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Alfalfa Stand Losses from Irrigation: Influence of Soil Temperature, Texture, and Aeration Status[1]

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ABSTRACT

Losses of alfalfa (*Medicago sativa* L.) occur under the combination of high summer temperatures and clay soils. This paper examines the relationship between these losses and soil temperature, texture, and aeration. The study consisted of short tests (one irrigation) and long-term experiments (2.5 yr) in the field, and gas exchange experiments in a greenhouse. The design for the field experiments was a randomized block with four replications for the short-term experiments and three replications for the long-term experiment. It was necessary to flood 56 h (silty clay soil under high temperatures) to damage alfalfa in the field. Root damage was only 1% in a clay loam soil compared to 10% in a silty clay soil (56-h flooding time and high temperature). Sufficient water could not be applied in the long term experiment to the alfalfa to leach salts (84% Epan treatment) without severe losses in stand. Long flooding times (96 h) at medium temperatures (maximum air temperature 32°C) did not result in root damage to the alfalfa. Oxygen deficiency, not ethylene toxicity, seemed to be the problem when alfalfa was flooded. Ethylene levels in the field were low and symptoms of toxicity were not observed. In the greenhouse, no damage to alfalfa occurred until O_2 fell to 0.01 L/L at high temperatures. Results of this experiment indicate that there is a high probability of damage to grower fields when O_2 stress under high temperature extends over many irrigations.

Additional Index Words: **ethylene, waterlogging, leaching, oxygen content, *Medicago sativa* L.**

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ALFALFA (*Medicago sativa* L.) is sensitive to flooding injury at high temperatures (1, 2, 3, 6). Lehman et al. (10) found a narrow range between the application of too little and too much irrigation water. It is difficult to replace seasonal evaportranspiration (around 200 cm in the Imperial Valley (9) plus 13% for the leaching requirement) without exceeding desired flooding times. High temperatures and clay soils reduce the desired flooding times in the Imperial Valley of California (10). Top growth of alfalfa was re-

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duced 50% when plants were flooded for 2 d at 32°C (Thompson and Fick, 16). Meek et al. (13) measured substantial losses of alfalfa in the Imperial Valley when alfalfa was flooded for 48 h. Cameron (2) found that flooding 5 d after cutting, with the soil temperature at 33°C, killed 35% of the plants.

Optimum yields of most field crops require adequate soil aeration. Low aeration levels occur temporarily when soils with a supply of readily decomposable organic matter are irrigated, especially when flooded under high temperatures. Soil aeration has been difficult to measure in the field because of the high spatial variability of soil factors that influence aeration (5).

Flooding injury may result in an increase in severity and incidence of disease resulting in a slow decline in alfalfa growth or in the sudden death of individual plants. Kuan and Erwin (8) found that flooding of soil predisposed alfalfa roots to Phytophthora root rot (*Phytophthora megasperma* f. sp. *medicaginis*). Hunt et al. (7) measured flooding injury to tobacco (*Nicotiana tabacum* L.) that was correlated with high soil ethylene levels.

The objectives of this study were to determine (i) the effect of texture, temperature, and flooding time on soil O_2 levels and stand losses during one irrigation, (ii) to determine the effect of the amount of water applied on stand losses and O_2 levels when multiple irrigations were applied, and (iii) to determine critical O_2 and ethylene levels necessary to kill alfalfa during one irrigation cycle. The objectives were achieved by conducting three separate experiments.

MATERIALS AND METHODS

Short-term Experiment

The experimental site was a calcareous Holtville series (hyperthermic Typic Torrifluvents) (saturated soil paste of 7.8 pH) at the Irrigated Desert Research Stn. in the Imperial Valley of California (14). The two textures studied were a clay loam and a silty clay (0–30 cm) with both soils having silty clay loam texture at the 30- to 60-cm depth.

This experiment consisted of three field trials which were (i) silty clay soil-high temperature (SCS-HT), (ii) clay loam soil-high temperature (CLS-HT) and silty clay soil-medium temperature (SCS-MT). The experiments were conducted either in the summer or fall to obtain the two temperatures. The medium temperature treatment would have been subjected to a shorter duration and intensity of light, and other conditions may have been different compared to the high temperature treatment. The two fields were about 1 km apart.

The experimental design was a randomized block with four replications. The area received a broadcast application of 225 kg P/ha before it was seeded to the alfalfa variety CUF 101 in October 1978. Plots were 5 by 5 m and a 60-cm high sheet of 0.1-mm plastic was used to form a dike around each plot. The bottom edge was buried 20 cm in the soil.

