656

Reprinted from *Agronomy Journal*
Vol. 80, No. 4

Daily and Seasonal Evapotranspiration and Yield of Irrigated Alfalfa in Southern Idaho

James L. Wright*

ABSTRACT

Daily water-use data are needed for the development of modern irrigation scheduling techniques, the optimum allocation of water and energy resources, and improved irrigation management practices. This field study was conducted to measure evapotranspiration (ET) of well-irrigated alfalfa (*Medicago sativa* L.) in the arid region of southern Idaho. The relationship of ET to forage yield was also investigated. The soil was Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthids) common to much of the region. Daily and seasonal ET data were calculated for seven growing seasons from measurements obtained with mechanical weighing lysimeters equipped with electronic load cells. Daily alfalfa ET was highly variable. It occasionally exceeded 10 mm d^{-1} and averaged 8 mm d^{-1} during peak ET periods. From April through October, measured ET averaged 1022 mm for three harvests per season for 5 yr when soil water was nonlimiting. Corresponding average forage yield was 17.6 Mg ha^{-1} (120 g kg^{-1} water content) giving an overall water requirement of 58.1 mm (depth equivalent) to produce 1 Mg ha^{-1} of forage (581 m^3 Mg^{-1}) for a water-use efficiency of 17.2 kg ha^{-1} mm^{-1}. Harvest period and seasonal ET appear linearly related to pan evaporation and forage yield. The actual ET of well-irrigated, high-yielding alfalfa may be as much as 50% greater than previous estimates indicated for southern Idaho.

Additional Index Words: **Consumptive water use, Water use efficiency, Weighing lysimeters, Pan evaporation, *Medicago sativa* L.**

ALFALFA is an important forage crop in irrigated areas of the western United States and other similar areas throughout the world. High-producing irrigated alfalfa has one of the greatest seasonal water requirements of irrigated crops, yet it is a desirable crop because it produces high-quality forage, has relatively low production costs as a perennial, supports symbiotic dinitrogen fixation, and provides favorable soil conditioning in crop rotations. Few detailed and accurate daily and seasonal evapotranspiration data for alfalfa have been reported. Reliable data are needed in the development of improved irrigation management technologies, such as irrigation scheduling (Jensen et al., 1971; Wright and Jensen, 1978), and irrigation project management to permit optimum allocation of water and energy resources.

Evapotranspiration (ET) is the main use of water by a growing crop and is strongly influenced by the nature and amount of leaf area, the water content of

USDA-ARS, Soil and Water Management Res. Unit, Rt. 1, Box 186, Kimberly, ID 83341. Contribution from the USDA-ARS. Received 26 Aug. 1986. *Corresponding author.

Published in Agron. J. 80:662–669 (1988).

the root zone, and weather conditions. Other water requirements include the small amount incorporated into plant tissues and, depending on soil and water conditions, some for leaching excess salt from the root zone. The term *consumptive use* includes water incorporated into plant tissue, but often is used interchangeably with ET.

Most previous studies on alfalfa water use have utilized soil sampling methods to determine soil water depletion with time, usually by harvest period, utilizing gravimetric sampling (Erie et al., 1965), the neutron moisture-meter (Bauder et al., 1978; Daigger et al., 1970; Retta and Hanks, 1980), or combinations of the neutron meter and nonweighing lysimeters (Sammis, 1981). Sutter and Corey (1970) estimated the monthly and seasonal water use for alfalfa in southern Idaho with the USDA-SCS modified Blaney-Criddle (SCS-BC) method using limited climatic data and an empirically derived crop coefficient (USDA-Soil Conservation Service, 1967). Alfalfa water use determined from soil sampling data at best only provides averages for several-day periods. Seasonal water-use values obtained by these methods are also subject to uncertainties in accounting for small changes in soil-water content, spatial variability and water movement into or out of the root zone during the sampling interval.

All the terms of the water balance equation can be measured with a lysimeter (Tanner, 1967), and reliable ET data are possible with lysimeters if the measurements are representative samples of the surrounding conditions. Sensitive mechanical weighing systems provide an accurate means of measuring daily water loss (McIlroy and Angus, 1963; Ritchie and Burnett, 1968). Weighing and nonweighing lysimeters are subject to errors due to the effects of containment in the soil bin, which can distort thermal, water-content, and rooting conditions, resulting in unrepresentative vegetative cover. The effects of exposure and the uniformity of the surroundings can also be limiting.

When the intent is to study potential ET, i.e., when water loss is unrestricted by soil water contents, the lysimeter requirements and limitations are much less critical (McIlroy and Angus, 1963; Tanner, 1967). Filled lysimeters are suitable, provided the soil bin is deep enough to permit sufficient rooting, with adequate aeration, to produce representative plant growth.

An evaporation pan integrates the effects of solar radiation, wind, temperature, and humidity on evaporation from a specific open water surface. Plants also respond to these climatic conditions, but the daily evaporation rates from a pan and a crop are usually different. Water loss from a pan and a crop can be compared for periods of 10 d or longer (Pruitt, 1966).

The main objectives of this study were to determine the daily ET of well-irrigated alfalfa in an irrigated region of the Snake River Plains in southern Idaho, to compute growth period and seasonal ET from summations of daily ET, and to relate crop ET to pan evaporation and forage yields. Daily alfalfa ET was measured for the April through October season for 7 yr, utilizing weighing lysimeters at two evapotranspiration field-study sites established for these purposes.

