vasey, 1977). On this basis, the recommended fertilizer N rate per acre would have been about 5 and 10 pounds per acre for Buse and Barnes, respectively, and none for Svea.

Failure to obtain grain yield response to fertilizer N on Buse, even though a deficiency is indicated, may have been due, in part, to the relatively large amount of available N present below the 2-foot depth. On Barnes, the quantity of available N below 2 feet was less than in Buse. The difference in available N content, together with the larger yields produced on Barnes, resulted in larger fertilizer N needs on Barnes than Buse.

Yields on Barnes and Svea were the same at the two lowest fertilizer N rates, but yields on Barnes were larger than on Svea at the two highest fertilizer N rates. Grain yields on Svea may have been "suppressed" by the two highest fertilizer N rates because a large supply of available N was added to an already large supply in the soil.

Grain yield per inch of water, termed water use efficiency, averaged 2.82, 3.72, and 4.03 on Buse-, Barnes-, and Svea-grown wheat, respectively (Table 8). For the calculation, total water use was taken as the sum of the growing season rainfall plus the difference in soil water loss to 6 feet between measurement of soil water content made closest to seeding and at harvest. Fertilizer N increased water use efficiency of Barnes-grown wheat

Table 8. Water use efficiency of Waldron wheat on three soil types fertilized with two nitrogen rates in each of three years.

Year	Soil	N rate	Water source			Grain yield	Water use efficiency
			Rain[1]	Soil[2]	Total water loss[3]		
		lbs/ac	----------------inches----------------			bu/ac	bu/ac/inch
1970	Buse	0	7.63	-3.75[4]	11.38	31.7	2.79
		70	7.63	-3.46	11.09	31.6	2.85
	Barnes	0	7.63	-2.41	10.04	34.7	3.46
		60	7.63	-2.89	10.52	41.9	3.98
	Svea	0	7.63	-0.85	8.48	36.6	4.32
		40	7.63	-1.55	9.18	34.3	3.74
1971	Barnes	0	11.20	3.48[5]	7.72	17.5	2.27
		40	11.20	2.68	8.52	26.4	3.10
	Svea	0	11.20	1.27	9.93	21.9	2.21
		40	11.20	2.87	8.33	27.8	3.34
	Hamerly	0	11.20	2.05	9.15	20.2	2.21
		40	11.20	2.66	8.54	25.6	3.00
1972	Buse	0	10.97	-3.25[6]	14.22	7.3	0.51
		100	10.97	-3.22	14.19	18.1	1.28
	Barnes	0	10.97	-4.25	15.22	13.8	0.91
		100	10.97	-4.55	15.52	28.1	1.81
	Svea	0	10.97	-3.74	14.71	30.2	2.05
		100	10.97	-4.39	15.36	35.6	2.32

[1] Measured at city of Lisbon.

[2] Change in available water content from date access tubes were installed to harvest, to a depth of 6 feet.

[3] Total water loss is precipitation plus the change in soil water content between first and last measurement of soil water.

[4] Soil water measurement began 23 days after seeding in 1970.

[5] The soil water content to 6 feet was larger at harvest than at seeding in 1971.

[6] Soil water measurement began 5 days after seeding.

Table 9. Nitrogen, as nitrate, in three contiguous soils in 1970, 1971, and 1972.

Date	Soil	N rate	Soil depth (feet)						Total[2]
			0-1	1-2	2-3	3-4	4-5	5-6	
mo/day/yr		lbs/ac	lbs N, as NO_3, per acre-depth						
5/25/70	Buse	0[1]	54	37	43	44	75	84	253
	Barnes	0	51	35	29	28	31	23	174
	Svea	0	101	51	42	42	30	31	266
4/26/71	Barnes	0[1]	58	14	13	7	6	6	98
	Svea	0	63	13	13	11	9	8	109
	Hamerly	0	80	15	11	6	4	4	116
5/1/72	Buse	0[1]	33	11	12	22	31		109
	Barnes	0	51	8	13	22	23		117
	Svea	0	98	57	85	44	21		305

[1] Soil samples removed from access tube installation points.

[2] Total to 5 feet.

about 0.5 bushel per inch but decreased it about 0.6 bushel per inch on Svea. While soil water loss from both Barnes and Svea was about 0.5 and 0.7 inch greater, respectively, where fertilizer N was applied, grain yields were increased by fertilizer on Barnes but not on Svea. On Buse, soil water loss was about 0.3 inch greater where no fertilizer N was applied, but water use efficiency was essentially the same on both N treatments.

