IRRIGATED ALFALFA FORAGE PRODUCTION ON A WELL-DRAINED SANDY LOAM AT OAKES, NORTH DAKOTA 1972-1977

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Alfalfa forage yield has been doubled with irrigation in an irrigation-soil fertility study conducted from 1972 to 1977 at Oakes, North Dakota. Forage yields were not increased by the 1973 addition of phosphorus (P), potassium (K), and sulphur (S) fertilizers on a soil that initially tested medium in P and K in the plow layer. Soil test levels of P and K were quite uniform below the plow layer of this alluvial soil. On the basis of five years of field data, farm managers may obtain forage increases of one-sixth to one-fifth ton of forage per acre per year for each inch of water applied until irrigation and precipitation water total 24 inches between late April and the latter part of August. Cumulative forage yields for the five-year study period indicate that alfalfa stand longevity is between five and seven years under dryland conditions on this well-drained Maddock fine sandy loam soil. Little or no stand loss has been observed on irrigated plots during the first five years of this study.

Introduction

Irrigated agriculture is steadily developing and expanding in southeastern North Dakota. Although government subsidized development has been slow, private development of irrigation water resources has been rapid. A demand for research relating to both proper farm management and efficiency of resource use has accompanied the growth in irrigation. In many instances both farm management and resource use ultimately relate back to the economics of irrigated agriculture.

Alfalfa has been grown as a feed base for livestock production in North Dakota for many years. In addition detailed studies of alfalfa production are not new to North Dakota farmers. As Bauer et al. (1974) reported,

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North Dakota ranked 11th among the states in alfalfa hay production in 1971. According to the North Dakota Crop and Livestock Reporting Service (1977) about 1.8 million acres of alfalfa were harvested in 1976 at an average yield of 1.7 tons per acre. Bauer et al. (1974) reported on yield surveys and other alfalfa studies conducted in North Dakota. Those data have been summarized in Table 1. Alfalfa yields ranged from 1 to over 7 tons per acre (at 12% moisture). At Oakes, North Dakota, Bauer et al. (1974) measured yields from 5.7 to 6.7 tons per acre during 1971 and 1972.

In North Dakota only a limited amount of information has been published dealing with alfalfa responses to fertilization under either dryland or irrigated conditions. Studies by Larson (1967) demonstrated significant alfalfa yield responses to P fertilization at Carrington. In more recent studies Dahnke (1974) measured no response to P at Carrington, Minot and Dickinson and significant response to 50 lb. P_2O_5 at Langdon. Bauer et al. (1974) observed no yield responses to phosphorus and potassium under irrigation at Oakes. In other studies, Holmen et al. (1961), working with an irrigated brome-alfalfa mixture at Upham, North Dakota, found that yields could be increased significantly with the addition of nitrogen fertilizer although fertilizer nitrogen is not needed when legumes are effectively inoculated.

Detailed alfalfa water-fertility studies were initiated at Oakes, North Dakota, in 1972 to determine alfalfa response to irrigation and P, K, and S fertilization and any possible interactions on a sandy loam soil.

Methods

As an expansion of studies reported by Bauer et al. (1974), an alfalfa water-fertility interaction study was conducted from 1972 to 1977. Four water levels and eight fertilizer levels were studied in a replicated split plot design. Experiments were conducted at the Oakes Irrigation Station, south of Oakes, North Dakota. Precipitation during the period from mid-April until late August is approximately 10 inches at the site. The soil on which the study was conducted is a Maddock sandy loam. Some of the soil's physical properties are shown in Table 2. The soil is well-drained with a water table at a depth of approximately twelve feet for most of the year.

"Vernal" alfalfa (*Medicago sativa L.*) was planted with oats (*Avena sativa*) as a nurse crop in the spring of 1972. The plot was seeded at a rate of 9 lb. of seed/A. The oats nurse crop was removed in mid-summer and alfalfa forage was harvested once in the fall of 1972. No yield measurements were made at that time.

