Modeling Evapotranspiration from Sagebrush-Grass Rangeland

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Abstract

Three models, CREAMS, SPAW, and ERHYM, were used to predict evapotranspiration (ET) from a sagebrush-grass range site in southwest Idaho. Model-predicted ET was compared with ET measured by a lysimeter and ET calculated with a water-balance equation using field-measured soil water and precipitation values. There was generally good agreement between the lysimeter and water-balance calculated ET and between these ET values and model-predicted ET. Maximum averaged daily ET rates were about 2.5 mm for April, May, and June with single day ET values from the lysimeter as high as 5.0 mm. Although the CREAMS predicted ET rates were generally higher than those predicted by SPAW and ERHYM or measured by the water-balanced method, all 3 models were functionally capable of simulating ET from sagebrush-grass range sites. ERHYM was the simplest of the 3 models to operate.

The sagebrush-grass ecosystem includes about 52.6 million ha in the western United States (U.S. Forest Service 1980). Although its productivity per unit area is low, the sagebrush ecosystem is a major resource in terms of livestock production, wildlife habitat, and as a watershed for onsite and downstream water resources. This ecosystem supplies an estimated 25 million animal unit months (AUM) of grazing for domestic livestock with a potential for 78 million AUMs with improved management and range condition (USDA-SEA-AR 1980).

Evapotranspiration (ET) is a major component of the soil water balance equation for semiarid rangelands. Branson et al. (1976) estimated that as much as 96% of the incoming precipitation was returned to the atmosphere as ET from such rangelands. Most estimates of ET from sagebrush-grass rangelands have been determined from field measurements of precipitation, soil water content, and runoff (Rawls et al. 1973, Sturgis 1979).

During the past decade, several water-balance, climate models have been developed that can be used to predict evapotranspiration from rangelands. Most of these models have been evaluated for the shortgrass and mixedgrass prairies (Innis 1978, Aase et al. 1973, Wight and Hanks 1981, de Jong and MacDonald 1975, Hanson 1976). Research on modeling ET from sagebrush-grasslands has been limited. Wight and Neff (1983) evaluated a water-balance, climate model in a sagebrush-grass community in southeastern Montana. Sonntag et al. (1982) developed an ecosystem model which included an ET component for a sagebrush-grass community in Nevada.

Accurate estimates of ET are essential in the development of effective hydrologic and plant growth models. This paper evaluates

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Study Area

The study site was located in southwestern Idaho on the Reynolds Creek Experimental Watershed (Robins et al. 1965) on a nearly flat ridge top, at an elevation of 1,649 m. The soil is a Searla gravely loam of the loamy, skeletal, mixed, frigid family of the Calcic Argixerolls subgroup. Soil in the area averages about 100 cm in depth over a basalt bedrock. Annual precipitation averaged 34.9 cm for the 1962-1982 period.

The site is dominated by low sagebrush (Artemisia arbuscula) with sandberg bluegrass (Poa sandbergii) and bottlebrush squirreltail (Sitanion hystrix) comprising the major grass species. Basal cover for the past 11 years averaged 24, 26, 28, and 22% for live plants, litter, rock, and bare ground, respectively. Foliar cover averaged 45%.

Methods

Lysimetry

The study lysimeter was installed in 1968. It enclosed an undisturbed cylindrical soil core 152 cm in diameter and 122 cm deep. Changes in weight were measured by electrical transducers and were recorded with a digital recorder.

Soil Water Measurements

Soil water was monitored biweekly throughout most of the growing season by the neutron scatter method. Water content was measured in the 0 to 23, 23 to 46, 46 to 76, and 76 to 106-cm soil layers, respectively, in the lysimeter and an adjacent area. ET from the adjacent area was calculated as the sum of the change in soil water content and precipitation that occurred during soil measurement intervals. This method assumes no runoff. Observations of the area indicated that runoff is generally negligible. The soil water values at the beginning of the growing season were used to initialize model simulations each year.

Model-predicted ET

Three models were used to predict ET for the period 1976-1981: (1) SPAW (Soil-Plant-Air-Water) (Saxton et al. 1974); (2) CREAMS Chemicals, Runoff and Erosion from Agricultural Management Systems) (Knisel 1980); and (3) ERHYM (Ekalaka Rangeland Hydrology and Yield Model) (Wight and Neff 1983). The models were parameterized with soil and soil water data from the area adjacent to the lysimeter. Comparative model performance over the 6-year period was similar and only the results from 1977, 1978, and 1979, low, above average, and average production years, respectively, are discussed in detail. The SPAW and CREAMS ET

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components were developed for cropland applications. The ERHYM ET component was originally developed for cropland application, but it has been modified for use on rangelands. The models were applied with essentially no "fitting" or calibration.

