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Evapotranspiration-Climate Relations for Several Crops in the Central Great Plains[1]

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ABSTRACT

Under dryland conditions after periods of substantial rains, evapotranspiration from oats, winter wheat, and native grass was as high as 2.0, 1.5. and 1.0 times the evaporation from a BPI pan. During periods of similar water availability, the ratio of ET to E pan for sudangrass was similar to that for native grass, whereas the ratio for sorghum and millet was about the same as that for wheat.

Additional key words: **net radiation, advection, dryland.**

IN the dryland area of the Central Great Plains crop production is primarily limited by inadequate water. Of primary importance to this area is the development of water conservation practices that maximize water-use efficiency of plants grown in the area. As pointed out by Staple (7), a better understanding of the soil, plant, and meteorological factors that influence water use by crops under field conditions is needed before further gains in moisture efficiency can be expected.

The evapotranspiration from any crop under dryland or irrigated conditions can be estimated for most purposes by the following equation

$$ET = R_n - S - A \qquad [1]$$

where ET is evapotranspiration, R_n is net radiation, S is soil heat flux, and A is sensible heat flux. The problem in applying equation [1] is that evaluation of the sensible heat exchange is very difficult (9). In humid regions the values of S and A, especially over periods of days or weeks, are small and ET is closely related to R_n(9). However, in dryland regions water limits ET so that the energy available from R_n appears as A or S. Over fairly long periods the value of S in almost all regions has been found to be small compared with R_n and A. Under extremely dry conditions, such as desert areas, the integrated value of A will be very nearly equal to R_n. Solution of equation [1] is further complicated in the dryland region because of the practices of strip-cropping and fallowing. Where fallow is practiced, evaporation from the soil will be equal to R_n for a very short period (on the order of a day or two) after a summer rain. Thus, soon after a rain, large amounts of the net solar energy, R_n, will appear as A. The cropped areas, adjacent to the fallowed areas, may contain sizeable reserves of stored soil water that will supply the crop for several weeks. Winds normal to the area will then blow the hot air from the fallow areas across the cropped areas, resulting in ET which may be much larger than R_n—S because of advection (A will be positive). Thus, the contribution of advection may be as important at times in the dryland region as it is in irrigated areas. As discussed by Penman, Angus, and van Bavel (5), where advection is important, local influences may be so great that general relationships may have to be modified by local research.

It was the purpose of this experiment to evaluate the relationship of evapotranspiration of several crops to net radiation, soil heat flow, and (by inference) sensible heat exchange with the air. Comparisons have also been made with total solar radiation and pan evaporation. Because of instrumentation difficulties, data are available only for intermittent periods.

PROCEDURE

The study was conducted at the Central Great Plains Experiment Station at Akron, Colorado. The average annual precipitation is 42.3 cm. The elevation at Akron is 1,395 meters (4,580 feet). The soil is a Rago silt loam.

Data have been collected for 1965, 1966, and 1967. A rotation of fallow, winter wheat (*Triticum vulgare* var. 'Wichita'), and grain sorghum (*Sorghum bicolor* (L.) Moench var. 'RS 610'), has been studied as well as native grass (mostly buffalograss). In addition, limited information has been collected on oats (*Avena sativa* var. 'Fulton'), millet (*Panicum miliaceum* local selection), and sudangrass (*Sorghum vulgare sudanese* var. 'Wheeler').

The evapotranspiration was evaluated using lysimeters having an area of 100 × 100 cm and a depth of 90 cm. The construction of these lysimeters has been described by Hanks and Shawcroft (4). The lysimeters were in the middle of a 55 × 55-meter (180 × 180-foot) plot. Daily measurements (except weekends and holidays) were made throughout the year. Most of the data, except oats and sudangrass, are averages of duplicate lysimeters. Net radiation was measured with net radiometers constructed in accordance with the design of Fritchen (1).

Soil heat flow was measured with soil heat flux plates constructed in accordance with the instructions of Tanner (8). The plates were buried at about 5 cm. The output of the net radiometers and soil heat flux plates was integrated with an electronic integrator described by Hanks and Gardner (3). Readings were taken at the same time as the lysimeter readings.

Sensible heat exchange with the air, A, was not measured directly but was calculated from equation [1] from the measurements of all of the other variables.

Total radiation was measured with silicon photovoltaic cells as described by Selcuk and Yellot (6). Integration of the output was similar to that described for net radiometers.

