Predicting peak standing crop on annual range using weather variables

MELVIN R. GEORGE, WILLIAM A. WILLIAMS, NEIL K. MCDOUGALD, W. JAMES CLAWSON, AND ALFRED H. MURPHY

Abstract

Wide yearly fluctuations in peak standing crop on California annual-type range are largely explained by temperature and precipitation patterns. The objective of this study is to improve the predictability of functions relating weather patterns and peak standing crop by including degree-days, dry periods, evaporation, season start dates, and lengths and precipitation as independent variables. Peak standing crop was regressed on these independent variables for the University of California Hopland Field Station (HFS) and San Joaquin Experimental Range (SJER). Fall and winter precipitation, winter degree-days, and longest winter dry period were related to peak standing crop at HFS (R^2=0.61). Spring precipitation, growing season degree-days, winter evaporation, and winter and spring start dates were related to peak standing crop at SJER (R^2=.72). The relationship of peak standing crop to accumulated precipitation on 20 November using 33 years of data (r^2=0.34) was weaker than previously reported for the first 16 years (r^2=0.49). This study suggests that timely prediction of peak standing crop may be possible at HFS but more difficult at SJER.

Key Words: heat units, evaporation, modeling, precipitation, forage yield, degree-days

Wide yearly fluctuations in peak standing crop on California annual-type range are largely explained by temperature and precipitation patterns (Talbot et al. 1939; Bentley and Talbot 1948, 1951; Talbot and Biswell 1942; Heady 1956, 1958; Jones et al. 1963; Hooper and Heady 1970; Murphy 1970; Duncan and Woodmansee 1975; Pitt and Heady 1978; George et al. 1985, 1988).

Murphy (1970) obtained a correlation coefficient (*r*) of 0.70 ($p<0.01$) between observed forage production and the amount of rain received by November 20 at the University of California Hopland Field Station (HFS). Pitt and Heady (1978) showed fall and winter minimum temperatures, fall and spring periods of little or no precipitation, and spring precipitation to be important weather variables associated with peak standing crop at HFS (R^2=0.90).

Duncan and Woodmansee (1975) found a weak relationship between forage yield and September, October, November or December precipitation ($r<0.28$) at San Joaquin Experimental Range (SJER). They found forage yield more closely related to precipitation in April (R=0.41), November and April (R=0.53), or November, January, and April (R=0.62), concluding that precipitation must be well distributed throughout the growing season to ensure abundant forage yield.

Continued collection of weather and peak standing crop data at HSF and SJER have provided additional data for regression analysis purposes. The objective of this study was to improve upon the predictability of functions relating weather patterns and peak standing crop by including degree-days, dry periods, evaporation, season start dates, and lengths, as well as precipitation distribution. This paper presents the results of multiple regression analysis of these variables.

Materials and Methods

The study was conducted using peak standing crop, daily precipitation, and temperature data from HFS and SJER. Hopland is located in Mendocino County, California. Approximately 64 km from the coast at 39 N Lat in the Coastal Range at elevations of 200 to 400 m, San Joaquin Experimental Range is located at 37 N Lat in the lower central foothills of the Sierra Nevada at elevations of 200 to 500 m approximately 40 km north of Fresno, California.

The independent variables which are listed in Table 1 were analyzed by stepwise multiple regression (BMDP2R, Dixon 1983) and all possible subsets regression (BMDP9R, Dixon 1983) to determine those that were closely associated with peak standing crop. As part of the regression procedure, residual plots were examined to assure fulfillment of statistical assumptions, and multicollinearity was checked to confirm compliance with the variance inflation factor criterion (Williams et al. 1979).

Table 1. Independent variables analyzed in multiple regression analyses of peak standing crop from University of California Hopland Field Station (HFS) and San Joaquin Experimental Range (SJER).

