WATER TABLE AND IRRIGATION EFFECTS ON ALFALFA GROWN ON SANDY SOILS

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The effects of water table depths and irrigation levels on production of alfalfa, *Medicago sativa* L., were evaluated and compared in field-plot and field-lysimeter studies on sandy soils in North Dakota. The two experiments were not conducted simultaneously. Water table depths dropped seasonally in the field-plot experiment but were kept constant in the lysimeter experiment. The field-plot experiment had three water table depths with four irrigation levels; the lysimeter experiment had four water table depths with three irrigation levels. For the field-plot experiment, yields over 2 yr were highest with seasonal average shallow water tables of 1.2 and 1.7 m, regardless of irrigation, and irrigation increased yields significantly with the deepest water table (2.3 m). During the second year, yields of 2 tonne/ha higher occurred. For the lysimeters, yields over 2 yr were significantly depressed with the 46-cm water table and consistently high yields were obtained with the 155-cm water table. Thus, water table depth significantly affects yield of irrigated alfalfa grown on sandy soils in the northern Great Plains and the optimum water table depth for maximum alfalfa production is between 1 and 2 m.

INTRODUCTION

In many agriculturally productive areas of the world, shallow water tables exist naturally or can form as a result of irrigation. Unsuitable water management practices on such areas can create problem soils and reduce crop production because of waterlogging and accumulation of soluble salts within the rooting zone. Water management practices, which provide for proper drainage and timely irrigations, combined with proven tillage and cropping sequences can create an environment in which plants can effectively utilize water from these shallow water tables without inducing problems.

Recent research has shown that a properly managed shallow water table can be a very important source of water to supply crop needs and thus save considerable irrigation water and energy (Benz et al. 1981). Subirrigation involving controlled water tables has been practiced in the north central United States (Criddle and Kalisvaart 1967). Williamson and van Schilfgaarde (1965) found that maximum corn yields were obtained in a sandy North Carolina soil when the water table was from 76- to 86-cm below ground surface. In Nevada, Tovey (1963) determined that the optimum water table depth for maximum production of alfalfa, *Medicago sativa* L., was about 61 cm. Hiler (1969) showed that several crops respond favorably to shallow water tables. From lysimeter studies with constant water tables, Doering et al. (1977) and Reichman et al. (unpubl. data) determined that maximum production on sandy soils was obtained with water table depths of 1.0 m for corn and 1.1 m for sugarbeets.

Subirrigation, or use of water from the water table, is a particularly desirable practice for crops grown on soils that are coarse-textured and have little capacity to hold water. Coarse-textured soils are less likely to develop salinity and aeration problems than fine-textured soils. Many of the soils proposed for irrigation in North Dakota are coarse-textured (Rivers and Shipp 1972).

The objective of this study was to evaluate the influence of water table depth and irrigation level on the growth of irrigated alfalfa (*M. sativa*). This paper reports results from field and lysimeter experiments with alfalfa grown on a sandy soil in the northern Great Plains.

MATERIALS AND METHODS

The research consisted of 3-yr field-plot and lysimeter experiments with alfalfa. Only 2 yr of crop production are reported because the first year was crop establishment year. The two experiments were conducted in different years, but on adjacent sites. The soils, an association of the Hecla-Arveson-Fossum series, are representative of many soils, ranging from sandy loams to loamy sands, scheduled for irrigation in eastern North Dakota. Hecla is an Aquic Haploboroll, Arveson is a Typic Calciaquoll, and Fossum is a Typic Haplaquoll (U.S. Dep. Agric. 1972). Vernal alfalfa (inoculated) and oats were seeded at rates of 13.5 and 54 kg/ha, respectively. Alfalfa yields are reported at 12% water (dry weight basis).

Field-plot Study

Three water table depths and four irrigation levels, arranged factorially, were replicated four times. It was impossible to establish the three water table depths for individual plots at one site. They were established at three different sites in an 8-ha area through topographic differences between sites and through drawdown adjacent to the drainage well. Each plot was 13.4 m long and 4.9 m wide.