Soil temperature, which may affect rooting depth and potential water loss, likely was not a factor effecting a difference in crop performance among these soils because soil temperatures at a given depth were essentially the same by June 12, 1970 (Table 10).

Table 10. Soil temperatures at several depths of three soils on several dates in 1970 and 1971.

Date	Soil	Soil depth (inches)[1]									
mo/day/yr		1	6	12	18	24	30	36	48	60	72
		degrees Fahrenheit									
5/25/70	Buse	60.0	54.2	52.5	51.4	50.6	48.5	49.6	47.5	46.0	45.0
	Barnes	62.5	55.8	54.5	53.0	51.0	49.8	50.1	47.3	46.0	45.3
	Svea	59.0	52.0	51.0	49.3	47.3	45.6	46.7	44.0	42.2	40.8
6/12/70	Buse	70.8	70.0	68.1	64.6	58.4	56.5	55.0	50.6	47.2	45.0
	Barnes	71.7	69.2	67.0	63.0	59.0	55.4	55.0	50.1	47.3	45.4
	Svea	73.7	69.1	66.4	62.7	58.6	55.0	54.9	50.4	47.0	45.0
6/30/70	Buse	80.3	72.2	66.4	63.6	61.4	58.5	59.2	57.3	54.4	—
	Barnes	80.7	70.3	65.6	61.1	—	54.5	58.4	55.0	52.2	50.4
	Svea	79.2	69.5	64.8	61.2	57.6	54.8	58.7	55.2	52.5	49.8
7/15/70	Buse	79.1	76.0	69.5	66.1	64.0	62.3	60.0	56.5	53.9	51.5
	Barnes	83.3	77.4	71.5	68.0	65.5	63.4	61.0	57.0	53.6	51.1
	Svea	81.6	76.2	69.6	66.4	64.2	62.5	60.0	56.4	53.2	50.6
7/31/70	Buse	72.0	71.8	71.6	68.4	64.6	62.1	60.9	58.2	56.0	54.1
	Barnes	71.9	73.8	73.5	69.8	66.5	64.0	62.0	58.7	55.7	53.5
	Svea	71.7	73.0	72.5	69.1	66.0	63.6	61.7	59.0	56.3	54.0
6/16/71	Barnes	—	—	64.4	62.0	59.0	53.0	48.5	45.0	43.5	42.0
	Svea	—	—	62.0	60.0	57.0	52.0	47.5	44.5	44.5	42.5
	Hamerly	—	—	61.5	59.0	55.5	51.0	47.5	45.0	44.5	43.0
8/5/71	Barnes	—	—	62.0	61.5	60.5	57.0	52.0	51.3	51.3	50.5
	Svea	—	—	63.0	62.2	60.5	57.5	54.8	52.8	53.0	52.0
	Hamerly	—	—	63.5	62.5	60.5	58.0	55.0	52.7	54.4	52.5

[1] One thermocouple per soil depth.

1971

Soil water data for 1971 are shown in Tables 3, 6, and 8. Information on rainfall amounts and the dates it was received is given in Appendix Table 5.

Soil water content was measured only on three dates so cumulative losses between successive dates are limited to two periods. Net soil water loss for the two periods was 1.24, 1.09, and 0.83 inches from Barnes, Svea, and Hamerly where no fertilizer N was applied, and 2.17, 1.51, and 0.72 inches, respectively, at the 40-pound fertilizer N rate per acre. Soil depth to which a net loss was measured in either of the periods was 4, 4, and 2 feet of Barnes, Svea, and Hamerly, respectively.

The available soil water content to 6 feet was greater at harvest than at seeding, the difference ranging from 1.27 inches in Svea to 3.48 inches in Barnes. The larger supply at harvest was caused by 7.18 inches of rain which fell after June 16 (Appendix Table 5).

Available soil water content in Hamerly at seeding was less than in Barnes or Svea. This is likely part of the reason for less soil water loss from Hamerly during April 23 to June 16 than from the other two soils.

Grain yields did not differ among soils (Appendix Table 2). But the wheat heads had fewer kernels and the 1000-kernel weight was heavier in Barnes-grown grain than in the grain grown on the other two soils. Test weight of grain grown on Hamerly was lower than the grain produced on the other two soils. Factors involved in causing these differences likely include both soil water supply and the microclimate. But the necessary measurements were not made to evaluate their contribution to the differences.