MATERIALS AND METHODS

The ET field research was conducted 1 km south of the USDA, Snake River Conservation Research Center, about 1.5 km east of Kimberly, ID. This site, at latitude 42°33′ N, longitude 114°21′ W and elevation 1207 m, is in the interior of a large irrigated region about 10 km east of Twin Falls and about 45 km in the prevailing downwind direction from nonirrigated sagebrush-grass rangeland to the west. The climate is arid, with much of the annual precipitation occurring during the nongrowing season. The average frost-free period is about 120 d, from mid-May to mid-September. The Portneuf silt loam soil at the site is about 4 m deep and is underlain by basalt bedrock. This soil has a hard layer at a depth of 0.5 to 1 m consisting of rounded nodules of very hard soil material that is partly restrictive to root penetration, but is permeable to water flow. The soil is well drained, without a water table, and is well suited for irrigation.

Evaporation Measurements

A weighing lysimeter (Lys. 1) was installed in 1968 near the center of a 2.6-ha field, while a second unit (Lys. 2) was similarly installed in 1971 in an adjoining westward field of about 2.2 ha. In each case, the surrounding field provided an upwind fetch of at least 75 m in the prevailing wind directions. The steel lysimeter soil tank was 1.83 m square by 1.22 m deep and rested on a mechanical platform scale. The scale mechanism transferred the downward force exerted by the soil bin to a tension-measuring electronic load cell. A pliable rubber seal was installed to cover the gap between the soil bin and outer steel retaining wall, forming a rim about 2.5 cm above the soil and 2.5 cm wide. While the rim area was about 5.6% of the surface area of the soil bin, it was mostly shaded from the overhang of plants from inside and outside the lysimeter. The sensitivity of the weighing system was enhanced because the scale assembly included a counter balance so that only about 10% of the total mass of the system was sensed by the load cell. An array of sintered stainless steel candles in the bottom of the soil tank permitted the evacuation of drainage water.

Evaporative loss of water from the soil and plant surfaces caused a decrease in tension at the load cell. The load cell signals were continuously recorded on strip chart recorders and at hourly or more frequent intervals with an automatic data acquisition system. The chart records were used to monitor lysimeter performance and to adjust for irrigations, precipitation, harvest, and other events. The load-cell tension data were converted to an equivalent water depth per unit area assuming a water density of 1 Mg m^{-3} and an effective surface area (mid-rim to mid-rim) of 3.44 m^2. Daily ET (ET_d) was calculated on a midnight-to-midnight basis. Total ET was calculated for each month, growth period, and the season from summations of ET_d.

The sensitivity of the lysimeter system was more than sufficient for daily ET measurements during the growing season. Considering hysteresis effects, nonlinearity, and seasonal drift, the complete system was capable of resolving a net change in mass equivalent to a water depth of 0.07 mm over the entire surface, about 1% of daily ET on a summer day. Daily ET data were lost during the 7-yr period on a few occasions for a day or two at a time. Lightning was the major cause of equipment failures.

Pan evaporation data, obtained by the National Weather Service with a U.S. Class A evaporation pan, were used to characterize general climatic conditions. On the average, water depth was maintained between 220 and 180 mm, or from 35 to 75 mm below the pan rim. The weather station was located about 0.8 km north of the lysimeter field site in a 45- by 36-m irrigated, clipped-grass plot surrounded by irrigated field plots planted to various crops each year.

Management Practices

Fertilizer was applied to maintain soil P concentrations above 16 mg kg^{-1} and K above 200 mg kg^{-1}, in accordance with University of Idaho fertilizer guides (University of Idaho, 1972). Traffic was limited near the lysimeters so that crop growth on and immediately around the lysimeters would be representative of the field.

The Lys. 1 site was planted to 'Ranger' alfalfa in May 1968 at a seeding rate of 9 kg ha^{-1}, without a nurse crop, and was harvested twice during 1968 so that the stand was well established at the beginning of this study on 1 Apr. 1969. The stand was maintained until mid-October 1971.

Alfalfa was similarly seeded at the Lys. 2 site, but in late August 1971, so that the plants were still in the young seedling stage on 1 Apr. 1972. The stand was maintained at this site until October 1975. Local farmers maintain alfalfa stands from 2 to 4 yr in typical rotations.

The alfalfa fields were surface-irrigated with furrows spaced at 0.76-m intervals. Soil-water status on and in the vicinity of the lysimeters was measured with tensiometers at depths of 0.15, 0.30, and 0.45 m. These were read two to three times per week. Irrigations were scheduled so that the soil-water tension at the 0.45-m depth did not exceed 75 kPa. The duration of irrigation was usually 24 h. Total available soil water for the top meter of the local soil is approximately a 160-mm water depth equivalent per meter of soil depth. At a tension of 75 kPa, about 60% of available soil water is depleted. The transpiration of alfalfa is not restricted until tensions exceed 100 kPa (Van Bavel, 1967).