Two-year average shallow, medium, and deep water table depths, respectively, were 146 cm (declining from 125 cm on 15 May to 175 cm on 30 Sept.), 195 cm (declining from 190 cm on 15 May to 222 cm on 30 Sept.), and 235 cm (declining from 230 cm on 15 May to 259 cm on 30 Sept.).

Amounts of irrigation water (*IW*) applied weekly were determined by

$$IW = C(ET_p \times K_c) - P + D \qquad (1)$$

where C is 0.5, 1.0, or 1.5 to provide the desired irrigation treatment, ET_p is the potential evapotranspiration calculated by the Jensen-Haise equation (Jensen et al. 1970) adapted for North Dakota (Follett et al. 1973), K_c is the crop coefficient which is equal to one for alfalfa (Pair 1975; Burman et al. 1980), P is the measured precipitation for the week, and D is the soil-water deficit carried over from the previous week. If the calculated IW amount was less than 7.6 mm, no irrigation was applied and that amount became D for the following week.

The nonirrigated treatment received precipitation only while the other three treatments (C = 0.5, 1.0 and 1.5) received irrigation plus precipitation. Irrigation was applied with rotating-boom plot-sprinkler irrigators (Bond et al. 1970) at a rate of 2.5 cm/h.

Daily rainfall amounts less than 2.5 mm were not considered effective precipitation and were excluded in the calculation of IW. Deep drainage and the contribution from the water table could not be measured in the field plots. Precipitation in excess of calculated ET plus D was assumed to move through the root zone i.e., negative values for IW were ignored.

At experiment start, ammonium nitrate (33-0-0) at 56 kg N/ha, concentrated superphosphate at 56 kg P/ha (0-46-0), and potassium sulfate (0-0-50) at 111 kg K/ha were applied broadcast to the plots before planting. Alfalfa was planted on 20 May, along with oats as the nurse crop. Alfalfa harvests were taken from 1.8 × 6.1-m areas on 9 June, 14 July and 23 Aug. the first year, and on 14 June, 17 July and 20 Aug. the second year after establishment.

Lysimeter Study

Twelve nonweighing lysimeters were constructed near the field plot area and filled with soil to reconstruct the original soil layers (Reichman et al. 1979). Each lysimeter was 2.44 m by 4.88 m in surface dimensions and had a depth to accommodate the design water tables. The top of each lysimeter frame was 20 cm below the ground surface to permit use of farm machinery for cultural practices.

Irrigation needs were calculated twice weekly and water was applied when needed each Monday and Friday for three irrigation levels (C = 0.3, 0.8, and 1.3 for Eq. 1).

Four constant water table depths (46, 101, 155, and 210 cm) were maintained in the lysimeters through pipes connecting each lysimeter to a stilling well, water supply, pump and instrumentation in a centrally located shelter. The water table level was automatically evaluated and adjusted every 30 min in each stilling well (Reichman et al. 1979).

Superphosphate (0-46-0) was broadcast at a rate of 112 kg P/ha and incorporated into the soil before seeding. Alfalfa was planted on 11 May, with oats as a nurse crop. Ammonium nitrate (33-0-0) was broadcast after seeding at a rate sufficient to bring the applied N plus available soil N in the upper 9.5 cm of the soil profile to a level of 90 kg N/ha. Alfalfa was harvested three times the first and second years after crop establishment from four 0.9 × 2.1-m quadrats in each lysimeter.

TABLE I. EVAPOTRANSPIRATION AND WATER DEFICITS AT OAKES, N. DAK.

Parameter	Month: May	June	July	August	Sept.	Season total
	Potential evapotranspiration (ET_p) (cm)					
a. Field experiment						
1st year	11.7	14.9	14.0	14.0	7.4	62.0
2nd year	11.3	16.7	17.5	15.2	6.4	67.1
b. Lysimeter experiment						
1st year	11.4	13.5	15.5	14.0	9.1	63.5
2nd year	7.4	11.9	14.2	10.2	6.9	50.6
	Water deficit (ET_p - P)† (cm)					
a. Field experiment						
1st year	0.5	11.6	0.3	11.0	6.4	29.8
2nd year	8.3	13.1	10.4	12.7	−5.3	39.2
b. Lysimeter experiment						
1st year	2.7	−2.9	12.6	10.3	4.9	27.6
2nd year	4.5	3.3	4.1	7.0	6.5	25.4

†P = Precipitation.