Plots were flooded for 32, 40, 48, and 56 h under the high temperature trials and 48, 72, and 96 h under the medium temperature trial. Water was maintained on the level plots at approximately the 5-cm depth by float valves. A manifold of plastic pipe connected each plot to the water source. The plastic dike was removed to drain the plots at the end of the trial.

Soil O_2 ethylene levels, and matric potentials were measured at the 15-, 30-, and 60-cm depths with duplicate measurements being made at each depth. Mercury manometers attached to tensiometers were used for measuring soil matric potential.

Soil O_2 in the field was measured using double-membrane polarographic probes similar to those designed by Willey and Tanner (17). Plastic access pipes (with inserts cemented into the bottom of the pipe) were inserted (one for each depth) to the desired depths. Probes were calibrated in air and inserted into the access pipe. The O-ring on the probe was firmly seated in the insert to form an airtight seal. A diagram of the setup plus a more complete procedure is given by Meek et al. (13).

Ethylene in the soil atmosphere was analyzed using a Sigma 3 Perkin-Elmer gas chromatograph[3] with a flame ionization detector and a porpak N column. A small plexiglass cylinder (20-mL volume) closed at the top and open at the bottom was buried in the soil at the correct depth. Copper tubing sealed with a serum cap was used to connect the buried cylinder with the soil surface. Samples were taken using syringes and analyzed in the laboratory within 2 h.

Plant root damage was evaluated 1 week after flooding by examining roots in two excavated 60- by 60- by 15-cm soil samples. Damaged roots were those which would change shape when squeezed by hand. Damage to top growth was evaluated for the trial (SCS-HT) only.

Long-term Experiments

Field plots were established in 1974. The area received a broadcast application of 225 kg P/ha before the alfalfa was seeded. Two alfalfa cultivars were seeded, Mesa Sirsa and Salton, and each occupied one-half of the plot. The experimental design was a randomized block with five replications and six irrigation treatments. Irrigation treatments were initiated in July 1975 and continued for 2.5 yr. Detailed procedures for this experiment are given in Donovan and Meek (4). Measurements reported in this paper were made in only three of the six irrigation treatments.

Oxygen and matric potential measurements were made in three replications of three of the irrigation treatments during three irrigations in 1976 (25 May, 31 May, and 8 July) and two irrigations in 1977 (2 June and 25 July). The three treatments received water equal to 66, 75, and 84% of pan evaporation (E_{pan}). All treatments were irrigated at the same time with different amounts of water being applied. Times between irrigations were adjusted so that approximately 7.5 cm of water was applied each irrigation for the 75% E_{pan} treatment (our best estimate of consumptive use). The time necessary for the water to infiltrate was measured.

Soil O_2 and matric potential were measured at the 15-, 30-, and 60-cm depths. Two O_2 sensors, of the same type as used in the short term experiment, were installed at each depth (one in each alfalfa variety) and values were recorded using potentiometric strip chart recorders. Matric potentials were measured daily using tensiometers (one at each depth).

Plant stand density counts were made 3 Feb. 1976, 7 Jan. 1977, and 6 Dec. 1977 and consisted of all living crowns within two areas (0.077 m^2 each) in each plot. Plant density measurements were made in two replications only.

Greenhouse Experiment

Columns were constructed using plexiglass cylinders (66-cm long and 20-cm diam). Copper tubing (1.65-mm i.d.) was inserted from the top of the cylinder to take samples of the soil atmosphere at 10-, 30-, and 50-cm depths (Fig. 1). All tubing had the ends covered with glass wool to prevent entry

[3] Mention of a trademark product does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