During a field irrigation, water was pumped onto the lysimeter surface from a nearby furrow with a small submersible pump. Only the amount of water necessary to replenish the depletion was applied, usually a 100- to 150-mm depth equivalent. Occasionally, when it was not possible to irrigate the field, water was hauled to irrigate the lysimeter to prevent the restricted root zone from becoming excessively dry. Soil-water contents are normally near field capacity at the beginning of spring growth due to wintertime precipitation. The local irrigation season begins in the latter part of April or early May.

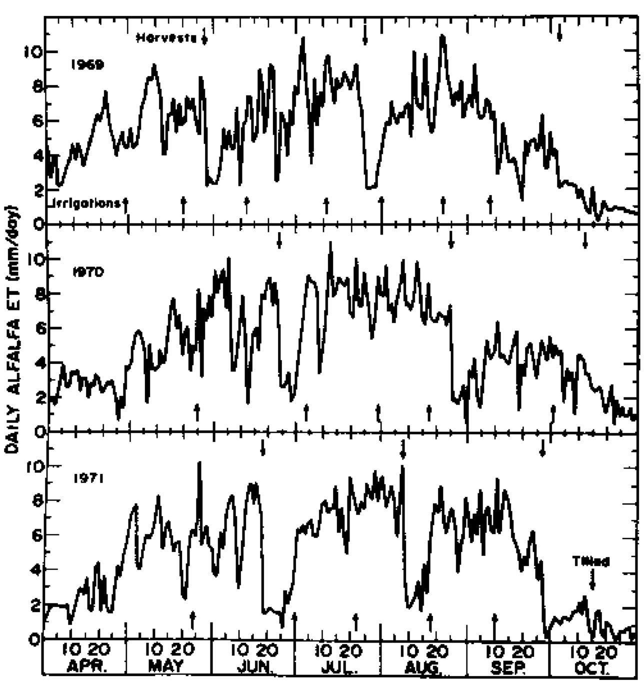

Fig. 1. Daily alfalfa ET measured with weighing lysimeter no. 1 for three growing seasons, with harvest and irrigation dates indicated, Kimberly, ID.

Forage Sampling

The alfalfa was harvested three times per season, as is typical for the area. Lysimeter forage was manually harvested within a day or two of when the adjoining fields were harvested, usually by swathing and baling. Forage samples were removed and oven dried to determine dry matter yield. Yields were adjusted to 120 g kg^{-1} water content (mass/mass) for consistency. Field yields were determined from commercial scale weights of total harvested forage, or from bale counts and sample bale-weights, which were obtained from weighing at least 10 bales selected at random across the field.

RESULTS AND DISCUSSION

Daily Evaporation

Values of ET_d obtained with Lys. 1 are shown in Fig. 1 for the 3 yr of measurement. Data obtained with Lys. 2 for 4 yr are shown in Fig. 2. Harvest and irrigation dates are designated. Data are shown for a 214-d period because spring growth begins in late March or early April, depending on general weather conditions, and ceases by November. There is no live aboveground growth at Kimberly during the winter. The gradual increase in ET_d in April and early May (Fig. 1 and 2) was due to the growth of the crop and the general increase in evaporative demand. The crop usually did not reach the condition of "effective-full-cover" [at least 30 cm in height as described by Wright and Jensen (1972)] until mid-May. Frosty periods occasionally retarded ET_d rates until about that time. During the spring of 1969 weather was warmer than

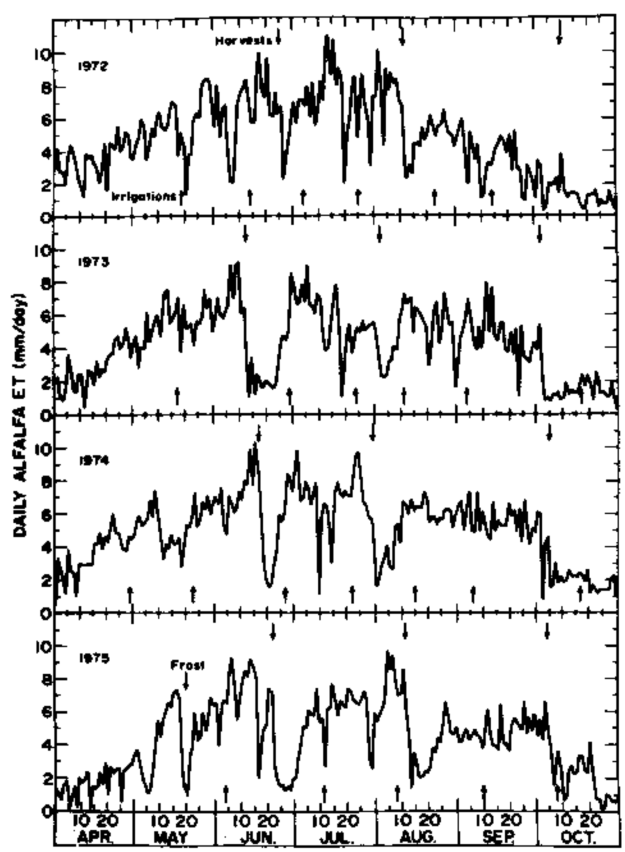

Fig. 2. Daily alfalfa ET measured with weighing lysimeter no. 2 for four growing seasons, with harvest and irrigation dates indicated, Kimberly, ID.

normal, so early crop development was more advanced than for the other 6 yr. This resulted in generally higher ET during that period.