Averaged over all soils, grain yield was increased about 5 bushels per acre by 20 pounds fertilizer N per acre. Grain yields obtained from higher fertilizer N rates were not significantly different from the yield with the 20-pound N rate. The available N supply to 2 feet at seeding prior to N fertilization ranged from 72 to 95 pounds per acre (Table 9). About 60 pounds available N in the upper 2 feet is considered adequate for a yield goal of 25 bushels of wheat per acre (Wagner et al., 1977).

Water use efficiency among soils was 2.21 to 2.27 bushels per inch of water with no N fertilization and 3.00 to 3.34 bushels per inch at the 40-pound fertilizer N rate (Table 8). Efficiency was increased with N fertilization because it increased grain yields.

1972

Available soil water content of the upper foot of Svea 5 days after seeding was more than an inch greater than in either Buse or Barnes. At all dates of measurement, available soil water was present in the upper foot of Svea where no fertilizer N was applied, but at the 100-pound rate, available soil water was exhausted from this depth on July 14, July 25, and August 9. Available water was exhausted from the upper foot of N-fertilized Buse and Barnes on June 15, but at the no fertilizer N rate, available soil water was present at this depth until the July 14 measurement. For all soils, available soil water was present at all depths below the upper foot throughout the growing season.

Available water supply increased in all three soils during May 2 to May 18. The increase in Svea to 4 feet exceeded the increase in the other two soils by as much as an inch. This greater increase in Svea is attributed to accumulation of runon from the upper slope. Physical evidence of runoff was observed from Buse and, to a lesser extent, from Barnes.

During the next six periods, May 19 to August 9, net soil water loss was 7.29, 7.74, and 8.07 inches from Buse, Barnes, and Svea, respectively where no fertilizer N was applied and 7.17, 8.32, and 9.21 inches, respectively, at the 100-pound fertilizer N rate. More than 90 per cent of the net water loss from Buse and Barnes, and 100 per cent from Svea, occurred during the four periods from May 19 to July 14. Water loss occurred to the 6-foot depth from all soils. The loss to this depth occurred by June 15 from Buse and Barnes and June 30 from Svea. Based on the average of both fertilizer N rates, net soil water loss from May 19 to June 2 was least from Svea, 0.13 inches, and most from Barnes, 1.06 inches. But during each of the next three consecutive periods ending July 14, net losses from Svea were largest, 4.24, 2.00, and 2.27 inches, followed by Barnes, 3.40, 1.07, and 2.06 inches, and least from Buse, 3.29, 1.01, and 1.79 inches.

The effect of fertilizer N rate on net water loss differed with soils during the four periods from May 19 to July 14. On Buse, net loss was greater from the 100-pound fertilizer N rate during the first three periods by a total of 0.91 inches, but the loss was 1.17 inches greater from the no fertilizer N rate during the fourth period (July 1 to July 14). On Barnes net loss was greater from the 100-pound fertilizer N rate by a total of 0.79 inches during the first two periods, but less but a total of 0.32 inches during the next two periods. On Svea, net water losses at the 100-pound fertilizer N rate were greater by a total of 1.56 inches during the second and fourth periods but less by a total of 0.52 inches during the first and third periods (May 19 to June 2 and June 16 to June 30).

Grain yield of Svea-grown wheat, averaged over all fertilizer N rates, was about 10 and 20 bushels per acre larger than the yield of Barnes- and Buse-grown wheat, respectively (Appendix Table 3). Straw yields correspondingly were 1.61, 1.18, and 0.87 tons per acre, respectively, on Svea, Barnes, and Buse. Net loss of soil water, summed over periods and averaged over fertilizer N rates, was 0.80 inches more from Barnes than Buse, and 0.61 inches more from Svea than Barnes.

The larger net soil water losses coinciding with larger grain yields support the premise that differences in water regime among these soils is a factor contributing to differences in grain yield—at least in some years. Available water content to 6 feet differed little among these soils on May 2, 5 days after seeding, except that Svea had about 1.7 inches more in the uppermost foot than did Buse. This difference in available water in the uppermost foot at seeding resulted in a difference in seedling population between Svea and Buse. The effect of the difference in seedling population apparently carried through the entire season, as indicated by the larger straw yields on Svea than Buse.