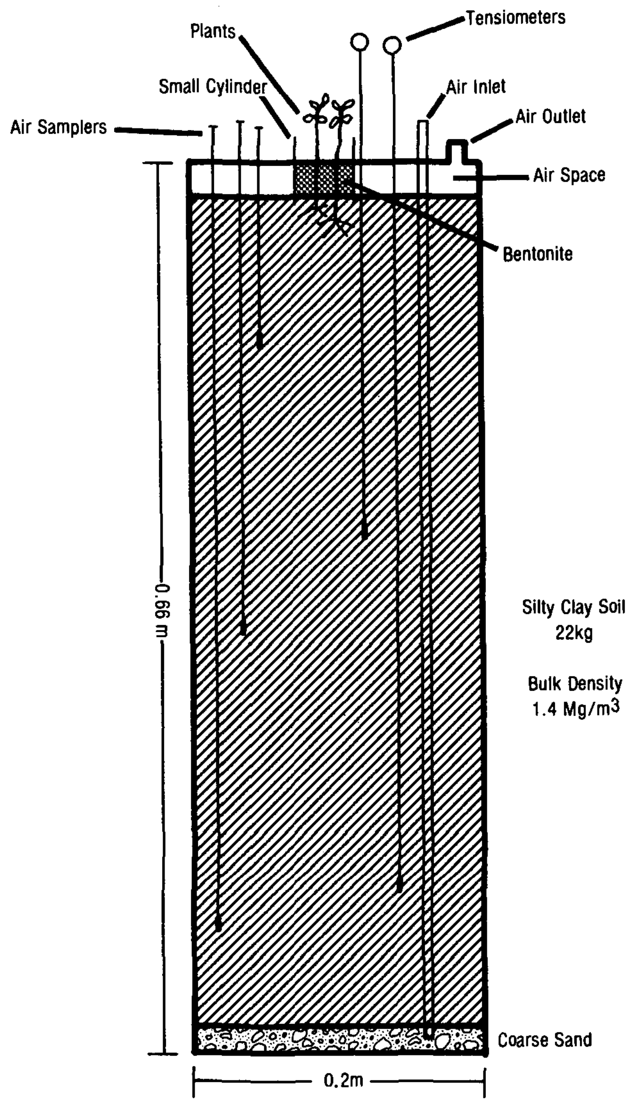

Fig. 1. Schematic diagram of column setup used for the greenhouse experiment.

of soil. Tensiometers were placed at the 25- and 50-cm depths in the soil. A plastic tube (9.5-mm o.d.) was inserted to the bottom of the cylinder for introducing gas mixtures.

The cylinder was sealed at the bottom and the sand and silty clay soil (fertilized at the rate of 225 kg P/ha) were added. The cylinder was tapped to achieve a soil bulk density of 1.4 Mg/m^3. The air samplers, tensiometers, and the plastic tube were inserted as the cylinder was filled. The top plate was cemented in place and all connections were checked to make sure they were airtight.

Ten alfalfa seeds, variety CUF 101 were planted in the small cylinder in the center of the column and 1 L of water added to the cylinder for germination. The alfalfa was thinned to four seedlings after 14 d and allowed to grow for 12 weeks, at which the roots had almost reached the bottom of the cylinder. The cylinders were irrigated during the 14-week period when the matric potential reached −80 kPa at the 25-cm depth.

To initiate a trial, alfalfa was harvested and then irrigated 6 d later. Columns were placed in a water bath and the heater set to come on when the water temperature of 25°C was reached. The greenhouse was cooled when the air temperature reached 43°C. This resulted in a water temperature range of 25 to 38°C measured by a thermograph (elevated

Table 1. Measured temperature extremes in three flooding experiments.

Experiment	Temperature: Air Maximum	Air Minimum	Soil† maximum	Water maximum
	°C			
Short term field				
SCS-HT‡	42	24	32	37
CLS-HT	42	22	31	36
SCS-MT	32	12	25	26
Long-term field§	39	20	30	
Greenhouse	43	22		38

† 10-cm depth.
‡ SCS = Silty clay soil, CLS = clay loam soil, HT = high temperature, MT = medium temperature.
§ Average temperatures 25 May to 19 August when O_2 levels were measured.

Table 2. The time interval that O_2 was <0.05 L/L in the soil as a function of flooding time in the short-term field experiment.

Treatment	Soil depth	Hours flooded: 32	40	48	56	72	96	r‡
	cm	h						
SCS-HT†	15	51	39	46	107			0.67**
	30	61	39	48	84			0.46**
	60	26	34	18	26			0.10
CLS-HT	15	64	48	61	74			0.27
	30	68	54	72	84			0.34
	60	36	72	114	72			0.50*
SCS-MT	15			64		110	120	0.76**
	30			53		106	134	0.80**
	60			20		57	151	0.86**

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† SCS = silty clay soil, CLS = clay loam soil, HT = high temperature, MT = medium temperature.
‡ Correlation coefficient.

air temperatures were present only a short time so air temperature was not reached). These water temperatures were selected to simulate soil temperature ranges that occur in the field under the high temperature treatments. A 2-cm deep bentonite slurry was poured in the small cylinder to seal around the alfalfa stems.