Irrigation and fertilization treatments, as shown in Table 3, were established in a complete factorial design with three replicates of all 32 treatments. Each individual fertility treatment plot was 6' x 21', and whole irrigation plots were 24' x 42'. Whole plots were separated by 4' wide alleys. Irrigation levels ranged from dryland to excessive irrigation; the former plots received no irrigation during the study period. Tensiometers were used to schedule all irrigations. In 1975 all irrigation amounts were evaluated and increased from 33 to 100 per cent. The 1973 and 1974 soil moisture measurements indicated that the irrigation levels established in 1973 were not high enough to allow for profile recharge during irrigation. Fertilization treatments included P, K, and S. The P, K, and S fertilizers were broadcast applied only once, in March 1973. The pretreatment surface soil P and K levels were 18 and 195 lbs/A, respectively. These levels are "medium" for phosphorus and "medium" for potassium, according to NDSU Soil Testing Laboratory standards.

Forage was harvested and measured from all plots annually from 1973 to 1977. A three-cut per year management program was employed with the first, second, and third harvests being made approximately during the third week of June, the third week of July and the last week of August, respectively. Harvest dates for the five-year study are shown in Table 4. Hand harvest was initiated at the one-tenth bloom stage of the W3 plots and all plots were cleared in one day. At harvest, the yield from one-half of each plot was weighed for total fresh weight yield and then the harvested yield was subsampled for moisture determinations. Subsamples were oven dried at 120°F to constant weight.

At the initiation of the experiment neutron probe access tubes were installed to a depth of 10 feet in plots representing each of the four soil moisture levels. The access tubes were used with an Am-Be source, neutron moderation-type moisture probe to determine soil water throughout the soil profile at regular intervals during each growing season.

Results and Discussion

Annual and five-year analyses indicated that significant yield differences could be attributed to 1) irrigation treatments, 2) harvest number within years and between years, and 3) irrigation treatment x harvest number interactions. Total yields also differed significantly between years. No significant yield responses to the fertilizer treatments were observed during the study period. Apparently the pretreatment levels of soil P and K were high enough to sustain five years of alfalfa growth. Periodic soil test analyses to 6' showed that P and K levels below the plow layer were uniform and high in contrast to levels normally measured at deeper depths on many finer-textured glacial till soils.

Annual forage yield for each irrigation treatment, averaged over all fertilizer treatments, is included in Table 4. Nonsignificant response at each cutting due to fertilizer treatments was deemed sufficient justification for averaging yields over all fertilizer levels within each irrigation level. Available soil water data were not sufficiently detailed to permit calculation of crop water use by harvest for each irrigation level. Water sources, along with seasonal water use efficiency, are also reported in Table 4.

Rainfall during the period from mid-April through late August varied considerably during the study period, ranging from 2.8 inches in 1976 to 18.8 inches in 1975. The average was 9.1 inches. Probably 1977 was the most typical year. Irrigation amounts varied inversely in response to seasonal precipitation. Maximum irrigation occurred in 1976. The W3 treatment, representing an optimum irrigation level, was the best indicator of irrigation requirements. The five-year-average data, summarized in Table 5, indicate that the average irrigation amount for alfalfa in this area is approximately 15 inches per season.

Drainage, or excessive irrigation, was assumed to be negligent in 1973 and 1974. Significant drainage occurred on the W3 and W4 plots in 1975 and 1977. In 1975 drainage was due to excessive soil recharge following three successive rainfall events, each in excess of 3 inches. Drainage on W4 in 1977 was due to intentional over-irrigation, while the drainage observed on W2 and W3 plots in 1977 was the result of a 2-inch rainfall event only two days after scheduled irrigations. Seasonal water use varied considerably from year to year, it being controlled by both the availability of water for plant use and by prevailing climatic conditions during the crop growing season. The dryland (W1) treatment water use is indicative of the ability of the soil to restrict water use, due simply to limited storage ability. The excessively irrigated W4 plots are indicative of the regulation of water use by climatic conditions. As shown in Table 5, average water use for the dryland plots is approximately 13 inches, while that for the irrigated plots is approximately 24 inches per season.