A difference in the amount of net water loss among soils during any period probably is another indicator that their water regime is not the same. Net water loss was largest from Barnes from May 19 to June 2, but thereafter to July 14 after the crop was headed, net loss was always largest from Svea and least from Buse. The more favorable water regime in Barnes and Svea than Buse, during the wheat tillering stage, conceivably resulted in production of more tillers or resulted in fewer abortions of those produced. The differences in straw yields among soils is likely a result, in part, of differences in numbers of tillers. As a result of more tillers, grain yields too were larger. Additional evidence that net water loss reflected a difference in water regime was in plant height. Wheat grown on Buse was about 9 inches shorter than the wheat on Svea. These height differences likely contributed to straw yield differences.

Buse-grown grain weighed 28.41 grams per thousand kernels while Barnes-grown wheat weighed 30.50 grams and Svea-grown 31.34 grams (Appendix Table 3). The lower kernel weight suggests a less favorable plant water status in Buse-grown wheat during the grain-filling period.

Soil water loss, measured as the difference between seeding and harvest soil water content to the 6-foot soil depth, was 3.25, 4.25, and 3.74 inches from Buse, Barnes, and Svea respectively, at the no fertilizer N rate, and 3.22, 4.55, and 4.39 inches, respectively, at the 100-pound fertilizer N rate. This outcome of less loss from Svea than Barnes supports the premise that runon water from upper slope positions contributed to the Svea water supply. At harvest, the amount of available water to 6 feet was about the same in all soils.

Water use efficiency was 0.90, 1.36, and 2.19 bushels per inch of water for Buse, Barnes, and Svea, respectively, averaged over both fertilizer N rates (Table 8). The calculation of water use efficiency likely is biased in favor of Barnes and Svea when soil water loss is determined as the difference between seeding and harvest soil water, because the quantity of runon water to Barnes and Svea is not known and is not considered as a source of water in the calculation.

Fertilizer N increased water use efficiency 0.77, 0.90, and 0.27 bushels per inch water on Buse, Barnes, and Svea, respectively. Improvement in water use efficiency with fertilization of nutrient deficient soils in semiarid and subhumid regions, or by any cultural practice that increases grain yield, has been reported extensively.

Grain and straw yield were simultaneously increased by fertilizer N rates on all three soils. Yield increases from fertilizer N were least on Svea. Available soil N, as NO_3, to 2 feet at seeding was 44, 59, and 155 pounds per acre in Buse, Barnes, and Svea, respectively (Table 9). By North Dakota State University soil test standards, 110 pounds available N in the upper 2 feet of soil is adequate for a 40 bushel per acre yield goal of wheat (Wagner et al., 1977). Grain yield on Svea without N fertilization was larger than the yield on Buse at any fertilizer N rate, and as large as or larger than on Barnes at any fertilizer N rate.

Grain Protein

Grain protein was increased by fertilizer N when the N was applied in larger amounts than needed to produce a grain yield increase, but very slightly, if at all, by fertilizer N rates that increased yields (Appendix Tables 2 and 3). This was noted also in previous studies (Bauer, Young and Vasey, 1966). In 1971, protein was increased about 1.3 percentage units by 60 pounds fertilizer N per acre applied in excess of the rate needed for grain yield increase (averaged over all soils). In 1972, protein was increased about 0.7 percentage units by an excess of 50 pounds per acre.

A significant soil-by-fertilizer N interaction occurred with grain protein in 1971. Without N fertilizer, grain protein content was larger in wheat grown on Hamerly than in grain grown on the other two soils. Although available soil N content in the upper foot, before N-fertilization, was larger in Hamerly than it was in the other two soils, it did not produce a larger grain yield on Hamerly.

SUMMARY AND CONCLUSION

Rate of fertilizer nitrogen (N) trials were conducted on three contiguous soils of the Barnes catena in each of 3 years to determine if topographic position caused variation in wheat yields because of soil fertility differences and/or because of differences in water regime.

The effect of kind of soil or fertilizer N rate on wheat grain yield was not consistent with years. Grain yield response to fertilizer N rate differed among soils in 1970. In 1971 and 1972, fertilizer N increased yields approximately the same amount on all soils. In 1972, grain yields differed among soils.