For April through October, evaporation from a free water surface was measured with a sunken pan, 1.83 m (6 feet) in diameter and 0.61m (2 feet) deep (known as the Bureau of Plant Industry Pan). In 1967, a standard U. S. Weather Bureau class A evaporation pan was installed. During 1967, evaporation from the Weather Bureau pan was 1.71 times that from the Bureau of Plant Industry pan.

RESULTS AND DISCUSSION

The precipitation and cumulative evapotranspiration for the 3 years are shown in Fig. 1. Precipitation in 1965 and 1967 was 15.0 and 5.0 cm above normal, whereas precipitation in 1966 was 6.6 cm below normal.

In all years, precipitation exceeded evaporation from the fallow plot (this plot was planted to winter wheat in mid-September). The storage values for fallow were

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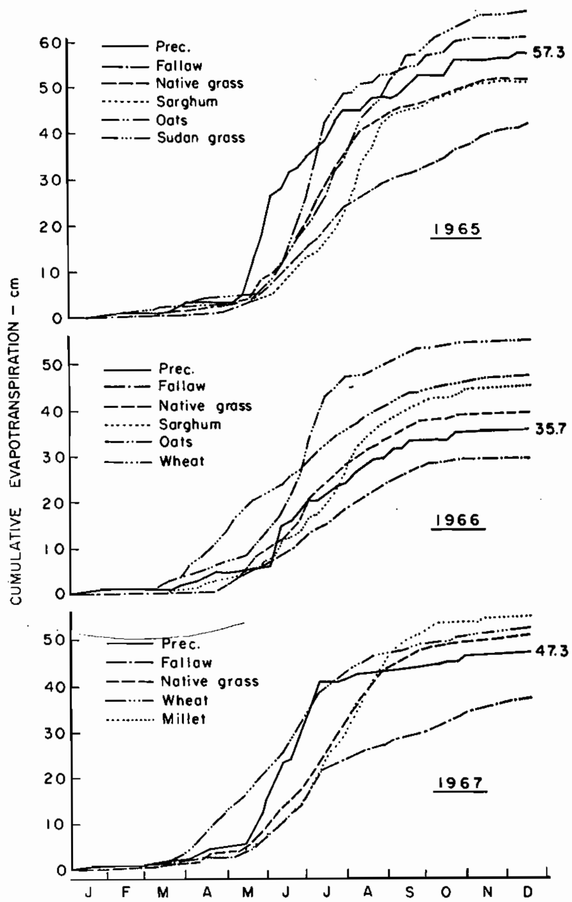

Fig. 1. Cumulative precipitation and evapotranspiration for the crops studied for 1965, 1966, 1967.

15.8, 9.8, and 6.2 cm for 1965, 1967, and 1966, respectively. The fallow efficiency percentages, defined as the ratio of water stored to precipitation (× 100), were 27.5, 20.5 and 17.5 for these years. Evaporation from the fallow plot was greatest during periods of frequent rains. For example, during the period from June 5 to July 10, 1967, precipitation was 21.5 cm. and evaporation was 13.0 cm (0.37 cm per day). During a fairly rainless period from July 10 to August 14, 1967, (1.1 cm of precipitation) evaporation decreased to 0.13 cm per day and totaled 4.7 cm.

The total evapotranspiration from the native grass plot was about 6 cm less than the precipitation in the wettest year, 1965, but was about 4 cm greater than the precipitation in 1966 and 1967. The maximum evapotranspiration rates, averaged over 7 days, were 0.82, 0.52 and 0.54 cm per day for 1965, 1966, and 1967, respectively.

The total evapotranspiration from the sorghum plot was 6 cm less than precipitation in 1965, but 10 cm greater than precipitation in 1966. The maximum evapotranspiration rates, averaged over 7 days, were 0.89 and 0.63 cm per day in 1965 and 1966 respectively.

The total evapotranspiration from oats was 4 cm greater than precipitation for 1965 and 19 cm greater for 1966. The maximum evapotranspiration rates, averaged over a 7-day period, were 1.15 and 1.07 cm per day for 1965 and 1966, respectively. This was the highest rate measured for any crop. Part of the reason for high water use in 1966, compared with other crops, was a high amount of stored water at the beginning of the year.

The total evapotranspiration from sudangrass in 1965 was 9 cm greater than the precipitation. This large total ET, compared with other crops for that year, was due to a high water content throughout the season. This crop was part of another experiment and water was added artificially to keep the water content nonlimiting throughout the season. The maximum measured, averaged over 7 days, was 0.74 cm per day.