Independent Variables	
D1	Fall degree-days
D2	Winter degree-days
D3	Spring degree-days
D4	Growing season degree-days
P1	Fall precipitation (mm)
P2	Winter precipitation (mm)
P3	Spring precipitation (mm)
P4	Growing season precipitation (mm)
N1	Fall longest dry period (days)
N2	Winter longest dry period (days)
N3	Spring longest dry period (days)
N4	Growing season longest dry period
G1	Dry days in month following germination
F1	Fall date
F2	Winter date
F3	Spring date
F4	Summer date
L1	Fall length (days)
L1	Winter length (days)
L3	Spring length (days)
L4	Growing season length (days)
SJER ONLY	
E1	Fall evaporation (mm)
E2	Winter evaporation (mm)
E3	Spring evaporation (mm)
E4	Growing season evaporation (mm)

Senior, second, and fourth authors are extension specialist, professor, and extension specialist, Agronomy and Range Sci. Dept. Univ. of California, Davis 95616. Third author is a farm advisor, Madera County, Univ. of California Cooper Ext., Berkeley, 94720. Fifth author is superintendent (retired), Univ. of California Hopland 95449.

The authors wish to acknowledge the many research assistants and others who faithfully collected weather and standing crop data at these research stations for many years.

Manuscript accepted 23 March 1989.

Daily temperature and precipitation data were available for 31 growing seasons (fall 1954–spring 1985) at HFS and 48 growing seasons SJER (fall 1936–spring 1984). A third analysis of the SJER data was conducted that included evaporation data (Table 1) from nearby Friant Dam (11 km south of SJER) with 30 growing seasons (fall 1954–spring 1984). In addition, Murphy's (1970) analysis of HFS precipitation and yield data (fall 1952–spring 1968) was repeated using HFS data from fall 1952 through spring 1985 and SJER data from fall 1936–spring 1984.

Accumulated degree-day values were determined using the sine function method described by Logan and Boyland (1983). Negative values were equated to zero. The base temperature used in this study was 5° C. Temperatures at or near 5° C have been used as the base temperature in degree-day calculations and in reports of minimum temperatures for growth for cool-season plants such as ryegrass (*Lolium perenne* L.) (Chang 1968), alfalfa (*Medicago sativa* L.), timothy (*Phleum pratensis* L.) and red clover (*Trifolium pratense* L.) (Bootsma 1984), Durum wheat (*Triticum durum* Desf. var. *Produra*) (Sherwood et al. 1978), cool season grasses and legumes (Fitzpatrick and Nix 1970), and annual range (Bentley and Talbot 1951). Representative species of the California annual range such as filaree (*Erodium botrys* (Cav.) Bertol.), soft chess brome (*Bromus mollis* L.), ripgut brome (*B. rigidus* Roth), foxtail fescue (*Vulpia megalura* (Nutt.) Rydb.), and rose clover (*Trifolium hirtum* All.) have minimum germination temperatures near a daily average of 5° C. (Young et al. 1973, 1975a, 197b).

Using the methods of George et al. (1988), the timing and length of the fall, winter, and spring seasons that comprise the annual-type range growing season were defined as follows:

1. Fall is the period between germination and the onset of cold weather. Germination is defined to begin the day after 25 mm of precipitation occurred in a 1-week period.
2. The first day of winter was defined as the first cold day (degree-days <3) in the first 7-day period that averaged less than 3-degree-days per day.
3. The first day of spring begins on the first warm day (degee days > 3) in the first 14-day period that averages more than 3 degree-days per day.
4. The dry season (summer) was defined to begin 2 weeks following the last rainfall total of 25 mm in 1 week.

The precipitation criteria for estimating the fall germination date are widely accepted, having been first proposed by Bentley and Talbot (1951). The criteria for the start of the winter and spring seasons were empirically derived by analyzing accumulated degree-day curves for over 100 growing seasons at HFS, SJER, University of California's Sierra Foothill Range Field Station (SFRFS) and 30 other weather stations maintained in the University of California's Integrated Pest Management data base. No fall season was

Table 2. Peak standing crop and accumulated effective precipitation totals for 1952–53 through 1984–85 growing season at Hopland Field Station.

