TABLE 2. EFFECTS OF SUGARCANE MOSAIC VIRUS INFECTION ON SWEET CORN HYBRIDS – 1971

HYBRIDS	Days to Maturity	Mature ears per plot			Unhusked ear diam.			Husked ear length			Husked ear weight			Mature plant height			SCMV		Rank Totals
		H*	D*	Rank†	H	D	Rank	H	D	Rank	H	D	Rank	H	D	Rank	Rank		
		no.			inches			inches			g			inches			rating‡		
NCX 2000	82	48.3	45.0	(2)	2.07	2.03	(2)	8.5	8.0	(5)	242	224	(5)	79	69	(5)	7.3	(2)	(21)
70-2109	82	47.0	36.0	(8)	2.00	2.00	(1)	8.5	8.5	(1)	231	233	(1)	82	70	(7)	5.0	(7)	(25)
Sunshine State	82	42.0	21.3	(14)	2.10	2.03	(3)	8.7	8.3	(1)	204	203	(2)	74	66	(2)	6.0	(5)	(27)
Goldie	81	57.3	37.7	(10)	1.97	1.97	(1)	8.5	8.2	(3)	241	227	(2)	72	61	(8)	6.7	(4)	(28)
XP 299	88	40.0	38.0	(1)	2.00	1.97	(4)	9.3	7.3§	(12)	197	163	(10)	84	73	(4)	7.0	(3)	(34)
NK 75	77	38.7	31.3	(4)	1.90	1.73	(8)	7.8	7.0	(8)	206	162	(11)	66	58	(3)	7.0	(3)	(37)
Jubilee	81	53.7	35.0	(11)	2.07	1.93	(6)	8.2	8.3	(4)	232	216	(3)	70	59	(6)	4.7	(8)	(38)
Bonanza	83	38.3	31.0	(5)	2.10	1.90	(11)	9.3	8.3	(9)	221	184	(9)	73	64	(6)	7.7	(1)	(41)
Sweet Tennessee	83	24.7	19.7	(6)	2.20	1.93	(13)	8.5	8.0	(5)	199	185	(4)	86	73	(10)	6.7	(4)	(42)
NK 51036	78	31.3	15.3	(15)	2.00	1.67	(15)	8.0	7.8	(2)	200	172	(8)	68	57	(9)	7.0	(3)	(52)
58-1804 C	80	57.3	23.7	(17)	1.97	1.87	(4)	7.8	7.3	(6)	208	190	(6)	77	62	(12)	5.0	(7)	(52)
Exp. 667	82	40.3	30.3	(9)	2.30	2.03	(12)	9.3	8.7	(7)	255	224	(7)	70	56	(13)	5.3	(6)	(54)
NCX 238	80	29.3	26.3	(3)	2.10	1.97	(5)	9.2	7.5	(10)	232	181	(12)	64	51	(14)	2.7	(11)	(55)
Merit	82	49.0	26.0	(13)	2.20	2.00	(9)	9.3	6.2§	(15)	263	172	(15)	75	66	(1)	6.7	(4)	(57)
Exp. 668	82	23.0	18.0	(7)	2.03	1.87	(7)	8.7	7.0	(11)	190	139	(13)	65	54	(11)	3.3	(9)	(58)
Continental	79	27.3	15.7	(12)	2.17	1.97	(10)	8.7	6.5	(13)	237	161	(14)	80	60	(17)	3.0	(10)	(76)
Stylepak	86	32.3	14.3	(16)	2.07	1.80	(14)	9.0	6.2§	(14)	260	154	(16)	73	57	(15)	3.0	(10)	(85)
FM Cross	82	39.3	12.3	(18)	2.23	1.77	(16)	8.5	4.7§	(16)	238	123	(17)	77	59	(16)	3.0	(10)	(93)

* H = Healthy; D = Diseased
† Ranked for per cent reduction in size in diseased plants; 1 = lowest per cent reduction
‡ Leaf symptoms rated July 13 on a 1–9 scale: 9 = no symptoms; 1 = severe
§ Nubbin ears prevalent on diseased plants

varies also among the hybrids, so that there was not a consistent tendency for high or low ranking for all characters. Thus, relatively high ear defects were coupled with the least reduction in number of ears produced (XP 299), and low ear production was coupled with ears which had few defects (Sunshine State). Stylepak and FM Cross, however, were consistent in defectiveness for all characters, while NCX 2000 and 70-2109 were the most consistent in being relatively free of defects.