Millet was grown only in 1967. The total ET from millet was 8 cm greater than the precipitation received. The maximum ET rate measured in 1967, averaged over 7 days, was 0.65 cm per day. This was the highest ET rate measured by the crops grown in 1967.

The data suggest that there may be a difference in ET from the different crops where weather factors and soil water storage are similar. Fig. 2, 3, and 4 show the ratio of ET to evaporation from the BPI pan, as well as the relative water content for all of the crops. These data should allow comparisons among crops, with the effect of different climatic factors minimized.

The data of Fig. 2 and 3 indicate that there was a difference in evapotranspiration from different crops grown under the dryland conditions of this study. Evapotranspiration from oats was greater than from any other crop where conditions of soil water content were similar. The ET from oats was greater than the E_{pan} for 8 consecutive weeks in 1965 and 3 weeks in 1966.

The ratio of ET/E_{pan} for native grass reached a value of about 1.0 when the water content was high

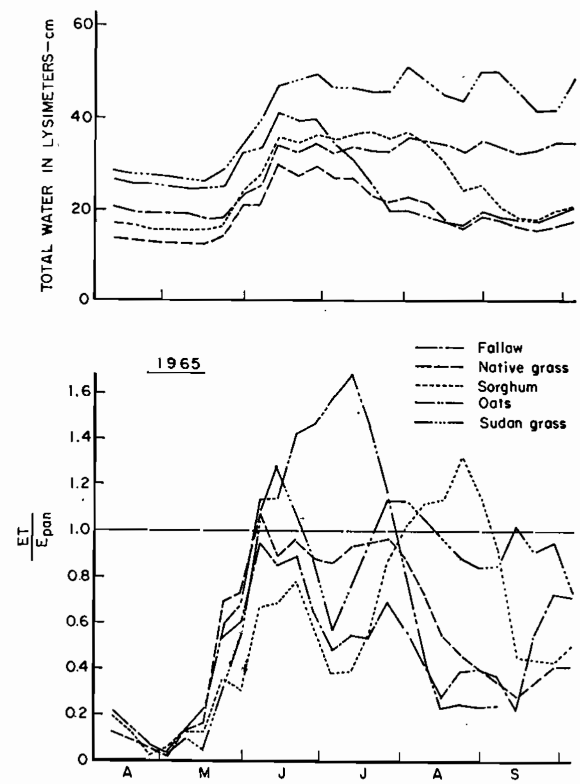

Fig. 2. Ratio of evapotranspiration to pan evaporation in 1965.

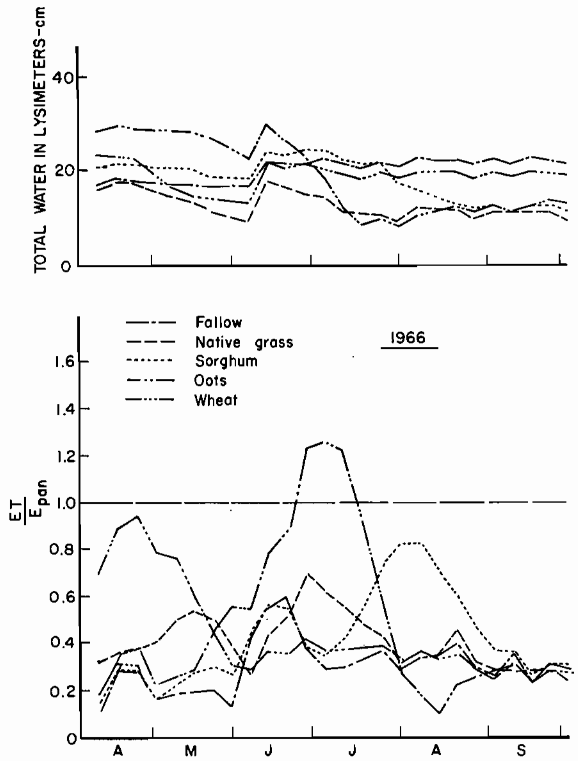

Fig. 3. Ratio of evapotranspiration to pan evaporation in 1966.