Year	Peak Standing Crop (kg/ha)	Precipitation (mm) Nov. 1	Nov. 5	Nov. 10	Nov. 15	Nov. 20	Nov. 25	Nov. 30	Dec. 31	Jan. 31	Feb. 28	Mar. 31	Apr. 30	May 31	Total Season
52-53	2240	0	0	0	68	68	68	68	498	770	778	880	958	1000	1018
53-54	2016	43	43	73	158	170	228	228	248	560	693	835	903	903	930
54-55	1008	18	18	73	158	165	165	165	338	428	480	493	590	590	590
55-56	1344	10	13	13	38	78	120	120	605	983	1183	1205	1243	1260	1263
56-57	1456	75	78	78	78	78	78	78	95	273	483	573	638	730	733
57-58	3136	243	243	250	273	280	280	280	423	648	1135	1325	1475	1490	1510
58-59	1904	0	0	10	18	35	35	35	78	380	583	625	638	638	638
59-60	1904	53	53	53	53	53	53	53	88	233	465	608	645	700	700
60-61	2464	20	20	23	80	90	130	155	350	463	560	708	745	765	768
61-62	1456	10	10	10	10	30	173	203	315	353	625	748	763	778	778
62-63	3248	233	233	238	238	240	240	293	393	503	625	800	975	1005	1008
63-64	3920	93	120	158	200	235	258	258	320	483	490	555	578	598	610
64-65	2912	75	88	195	225	225	240	270	675	888	920	945	1075	1075	1075
65-66	2352	0	0	23	145	190	228	240	363	600	685	728	755	760	765
66-67	2912	0	0	20	63	198	225	238	433	675	685	875	993	1003	1028
67-68	2464	53	53	63	90	93	93	105	263	510	628	743	758	775	778
r†		.57*	.61*	.63**	.63**	.70**	.61**	.63**	.24	.19	.09	.20	.25	.24	.21
68-69	2912	65	65	70	108	118	130	138	483	845	1095	1138	1198	1198	1200
69-70	1904	75	75	95	98	98	98	98	415	930	1030	1095	1103	1108	1123
70-71	2128	108	108	123	130	130	145	248	538	675	685	843	878	905	905
71-72	2352	10	10	25	58	58	58	90	270	345	428	465	523	535	535
72-73	3808	130	130	168	230	260	260	260	400	728	948	1043	1048	1050	1050
73-74	3472	115	115	213	355	425	445	498	680	948	1053	1375	1435	1438	1438
74-75	3360	38	38	45	45	50	73	73	210	270	555	815	858	858	860
75-76	2912	103	103	115	130	140	140	140	185	198	265	310	385	385	385
76-77	1680	0	0	0	63	63	63	63	78	135	203	278	280	335	335
77-78	3360	110	110	110	113	113	190	190	393	818	1023	1153	1293	1298	1298
78-79	2688	0	0	0	8	15	28	28	45	265	473	570	628	655	655
79-80	3136	15	15	20	20	260	288	298	488	665	938	990	1048	1063	1073
80-81	2912	33	33	38	38	40	45	53	228	463	538	625	648	660	660
81-82	3136	153	153	160	245	348	460	488	715	905	1020	1208	1355	1355	1355
82-83	2912	143	143	153	153	223	243	333	565	818	1095	1523	1675	1690	1693
83-84	3360	43	43	123	230	325	373	373	703	718	838	915	958	963	973
84-85	2912	70	100	138	238	293	320	368	438	455	505	633	635	635	635
r††		.49**	.51**	.55**	.51**	.58**	.53**	.51**	.34*	.27	.28	.34	.36*	.34	.34

†Correlation coefficients for 1952-53 through 1966-67 growing seasons (Murphy 1970).
††Correlation coefficients for 1952-53 through 1984-85 growing seasons.
*=$p<0.05$
**=$p<0.01$

considered to occur in years where cold weather began before the germination criteria occur. The criterion for the start of the dry season (summer) was determined by reviewing dry matter production curves for 99 growing seasons simulated by the Annual Grassland Ecosystem Model (Pendleton et al. 1983) using daily weather data from HFS, SJER, and SFRFS.

Daily precipitation, degree-days, evaporation, and days without rainfall were summed within each season to derive the independent variables (Table 1).