Leaf symptoms were not always well correlated with ear quality and the number of ears produced. Note that NK 75, Bonanza, and XP 299 had good ratings for leaf symptoms, yet all were at least moderately affected in ear quality. On the other hand, 70-2109 expressed obvious leaf symptoms, but produced ears that were free of defects.

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WATER USE BY CROPS AS AFFECTED BY CLIMATE AND PLANT FACTORS

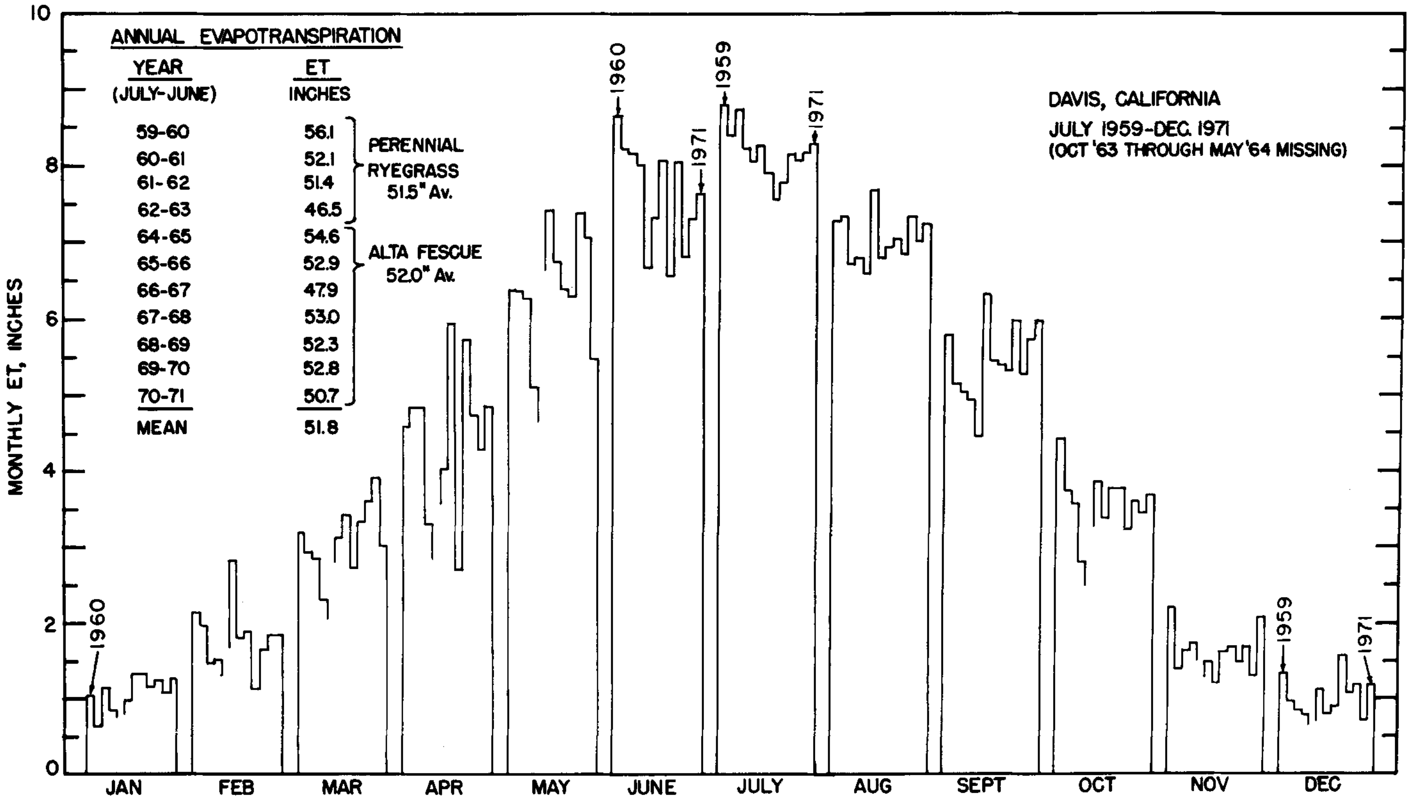
W. O. PRUITT · F. J. LOURENCE · S. VON OETTINGEN

THE WEATHER LARGELY DETERMINES the use of water, or evapotranspiration (ET), by most crops during times when the plants are healthy and fully shade the ground. Even under full-cover conditions, however, the evapotranspiration of various crops can vary significantly with differences in stomatal or surface resistance, reflectance, and aerodynamic roughness. However, during early stages of crop growth, transpiration is very limited, and the controlling factor in water use is basically the moisture status of the soil surface. How frequently the surface receives water from rain or irrigation—along with the weather conditions—largely determines evapotranspiration rates.