Forage yield, although not significantly affected by fertility treatments, was significantly correlated with amount of seasonal precipitation, seasonal irrigation, and total seasonal water use. Studies by Dreibelbis and Harrold (1958), Penman (1956) and Pearson, Cleasby, and Thompson (1961) of several other crops have shown that plant dry matter yield is directly related to seasonal evapotranspiration, the amount of water used by the crop during the growing period. As anticipated, the lowest yields were measured on the dryland plots. Forage yield from the dryland plots averaged 2.26 tons/acre/year, it being approximately half that from the optimum irrigation (W3) plots in all years but 1975. In 1975 excessive rainfall during the growing season significantly reduced the stress effect on dryland plots. Forage yields from the deficient irrigation treatments were always greater than from the dryland plots. Only in 1975, when growing season precipitation was 18.8 inches, did the yield from the deficient irrigation plots exceed yields from the intended optimum irrigation plots. In three of the five study years the forage yields from the optimum irrigation treatments were essentially the same as those on the excessive irrigation treatments. The five-year averages (Table 5) indicated a difference of only one-fourth to one-half ton of forage per acre per year between the deficient, optimum, and excessive irrigation treatments.

Water-use efficiency, or forage yield per inch of water used by the crop, varied among irrigation treatments and years. During all years but 1975 the highest water use efficiency was measured on the optimum or excessive irrigation treatments. In 1975 the highest water use efficiency was measured on the dryland plots. The five-year average results, as shown in Table 5, indicate that the water-use efficiency for all irrigation treatments was the same. The data indicated that forage increases of one-sixth to one-fifth ton per acre per year may be obtained from each inch of irrigation water applied until combined irrigation and precipitation water total approximately 24 inches per season, when the water is distributed rather uniformly throughout the growing season.

The seasonal forage yield data and water use data were used to plot Figure 1. The relationship between forage yield and water use was determined. The regression equation presented in Figure 1 applies to the situation where yield is not limited by P, K, or S fertility, as was the case here. Alfalfa yield data of Haas and Willis (1971) were imposed on the graph for purposes of comparison. Those data agree well with the data collected during the trials reported here. Using the regression equation presented in Figure 1, it is possible to predict within reasonable limits, what the forage yield might be for a given amount of rainfall and irrigation water when P, K, and S fertility are not limiting factors.

Forage yield data from each cutting for each irrigation level were used to plot Figure 2, the cumulative forage yield. Cumulative yield from 1973 to 1977 was directly related to irrigation level and hence water use. Maximum cumulative yield was obtained from the W3 and W4 treatment plots. On the irrigated plots (W2, W3, W4) the cumulative yield was increased at the same rate with each cutting. The constant rate of increase in cumulative yield on these treatments was indicative of stand survival during the five-year study period. In contrast to this response, the cumulative yield on the dryland plots (W1) did not increase at a constant rate from 1973 to 1977. The leveling out and flattening of the cumulative yield curve for the dryland plots (W1) is indicative of a continually decreasing yield. A logical explanation for this is an increasing rate of stand loss each year during the study period. At the present rate of decrease, it is anticipated that annual forage yields from the dryland plots would be reduced to essentially zero within the next two years.

Conclusions

At Oakes, North Dakota, during five years of an irrigation-fertility study, alfalfa did not respond to P, K, S fertilizer on a well-drained fine sandy loam soil that initially tested medium in phosphorus and potassium in the plow layer. Significant forage yield responses to irrigation treatments and seasonal precipitation were measured. Annual and cumulative forage yield was significantly and directly correlated with seasonal plant water use. Although seasonal plant water-use efficiency varied with irrigation treatments, there was no difference in the five-year-average water-use efficiency of each irrigation treatment. Farm managers may obtain alfalfa forage increases of one-sixth to one-fifth ton per acre for each inch of irrigation water applied until irrigation and seasonal precipitation water total 24 inches, when available water is uniformly distributed during the growing season. Long term average annual alfalfa forage yields and water requirements for this region are approximately 5 tons/A and 24 inches. On the basis of cumulative forage yields over the five-year study period it can be concluded that alfalfa stand longevity is between five and seven years under dryland conditions on a Maddock fine sandy loam soil. Little or no stand loss occurred under deficient, optimum, or excessive irrigation during the study period. In addition, seasonal and cumulative forage yields were doubled by switching from dryland to irrigated management on this soil in southeastern North Dakota.