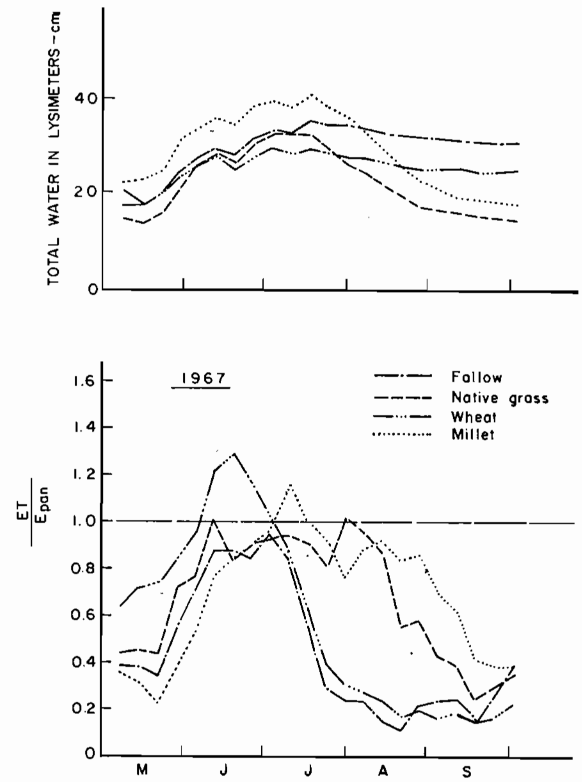

Fig. 4. Ratio of evapotranspiration to pan evaporation in 1967.

and (was probably) nonlimiting. In 1966, the dryest year, water was apparently limiting most of the year because the ratio never exceeded 0.7.

Sudangrass appears to be similar to native grass in that the ratio of ET/E_{pan} averaged very close to 1.0 after the crop was growing actively and completely covered the ground (about July 10). The first maximum in the sudangrass curve, shown in Fig. 2, occurred in early June at planting time when the soil was fallow and being tilled for seedbed preparation. Because water was artificially added to the plot, the soil water content of sudangrass lysimeter was higher throughout the 1965 season than that of any other crop. These data for sudangrass are similar to those obtained by Fritchen and van Bavel (2).

The data for sorghum, Fig. 2 and 3, show that the ratio of ET/E_{pan} was about the same as for fallow until about the middle of July. This is because sorghum is planted in mid-June and it takes about a month before plant roots begin to extract a significant amount of water from the soil. However, once the crop was growing vigorously, ET was greater than the ET from native grass or sudangrass when other factors were equal.

The data of Fig. 1, as well as that of Fig. 3 and 4, show the earlier use of water by wheat than by the other crops. Since oats are planted in early spring and sorghum and millet in late spring, the only other crop with good cover that is well established early in the spring is native grass. The native grass was mostly Buffalo grass, a warm season grass, that didn't appear to use substantial water until May. Thus, winter wheat was the only crop actively growing in April and the first part of May. The data of Fig. 4 show that ET/E_{pan} for wheat was significantly greater than 1.0 when soil water was high and the plant was still growing actively. Wheat matured about the first of July and ET decreased even though the average water content in the lysimeter stayed about constant.

The data of Fig. 2, 3, and 4 show that in general the ratio of E/E_{pan} was lowest for the fallow treatments. The data for sorghum and millet were essentially the same as fallow until mid-July. Although not shown by the weekly averages of Fig. 2, 3, and 4, the daily measurements showed that when the surface soil was wet after a rain, evaporation from the fallow soil was greater than ET from native grass. The data for sudangrass in early June 1965, where the water content was maintained high and tillage for seeding was done (fallow condition), also show greater evaporation than from native grass. The fallow soil before a rain was usually warmer than a cropped soil so more heat was available for evaporating water. However, the soil surface dried within a day or two after being wetted because conduction of water to surface apparently was not maintained within the soil and evaporation decreased rapidly thereafter.

The data for millet (Fig. 4) show a ratio of ET/E_{pan} greater than 1.0 for only a short period. About mid-July millet began to suffer from lack of water, judging from plant symptoms. Millet is a very shallow-rooted crop and, although the total amount of water in the lysimeter was higher for millet than any other crop until August 1, probably began to suffer from lack of water earlier than other crops. It appears that ET from millet was greater than from native grass where soil water was nonlimiting.