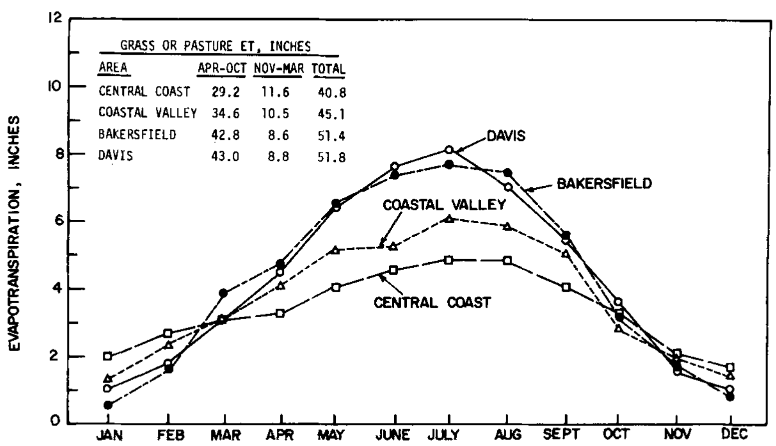
Early studies of water use by crops as well as studies in the past decade by the University and by the State Department of Water Resources have been particularly valuable in sorting out some of these factors. In the first place, the year-around seasonal pattern of loss by a standardized surface (short grass or pasture) has been determined for a number of locations in the state ranging from coastal to Central Valley to mountain valley locations. Secondly, in many of these locations, water use has been determined for a number of other crops at various stages of growth and maturity.

This report examines the variation of water use by grass at Davis, month-by-month over a 12½-year period, to indicate seasonal patterns and the variability between months. Then it presents the variation of seasonal patterns of water use by grass for four locations in California. Finally, specific results of Davis studies illustrate general relationships

GRAPH 1. MONTHLY WATER USE—OR EVAPOTRANSPIRATION (ET)—BY A FREQUENTLY-IRRIGATED, FREQUENTLY-MOWED GRASS TURF AT DAVIS, CALIFORNIA, JULY 1959–DECEMBER 1971.



GRAPH 2. MEAN MONTHLY EVAPOTRANSPIRATION FOR GRASS OR PASTURE FOR VARIOUS LOCATIONS IN CALIFORNIA. ALL BUT THE DAVIS DATA CAME FROM STATE DEPARTMENT OF WATER RESOURCES BUL. 113-2 (1967).



which should be useful in helping evaluate expected differences in water use of various types of crops as affected by different climatic conditions, stage of growth, irrigations, etc.