Daily ET exceeded 10 mm d^{-1} a few days each season, except in 1973 and 1975. The pronounced variation of ET_d (Fig. 1 and 2) was due primarily to changes in daily weather. This correspondence can be seen in Fig. 3 where daily Class A pan evaporation (Epan) and ET_d are graphed for 30 d when crop conditions assured potential ET rates. The daily patterns were mostly similar except on a few days, such as 26 June and 6 July, when ET_d exceeded Epan. The mean ratio of ET_d to Epan for the 31 d plotted was 0.932 (SE= 0.118).

At harvest ET_d was reduced to 25% or less of pre-harvest rates for several days until regrowth began (Fig. 1 and 2). Depending on soil moisture and stand conditions, after 14 to 21 d ET_d returned to pre-harvest rates. Once regrowth began after the first and second harvests, ET_d sometimes increased to near maximum rates in just 5 to 7 d. The delay in recovery of ET following the first harvest in 1973 and 1975 was due to suboptimal available soil water in the lysimeter. Delay in removing the harvested hay from the field delayed post-harvest irrigation, and water was not hauled to the lysimeter in those two cases. Regrowth following third harvests was generally slower at the end of the growing season.

Daily ET was reduced much less after the harvest of a first-year stand than for older stands, as can be seen by comparing the results for 1972 with those of the other years (Fig. 2). This result agreed with field observations in that, after harvest the stubble of the young stands still contained some leaves, and new shoots appeared more quickly than for older stands.

Seasonal Evaporation

Total alfalfa ET, derived from summations of ET_d, and corresponding pan evaporation data are listed in Table 1 for each month of the 214-d growing season and the 7-yr period of study. The mean ($\bar{x}$) and the coefficient of variation (CV) are listed for each month

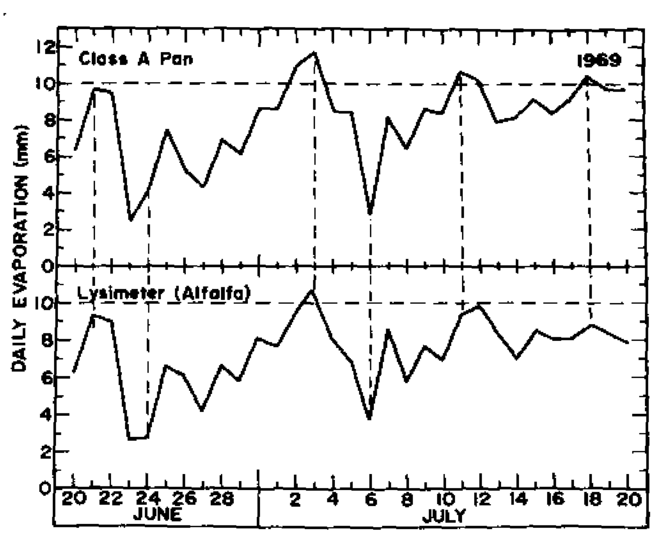

Fig. 3. Comparison of daily Class A pan evaporation and alfalfa ET for a 31-d period when crop cover assured maximum ET.

and seasonal period. Seasonal totals are included for both the April through September and April through October periods, since complete pan evaporation data were not available for October of 1973, 1974, and 1975 Seasonal totals of alfalfa ET and pan evaporation are shown as a percentage of the respective 7-yr means to provide a relative yearly index of alfalfa ET in comparison with general weather conditions, as represented by pan evaporation. The two highest ET years, 1969 and 1974, correspond to the two highest pan years, while 1975 is lowest for both. The seasonal CV for alfalfa ET is greater than the CV for pan evaporation because of greater variation in ET early and late in the season and the effects of harvest.

The data of Table 1 show that ET relative to pan evaporation was proportionately higher for Lys. 1 than for Lys. 2. This difference between the two lysimeters was partly due to the drier soil conditions of Lys. 2, during short periods in 1973 and 1975 (Fig. 2), but also seemed due to differences in growth of the two crops. The alfalfa stands were established with different lots of seed, supposedly of the same variety. How-

Table 1. Summary of alfalfa ET by month and season obtained from summations of daily ET, corresponding Class A pan evaporation, respective monthly means ($\bar{x}$) and coefficients of variation (CV), and seasonal totals as a percentage of the 7-yr mean. Alfalfa ET was measured with two weighing lysimeters during 7 yr at Kimberly, ID.