Available soil water content in the upper foot of soil affected seedling population among soils in 1972. Population differences occurred between Buse and Svea when the available soil water in the upper foot 5 days after seeding was about 50 per cent of field capacity in Buse and about 100 per cent of capacity in Svea. In the other 2 years, seedling population did not differ among soils containing less than about 35 per cent of the available water capacity on the date of first measurement. Seedling populations, average of all soils, were lower in 1970 and 1971 than in 1972.

Loss of available water during the growing season occurred to soil depths of as much as 6 feet. Amount of loss from each foot of soil between periods of measurement differed with soils. At the time of measurement, available soil water was always present in soil depths below three feet.

Quantity of water lost from a given soil between seeding and harvest was not always greater from the N-fertilized treatment than from the no fertilizer N treatment, even though fertilizer N increased grain yields.

A difference in soil water supply among soils of the Barnes catena is a major contributor to grain yield differences. The major cause is precipitation runoff from some soils and, concomitantly, runon to others. The difference in supply from runoff-runon can develop before or during the growing season. When supply differs at seeding, the effect can be a difference in seedling population. This population difference, in turn, can be translated into grain yield differences because numbers of main-stem heads produced per unit area may not be the same. Although tillering can compensate for low seedling population, grain yield per unit tiller-head is less than per unit main stem-head. Depending upon subsequent rainfall amount and distribution, a difference in seeding-time soil water supply also can affect numbers of tillers produced or the percentage of tillers producing heads.

A difference in water supply resulting from runon during the growing season can alter the grain yield potential because the additional water can delay the onset of, or decrease the intensity of, water shortage. Lateral subsurface transfer of water to soils in lower topographic positions also can contribute to water supply differences. But because hydraulic conductivities of glacial till-derived soils are very low, differences in supply effected in this manner are considered minor.

Differences in degree of nutrient deficiency among soils is another major contributor to grain yield differences. Deficiency differences can be eliminated if appropriate amounts of fertilizers are applied to each soil. However, although nutrient levels among soils can be made equal, yield differentials among soils may persist if a factor, such as water quantity, is not uniformly available over space and time.