Instrumentation

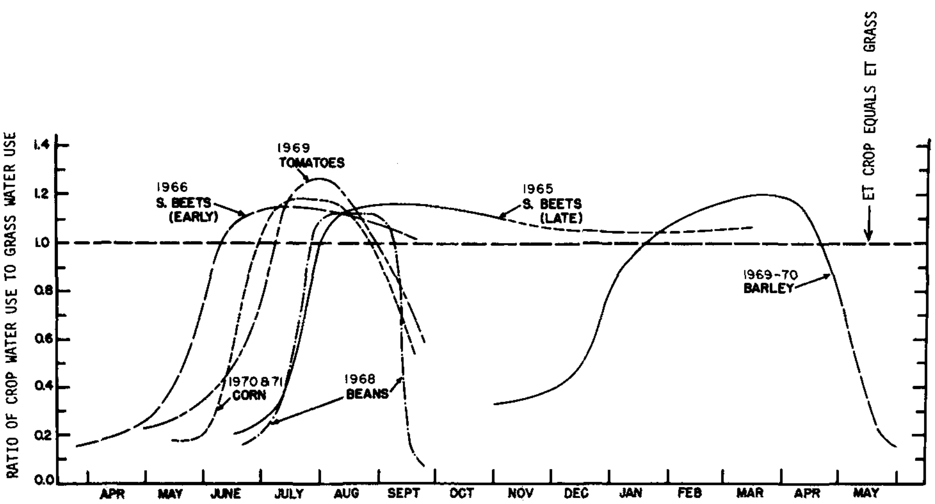
The University of California, Davis is fortunate to have some of the best equipment available for measuring evapotranspiration by crops. In preparation for basic studies of the interaction of plants and the microclimate, the Department of Irrigation (now the Department of Water Science and Engineering) installed a large weighing lysimeter in 1958–59. This 20-ft-diameter by 3-ft-deep tank, filled with soil, rests on an underground 50-ton scale and until recent refinements were made, weighed to the nearest 2 lbs every 4 minutes. The sensitivity of the system is now actually better than 1 lb, which is equivalent to less than 0.001 of an inch of evapotranspiration or rainfall. Thus, it can give good accuracy for periods as brief as ½-hour, which of course means very excellent accuracy over daily periods.

A second large lysimeter, identical in size to the earlier one, was installed in 1962 for basic studies in micrometeorology under an Army grant supervised by the late Dr. F. A. Brooks. This unit, rather than being weighed on a scale, is actually a floating lysimeter. The depth of the water in which the unit floats indicates weight with a sensitivity quite close to that of the weighing unit. The floating lysimeter was used in collecting the evapotranspiration data reported here for field beans, tomatoes, corn, and barley. The photo shows this unit in 1968 before the bean crop fully shaded the ground.

Until the 1968 season, both lysimeters were in grass, and were located about 130 ft apart near the middle of a 10- to 13-acre field of grass. In 1968 an area of 1.5 acres, which included the floating lysimeter, was cropped to Sutter Pink dry beans and in successive years to tomatoes, barley, and corn. The sugar beet data reported in this paper came from a 6 × 8 × 4-ft-deep hydraulic pillow-type lysimeter. It is far less accurate than the larger lysimeters but provides fairly reliable data for daily or longer periods.

The results presented for locations away from Davis were obtained with various types of lysimeters. For details, see State Department of Water Resources Bulletin 113–2, published in 1967, which contains much additional data on water use by various crops, as well as grass.

GRAPH 3. GENERALIZED CURVES FOR RATIO OF CROP EVAPOTRANSPIRATION FOR SEVERAL CROPS TO THAT FOR GRASS AT DAVIS, BASED ON ONE OR TWO YEAR STUDIES WITH EFFECTS OF EARLY IRRIGATIONS OR RAIN SMOOTHED OUT.



Seasonal and annual variation

As indicated earlier, weather conditions largely determine the rate of evapotranspiration by crops, especially under full-cover conditions. Graph 1 provides a good illustration of the variation in demand for water which can be expected on a month-by-month basis under Central Valley conditions. Seasonally, the average monthly use varies from a low of around 1.0 inch in December and January to a high of 8.2 inches in July. During the mid-summer months, the variation in use between months from year to year is fairly minor, reflecting the normal small degree of variability in climate. Of the 12 months, April showed the greatest variability (from 2.7 inches, in 1967, to 6 inches, in 1966). For the fiscal year July 1 to June 30, the seasonal water use totals ranged from a low of 46.5 inches to a high of 56.1 inches (mean 51.8). The average yearly value was 51.5 inches for the first four years when perennial ryegrass was being tested. For the remaining years, the average annual evapotranspiration was 52.0 inches.

Distance from coast

Graph 2 reproduces evapotranspiration data from SDWR Bulletin 113-2, along with Davis results. The lower curve, identified as "central coast," is based on 2½ years (1963–1965) of pasture data obtained with floating lysimeters by the SDWR at Guadalupe, near Santa Maria very close to the ocean. The "coastal valley" data were obtained during 1963–1965 by the SDWR with weighing tanks in an improved pasture at Soledad, south of Salinas about 30 miles downwind from the ocean. The data from Bakersfield (actually at Arvin, 15 miles to the southeast) were obtained by the SDWR with 6-foot-diameter floating lysimeters.