RESULTS AND DISCUSSION

In the field-plot experiment, the uncontrolled water-table depths fluctuated seasonally and between years. The lysimeter experiment was conducted because it had been impossible to maintain relatively constant water table depths in the field-plot experiment.

Evapotranspiration data and water deficits for the 2 yr for both the field and lysimeter experiments are given in Table I. Monthly and seasonal irrigation and rainfall for the two experiments are given in Table II and statistical analyses in Table III.

Field Experiment

Annual yields of alfalfa from three harvests for the four irrigation levels as a function of the three water table depths are shown in Figs. 1 and 2. Yields ranged

TABLE II. IRRIGATION WATER APPLIED TO FIELD PLOTS AND LYSIMETERS EXPERIMENTS†

	May		June		July		August		September		Irrigation total		Irrigation + rainfall	
	Year		Year		Year		Year		Year		Year		Year	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Field-plot experiment														
Irrigation level (cm)														
0.0 IR (rainfall)‡	11.0	3.1	3.3	3.5	13.6	7.2	3.2	2.5	1.1	11.6			32.2	27.9
0.5 IR	0	1.3	4.0	1.3	2.1	4.9	5.6	6.8	2.1	1.1	13.8	15.4	46.0	43.3
1.0 IR	0	1.3	4.5	1.3	4.4	10.0	13.2	15.7	4.6	2.2	26.7	30.5	58.9	58.4
1.5 IR	0	1.3	5.1	1.3	8.6	16.0	21.2	24.7	5.8	3.5	40.7	46.8	72.9	74.7
Lysimeter experiment														
Irrigation level (cm)														
Rainfall	8.7	2.9	16.4	8.6	2.9	10.1	3.6	3.2	4.2	0.4			35.9	25.2
0.3 IR	0	0	1.0	1.0	2.8	3.3	1.9	1.6	1.1	0	6.8	5.9	42.7	31.1
0.8 IR	0	0	4.9	5.3	10.3	7.9	8.3	6.2	4.1	2.5	27.6	21.9	63.5	47.1
1.3 IR	0	0	9.0	9.2	17.8	13.3	14.5	11.0	7.0	3.7	48.3	37.3	84.2	62.5

†The same irrigations were applied to all water table depth treatments.
‡All irrigation levels (IR) received precipitation and the 0.0 IR received precipitation only.

TABLE III. STATISTICAL SIGNIFICANCE OF WATER-TABLE DEPTH AND IRRIGATION ON ALFALFA YIELDS IN FIELD AND LYSIMETER EXPERIMENTS

	PR>F and Significance†					
	Field			Lysimeters		
Source of Variation	d.f.	1st yr	2nd yr	d.f.	1st yr	2nd yr
Water table (WT)	2	0.0001**‡	0.0005**	3	0.0001**	0.0001**
Irrigation (IRR)	3	0.0100**	0.0001**	2	0.0207*	0.0096**
WT × IRR	6	0.0089**	0.1942	6	0.6267	0.0010**
Corrected total	47			47		

†The *PR>F* value is a measure of evidence concerning the equality of means. For example a *PR>F* = 0.0600 says there is a 6% probability that the assumption of equal means is correct. Thus, the smaller *PR>F* becomes, the more evident it becomes that the assumption of equal means is wrong or, conversely, the more evident it becomes that the means are, in fact, different.
‡Statistical significance symbols: ** = 99%; * = 95% confidence level.

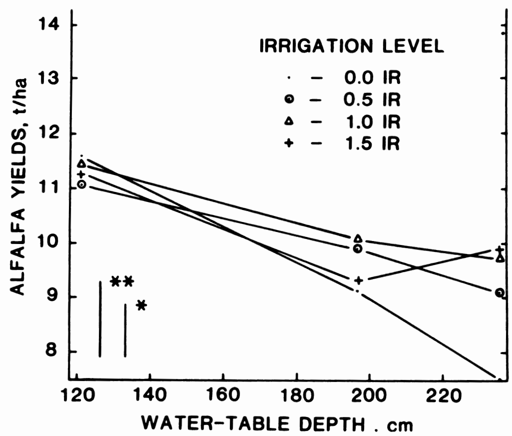

Figure 1. Alfalfa yields, first-year after establishment, from a field experiment as functions of water table depth and irrigation. Means separated by more than one length of the vertical bar are significantly different at the 95% (*) or 99% (**) confidence level.