Herbage yield at peak standing crop was estimated annually in late spring in caged exclosures by clipping twenty and forty 0.09-m^2 quadrats at HFS and SJER, respectively. The monitored sites were grazed by sheep at HFS and cattle at SJER.

Results

Murphy (1970) obtained a correlation coefficient of 0.70 (r^2=0.49) between forage yield and the amount of rain accumulated by 20 November based on data for the growing seasons of 1952–53 through 1967–68. When Murphy's analysis was repeated using rainfall data from the 1952–53 growing season through the 1984–85 growing season (Table 2), the correlation coefficient decreased to 0.58 (r^2=0.34). When SJER data were subjected to Murphy's analysis, precipitation accumulated by 31 January through 31 May and total precipitation were more closely related to peak standing crop ($r \geq 0.47$, $p < 0.01$) than fall precipitation (Table 3).

Table 3. Peak standing crop and accumulated effective precipitation totals for 1936–37 through 1983–84 growing seasons at San Joaquin Experimental Range.

Year	Peak standing Crop (kg/ha)	Precipitation (mm) Nov. 1	Nov. 5	Nov. 10	Nov. 15	Nov. 20	Nov. 25	Nov. 30	Dec. 31	Jan. 31	Feb. 28	Mar. 31	Apr. 30	May 31	Season Total
36-37	1897	53	55	55	55	55	55	55	183	264	434	544	559	559	559
37-38	2981	1	1	1	8	13	14	14	172	308	489	749	812	816	825
38-39	1626	41	43	49	50	50	50	60	92	163	225	297	305	306	310
39-40	2168	53	53	53	53	53	53	54	69	312	443	491	521	521	522
40-41	2304	40	42	42	42	42	42	42	248	339	522	587	700	700	700
41-42	2281	27	28	28	28	31	31	57	259	336	389	436	513	537	537
42-43	2718	0	11	11	20	47	47	50	101	209	265	387	416	416	416
43-44	1827	5	5	5	5	13	20	20	74	135	230	279	324	338	339
44-45	2905	27	54	83	150	150	150	150	222	230	336	444	452	462	463
45-46	2033	45	45	48	50	52	68	78	170	192	242	324	326	340	340
46-47	2033	39	39	39	53	107	137	137	231	243	282	306	316	331	332
47-48	1670	48	61	61	61	65	65	65	89	91	121	228	331	344	361
48-49	1558	6	11	11	11	11	11	11	68	114	162	264	264	301	301
49-50	3183	0	0	38	38	38	38	38	87	216	281	342	394	396	397
50-51	2794	62	62	62	87	224	224	248	331	405	468	488	520	521	522
51-52	2869	18	18	18	18	46	72	72	210	356	396	539	596	597	597
52-53	2191	8	8	8	50	65	65	65	222	274	277	309	351	366	377
53-54	2894	11	11	11	64	72	72	72	106	174	235	335	365	366	383
54-55	2443	0	0	0	34	60	60	61	123	258	305	315	367	405	405
55-56	2206	2	2	2	41	52	63	63	394	508	532	532	591	649	649
56-57	2199	45	45	45	45	45	45	45	70	130	185	248	285	353	357
57-58	2395	40	60	60	76	76	76	76	150	261	423	675	765	776	777
58-59	879	9	9	11	15	15	15	15	28	107	219	220	243	246	246
59-60	2191	91	91	91	91	91	91	91	100	157	265	315	377	378	378
60-61	1515	23	38	54	91	92	92	122	143	196	219	263	279	298	304
61-62	2208	3	3	3	3	27	55	82	128	191	435	494	499	500	500
62-63	3422	40	40	40	40	40	40	43	73	157	256	360	479	492	495
63-64	2793	46	48	90	112	145	161	161	172	203	203	253	289	310	311
64-65	4226	56	61	90	126	126	126	131	262	336	348	383	488	488	488
65-66	2444	10	10	10	52	95	145	146	221	248	282	286	307	315	317
66-67	3286	3	3	21	21	55	67	75	220	322	344	445	665	681	694
67-68	2574	11	11	11	13	39	39	66	111	150	191	257	268	288	290
68-69	3051	40	75	75	102	102	106	106	202	438	632	695	768	768	793
69-70	3389	18	18	49	49	49	49	49	120	272	308	392	396	396	422
70-71	3054	2	4	12	16	16	21	98	220	249	258	293	316	378	378
71-72	1975	5	5	5	44	44	44	52	173	183	221	221	239	246	270
72-73	3395	16	31	39	122	146	146	146	208	297	470	566	579	580	582
73-74	3191	64	64	66	97	134	136	138	256	385	452	569	644	645	647
74-75	2932	79	79	80	80	80	106	106	174	208	313	420	466	468	468
75-76	2862	76	76	79	79	80	80	90	100	104	239	280	308	309	314
76-77	1167	59	59	59	88	88	88	88	110	139	151	174	175	212	228
77-78	5067	2	16	16	16	16	37	37	183	344	507	659	777	777	777
78-79	3758	32	32	32	47	47	102	102	143	284	382	485	492	496	507
79-80	4433	23	39	39	39	62	64	69	113	288	411	474	498	506	506
80-81	2855	14	14	14	14	14	14	14	54	162	194	296	328	328	328
81-82	4380	28	28	29	68	84	84	98	159	292	361	525	613	613	628
82-83	4066	88	88	110	122	162	165	193	285	459	596	812	845	889	891
83-84	2043	26	26	26	72	72	132	162	286	294	331	378	391	391	402
r†		.02	.07	.16	.17	.20	.21	.21	.23	.47**	.47**	.53**	.57**	.56**	.56**