The influence on evapotranspiration of the gradual modification of the air mass as air moves in from the ocean is clearly evident in graph 2. For the mid-summer months, the air mass warms up and becomes relatively drier as it moves inland, producing an average 20% increase in ET at Soledad but a 60 to 65% higher loss at Bakersfield and Davis in the much warmer and drier Central Valley. Considering the totals for the April–October period shown in graph 2, the average increases for coastal valley and Central Valley locations were 18% and 47% respectively. One of the factors influencing the difference between the locations in summer months is the fog which blanks out part of the incoming solar radiation at the coastal location.

Reversal

The reversal in trends for the winter months is noteworthy. During this time of the year the air temperature is modified in the opposite way, with inland areas averaging colder temperatures than at the coast. A factor is doubtless the prevalence of more fog in the Central Valley than at the coast, during some of the winter months, producing some 25% reduction in ET from that on the coast. Because of the mid-winter reversal in trends, the yearly totals of ET are only 27% higher for the Central Valley than for the coastal site.

It is assumed that the mean of the long-term record for well-irrigated, frequently-mowed grass kept between 4 and 8 inches tall, represents a good estimate of potential evapotranspiration (ET_p) for normal Davis conditions. The fact that all other crops tested used more water at times than did grass does not detract significantly from the suggestion above. In semi-arid or arid climates, crops which are taller and rougher than short grass should be expected to experience greater transpiration losses than grass, especially during hotter and drier times of the year. Nevertheless, grass offers one of the few types of crops which can be maintained year around in our climate to provide a standard, uniform canopy of readily transpiring plants with near constant roughness, always having a leaf area index of 3.0 or higher—and with sufficient plant cover to reduce variations of evaporation from the soil surface to a fairly insignificant factor.

Trends

So far we have looked at trends of evapotranspiration for grass and pasture situations where essentially full-cover conditions persisted. Assuming that these data are equivalent to potential evapotranspiration, let us now look at some seasonal patterns of the relationship of actual to potential evapotranspiration for several annual crops at Davis, all with somewhat different growth and maturity characteristics.

Graph 3 shows smooth curves for seasonal variation of the ratio of ET loss by several crops to that by grass (potential ET). They are based on results of one-year studies for field beans, tomatoes, barley, and early and late-planted sugar beet crops. The curve for corn is from the mean of a two-year study. The curves for barley during the last month and from November 3 on for the late-planted sugar beet crop were estimated, since for various reasons, actual harvest took place earlier than normal.

It is not logical here to present the detailed daily data for each crop from which the smooth curves of graph 3 were derived. Briefly, however, it should be mentioned that the curves are highly generalized. Actual water use during early stages of growth is very much a function of soil surface moisture.

For a day or two after each irrigation, water use (mainly evaporation) is very much higher than just prior to irrigation. When the plants are very small, wetting of the surface by irrigation or rainfall results in daily losses the next day 60 to 80% as great as the loss by grass. Later with plants shading half the soil surface,

A view of the large 20-foot-diameter lysimeter at Davis planted to beans in 1968.

an irrigation or rainfall may even produce 10 to 30% greater losses by row crops than by grass. In graph 3 the curves take into account actual losses but smooth out the effects of irrigation or rainfall.

A few precautions are needed in interpreting the curves in graph 3. As an example, *if* in 1966 frequent rains had occurred in April and May, the curve for sugar beets would have been considerably higher because of greater evaporation from the exposed soil surface. The actual relationship of ET (barley)/ET (grass) could also be expected to be highly variable during November and December, depending upon the frequency of rainfall days. Once near-full cover is attained by any of the crops, the ratios would be affected little by rain, as long as an adequate irrigation program is followed.

Estimated seasonal patterns

The grass data in graph 1 clearly point out that a one- or two-year study can hardly be expected to give a reliable picture of normal monthly or even total seasonal evapotranspiration. However, the mean data from the long-term grass study at Davis, along with the relationships shown in graph 3 obtained from one- or two-year studies with other crops, should yield a good estimate of normal seasonal evapotranspiration patterns for the various crops.

Graph 4 shows the pattern of mean ET loss by grass over the 1959–1971 period, month by month. The light dashed lines (Nov. through May) above and below the heavy solid line representing the mean are based on record-low and record-high monthly ET losses by grass during the 12½-year study.