Ten days after harvest, a flow of the gas mixture under study was introduced into the bottom of the column. Bubbles flowing out of the outlet at the top of the column indicated a positive pressure and the rate of flow of the gas mixture through the column. Gas mixtures tested were 0.075, 0.05, 0.025, 0.01, and 0.005 L/L O_2 (all in N with 0.0003 L/L CO_2) and 8, 4, and 2 μL/L ethylene (all in air). The gas flowing out of the outlet was analyzed at selected times to make sure it was near the concentration of the gas mixture entering the bottom of the column. If not, the gas flow was increased. Tests were conducted for 72 h with two columns for each treatment.

RESULTS

When air temperatures were 42°C, soil temperatures at the 15-cm depth were only 32°C (Table 1). The temperatures for the long-term experiment were slightly less than for the short-term high temperature experiments.

Short-term Experiment

Flooding for 56 h doubled the time that soil O_2 was <0.05 L/L (15-cm depth) compared to other flooding

Table 3. The time interval that O_2 was <0.01 L/L in the soil as a function of flooding time in the short-term field experiment.

Treatment	Soil depth	Hours flooded 32	40	48	56	72	96	r‡
	cm	h						
SCS-HT†	15	12	15	37	28			0.50*
	30	39	30	36	23			0.46**
	60	6	10	21	35			0.71**
CLS-HT	15	38	16	14	39			0
	30	21	15	30	46			0.43
	60	8	26	80	32			0.44
SCS-MT	15			38		44	49	0.14
	30			22		33	58	0.39
	60			3		27	61	0.64**

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† SCS = silty clay soil, CLS = clay loam soil, HT = high temperature, MT = medium temperature.
‡ Correlation coefficient.

Table 4. The time interval taht soil matric potential was >−10 kPa as a function of flooding time in the short-term field experiment.

Treatment	Soil depth	Hours flooded 32	40	48	56	72	96	r‡
	cm	h						
SCS-HT†	15	80	139	144	145			0.75**
	30	81	114	117	146			0.64**
	60	28	42	56	59			0.82**
CLS-HT	15	80	80	78	98			0.39
	30	92	77	78	96			0.12
	60	48	48	48	56			0.38
SCS-MT	15			160		154	188	0.65**
	30			125		160	172	0.54*
	60			82		87	110	0.60*

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† SCS = silty clay soil, CLS = clay loam soil, HT = high temperature, MT = medium temperature.
‡ Correlation coefficient.

Table 5. Damage to alfalfa plants as a function of flooding time.

Treatment	Type of damage	Hours flooded 32	40	48	56	72	96	r‡
		%						
SCS-HT†	Some leaves	12	26	46	51			0.81**
	Most leaves	5	10	26	31			0.89**
	Soft roots	1	2	4	10			0.65**
CLS-HT	Soft roots	0	0	0	1			0.54*
SCS-MT	Soft roots			0		0	0	

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† SCS = silty clay soil, CLS = clay loam soil, HT = high temperature, MT = medium temperature.
‡ Correlation coefficient.

times in the silty clay soil (SCS-HT), but it did not significantly increase the time in the clay loam soil (CLS-HT) (Table 2). There was no significant correlation between flooding time and hours O_2 was below 0.05 L/L (15-cm and 30-cm depths) in the clay loam soil. Flooding for 96 h under medium temperatures resulted in long periods where the oxygen was <0.05 L/L. Flooding for 56 h resulted in soil O_2 levels <0.01 L/L for 28 h (Table 3). There were few significant differences in the number of hours <0.01 L/L O_2 as a function of flooding time but the differences may have been masked by the large spatial variability.

Soil matric potential was above −10 kPa (15-cm depth) for 144, 78, and 160 h (when flooded for 48 h) for the SCS-HT, CLS-HT, and SCS-MT treatments respectively (Table 4). The shorter time period for the CLS-HT treatment was due to rapid drainage of the large pores of this soil. However, both treatments had about the same number of hours that were <0.05 L/L O_2.

Soil ethylene levels were low, <2.4 μL/L and avg 0.5 μL/L. The average ethylene content for all depths of the 48- and 56-h flooding periods exceeded that of the 40-h flooding period.

Root damage was 10% in the SCS-HT treatment when plots were flooded for 56 h (Table 5). Also, leaf damage for this treatment increased when plots were flooded for increasing periods of time. The minor damage for the treatment CLS-HT is probably the result of a greater proportion of large pores that would have increased O_2 diffusion and drained more rapidly compared to the SCS-HT treatments. For example, at the 15-cm depth, the soil matric potential remained above −10 kPa for 145 h (for the 56-h flooding) in the silty clay soil (SCS-HT), but only 98 h for the clay loam soil (CLS-HT).