	Lys. 1			Lys. 2				Lys. 1 and 2	
	1969	1970	1971	1972	1973	1974	1975	$\bar{x}$	CV
	Alfalfa ET								
	mm								%
Apr.	136	80	75	105	83	105	51	90.7	30.2
May	194	167	182	171	171	166	135	169.4	10.7
June	168	178	142	186	138	186	163	166.0	11.8
July	211	233	232	222	175	211	177	208.7	11.4
Aug.	223	197	188	179	155	165	160	181.0	13.3
Sept.	150	125	172	105	140	169	143	143.3	16.3
Oct.	45	80	35	44	50	71	75	57.1	31.2
Σ(Apr.–Sept.)	1083	980	991	968	861	1001	829	959.0	9.0
Σ(Apr.–Oct.)	1128	1060	1025	1012	912	1073	904	1016.3	8.2
	Percentage of 7-yr mean								
Apr.–Sept.	113	102	103	101	90	104	86	100	9.10
	Pan evaporation								
	mm								%
Apr.	200	153	149	156	150	184	110	157.4	18.2
May	262	208	221	223	261	227	194	228.0	11.1
June	213	218	225	226	244	294	243	237.6	11.6
July	278	267	265	282	240	257	252	263.0	5.6
Aug.	273	256	250	241	215	239	216	241.4	8.7
Sept.	181	162	181	139	145	213	181	171.7	14.7
Oct.	91	114	94	80	-M-	-M-	-M-	94.8	15.0
Σ(Apr.–Sept.)	1408	1265	1292	1267	1254	1414	1195	1299.3	6.3
Σ(Apr.–Oct.)	1499	1379	1386	1347	–	–	–	1402.8	4.7
	Percentage of 7-yr mean								
Apr.–Sept.	108	97	99	98	97	109	92	100	6.3
	Ratio of ET to pan evaporation								
Apr.–Sept.	0.77	0.78	0.77	0.76	0.69	0.71	0.69	0.738	5.44

Table 2. Summary of alfalfa harvest dates, length of corresponding growing periods, and lysimeter forage yield with means ($\bar{x}$) and coefficients of variation (CV) for 7 yr at Kimberly, ID.

Harvest	Lys. 1			Lys. 2				Lys. 1 and 2	
	1969	1970	1971	1972	1973	1974	1975	$\bar{x}$	CV
	Harvest date								
1st	28 May	24 June	18 June	26 June	12 June	17 June	22 June	17 June	--
2nd	24 July	25 Aug.	8 Aug.	11 Aug.	2 Aug.	30 July	11 Aug.	7 Aug.	--
3rd	3 Oct.	12 Oct.	27 Sept.	11 Oct.	2 Oct.	5 Oct.	4 Oct.	5 Oct.	--
	Length of growing period								
	d								%
1st†	58	85	79	87	73	78	83	77.6	12.6
2nd	57	62	51	46	51	43	50	51.4	6.4
3rd	71	48	50	61	61	67	54	58.9	8.6
Total	186	195	180	194	185	188	187	187.9	5.2
	Lysimeter forage yield (120 g kg^{-1} water content)								
	Mg/ha								%
1st	6.08	8.57	9.62	6.39	6.52	8.03	8.22	7.63	17.4
2nd	6.06	6.32	5.86	5.51	5.38	5.36	5.51	5.71	6.5
3rd	5.77	2.19	4.75	2.84	3.54	4.27	-M-	3.89	33.2
Total	17.91	17.08	20.23	14.74	15.44	17.66	--	17.18	11.4

† Note: First period assumed to begin 1 April each year.

ever, the crop on Lys. 2 was less upright, had finer stems, and was more prone to lodge than that on Lys. 1. Such variations in plant morphology have been noted between strains of given alfalfa varieties (Lowe et al., 1972). The Lys. 2 site also had less topsoil and more of the highly calcareous subsoil mixed in the surface-soil layer because of previous land leveling than did the Lys. 1 site. This may have contributed to less vigorous growth. Differences in forage yield relative to ET will be discussed in a later section.

The mean ratio of ET to pan evaporation, sometimes called a pan factor, was 0.74 for the entire 214-d, 7-yr period. The mean for Lys. 1 alone was 0.77, and for Lys. 2 alone, 0.73, excluding the 2 yr when Lys. 2 was drier than desired for short periods.

Table 3. Summary of total and mean daily alfalfa ET by harvest period, corresponding Class A pan evaporation, and respective means ($\bar{x}$) and coefficients of variation (CV) for 7 yr at Kimberly, ID.

Harvest	Lys. 1			Lys. 2				Lys.1 and 2	
	1969	1970	1971	1972	1973	1974	1975	$\bar{x}$	CV
	Total alfalfa ET per harvest								
	mm								%
1st	323	410	376	444	338	396	335	374.4	12.0
2nd	367	434	322	325	240	269	274	318.7	20.8
3rd	401	182	289	221	293	358	242	283.7	27.1
Total	1091	1025	987	990	870	1023	851	976.7	8.9
	Mean daily ET per harvest								
	mm d^{-1}								%
1st	5.6	4.8	4.8	5.1	4.6	5.1	4.0	4.9	9.6
2nd	6.4	7.0	6.3	7.1	4.7	6.3	5.5	6.2	13.6
3rd	5.7	3.8	5.8	3.6	4.8	5.3	4.5	4.8	17.9
Seasonal mean	5.9	5.3	5.5	5.1	4.7	5.4	4.6	5.2	8.9
	Pan evaporation								
	mm								%
1st	434	530	491	567	510	567	491	512.9	9.2
2nd	456	531	440	414	401	385	392	431.3	11.8
3rd	533	264	352	318	365	467	334	376.1	24.6
Total	1423	1325	1283	1299	1275	1419	1217	1320.1	5.8

Harvest Period Evaporation and Yield

The dates of harvest, the corresponding length of the respective growing periods, and the lysimeter forage yields are summarized in Table 2. The first growth period was assumed to begin on 1 April each year. The harvest dates were generally typical of local farms, except for the second harvest in 1970 that was delayed until late August (Fig. 1) to accommodate some associated research. The total growing period contributing to the three harvests, averaging about 188 d, was less than the April through October period of 214 d, as used in Table 1. Forage growth after the third harvest was not harvested for yield analysis. The forage sample for the third-growth period of 1975 was inadvertently discarded before dry weights were obtained.