Table 1. Alfalfa forage yields for several North Dakota locations.

Researcher	Period	Measured forage yield tons/acre/year*	Study locations and conditions
Lorenz & Rogler	1951-1957	4.6-7.3	Irrigated — Mandan, Bowbells, Upham
Carter	1943-1963	4	Dryland — eastern North Dakota
		1	Dryland — western North Dakota
		6	Irrigated — eastern North Dakota
Holmen et al.	1955-1956	3-4	Irrigated — Upham
Haas & Willis	1964-1968	2-6	Irrigated — Mandan
N.D. Agr. Exp. Stat.	1964	7.35	Irrigated — Williston
Bauer et al.	1971-1972	5.7-6.7	Irrigated — Oakes

**Forage yields are reported as weight at 12% water.*

Table 2. Selected physical properties of Maddock sandy loam.

	Particle size Distribution				Water content						
					Soil moisture tension (atmospheres)						
Depth	Sand	Silt	Clay	Bulk density	1/10	1/3	1/2	1.0	15	*In situ* field capacity	Available H_2O
inches	— % by weight —			g/cm³	— % by weight —						inches
0-6	66	21	13	1.37	25.7	18.8	14.8	11.6	8.1	17.6	0.8
6-12	64	21	15	1.40	14.4	10.2	8.9	7.8	6.0	14.2	0.7
12-18	70	16	14	1.48	5.4	4.4	4.1	3.8	3.3	8.1	0.4
18-24	86	5	9	1.46	8.2	7.9	5.7	5.5	4.0	6.7	0.2
24-36	91	4	5	1.47	4.4	4.4	3.5	3.1	2.3	6.6	0.8
36-48	92	4	4	1.44	3.0	2.7	2.3	2.0	1.7	6.5	0.8
48-60	92	4	4	1.37	4.0	3.5	3.0	2.7	2.2	7.1	0.8
Total											4.5

Table 3. Fertilizer and irrigation treatments applied to "Vernal" alfalfa at the Titus site, Oakes, N.D. (Fertilizer applied in March 1973 only)*

Fertilizer rate lbs P_2O_5-K_2O-S/A**	Fertilizer rate lbs P_2O_5-K_2O-S/A**
0-0-0	0-90-0
50-0-0	300-90-0
100-0-0	300-180-0
300-0-0	300-180-50

Treatment	Irrigation amount
W1	Dryland — no irrigation
W2	Deficient — 60% depletion: 1-2 inches/ irrigation
W3	Optimum-20-40% depletion: 2-3 inches/ irrigation
W4	Excessive-10-20% depletion: 3-4 inches/ irrigation

**All possible combinations of fertilizer treatments and irrigation amounts were studied; a total of 32 different treatments were established.*

***Source of P_2O_5 was 0-46-0*
Source of K_2O was 0-0-60
Source of S was $CaSO_4$ (gypsum)

Table 4. Summary of alfalfa forage yield and water use data at Oakes, N.D. 1973-1977

Year/Ppt. (in)	Treatment	Irrigation (in)	Drainage (in)	Total seasonal water use (in)	Forage field* tons/A	Harvest dates	Water use efficiency tons/in H_2O/A
1973	W1	0	0	13.9	2.05	6/19	0.15
6.4	W2	12.0	0	24.6	3.87	7/17	0.16
	W3	14.0	0	26.0	4.06	9/4	0.16
	W4	16.0	0	26.7	4.11		0.15
1974	W1	0	0	14.3	1.75	6/19	0.12
7.4	W2	8.0	0	22.1	3.05	7/22	0.14
	W3	12.0	0	25.0	3.64	9/4	0.15
	W4	12.5	0	25.3	3.54		0.14
1975	W1	0	0	17.4	4.40	6/16	0.25
18.8	W2	8.0	0.63	23.4	5.06	7/17	0.22
	W3	9.0	6.30	23.3	4.93	9/4	0.21
	W4	16.0	8.66	27.4	5.08		0.19
1976	W1	0	0	7.8	1.04	6/16	0.13
2.8	W2	18.0	0	24.6	3.44	7/13	0.14
	W3	24.0	−0.39	27.3	3.87	8/30	0.14
	W4	28.0	2.76	28.5	4.50		0.16
1977	W1	0	0	11.5	2.08	6/7	0.18
10.1	W2	12.0	1.38	20.7	4.18	7/8	0.20
	W3	15.0	2.89	20.8	4.33	8/23	0.21
	W4	16.0	4.70	21.0	5.05		0.24