By taking ET data for 5-to-10-day intervals from the 1959–71 grass curve and multiplying by data obtained from the ratio curves of graph 3 for the same time intervals, a prediction of normal smoothed patterns of ET for various crops was obtained as shown in graph 4.

Although these results have many interesting aspects, briefly, it is apparent that time of planting, as well as plant species, is a major factor in determining how quickly the development of sufficient plant cover is reached so that ET losses will exceed those by grass. For example, a sugar beet crop planted in mid-June at a 24-inch row spacing reached this stage almost as quickly as beans (30-inch spacing) or corn (30-inch spacing) but took almost twice as long when planted in late March. Barley likewise takes a long time to reach losses equal to ET_p. Tomatoes (a machine-harvest variety planted at 5-ft row spacing) are an in-between crop, taking just over two months to reach a loss equal to ET_p. It is interesting that although the tomato crop never developed complete ground cover, the ET loss exceeded that of any other crop for about four weeks, running 25% greater than grass for a peak 10-day period.

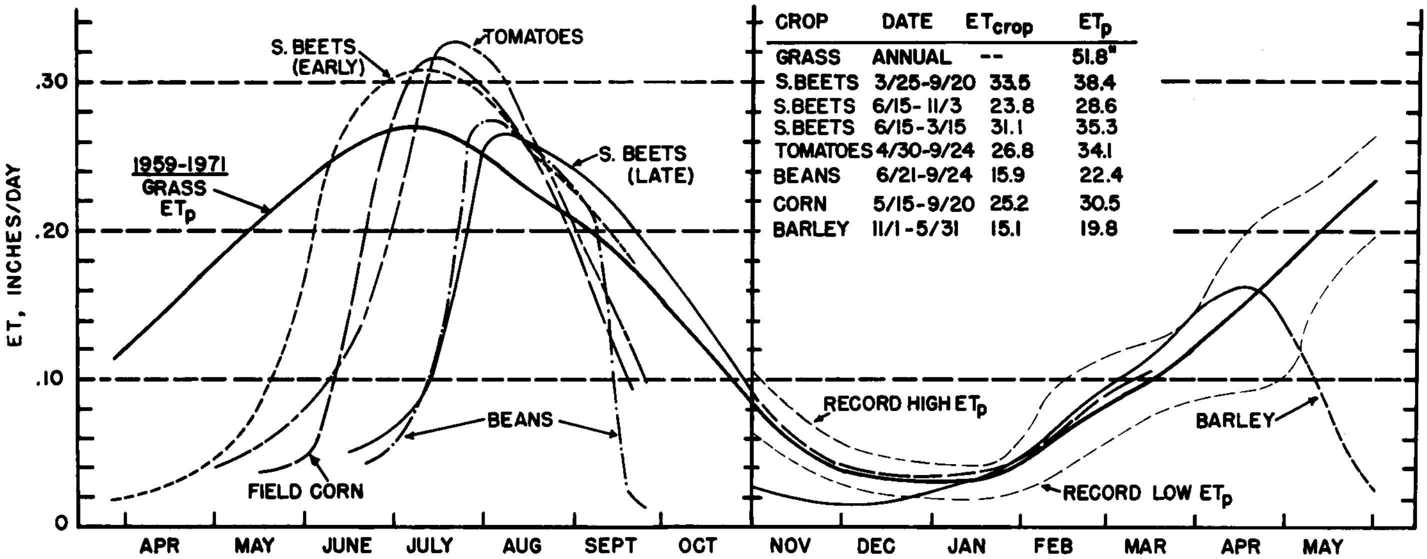
The effects of the onset of maturity or the approach of normal harvest periods are quite varied, ranging from an almost complete cut-off of ET for field beans, just before harvest, to only slight reductions below a normal potential loss in early-planted sugar beets. The curve for late-planted sugar beets showed no decrease below a potential loss by the time of actual harvest on November 3. The dashed line beyond November 3 provides only an estimate of ET losses for a crop not harvested until late winter, a cultural practice commonly followed in the area for late-planted beets. Verification of these data is still needed.

It should be pointed out that although the ratio curve in graph 3 for barley would run considerably closer to ratios of 1.0 if rains were frequent in November and December, the actual ET by barley would not be significantly greater than graph 4 indicates. In such weather conditions, the potential losses are dramatically reduced, as indicated by the lower light-dashed line for ET_p. Similar implications could be applied with regard to early-planted sugar beets for years with frequent April rainfall periods.