†Correlation coefficients for 1936–37 through 1982–83 growing seasons.
*=p<0.05
**=P<0.01

Table 4. Peak standing crop, winter degree-days (D2), fall(P1), and winter (P2) precipitation and longest dry period (N2) for 1954–55 to 1984–85 growing seasons at Hopland Field Station.

Year	Peak Standing Crop (kg/ha)	D2	P1	P2	N2
			(mm)		(days)
54-55	1008	284	95	426	17
55-56	1344	166	0	1172	12
56-57	1456	422	0	556	31
57-58	3136	330	185	869	12
58-59	1904	362	0	572	24
59-60	1904	232	2	473	12
60-61	2464	137	15	268	19
61-62	1456	296	0	717	15
62-63	3248	312	372	232	27
63-64	3920	274	156	328	15
64-65	2912	275	143	707	8
65-66	2352	179	135	503	11
66-67	2912	503	158	804	14
67-68	2464	152	64	440	19
68-69	2912	199	91	1021	6
69-70	1904	153	55	375	20
70-71	2128	296	115	613	18
71-72	2352	93	1	311	20
72-73	3808	358	220	782	9
73-74	3472	290	307	752	10
74-75	3360	355	15	765	15
75-76	2912	281	56	191	23
76-77	1680	107	30	83	35
77-78	3360	132	71	196	13
78-79	2688	207	0	507	17
79-80	3136	200	231	406	22
80-81	2912	214	13	416	10
81-82	3136	404	420	810	15
82-83	2912	162	85	490	11
83-84	3360	229	246	550	18
84-85	2912	95	253	223	10
Regression coefficient		2.2	2.76	−1.46	−56.7
Standardized coefficient		.33	.47	−.54	−.62
R^2 increment††		.06	.18	.14	.22
p		0.58	.002	.006	.001

R^2 = 0.61, p <0.01

†The contribution to R-square for each variable is the amount that the overall R-square would be reduced if that variable were omitted.

Table 5. Peak standing crop, fall (P1), winter (P2) and spring (P3) precipitation (mm) for 1936–37 through 1983–84 at San Joaquin Exper. Range.