Each model uses a different procedure for calculating potential evapotranspiration (ET_p) , potential transpiration (T_p) , and potential soil evaporation (E_p) (Table 1). Actual transpiration (T) in each

Table 1. Methods of calculating potential evapotranspiration (ET_p), potential transpiration (T_p), and potential soil evaporation (E_p).

Model	EΤ _p	Tp	E _p *			
SPAW	(E _{pan}) (PC)	(ET _p)(CF)(PF)	(ET_p) $(ET_p)(e^{-0.4LAI})$ ET_p-T_p			
CREAMS	Ritchie†	(ET _p)(LAI/3)‡				
ERHYM	(ET _{J-H})(K _c)	(ET _p)(TRC)(RGC)				

PC = Pan coefficient

CF = Cover factor

PF = Phenology factor

LAI = Leaf area index

TRC = Transpiration coefficient = 0.0213 + 0.0162 (average site yield, $lb/acre)^{1/2}$ RGC = A relative growth curve that varies between 0.0 and 1.0

ET_{J-H} = Jensen-Haise calculated ET_p

*E_p is never allowed to exceed $ET_p - \hat{T}_p$

†From Ritchie (1972). ‡For LAI values >3.0, T_p = ET

 $\$For LAI values < 1.70, E_p = 0.5 ET_p$

model is controlled by available soil water as indicated in Figures 1a, 1b, and 1c. Water movement and root distribution vary among models. All models operated on a daily time scale.

SPAW

SPAW is a fairly comprehensive crop model that utilizes pan evaporation and a pan coefficient (PC) to calculate ET_p . Water added to the soil moves through the profile along hydraulic gradiants. Water in excess of field capacity is drained through the soil as percolate. T_p is controlled by a plant cover factor (CF), a phenology factor (PF), and available by soil water (Fig. 1a). Soil evaporation is represented by an inclusion of a separate thin (1.3 cm) upper boundary layer (evaporation layer of soil in the soil profile). Water is evaporated from this layer and is limited only by ET_p and water content. Water content of this layer varies between air dry and field capacity and water is replenished by upward movement from the second soil layer driven by a Darcian type equation. The SPAWET model is the most process oriented of the 3 models evaluated.

CREAMS

The hydrologic component of CREAMS utilizes an ET routine developed by Ritchie (1972). ET_p is calculated from solar radiation, average air temperature, albedo, a psychometric constant, and a leaf area index. T equals T_p until 75% of the available water is removed (Fig. 1b). Transpiration demand is distributed down through the profile based on a root distribution that is described by an exponential function. Soil evaporation is calculated by the two-stage drying process and is limited to the top 15-cm layer of soil profile.

ERHYM

This model calculates ET_p as the product of the Jensen-Haise calculated ET_p (alfalfa as the reference crop) and a crop coefficient (K_c) (Jensen and Haise 1963). In addition to water content (Fig. 1c), transpiration from specific soil layers is controlled by the product of a transpiration coefficient, soil temperature, and a root density factor. The transpiration coefficient represents the portion of ET which can be T at peak standing crop. Soil temperatures are obtained from a soil temperature simulation routine. The root density factor is a recent modification of the original model which controls rate of water uptake based on the density of roots in each soil layer. Soil evaporation is limited to the top 30 cm of the soil profile and utilizes a one-stage drying process.



Fig. 1a. The relationship between $T/T_{\rm P}$ and available soil water as used in SPAW where curves A, B, C, and D represent different levels of atmospheric demand (potential ET). (From Saxton and McGuiness 1982.)



Fig. 1b. The relationship between T/T_p and soil water as used in CREAMS.



Fig. 1c. The relationship between T/T_p and available soil water as used in ERHYM.

Results and Discussion

A typical set of growing season ET_p curves as calculated by the 3 models is presented in Figure 2. The CREAMS and SPAW ET_p are



Fig. 2. Cumulative potential evapotranspiration as calculated by SPAW, CREAMS, and ERHYM. Reynolds Creek, 1977.