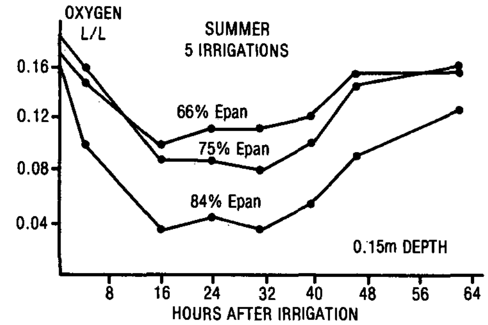

Fig. 2. Oxygen levels in the long term experiment as a function of hours after irrigation for three treatments averaged for five summer irrigations in 1976 (25 May, 31 May, and 8 July) and 1977 (2 June, and 25 July).

Long-term Experiment

When alfalfa was irrigated at a rate greater than consumptive use (84% E_{pan}) O_2 levels were lowered at the 15-cm depth (Fig. 2). There were no significant differences in O_2 level between the 66 and 75% E_{pan} treatments. Average oxygen levels at the 30- or 60-cm depths for the three irrigation treatments remained above 0.12 L/L.

Soil matric potentials at the 15-cm depth increased to −10 kPa after irrigation for the three irrigation treatments. Averaged soil matric potentials were always low (<−35 kPa) at the 30- and 60-cm depths (data not tabularly presented).

The treatment 84% E_{pan} resulted in a loss of stand (no differences on 3 Feb. 1976 but differences in counts conducted on 7 Jan. 1977 and 6 Dec. 1977) with time compared to the other treatments but no decrease in yield. Stand counts in December 1977 were 182, 176, and 46 crowns/m^2 for the treatments 64, 75, and 84% E_{pan}, respectively. The reason that yield did not decrease is that the increased leaching would have decreased salinity and promoted increased growth. Total yields (2.5 yr) were 46, 55, and 53 Mg/ha for the treatments 66, 75, and 84% E_{pan}, respectively.

The average infiltration times (time for the irrigation water to infiltrate into the soil) for the five summer irrigations were 10, 15, and 17 h for the 66, 75, and 84% E_{pan}, respectively. Correlation between the infiltration times and the hours that soil O_2 was below 0.05 L/L was $r = 0.78$.

Greenhouse

There was no damage to alfalfa when the O_2 concentration was 0.025 or 0.075 L/L but some leaf damage occurred at 0.01 L/L and plants died at 0.005 L/L. Plant symptoms appeared 48 h after treatments were initiated.

There was no damage to alfalfa when the ethylene levels were 2 or 4 μL/L, but plants died at 8 μL/L (all at 0.21 L/L O_2). Plants injured from high levels of ethylene collapsed, which is a different symptom than that for scald damage where dessication occurs but plants remain upright.

DISCUSSION

Results of these experiments indicate that there is a high probability of damage to grower fields when O_2 stress extends over many irrigations. Extreme conditions are required to kill plants during one irrigation (56 h of flooding at high temperatures). This seldom occurs in grower fields. Our results agree with the data of Thompson and Fick (16), who found that yield of alfalfa decreased as the period of flooding increased. Twenty-four hours of flooding at 32°C decreased growth rate. They found that at 32°C the stand was effectively lost by 144 h of flooding. The difference between the two studies was that Thompson and Fick (16) pasteurized their soil, which would have reduced Phytophthora.

Damage to alfalfa roots occurred in the silty clay soil but not in the clay loam soil when both were flooded for equal times at high temperatures, even though O_2 levels were similar.

Salts could not be leached from alfalfa stands (84% E_{pan} treatment equal to 12% leaching) without plant damage in long term experiments under high temperatures in a silty clay soil. Lehman et al. (10) also found that it was difficult to leach alfalfa during the summer but much easier in the winter.

Oxygen deficiency, not ethylene toxicity, seemed to be the problem when alfalfa was flooded. Ethylene levels in the field were low and symptoms of toxicity were not observed. In the greenhouse, no damage to alfalfa occurred until O_2 fell to 0.01 L/L at high temperatures. Plant symptoms occurred after the alfalfa root system was maintained at 0.01 L/L O_2 for 48 h. In the field studies O_2 decreased at the 15-cm depth to <0.01 L/L for periods of up to 49 h. In this study it was necessary to have both low O_2 levels (<0.05 L/L for about 100 h) and high temperatures (about 42°C maximum air temperature) to damage alfalfa. There was no root damage when O_2 remained <0.05 L/L for 188 h at a maximum air temperature of 32°C.