**Yield data are reported as yield at 12% H_2O, averaged over all fertility levels for each water level.*

Table 5. Summary of five years water application and use, forage yield, and water use efficiency of irrigated alfalfa production at Oakes, N.D. 1973-1977.

Treatment	Average[1] H_2O applied (in)	Average precipitation (in)	Average[2] water use (in)	Average yield (tons/A)	Average WUE (tons/A/in)
W1	0	9.1	12.9	2.26	0.175
W2	11.6	9.1	23.1	3.92	0.170
W3	14.8	9.1	24.5	4.17	0.170
W4	17.7	9.1	25.8	4.46	0.173

[1]*All averages are calculated on a year basis, i.e., H_2O applied/year, etc.*
[2]*Drainage included*

Figure 1. Annual alfalfa yield as affected by seasonal water use, Oakes, North Dakota 1973-1977

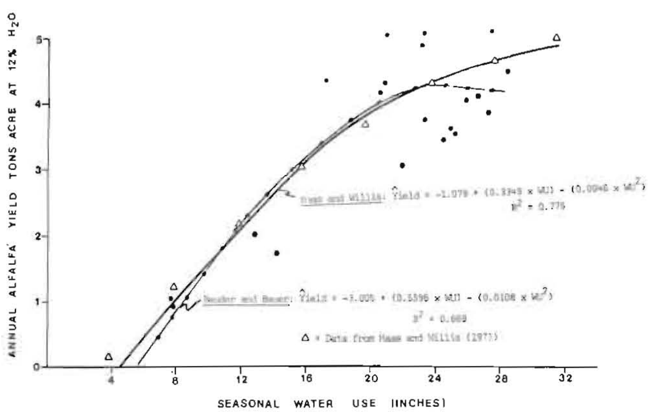
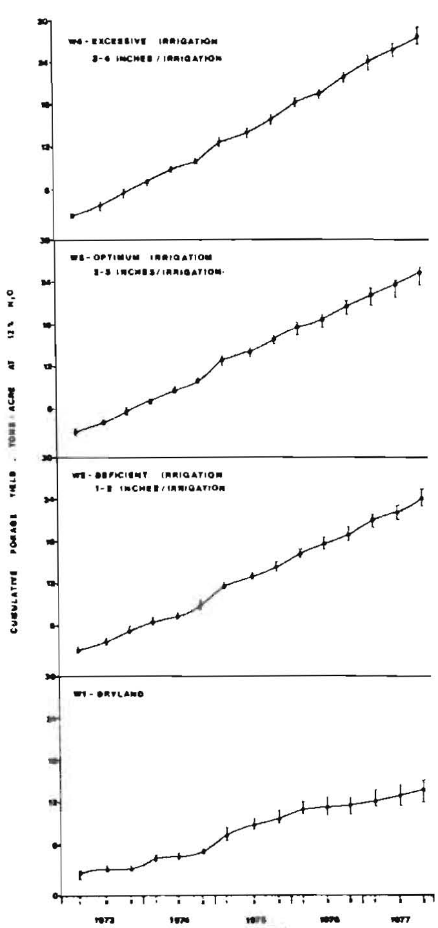


Figure 2. Cumulative forage yield, as function of irrigation level, 1973-1977, Oakes, North Dakota I= range between max and min yield



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