	April	May	June	July	August	September	BSW†		
		(mm/day)							
1977									
Lysimeter	nd*	1.98	2.67	1.59	0.96	1.14	18		
Water balance	0.34	1.42	1.63	1.28	0.32	0.92	2		
SPAW	0.62	1.65	1.67	0.48	0.35	0.56	2		
CREAMS	1. 46	2.80	2.01	0.39	0.81	0.22	2		
ERHYM	0.46	1.32	2.24	0.70	0.27	0.28	2		
Precipitation (mm/month)	2	63	47	10	15	14			
1978									
Lysimeter	2.40	1.77	2.53	1.15	0.88	1 11	110		
Water balance	2.57	1.63	2.15	1.14	0.73	0.67	86		
SPAW	2.32	3 14	1.58	0.91	0.41	0.07	86		
CREAMS	2 82	3.01	1.62	0.67	0.41	0.75	00		
ERHYM	1.01	1.83	2.57	1.13	0.62	0.58	86		
Precipitation	84	18	17	12	12	22			
1979									
Lysimeter	1.35	2.45	2.41	0.69	1 25	0.55	120		
Water balance	0.97	1.39	1 37	0.82	1.04	0.55	54		
SPAW	2 16	1.65	0.52	0.16	0.76	0.12	54		
CREAMS	2.00	2 43	0.92	0.10	1.00	0.15	54		
ERHYM	0.89	1.83	1 45	0.32	1.09	0.56	54		
	0.07	1.05	1.45	0.52	1.07	0.57	24		
Precipitation	20	28	11	5	49	2			

Table 2. Model-predicted and field-measured evapotranspiration, beginning soil water content, and monthly precipitation for 3 growing seasons at the Reynolds Creek study site.

nd = no data available.

[†]Amount of available plant soil water in the root zone at the beginning of the growing season (approximately April 1).

considerably higher than the ERHYM ET_p. The Jensen-Haise based ET_p in ERHYM is calculated by an empirical equation which was developed using alfalfa as a reference crop. For this study, a crop coefficient (Kc) of 0.85 was used to convert the Jensen-Haise ET_p to a rangeland ET_p. This K_c value was determined using lysimeter data from a mixed prairie grassland in eastern Montana (Wight and Hanks 1981).

Alfalfa requires relatively warm weather before it begins growth in the spring, thus the ET_p based on the Jensen-Haise method is limited by cool weather and this is reflected by the low values calculated for the early spring. Similar limitations would occur during the fall and winter periods.

In addition to solar radiation and temperature, CREAMS uses an albedo input in calculating potential evaporation. An average albedo of 0.15 for the study site area was reported by Belt (unpublished data 1972). Dirmhirn and Belt (1971) reported an albedo of 0.13 for a similar site in southeastern Idaho. These albedo values represented midday measurements and are somewhat lower than would be expected for daily averages. The low albedo helps account for the high ET_p values calculated by CREAMS.

Average daily ET rates for each month as measured by the lysimeter and water-balance methods and the model-predicted ET values are presented in Table 2. The good agreement between lysimeter and water-balanced measured ET values supports the reliability of the water-balance ET data. The major differences between the 2 methods were due to differences in soil water contents at the beginning of the growing season. These differences were probably due to seepage of rain water along the inside walls of the lysimeter and/or the restriction to drainage through the lysimeter. Maximum averaged daily ET rates were about 2.5 mm/day for April, May, and June. The availability of soil water significantly limited ET during the remainder of the growing season. ET values from the lysimeter on days following significant precipitation reached maximum values of 4.5 to 5.00 mm in the summer months.

For most of the growing season, the SPAW, ERHYM, and lysimeter cumulative ET curves were parallel, indicating good

agreement on daily ET rates (Fig. 3). The CREAMS ET values were a little higher than the values determined by the other methods, but the seasonal dynamics were very similar. The high ET rates measured by the lysimeter at the beginning of the growing season (Julian days 124 to 128) indicate a weakness of the models in



Fig. 3. Model-predicted and lysimeter-measured evapotranspiration. Reynolds Creek, 1977.

accounting for ET under some weather conditions. Wet cool weather prevailed during the period Julian day 121 to 131 with numerous precipitation events totaling about 5 cm and mean daily temperatures averaging about 6° C. During this period both the lysimeter and the evaporation pan measured about 3 cm of ET and evaporation, respectively. The model-predicted values were significantly lower than the lysimeter-measured values. Apparently, the models underpredicted the evaporation from an essentially free water surface that occurred during this period. Also, the model ET_p may have been unrealistically low, possibly due to very low temperatures.

Comparisons of model-predicted and water-balance-calculated ET for the area adjacent to the lysimeter are presented in Figures 4a, 4b, and 4c. For the average and below-average production years, CREAMS predicted higher ET than did ERHYM or SPAW,



Fig. 4a. Seasonal evapotranspiration as determined by the models and water-balance method. Reynolds Creek, 1977.