The temperature by aeration interaction can be explained in a number of ways. Luxmoore et al. (12) proposed that the "induced O_2 shortage resulted from the greater O_2 depletion at higher temperatures due to the elevated respiration rate of both the plant roots and competing microorganisms." Leaf damage at high air temperatures could result from heating caused by stomatal closure resulting from the blockage of water uptake by low soil O_2 (Sojka and Stolzy, 15). Letey et al. (11) found that a higher diffusion rate was required to maintain optimum root growth under higher aerial temperatures but diffusion rate requirement was affected very little by soil temperature.

This study illustrates the difficulty of managing alfalfa under clay soils and high temperatures. A grower may not be able to leach to reduce salinity during alfalfa production so it is important to leach before planting. Leaching might also be done during cooler temperatures. Practices to reduce the time necessary for the irrigation water to infiltrate, such as reducing soil compaction, will result in increased alfalfa growth.

REFERENCES

1. Barta, A.L. 1980. Regrowth and alcohol dehydrogenase activity in waterlogged alfalfa and birdsfoot trefoil. Agron. J. 72:1017–1020.
2. Cameron, D.G. 1973. Lucerne in wet soil—the effect of stage of regrowth, cultivar, air temperature, and root temperature. Aust. J. Agric. Res. 24:851–861.
3. Erwin, D.C., B.W. Kennedy, and W.F. Lehman. 1959. Xylem necrosis and root rot of alfalfa associated with excessive irrigation and high temperatures. Phytopathology 49:572–578.
4. Donovan, T.J., and B.D. Meek. 1983. Alfalfa responses to irrigation treatments and environment. Agron. J. 75:461–464.
5. Fluhler, H., L.H. Stolzy, and M.S. Ardakai. 1976. A statistical approach to define soil aeration in respect to denitrification. Soil Sci. 122:115–123.
6. Heinrichs, D.H. 1972. Root-zone temperature effects on flooding tolerance of legumes. Can. J. Plant Sci. 52:985–990.
7. Hunt, P.G., R.B. Campbell, R.E. Sozka, and J.E. Parsons. 1980. Flooding-induced soil and plant ethylene production and response of field-grown tobacco. Plant Soil 59:427–439.
8. Kuan, T.L., and D.C. Erwin. 1980. Predisposition effect of water saturation of soil on Phytophthora root rot of alfalfa. Phytopathology 70:983–986.
9. Lehman, W.F. 1979. Alfalfa production in the low desert valley areas of California. U.C. Cooperative Extension Leaflet 21097, University of California, Berkeley.
10. Lehman, W.F., S.J. Richards, D.C. Erwin, and A.W. Marsh. 1968. Effect of irrigation treatments on alfalfa (*Medicago sativa* L.) production, persistence, and salinity in southern California. Hilgardia 39:(9) 277–295.
11. Letey, J., L.H. Stolzy, N. Valoras, and T.E. Szuszkiewiez. 1962. Influence of oxygen diffusion rate on sunflower growth at various soil and air temperatures. Agron. J. 54:316–319.
12. Luxmoore, R.J., R.E. Sojka, and L.H. Stolzy. 1971. Root porosity and growth response of wheat to aeration and light intensity. Soil Sci. 113:354–357.
13. Meek, B.D., T.J. Donovan, and L.E. Graham. 1980. Summertime flooding effects on alfalfa mortality, soil oxygen concentrations, and matric potential in a silty clay loam soil. Soil Sci. Soc. Am. J. 44:433–435.
14. Perrier, E.R., A.J. MacKenzie, and R.P. Zimmerman. 1974. Physical and chemical properties of major Imperial Valley soils. Western Region Pub. W-17. USDA-ARS, Berkeley, CA.
15. Sojka, R.E., and L.H. Stolzy. 1980. Soil-oxygen effects on stomatal response. Soil Sci. 130:350–358.
16. Thompson, T.E., and G.W. Fick. 1981. Growth response of alfalfa to duration of soil flooding and to temperature. Agron. J. 73:329–332.
17. Willey, C.R., and C.B. Tanner. 1963. Membrane covered electrode for measurement of oxygen concentration in soil. Soil Sci. Soc. Am. Proc. 27:511–515.