Year	Peak Standing Crop (kg/ha)	P1	P2	P3
			(mm)	
36-37	1897	30	311	188
37-38	2981	58	126	484
38-39	1626	26	221	38
39-40	2168	36	178	264
40-41	2304	3	0	696
41-42	2281	0	361	118
42-43	2718	3	179	159
43-44	1827	0	259	0
44-45	2905	113	295	8
45-46	2033	0	164	84
46-47	2033	12	205	37
47-48	1670	24	166	75
48-49	1558	0	151	102
49-50	3183	1	241	114
50-51	2794	287	159	0
51-52	2869	0	521	57
52-53	2191	0	232	0
53-54	2894	0	258	13
54-55	2443	29	245	11
55-56	2206	0	531	116
56-57	2199	0	86	107
57-58	2395	36	379	322
58-59	879	0	208	0
59-60	2191	0	178	50
60-61	1515	37	128	29
61-62	2208	0	478	19
62-63	3422	3	70	379
63-64	2793	80	113	57
64-65	4226	39	253	145
65-66	2444	79	128	20
66-67	3286	44	259	371
67-68	2574	0	111	118
68-69	3051	73	577	99
69-70	3389	0	223	125
70-71	3054	54	177	7
71-72	1975	0	187	2
72-73	3395	115	394	41
73-74	3191	57	353	191
74-75	2932	92	294	18
75-76	2862	33	200	0
76-77	1167	0	51	0
77-78	5067	1	306	433
78-79	3758	0	380	84
79-80	4433	0	226	218
80-81	2855	0	168	147
81-82	4380	56	208	321
82-83	4066	45	371	431
83-84	2043	16	222	97
Regression Coefficient		3.37	1.96	3.73
Standardized Coefficient		.20	.28	.58
R^2 increment†	.04	.08	.32	
p		.135	.034	.00

R^2 = 0.40, p<0.01

†The contribution to R-square for each variable is the amount that the overall R-square would be reduced if that variable were omitted.

When annual peak standing crop for 31 years at HFS (Table 4) was regressed on the variables in Table 1 (excluding evaporation), 4 fall and winter weather variables were strongly associated with peak standing crop (R^2=0.61). Fall precipitation and winter degree-days were positively related to peak standing crop while winter precipitation and longest winter dry period were negatively related.

When annual peak standing crop was regressed on the same independent variables (Table 1) for 48 years at SJER (Table 5), fall, winter, and spring precipitation were found to be positively related to peak standing crop (R^2=0.40).

Soil moisture loss should be an important variable in seasonal forage productivity; however, these data have not been collected at the 2 study locations. Evaporation data were collected at Friant Dam near SJER. When these evaporation data (Table 6) were included with the other Table 1 variables for SJER, then winter evaporation, spring precipitation, growing season degree-days, and the first day of winter were positively related and starting-date-of-spring negatively related to peak standing crop (R^2=0.72).

Discussion

This study found that at HFS fall and winter precipitation, winter temperature, and winter dry period patterns have a strong influence on peak standing crop. This relationship improved substantially on the correlation of forage yield with the amount of rain received by November 20 (R^2=0.61 versus 0.34). Pitt and Heady (1978) reported a strong relationship between 5 fall, winter, and spring variables and June peak standing crop at HFS (R^2=0.90). However, their relationship is not useful as an early predictive

Table 6. Peak standing crop, winter (F2) and spring (F3) starting date, annual growing season degree-days (D4), spring (P3) precipitation, and winter evaporation (E2) 1954–55 to 1983–84 growing seasons at San Joaquin Experiment Range.

Year	Peak Standing Crop (kg/ha)	F2	F3	D4	P3	E2
		(day†)			(mm)	
54-55	2443	80	186	201	11	132
55-56	2206	72	191	748	116	160
56-57	2199	95	160	413	107	62
57-58	2395	93	196	1459	322	101
58-59	879	73	177	517	0	82
59-60	2191	95	187	1153	50	99
60-61	1515	75	181	337	29	147
61-62	2208	76	195	728	19	154
62-63	3422	90	152	914	379	50
63-64	2793	77	197	625	57	164
64-65	4226	71	170	869	145	110
65-66	2444	86	171	563	20	106
66-67	3286	83	174	1286	371	97
67-68	2574	85	156	557	118	79
68-69	3051	82	197	1510	99	149
69-70	3389	92	156	607	125	78
70-71	3054	99	196	438	7	151
71-72	1975	73	164	419	2	95
72-73	3395	79	205	1051	41	185
73-74	3191	77	178	914	191	127
74-75	2932	95	222	709	18	228
75-76	2862	77	191	651	0	171
76-77	1167	83	164	177	0	55
77-78	5067	99	157	1738	433	76
78-79	3758	71	184	822	84	147
79-80	4433	79	153	1181	218	82
80-81	2855	94	162	770	147	74
81-82	4380	84	166	1352	321	76
82-83	4066	68	154	1939	431	92
83-84	2043	79	148	832	97	53
Regression Coefficient		22.6	−50.7	.52	4.9	29.8
Standardized Coefficient		.24	−1.09	.16	.67	1.36
R^2 increment††		.04	.18	.02	.27	.27
p		.071	.001	.208	.00	.00
$R^2 = 0.72$, $p<0.01$						