Total and mean daily ET and total pan evaporation are listed by growth period in Table 3. Mean daily ET was calculated from the sum of ET_d for the respective period and the length of the period as listed in Table 2. The mass of the dry matter removed from the lysimeter surface at harvest was small compared to the mass of the water transpired. The average dry matter removed per harvest was 511 g m^{-2} (Table 2), which was equivalent to an ET of a 0.511-mm water depth equivalent or about 0.16% of mean ET_d (Table 3).

The joint variation of ET_d and Epan by growth period is shown in Fig. 4 for each of the 21 periods included in Table 2. Points are distinguished by lysimeter and growth period. The linear correlation equation relating ET_d to Epan is shown in Fig. 4. Excluding the one 1973 point changed the slope (b), intercept (a), and correlation (r) coefficients to 0.772, −11, and 0.95, respectively, where ET_d and Epan are in millimeters. The linear correlation equation indicated in Fig. 4 did not include the five points plotted for the fourth growth period, from third harvest until 1 No-

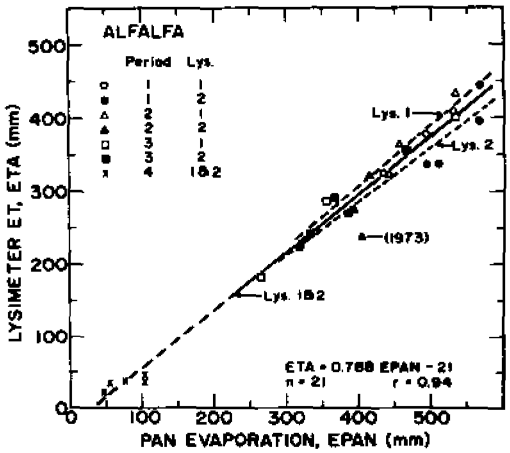

Fig. 4. Joint variation over a 7-yr period of total lysimeter ET and pan evaporation by harvest period for two lysimeter sites and three harvests per growing season. Period 4 was from third harvest until 1 Nov.

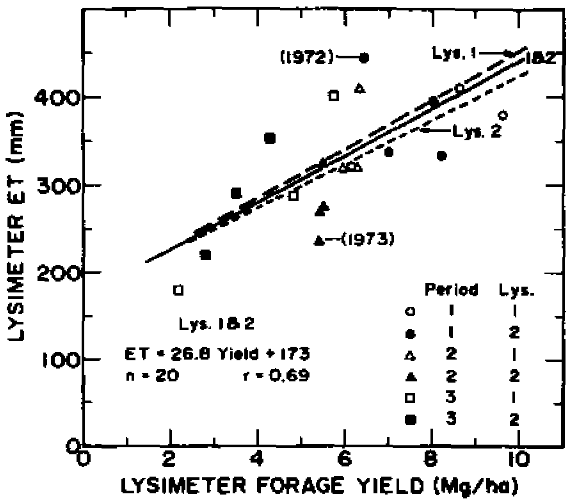

Fig. 5. Joint variation over a 7-yr period of total lysimeter ET and lysimeter forage yield (120 g kg^{-1} water content) by harvest period for two lysimeter sites and three harvests per growing season.

vember, since complete data were not available for that period. It can be seen, however, that these points were clustered closely about the indicated linear relationship.

The best-fit linear correlations for Lys. 1 and Lys. 2, considered individually, are also plotted in Fig. 4. The b, a, and r coefficients for Lys. 1 alone (n=9) were: 0.892, −26, and 0.98; for Lys. 2 alone (n=12) they were: 0.734, −7, and 0.92; and for Lys. 2 excluding the one 1973 point: 0.712, 6, and 0.94; where ET_d and Epan are in millimeters. A negative intercept coefficient was expected since Epan is not affected by the amount of crop cover.

The joint variation of lysimeter ET and forage yield is shown in Fig. 5, with points distinguished by lysimeter and harvest. There was less association between ET and yield than there was between ET and pan evaporation, indicating that crop growth was not as closely coupled to the climatic factors as was evaporation. The one 1973 point was again on the outer limit of the cluster of points, but in this relationship it showed a higher water-use efficiency (WUE) than most of the other points, i.e., there was less ET per unit of forage produced. This occurred because ET was suppressed immediately following harvest until irrigation and then regrowth was very rapid (Fig. 2). The indicated 1972 first-harvest point represented a lower WUE. The alfalfa early in that growth period was still in the small seedling stage; thus, evaporation from the soil was proportionally higher and crop production lower than for an established crop. Twenty points were included in the correlation analysis because the forage yield for the third-harvest of 1975 was not available.

The lines for the linear correlations obtained considering the ET and yield data for Lys. 1 and Lys. 2 individually are also included in Fig. 5. The relationship of these two lines to the combined line is similar to the pattern of Fig. 4. The b, a, and r coefficients for the linear correlation equation for Lys. 1 alone (n= 9) were: 27.5, 176, and 0.76; and for Lys. 2 alone (n= 11) they were: 24.5, 180, and 0.60, respectively.