The data of Fig. 2 and 3 for oats were based on data from one lysimeter only. All other data except sudangrass were duplicated. Other data collected show that the large ET by oats was real, however. In 1967

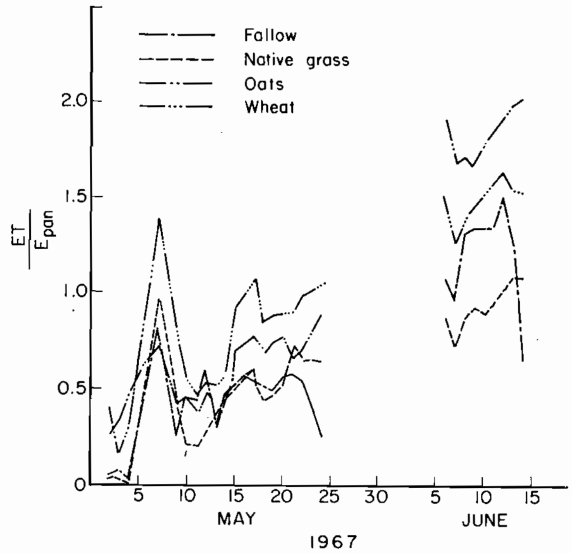

Fig. 5. Ratio of evapotranspiration to pan evaporation for a short period in 1967.

another experiment was initiated which had a 4-hectare (10-acre) field in which 10 lysimeters were installed in 1966. This field was uniformly planted to oats until June 13 when the oats were disced under. Until the first of May, 1967, was a very dry year. From May 5 to May 25 there was 4.9 cm of rain and from May 25 til June 5 there was 11.1 cm of rain. Fig. 5 shows the ET/E_{pan} ratios for wheat, oats, and native grass during this period. Prior to May 25 the data indicate insufficient rainfall limited ET on all crops. However, from June 6 through June 13 the data show that crop factors rather than soil water factors influenced ET. ET from oats was almost double that from native grass. The ET/E_{pan} ratio of wheat during this time was about 1.5 times that of native grass. The data show evaporation from fallow was greater than ET from native grass. The reason for this was discussed earlier. The soil was probably kept wet on the fallow because there was 1.9 cm of rain on June 7 and 1.4 cm on June 10 in addition to the 11.1 cm received between May 25 and June 5.

Measurements of net radiation and soil heat flow were made for limited periods in 1966 and 1967. During the time of measurement, sensible heat exchange with the air, A, was mostly positive for native grass (Table 1). This indicates that most of the time the air over the native grass plot was being heated. This was undoubtedly also the case with fallow, although only one measuring period indicated this. Frequent rains during the 10-day period, June 4 to 14, 1966, caused ET from fallow to be almost equal to R_n. Some heat was extracted from the air to cause the soil to heat up. R_n for wheat was usually as great as, or greater than, ET.

The data of Table 1 indicate that the largest amount of energy being extracted from the air, the most negative value of A, occurred with oats. During the period, July 4 to 14, ET was about 1.5 times R_n.

Part of the reason that the ET from oats was greater than from other crops was because R_n was higher most of the time. The ratio of the R_n (oats)/R_n(grass) increased from 0.92 for May 15 to 25, to 1.16 for June

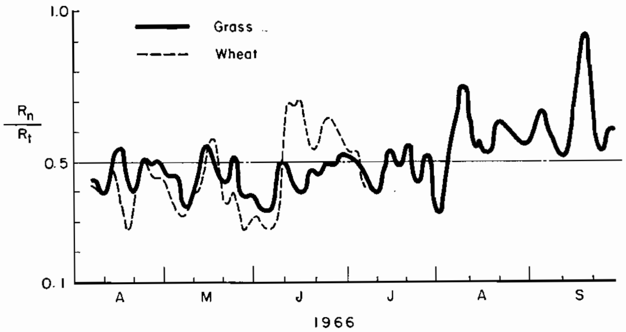

Fig. 6. Ratio of net radiation, R_n, to total incoming solar radiation, R_t, for wheat and grass in 1966.

Table 1. Total radiation, R_t, soil heat flux, S, evapotranspiration, ET, and sensible heat flux to the air, A, (assuming R_n — S + ET + A) for various crops at Akron, Colo. Values are cm of water equivalent per day.