from 11.1 and 11.6 tonne/ha the first year after crop establishment (Fig. 1) over all four irrigation levels with the shallowest water table (121 cm); but the differences were not significant, i.e. alfalfa yields were not affected by irrigation. Yield differences due to irrigation were also not significant with the medium water table (197 cm), but yields were significantly increased with irrigation for the deep (236 cm) water table. However, yields were much lower for the medium and deep water table treatments compared with the shallow water table with the highest yield being 10.2 tonne/ha and the lowest yield 7.6 tonne/ha.

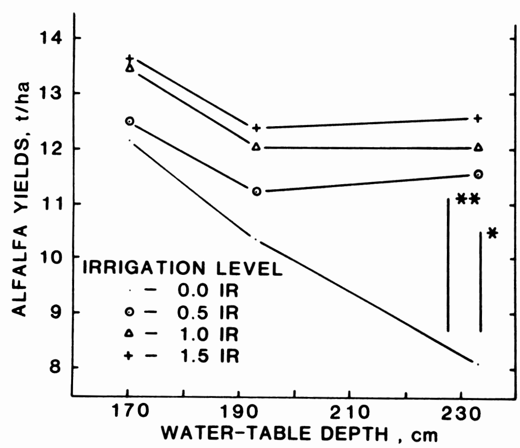

Figure 2. Alfalfa yields, second-year after establishment, from a field experiment as functions of water table depth and irrigation. Means separated by more than one length of the vertical bar are significantly different at the 95% (*) or 99% (**) confidence level.

Water table depths were not constant during the growing season and, in fact, receded from a high in the spring to a depth about 30 cm lower in the fall each year. The water table depths shown in Fig. 1 were averages for the growing season.

Alfalfa yields the second year after crop establishment, as shown in Fig. 2, averaged (over four irrigation levels) slightly higher (13.0 tonne/ha) for the shallow (170-cm) compared to the medium and deep water table. The shallow water table was about 50 cm lower than in the first year. As in the previous year the shallow water table treatments produced the highest yield for each irrigation level. For the deep water table (233 cm) the second year, maximum yield was 12.6 tonne/ha with the 1.5 irrigation level. Irrigation increased yields significantly with the deep water table. The lowest yield was 8.1 tonne/ha with the 0.0 irrigation level. With the medium water table (193 cm), yields were a little below those from the shallow and deep water tables for the three irrigated treatments, and only the yield for the 1.5 irrigation level was significantly different from the yield for the nonirrigated treatment.

Comparisons between years for the field experiment show that yields were about 2 tonne/ha greater the second year for all water table and irrigation treatments. This may be related to crop age, i.e., 1 vs. 2 yr after establishment, and other factors such as seasonal water table depth and *ET*. These field-plot data were not conclusive in determining optimum water table depth and irrigation level for maximum yields. The yield curves (Figs. 1 and 2) slope upward to the left indicating that a water table depth less than 120 cm the first year and less than 170 cm the second year could have resulted in greater yields. Yield data were not available for intermediate water table depths between 121 and 197 cm for the first year and neither were yield data available for water table depths less than 170 cm for the second year. Had these data been available they may have shown, similar to the lysimeter data, that the optimum water table depth was about 155 cm for maximum yields of alfalfa.

Lysimeters

Annual alfalfa yields for 2 yr are shown as functions of water table depth and irrigation levels (Figs. 3 and 4). The four water table treatments included a wider range of depths in the lysimeters than in the field-plots, and water tables were maintained at constant depths.

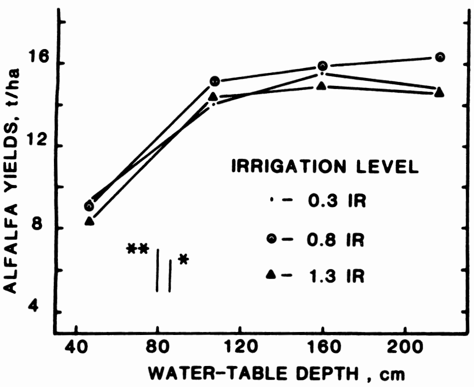

Figure 3. Alfalfa yields, first-year after establishment, from a lysimeter experiment as functions of water table depth and irrigation. Means separated by more than one length of the vertical bar are significantly different at the 95% (*) or 99% (**) confidence level.