Fig. 4b. Seasonal evapotranspiration as determined by the models and water-balance method. Reynolds Creek, 1979.



Fig. 4c. Seasonal evapotranspiration as determined by the models and water-balance method. Reynolds Creek, 1978.

which were in general agreement with the field-measured values. For the above-average production year (1978), both CREAMSand SPAW-predicted ET were in good agreement with the fieldmeasured ET, while ERHYM-predicted ET was slightly lower than the field-measured ET. Differences in ET rates were most pronounced early in the growing season when soil water was most plentiful.

The CREAMS ET routine allows up to 75% of the available water to be removed before water content limits T (Fig. 1b). This is reflected by a higher percentage of ET attributed to T by the CREAMS model than by the other 2 models (Table 3). By allowing only 30% of the available soil water to be removed before water content limits T as suggested by de Jong and MacDonald (1975) for native grass, ET was reduced 10% during the first 60 days of the growing season, making it more in line with the other models and field-measured values. Such modifications are simple to make and should be considered before applying CREAMS type ET routines to rangeland sites.

The models partitioned ET into E and T somewhat differently (Table 3). The SPAW model predicted little or no T in August and September, while CREAMS predicted relatively high T rates during those 2 months. These extreme values probably reflect some of the difficulties in the direct application of cropland ET models to rangeland plant communities. Quantification of crop-developed parameters such as leaf area index and phenological, or plant cover curves for rangeland conditions would realistically take a little calibration and tuning.

Model-predicted ET was regressed on the water balancecalculated ET for the periods that coincided with the soil water measurements (approximately 2-week intervals) and the coefficients of determination (r^2 values) were calculated (Table 4). The slopes and y-intercepts of the regression lines indicate that SPAW and ERHYM simulated ET a little better than did CREAMS. However, with some adjustments of the ET controlling parameters, all models may have been equal in performance.

As would be expected, the model-predicted and field-measured ET rates all approached zero at the end of the season, indicating that all available water had been evapotranspired. For semiarid rangeland, this is normally the case and is an advantage in longterm simulations in that the models are "zeroed out" each year, preventing cumulative errors in soil water accounting.

Conclusions

All 3 models appeared to be functionally capable of simulating ET from sagebrush-grass rangelands. Major differences in the models' performance were generally at the beginning of the growing season and during the below-average and average production years. Performance of the 3 models probably could have been improved by tuning or calibration through the adjustment of soil and vegetation parameters. All vegetation parameters were based on average conditions and were not sensitive to the annual variations of a native plant community. Of the 3 models tested, SPAW and ERHYM were best able to simulate ET from the study site. Compared to SPAW and CREAMS, ERHYM is simpler to operate and the required input data were more readily available.

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Table 3. Percent of model-predicted evapotranspiration attributed to transpiration at Reynolds Creek.

	April	May	June	July	August	September	Seasonal	
1977								
SPAW	72	36	47	29	0	0	37	
CREAMS	54	60	43	23	31	38	50	
ERHYM	29	45	34	9	9	0	32	
1978								
SPAW	34	67	73	51	3	0	51	
CREAMS	36	68	73	45	29	38	53	
ERHYM	14	66	59	57	36	16	51	
1979								
SPAW	50	67	27	0	0	0	43	
CREAMS	37	73	70	48	28	38	52	
ERHYM	47	62	44	52	26	3	44	
Mean								
SPAW	52	57	49	27	3	0	44	
CREAMS	42	67	62	39	29	38	52	
ERHYM	30	58	46	39	24	6	42	

Table 4. Means, slopes, Y-intercepts, and r² values for the regressions of model-predicted evapotranspiration on water-balance ET measured at bi-weekly intervals* during the growing season.

		Water-Balance				SPAW			CREAMS			ERHYM			
	1977	1978	1979	Mean	1977	1 9 78	1979 Mean	1977	1978	1979	Mean	1977	1978	1979	Mean
Mean (mm)	3.32	7.09	3.92	4.78	3.56	7.50	4.32 5.12	5.64	7.93	5.45	6.34	3.62	5.84	4.13	4.53
Slope			_	_	0.90	0.99	0.73 0.87	1.26	0.99	1.07	1.10	1.03	0.93	1.04	1.00
Y-intercept (mm)		_	_		0.57	0.51	1.47 0.85	1.44	0.90	1.23	1.19	.19	-0.74	0.07	0.33
r ²	—	_			0.96	0.98	0.88 0.94	0.92	0.97	0.94	0.94	0.97	0.98	0.99	0.98

*N for 1977, 1978, and 1979 was 13, 12, and 13, respectively.

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