LITERATURE CITED

1. Bauer, Armand and R. A. Young. 1966. Soil fertility and water relations. North Dakota Agr. Exp. Stn. Farm Res. 24(6):8-11.
2. Bauer, Armand. 1972. Effect of water supply and seasonal distribution on spring wheat yields. North Dakota Agr. Exp. Sta. Bull. 490.
3. Bauer, Armand, E. B. Norum, J. C. Zubriski, and R. A. Young. 1966. Fertilizer for small grain production on summerfallow in North Dakota. North Dakota Agr. Exp. Stn. Bull. No. 461.
4. Bauer, Armand, R. A. Young and E. H. Vasey. 1966. How nitrogen affects protein and test weight. North Dakota Agr. Exp. Stn. Farm Res. 24(5):18-22.
5. Bremner, J. M. 1965. Soil nitrogen. *In:* Methods of soil analysis. Vol. 2, p. 1149-1178. C. A. Black (ed.) Amer. Soc. Agron., Madison, Wis.
6. Buol, S. W., F. D. Hole, and R. J. McCracken. 1973. Soil genesis and classification. The Iowa State University Press, Ames.
7. Cassel, D. K. and M. D. Sweeney. 1974. *In situ* soil water holding capacities of selected North Dakota soils. North Dakota Agr. Exp. Stn. Bull. No. 495.
8. Dahnke, W. C. 1971. Use of the nitrate specific ion electrode in soil testing. Soil Sci. and Plant Anal. 2:73-84.
9. Doughty, J. L., W. J. Staple, J. J. Lehane, F. G. Warder, and F. Bisal. 1949. Soil moisture, wind erosion and fertility of some Canadian Prairie Soils. Dominion of Canada-Dept. Agr. Tech. Bull. 71.
10. Environmental Science Services Administration. 1970, 1971, 1972. Climatological data. U. S. Dept. Commerce, Vol. 79, 80, 81.
11. Ferguson, W. S. and B. J. Gorby. 1967. The effect of soil catena and phosphorus on the yield of wheat in western Manitoba. Can. J. Soil Sci. 47:39-48.
12. Large, E. C. 1954. Growth stages in cereals—Illustrations of the Feeke's scale. Plant Path. 3:128-129.
13. LeClerg, E. L., W. H. Leonard, and A. G. Clark. 1962. Field plot technique. Second Ed. Burgess Pub. Co., Minneapolis, MN.
14. Lindstrom, M. 1973. A model to predict emergence of winter wheat (*Triticum aestivum* L.) based on soil temperature, water potential, and depth of coverage. Ph. D. Thesis. Washington State Univ., Univ. Microfilms Intl., Ann Arbor, Michigan.
15. Malo, D. D. and B. K. Worcester. 1974. Plant height and yield of sunflowers at different landscape positions. North Dakota Agr. Exp. Stn. Farm Res. 31(5): 17-23.
16. Malo, D. D., B. K. Worcester, D. K. Cassel, and K. D. Matzdorf. 1974. Soil-landscape relationships in a closed drainage system. Soil Sci. Soc. Amer. Proc. 38:813-818.
17. Matzdorf, K. D., D. K. Cassel, B. K. Worcester, and D. D. Malo. 1975. *In situ* hydraulic conductivity at four hillslope locations in a closed drainage system. Soil Sci. Soc. Amer. Proc. 39:508-512.
18. Omodt, H. W., G. A. Johnsgard, D. D. Patterson, and O. P. Olson. 1968. The major soils of North Dakota. North Dakota Agr. Exp. Stn. Bull. No. 472.
19. Power, J. F. and J. Alessi. 1978. Tiller development and yield of standard and semidwarf spring wheat varieties as affected by nitrogen fertilizer. J. Agr. Sci., Camb. 90:97-108.
20. Radomski, Czeslaw, Romuald Madany, and Aleksander Nozynski. 1977. Effect of slope microclimate on yield of cereals. Agric. Meteorol. 18:203-209.
21. Rennie, D. A. and J. S. Clayton. 1960. The significance of local soil types to soil fertility studies. Can. J. Soil Sci. 40:146-156.
22. Spratt, E. D. and R. N. McIver. 1972. Effects of topographical positions, soil test values and fertilizer use on yields of wheat in a complex of Black Chernozemic and Gleysolic soils. Can. J. Soil Sci. 52:53-58.
23. Stone, J. F., D. Kirkham, and A. A. Read. 1955. Soil moisture determination by a portable neutron scattering moisture meter. Soil Sci. Soc. Amer. Proc. 19:419-423.
24. Wagner, D. F., W. C. Dahnke, and E. H. Vasey. 1977. Fertilizing small grains. North Dakota Coop. Ext. Serv. Circ. S-F 2, revised.

Appendix Tables

Appendix Table 1. Measurements of the performance of Waldron spring wheat grown on three soils fertilized with four nitrogen rates, 1970.

Measurement	Soil	Fertilizer nitrogen rate[1] N_1	 N_2	 N_3	 N_4	Average[6]
Seedlings (6/3)[5]	Buse	137[2]	149	139	158	145
(no/18 feet)	Barnes	145	163	149	139	149
	Svea	163	162	172	168	167
	Average	149	158	154	155	
Height@harvest	Buse	32.3	35.8	35.0	35.0	34.6
(inches)	Barnes	33.9	35.0	34.6	36.2	35.0
	Svea	37.0	37.4	35.8	36.2	36.6
	Average	34.3 a[3]	35.0 b	35.8 c	36.2 c	
Grain yield	Buse	31.7 a[4]	32.7 a	31.6 a	33.5 a	32.4
(bu/acre)	Barnes	34.7 ab	39.6 bc	41.9 c	47.9 d	41.0
	Svea	36.6 abc	40.0 bc	34.3 ab	34.8 ab	36.4
	Average	34.3	37.4	35.9	38.7	
Test weight	Buse	60.9	59.1	57.6	57.8	58.8
(lbs/bu)	Barnes	61.2	59.5	58.7	59.1	59.6
	Svea	58.6	58.3	57.0	56.8	57.7
	Average	60.2 a[3]	58.9 b	57.8 b	57.9 b	

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[1] Fertilizer nitrogen (N) rates in pounds per acre were:

	N_1	N_2	N_3	N_4
Buse	0	35	70	140
Barnes	0	30	60	120
Svea	0	20	40	80

[2] Letters to indicate significant differences among averages are not listed when the variance source was not statistically significant.

[3] Numbers followed by different letters in this row differ at the 5% probability level according to Duncan's multiple range test.

[4] Numbers followed by different letters in this table differ at the 5% probability level according to Duncan's multiple range test.