The tabular data in graph 4 provide an estimate of normal seasonal ET for the various crops, planted and harvested at the times indicated. Grass is the largest user of water during the year because of its 12-month season with full cover at all times. Even during the growing season of each of the other crops the ET loss by them failed to match the total loss by grass. The higher mid-season ET by each crop failed to make up for losses which were lower than grass losses during other times of the season.

From the small degree of variation of ET_p in mid-summer months, it is assumed that the seasonal totals listed for corn, tomatoes, and beans will apply within 5% or so for most years at Davis. Greater

GRAPH 4. ESTIMATED NORMAL SEASONAL EVAPOTRANSPIRATION PATTERNS FOR SEVERAL CROPS AT DAVIS, COMPARED WITH THE LONG-TIME MEAN MEASURED LOSSES BY GRASS, ET_p. (SEASONAL TOTALS ARE GIVEN FOR EACH CROP) TOTAL LOSS BY GRASS FOR EACH RESPECTIVE CROP SEASON IS ALSO GIVEN.



variations might be expected for the longer-season crops, especially late-planted sugar beets and barley, because of the much wider variability in potential ET for late fall and winter months. Using ET_p as an example, if each of the record-high ET_p months had fallen in a single November-through-April-period, the total ET_p would have been 17.82 inches. If all record lows had fallen in consecutive months, a loss of only 8.78 inches would have resulted.

Actually, for the eleven years with available consecutive-month data, November through April, the high total ET_p was 14.69 inches while the low season showed 10.57 inches with an 11-year mean of 13.27 inches. For the Davis area, this indicates that grass pastures on the average may require around 80% of the normal November–April precipitation (16.64 inches for the same 11 years of record). In dry seasons, an irrigation may be required in late October or November and again by late March, if readily available soil moisture is desired.

Other areas or climates

It appears from the literature that the generalized curves of graph 3 probably have rather wide applicability. Hence in areas where measurements of ET_p are available (e.g., in California at sites indicated in graph 2), it should be possible to derive quite reliable normal seasonal patterns of ET, at least for the crops included in this study. From detailed studies of the State Department of Water Resources, especially in the Bakersfield area, comparisons of ET by various crops with grass ET and/or pan evaporation, provide a background for the development of curves like those in graph 3 for many other crops.

Theoretically, under full-cover conditions in very humid and cooler climates, one could expect less difference between ET for grass and ET for the taller and rougher crops. Under such conditions the effect of widely differing aerodynamic roughness of surfaces may be rather minimal. The opposite should be true for climatic zones with even drier and hotter weather than at Davis, especially in windy areas. Other factors may also be important, such as differences in stomatal resistance or in the albedo (reflectance) of various crops. The high stomatal resistance of several crops such as citrus and pineapple restrict losses to levels well below potential evapotranspiration. On the other hand, corn canopies absorb around 80 to 82% of the impinging solar radiation as compared with only 73 to 76% in the case of grass. This factor alone could account for 5 to 8 % higher ET by corn than by grass.

On a provisional basis, we suggest that for cool, coastal climates or during cooler more humid times of the year anywhere in California, the ratios of ET for typical row-crops to ET_p (for grass) be reduced to values between 1.05 to 1.10 during full-cover conditions. For drier, hotter and windier areas than Davis, values of 1.20 to 1.30 may be more appropriate. Hot humid areas should fall somewhere in between.

Since ET_p data based on reliable studies with grass are quite scarce, evaporation from Weather Bureau Class A pans *located in an irrigated pasture environment* (or its equivalent) may be used to estimate ET_p. A coefficient of 0.8 at Davis provides an excellent estimate of ET_p except under strong, dry wind conditions, when this may drop to as low as 0.65. A serious precaution should be noted here. If a Class A pan is located in a nonagricultural site or is surrounded by several score or more feet of dry surface material, even in an agricultural environment, the pan data may need to be multiplied by a somewhat lower coefficient, which (regrettably) seems to vary with climate also. In cooler humid climates little correction is needed for differences in local pan environment, but in an arid climate, especially if brisk winds are encountered, a pan coefficient approaching 0.55 to 0.6 would likely provide a more reliable estimate of ET_p.

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