Excluding the first-growth period of 1972 and the second-growth period of 1973 (Fig. 5), the linear correlation equation between lysimeter ET and lysimeter yield (Y_ℓ), for Lys. 1 and Lys. 2 combined (n=18), was:

$$ET = 25.4\ Y_\ell + 180;\ r = 0.74\,, \qquad [1]$$

and between Y_ℓ and ET it was:

$$Y_\ell = 0.0216\ ET - 1.24;\ r = 0.74\,, \qquad [2]$$

where yield is in megagrams per hectare (120 g kg^{-1} water content) and ET is in millimeters. The overall mean ET to produce 1 Mg ha^{-1} was 56.9 mm, giving a corresponding WUE of 17.6 kg ha^{-1} mm^{-1}.

For 17 harvests when field yield data were available, the mean yields per harvest for the field and lysimeter were 5.75 (SE=0.42) and 6.05 (SE=0.43) Mg ha^{-1}, respectively, giving a ratio of mean field to mean lysimeter yield of 0.95. The linear correlation of the association between field yield (Y_f) and Y_ℓ was:

$$Y_f = 0.968\ Y_\ell - 0.029;\ r = 0.99\,, \qquad [3]$$

where yield is in megagrams per hectare (120 g kg^{-1} moisture). Field yields were slightly below lysimeter yields, probably because of the inclusion of lower producing areas of the field in the field yield and the effects of machine harvesting on regrowth. Regrowth in the field was also delayed under windrows because of shading and the concentration of insects. Regrowth between windrows sustained some damage during baling and bale pick up. Nonetheless, agreement between field and lysimeter yields (Eq. [3]) was considered adequate for the lysimeter ET-yield relationships (Eq. [1] and Eq. [2]; Fig. 5) to be representative of field water use. Thus the seasonal field water use would be expected to have been about 5% less than that of the lysimeter.

Field yields obtained in this study were generally comparable with those obtained on well-managed farms of the area but above county averages. The published Twin Falls County average for 1978 was about 11.4 Mg ha^{-1} (USDA Economics, Statistics and Cooperative Service, 1980), which was about 40% less than the mean lysimeter yield (Table 3). The county-wide yield included several large areas where there is a shortage of irrigation water most years and alfalfa production is given a low priority relative to other crops.

The seasonal water use by alfalfa in southern Idaho estimated with the SCS-BC method (USDA-Soil Conservation Service, 1967) by Sutter and Corey (1970) was 646 mm. The three-crop mean ET of 977 mm obtained in this study (Table 3) was thus nearly 50% greater than that previous estimate. The intent of Sutter and Corey (1970) was to provide estimates for alfalfa representative of conditions when crop growth is not limited by lack of water at any time during the growing season and growth is mainly dependent on climatic conditions. However, as concluded by Sammis et al. (1982), it seems that the estimates are more applicable to average county-wide conditions than to conditions of negligible moisture stress. Application of the SCS-BC method for high producing alfalfa in irrigated areas could lead to a serious underestimation of alfalfa water use.

Another possible cause of the lower estimates is that alfalfa crop coefficients for the SCS-BC method were derived from the results of water use based on soil sampling data. Crop water use obtained by soil sampling methods could be less than that obtained with weighing lysimeters, because a period of several days is often allowed after an irrigation before the soil-water content is measured. While this may avoid errors due to the drainage of excess water from the soil profile, it also misses the higher daily ET that may occur immediately after an irrigation (Fig. 1 and 2). With soil sampling methods, deep measurements have sometimes been omitted, and it is often difficult to account for water extraction from the deeper layers of the root zone because of the relatively small changes in water contents with time. It is also difficult to assess the lateral or vertical movement of water into the root zone from adjacent wet soil or from deep water tables. These errors are avoided with an adequately irrigated lysimeter.

While the 1.2-m depth of the lysimeters of this study was less than the rooting depth of the alfalfa in the surrounding fields, the depth should have been sufficient to avoid rooting depth problems (McIlroy and Angus, 1963; Tanner, 1967). Sufficiently high soil-water contents were maintained (except in a few cases) so that measured ET was usually the maximum possible for the given climatic and crop conditions. The data of Fig. 3 establish that lysimetrically measured alfalfa ET closely followed pan evaporation, which would not have occurred if rooting depth were a problem. Errors due to limited rooting depth would be in the direction of reduced plant growth and ET; however, lysimeter yields were generally greater than field yields.

Soil sampling methods also often miss relatively low ET rates during early and late portions of the growing season, rainy periods, or from harvest until major regrowth. Water-content measurements often have not been initiated until about mid-May, at the beginning of the frost-free period (Bauder et al., 1978; Retta and Hanks, 1980). The lysimeter data of this study (Fig. 1 and 2; Table 1) show a total ET from 1 April until mid-May of about 100 mm, and from mid-September until 1 November of about 75 mm, for a total of 175 mm occurring before and after the frost-free period, or 17% of the April through October total. Whereas soil-sampling methods permit spatial sampling throughout a field, the results from a single lysimeter are effectively an average for a surface area that is equivalent to several soil sampling sites.