[5] Counted on June 3.

[6] Some averages among soils differed at the 10% probability level.

Appendix Table 2. Measurements of the performance of Waldron spring wheat grown on three soils fertilized with four nitrogen rates, 1971.

Measurement	Soil		Fertilizer nitrogen, lbs N per acre				Average
			0	20	40	80	
Seedlings (5/19)[5]	Barnes		176[1]	182	166	182	177
(no/18 feet)	Svea		194	185	197	197	193
	Hamerly		165	179	173	169	171
		Average	179	182	178	183	
Heads (8/4)[5]	Barnes		236	312	297	316	289
(no/18 feet)	Svea		167	264	213	299	236
	Hamerly		210	278	276	314	269
		Average	205 a[2]	284 bc	259 b	310 c	
Grain yield	Barnes		17.5	21.2	26.4	27.7	23.2
(bu/acre)	Svea		21.9	29.7	27.8	31.2	27.7
	Hamerly		20.2	24.1	25.6	25.5	23.1
		Average	19.8 a[2]	25.0 b	26.6 b	27.1 b	
Test weight	Barnes		59.3	59.9	60.0	58.3	59.4 b[3]
(lbs/bu)	Svea		59.0	59.2	58.5	57.6	58.6 b
	Hamerly		55.9	56.3	57.4	56.1	56.4 a
		Average	58.1 b[2]	58.5 b	58.6 b	57.3 a	
Grain protein[6]	Barnes		13.7 a[4]	13.8 a	14.3 ab	15.9 e	14.5
(percent)	Svea		14.0 a	13.8 a	14.2 ab	15.2 cd	14.3
	Hamerly		14.7 bc	14.7 bc	14.8 bcd	15.4 de	14.9
		Average	14.1 a[2]	14.1 a	14.4 a	15.4 b	
Kernel weight	Barnes		33.45	35.28	36.18	36.19	35.27 b[3]
(grams/1000)	Svea		33.45	34.59	33.75	33.44	33.81 a
	Hamerly		33.17	33.64	33.68	32.84	33.33 a
		Average	33.35	34.50	34.54	34.15	
Kernels/head	Barnes		14.4	12.7	16.9	15.8	14.9 a[3]
(no.)	Svea		20.6	17.3	21.4	16.5	19.0 b
	Hamerly		16.5	17.0	18.1	14.6	16.4 ab
		Average	16.9 ab[2]	15.7 a	18.8 b	15.6 a	

[1] Letters to indicate significant differences among averages are not listed when the variance source was not statistically significant.

[2] Numbers followed by the different letters in this row differ at the 5% probability level according to Duncan's multiple range test.

[3] Numbers followed by the different letters in this column differ at the 5% probability level according to Duncan's multiple range test.

[4] Numbers followed by different letters in this table differ at the 5% probability level according to Duncan's multiple range test.

[5] Date of measurement, month/day.

[6] Reported at 14 per cent water content.

Appendix Table 3. Measurements of the performance of Waldron spring wheat grown on three soils fertilized with four nitrogen rates, 1972.

Measurement	Soil		Fertilizer nitrogen, lbs N per acre				Average
			o	50	100	150	
Seedlings (5/26)[4] (no./18 feet)	Buse		163	175	191	205	184 a[3]
	Barnes		154	206	233	225	205 ab
	Svea		265	237	272	245	255 b
		Average	194	206	232	225	
Height at harvest (inches)	Buse		25.2	30.7	34.6	35.4	31.5 a[3]
	Barnes		30.7	35.4	35.8	37.0	34.6 a
	Svea		37.4	40.6	40.9	40.9	40.2 b
		Average	31.1 a[2]	35.4 b	37.0 b	37.8 b	
Grain yield (bu/acre)	Buse		7.3[1]	14.8	18.1	18.8	14.7 a[3]
	Barnes		13.8	26.2	28.1	30.5	24.7 b
	Svea		30.2	33.5	35.6	37.5	34.2 c
		Average	17.1 a	24.8 b	27.3 bc	29.0 c	
1000-kernel weight (grams)	Buse		27.13	28.54	28.69	29.29	28.41 a[3]
	Barnes		28.88	30.62	30.89	31.62	30.50 b
	Svea		30.98	31.55	31.38	31.46	31.34 b
		Average	29.00 a[2]	30.23 b	30.32 b	30.79 b	
Test weight (lbs/bu)	Buse		59.1	59.2	58.7	58.6	58.9
	Barnes		59.8	59.9	59.6	59.6	59.7
	Svea		58.7	59.1	58.5	58.0	58.6
		Average	59.2 bc[2]	59.4 c	58.9 ab	58.7 a	
Grain protein[5] (percent)	Buse		14.1	14.2	15.2	15.6	14.7 b[3]
	Barnes		13.0	13.4	14.3	15.1	13.9 a
	Svea		15.0	15.3	15.5	15.6	15.3 c
		Average	14.0 a[2]	14.3 a	15.0 b	15.4 b	
Straw yield (tons/acre)	Buse		0.39	0.87	1.03	1.17	0.87 a[3]
	Barnes		0.71	1.31	1.28	1.40	1.18 b
	Svea		1.33	1.60	1.74	1.76	1.61 c
		Average	0.81 a[2]	1.26 b	1.35 bc	1.45 c	