The highest alfalfa yield (16.3 tonne/ha), the first year after crop establishment, was with the 0.8 irrigation and at the 210-cm water table (Fig. 3). Yields from all irrigation applications varied less than 2.5 tonne/ha for the 101-, 155-, and 210-cm water tables. Overall, the data show that a water table depth of about 155 cm was probably near the optimum for maximum crop production and that irrigation had little effect in increasing yields at any water table depth. The shallow water table (46 cm) caused depressed yields, and irrigation had no effect on production.

The second year after crop establishment (Fig. 4), crop yields were reduced to about one-half with the shallow water table compared to the other three water table treatments. At the 46-cm water table, alfalfa yields ranged from 7.1 to 4.9 tonne/ha with the yield for the 1.3 irrigation level being significantly lower (95% confidence level) than the yields for the lower irrigation levels. Alfalfa yields were significantly higher for 0.8 IR and 1.3 IR than for 0.3 IR with both the 155- and 210-cm water tables. For the lowest irrigation level (0.3 IR), alfalfa yields decreased as water table depth increased, i.e. 13.9, 13.3 and 12.5 tonne/ha, for the 101-, 155-, and 210-cm water tables, respectively.

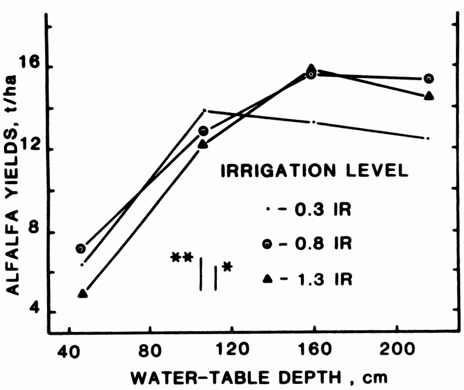

Figure 4. Alfalfa yields, second-year after establishment, from a lysimeter experiment as functions of water table depth and irrigation. Means separated by more than one length of the vertical bar are significantly different at the 95% (*) or 99% (**) confidence level.

Statistical analyses (Table 3) show water table and irrigation effects on yield were significant. The interaction of water table × irrigation significantly affected yields only during the second year when irrigation treatments over the 46- and 101-cm water tables caused different yield responses than did the same irrigation treatments over the 155- and 210-cm water tables. Confidence intervals in Figs. 3 and 4 show yields were significantly influenced by water table depth.

SUMMARY

Field-plot and lysimeter experiments were conducted to evaluate alfalfa yields for 2 yr as functions of water table depth and irrigation amounts for a sandy soil in North Dakota. The field experiment and lysimeter experiment had, respectively, three and four water table depths and four and three irrigation levels. Water table depths dropped seasonally in the field-plot experiment but were kept constant in the lysimeter experiment.

For the field-plots for both years, yields were highest with the shallowest water table (1.2 m the first year and 1.7 m the second year) regardless of irrigation amounts. Alfalfa yields averaged about 2 tonne/ha higher the second year. For the deepest water table (2.3 and 2.4 m) yields generally increased with irrigation.

For the lysimeters, yields were significantly depressed with the 46-cm water table. Consistently high yields were obtained when the water table depth was 155 cm, and irrigation usually increased yields at the 155- and 210-cm depths.

These data show that water table depth significantly affected alfalfa yields. A shallow water table (46 cm) depressed yields and land with a deep water table (210 cm) required more irrigation for maximum yield. The field experiment data indicated the optimum water table depth was less than 1.7 m for maximum production of irrigated alfalfa grown on sandy soils. The lysimeter data indicated an optimum water table between 1.4 and 2.0 m for maximum irrigated alfalfa yields. Consolidation of data from the two experiments does not give conclusive results but does show an optimum water table depth of between 1.4 and 1.7 m for greatest alfalfa production.

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