CONCLUSIONS

Alfalfa ET, as measured with weighing lysimeters, was highly variable on a daily basis in response to general weather conditions. Daily ET exceeded 10 mm d^{-1} for a few days in most seasons. Forage harvest reduced ET to less than 25% of pre-harvest levels for about a week. Another 1 to 2 wk elapsed before regrowth was sufficient to return ET to potential rates. Thus, improved irrigation management practices such as irrigation scheduling will in many cases require accurate estimates of daily ET.

Seasonal ET averaged 1016 mm. The mean ratio of seasonal alfalfa ET to Class A pan evaporation was 0.74 for April through September. The ratio of alfalfa ET to pan evaporation averaged 0.93 when alfalfa was in a full-cover state. Total monthly and growth-period ET were linearly related to corresponding total pan evaporation. Total ET per growth period was also linearly related to forage yield, even for well-irrigated conditions, but to a lesser degree than was the relationship to pan evaporation. Lysimeter forage yields averaged about 5% greater than surrounding field yields. Average ET per unit of forage produced was 581 m^3 Mg^{-1} (120 g kg^{-1} water content) for an overall WUE of 17.2 kg ha^{-1} mm^{-1}.

Seasonal water-use values obtained in this study were about 50% greater than previously reported water-use estimates for southern Idaho based on the SCS modified Blaney-Criddle method. Thus, a greater portion of irrigation water diverted to amply irrigated, high-producing alfalfa fields of the region is lost to the atmosphere by evaporation than has often been considered to be the case. This has an impact on estimates of drainage, ground-water recharge, and irrigation efficiencies for the region. Accurate assessments of irrigation water requirements for high-producing alfalfa under the arid conditions of southern Idaho will require changes in the crop factors used in the SCS-BC method or use of other more accurate methods.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance of John L. Stevens and James E. Chapman in conducting the field experiments and analyzing data.

REFERENCES

Bauder, J.W., A. Bauer, J.M. Ramirez, and D.K. Cassel. 1978. Alfalfa water use and production on dryland and irrigated sandy loam. Agron. J. 70:95–99.

Daigger, L.A., L.S. Axthelon, and C.L. Ashburn. 1970. Consumptive use of water by alfalfa in western Nebraska. Agron. J. 62:507–508.

Erie, L.J., O.F. French, and K. Harris. 1965. Consumptive use of water by crops in Arizona. Univ. of Arizona Agric. Exp. Stn., Tech. Bull. 169.

Jensen, M.E., J.L. Wright, and B.J. Pratt. 1971. Estimating soil moisture depletion from climate, crop, soil data. Trans. ASAE 14:954–959.

Lowe, C.C., V.L. Marble, and M.D. Rumbaugh. 1972. Adaptation, varieties, and usage. p. 391–413. *In* C.H. Hanson (ed.) Alfalfa science and technology. ASA, Madison, WI.

McIlroy, I.C., and D.E. Angus. 1963. The Aspendale multiple weighed lysimeter installation. Div. of Meteorol. Physics Tech. Paper 14. CSIRO, Melbourne, Australia.

Pruitt, W.O. 1966. Empirical methods of estimating evapotranspiration using primarily evaporation pans. p. 57–61. *In* Evaporation and its role in water resources management. ASAE, St. Joseph, MI.

Retta, A., and R.J. Hanks. 1980. Corn and alfalfa production as influenced by limited irrigation. Irrig. Sci. 1:135–147.

Ritchie, J.T., and E. Burnett. 1968. A precision weighing lysimeter for row crop water use studies. Agron. J. 60:545–549.

Sammis, T.W. 1981. Yield of alfalfa and cotton as influenced by irrigation. Agron. J. 73:323–329.

———, E.J. Gregory, and C.E. Kallsen. 1982. Estimating evapotranspiration with water production functions or the Blaney-Criddle method. Trans. ASAE 25:1656–1661.

Sutter, R.J., and G.L. Corey. 1970. Consumptive irrigation requirements for crops in Idaho. Univ. of Idaho Bull. 516.

Tanner, C.B. 1967. Measurement of evapotranspiration. p. 573–574. *In* R.M. Hagan et al. (ed.) Irrigation of agricultural lands. ASA, Madison, WI.

University of Idaho. 1972. Idaho fertilizer guide—irrigated alfalfa. Univ. of Idaho Coop. Ext. Serv.

USDA Economics, Statistics and Cooperative Service. 1980. Idaho agricultural statistics. 1980. Idaho Crop and Livestock Reporting Service, Boise, ID.

USDA Soil Conservation Service. 1967. Irrigation water requirements. Eng. Div. Tech. Release 21 (revised 1970). U.S. Gov. Print. Office, Washington, DC.

Van Bavel, C.H.M. 1967. Changes in canopy resistance to water loss from alfalfa induced by soil water depletion. Agric. Meteorol. 4:165–176.

Wright, J.L., and M.E. Jensen. 1972. Peak water requirements of crops in southern Idaho. J. Irrig. Drain. Div. Am. Soc. Civ. Eng. 98(2):193–201.

———, and ———. 1978. Development and evaluation of evapotranspiration models for irrigation scheduling. Trans. ASAE 21:88–96.