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[1] Letters to indicate significant differences among averages are not listed when the variance source was not statistically significant.

[2] Numbers followed by different letters in this row differ at the 5% probability level according to Duncan's multiple range test.

[3] Numbers followed by different letters in this column differ at the 5% probability level according to Duncan's multiple range test.

[4] Date of measurement (mo/day).

[5] Reported at 14 per cent water content.

Appendix Table 4. Rainfall amounts at Lisbon[1] from seeding to harvest and dates of soil water measurements, 1970.

Day	Month May	 June	 July	
		inches		
1				
2	Seeded			
3				
4				
5				
6				
7				
8				
9		0.01		
10				
11		0.01		
12		$\boxed{0.24}$	0.02	
13				
14	0.30		0.08	
15	0.04	1.19	☐	
16		0.79		
17		0.10		
18		0.01		
19	0.08	0.16		
20	0.02	1.25		
21				
22		0.02		
23	0.21			
24				
25	$\boxed{0.11}$[3]	0.11		
26				
27	0.09			
28				
29	2.46			
30	0.06	☐	Harvest	
31	0.27		☐	
Total	3.64	3.89	0.10	7/63[2]

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[1] Official US Weather Bureau weather station in Lisbon.

[2] Seeding to harvest rainfall.

[3] Indicates dates of soil water content measurement.

Appendix Table 5. Rainfall amounts at Lisbon[1] from seeding to harvest and dates of soil water measurements, 1971.

Day	Month April	 May	 June	 July	 August	
			inches			
1			.03			
2						
3						
4			.32	.33	Harvest	
5			.07		☐	
6			.01			
7				.42		
8						
9						
10		.10	.22			
11			.02			
12			.04	1.30		
13						
14						
15						
16			☐			
17			1.04			
18				.03		
19						
20						
21		.02	.01			
22		.29	1.58	.14		
23	$\boxed{\text{Seeded}}$[3]	.77	.14			
24		.32	1.18			
25		.02	.02	.40		
26						
27	.72			.03		
28	.23					
29	.06		.38	.10		
30	.02	.05	.08			
31		.71				
Total	1.03	2.28	5.14	2.75	0.00	11.20[2]

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[1] Official US Weather Bureau weather station in Lisbon.

[2] Seeding to harvest rainfall.

[3] Indicates dates of soil water content measurement.

Appendix Table 6. Rainfall amounts at Lisbon[1] from seeding to harvest and dates of soil water measurements, 1972.

Day	Month April	 May	 June	 July	 August	
			inches			
1		.06				
2		$\boxed{.20}$[3]	☐			
3		.02	.07	.01		
4						
5		.82				
6				.01	.13	
7						
8				.02		
9					$\boxed{\text{Harvest}}$	
10						
11		.27				
12		.15		.35		
13		1.94				
14		.12		$\boxed{.60}$		
15		.40	☐			
16				.10		
17		.01		.15		
18		☐				
19						
20				.05		
21			1.00	.23		
22		.32				
23		1.00		.70		
24		.11				
25				☐		
26		.33		.53		
27		.50	.02			
28	Seeded	.38	.02			
29		.15		.20		
30			☐			
31						
Total	0.00	6.78	1.11	2.95	.13	10.97[2]

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[1] Official US Weather Bureau weather station in Lisbon.

[2] Seeding to harvest rainfall.

[3] Indicates dates of soil water content measurements.