Date	R_t	R_n	S	ET	A	R_n	S	ET	A
		Native grass				Winter wheat			
1966									
4/5-4/15	+0.71	+0.32	+0.12	+0.08	+0.12	+0.30	+0.08	+0.25	-0.03
4/15-4/25	+ .73	+ .35	+ .04	+ .13	+ .18	+ .30	+ .07	+ .30	- .07
4/25-5/5	+1.03	+ .49	+ .10	+ .24	+ .15	+ .43	+ .14	+ .43	- .14
5/5-5/15	+ .82	+ .36	+ .04	+ .24	+ .08	+ .31	+ .13	+ .34	- .16
						Oats			
5/15-5/25	+1.02	+ .48	+ .08	+ .28	+ .12	+ .42	-0.01	+ .19	+ .24
5/25-6/4	+1.06	+ .39	+ .07	+ .19	+ .13	+ .42	+ .05	+ .41	- .04
6/4-6/14	-	-	-	-	-	+ .38	- .01	+ .33	+ .06
6/14-6/24	+ .99	+ .44	+ .09	+ .36	- .01	+ .50	+ .00	+ .59	- .09
6/24-7/4	+1.10	+ .56	+ .07	+ .46	+ .03	+ .66	+ .01	+ .90	- .25
7/4-7/14	+1.04	+ .47	+ .08	+ .41	- .02	+ .67	+ .03	+ .95	- .31
7/14-7/24						+ .49	- .02	+ .39	+ .12
7/24-8/3						+ .56	- .04	+ .15	+ .45
						Fallow			
5/15-5/25						+0.49	+0.03	+0.08	+0.38
6/4-6/14						+ .39	+ .10	+ .38	- .09
1967						Winter wheat			
5/29-6/5	+0.91					+0.55		+0.28	
6/5-6/12	+ .89					+ .61		+ .45	
6/12-6/19	+ .88					+ .68		+ .58	
6/19-6/26	-					+ .58		+ .39	
6/26-7/3	+ .95					+ .62		+ .47	
7/3-7/10	+1.07					+ .69		+ .57	
7/10-7/17	+ .98					+ .66		+ .31	
7/17-7/24	+ .94								
7/24-7/31	+ .95	+0.60	+0.07	+0.47	+0.06				
7/31-8/7	+ .90	+ .57	+ .01	+ .43	+ .13				
8/7-8/14	+ .88	+ .54	+ .02	+ .37	+ .15				
8/14-8/21	+ .91	+ .55	-	+ .36	+ .19				
8/21-8/28	+ .90	+ .47	+ .02	+ .29	+ .16				

14 to 24, to 1.30 for July 4 to 14. The ratio of R_n (wheat)/R_n(grass) was quite consistent from April 5 to May 15, 1966 at about 0.88.

It appears that in dryland areas where large amounts of advective energy are available, from surrounding fallow or range, crops differ in the amount of this energy used in evapotranspiration. There must be some physiological or anatomical reason why oats would cause large amounts of advective energy to be converted into evapotranspiration, whereas sudangrass would not.

We had considerable difficulty trying to keep the net radiometers and soil heat flow plates functioning over long periods of time. Leaks developed in the plastic domes of the net radiometers due to blowing soil, weeds or hail. Consequently, the data have been analyzed to determine if there was a consistent relation between net radiation and total radiation. Total radiation is more easily measured because the instruments are more rugged. Fig. 6 shows a plot of the ratio of net radiation to total radiation for wheat and grass in 1966. As can be seen from the graph, there are large variations in this ratio for both crops. It would appear from these data that very large errors may result if total radiation only is used to estimate net radiation. Since the albedo of the crop would not be expected to change to any large extent, the variation shown in Fig. 6 must be due to differing amounts of back long-wave radiation. Back radiation variation may be more apparent in the high altitudes at the site of this experiment.

CONCLUSIONS

Under dryland conditions of the Central Great Plains, there were periods when evapotranspiration from all the crops studied was less than net radiation, or evaporation from a free water surface, because soil water was limiting. However, after periods of substantial rains where soil water was not limiting, evapotranspiration was highly dependent on the crop. During 1965, 1966, and 1967, the ratio of ET to E_{pan} for oats was as high as 1.6, 1.3, and 2.0, respectively. In contrast, the ratio of ET to E_{pan} for native grass reached a maximum of about 1.0. Sudangrass was similar to native grass even though the highest soil water level of any crop was maintained artificially on this crop. When soil water was not limiting, ratios of ET to E_{pan} substantially above 1.0 were also measured for millet, sorghum, and wheat. Limited measurements of net radiation and soil heat flow indicated very few periods where part of the energy from net radiation was not going to sensible heating of the air for native grass. This contrasts with oats where, for a 20-day period, a third of the energy used for evapotranspiration was advective energy.

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