†day 1 is September 1.
††The contribution to R-square for each variable is the amount that the overall R-square would be reduced if that variable were omitted.

value because it requires spring variables available only a few weeks or days before peak standing crop is known.

Spring precipitation at SJER had a positive influence on peak standing crop as previously suggested by Duncan and Woodmansee (1975). The importance of spring precipitation was also indicated by the importance of spring starting date at SJER. The starting date of the spring season is negatively correlated with annual forage yield. As the spring starting date increases (spring starts later), the probability of having a short spring and therefore less precipitation and few accumulated degree-days increases. Winter evaporation at SJER was positively associated with peak standing crop. We suggest that the associated high solar intensities in dry, cloudless periods may increase available energy and subsequent plant productivity.

Peak standing crop is heavily influenced by fall and winter weather variables at HFS, while at SJER it is more dependent on spring weather variables. Most of the annual herbage production at SJER occurs during the spring season (Pendleton et al. 1983); therefore, abundant spring precipitation and early spring starting dates tend to increase peak standing crop. The evidence shows that fall weather has a smaller influence on peak standing crop at SJER than it does at HFS. The reason seems to be that the start of the fall season, which is dependent on fall rains, is earlier and more dependable at HFS than at SJER (George et al. 1988). Dependability of precipitation, as Duncan and Woodmansee (1975) indicated, is particularly important. At HFS spring rains are reasonably dependable, while fluctuation of fall and winter precipitation contribute greatly to the between-year variation in peak standing crop. Precipitation is generally more variable at SJER than at HFS; however, because most production occurs in the spring, between-year variation in spring variables have a greater influence on SJER peak standing crop.

Mild winters of adequate precipitation appear to be positively associated with increased peak standing crop at HFS and SJER for the following reasons. The relationship between winter evaporation and peak standing crop is positive at SJER, suggesting that high evaporation is indicative of high solar intensity resulting in increased primary productivity. Winter precipitation is negatively associated with peak standing crop at HFS, suggesting that excessive precipitation and the associated cold, cloudy weather condition suppress production (Bentley and Talbot 1951).

Pitt and Heady (1978) discussed the utility of multiple regression as a predictive tool for stocking rate decisions. Stocking rate decisions are generally made early in the growing season, requiring a predictive tool based on fall and winter weather variables. Pitt and Heady's (1978) regression model for June standing crop is a strong relationship (R^2=0.90) but requires spring weather variables. Murphy's regression model based on precipitation to 20 November is simple, but the strength of the relationship has declined as additional years of data were used to derive the model. This study proposes a regression model for HFS and similar environments based on fall and winter weather parameters. A suitable scheme is to use Murphy's model:

$$Y = 1958 + 4.1\,X \quad (1)$$

where X is accumulated precipitation (mm) to 20 November for early prediction. Prediction based on Murphy's relationship could be adjusted at the end of winter (usually mid to late February) based on the relationship reported in this study:

$$Y = 3640 + 2.8\,P1 - 1.5\,P2 + 2.2\,D2 - 57\,N2 \ (R^2{=}0.61) \quad (2)$$

where P1 = Fall Accumulated Precipitation (mm)
P2 = Winter Accumulated Precipitation (mm)
D2 = Winter Degree-Days (C)
N2 = Longest Winter Dry Period (days)

Because of the importance of spring weather to total forage yield at SJER, it is more difficult for regression analysis of weather variables to provide a timely predictor of peak standing crop in the environments it typifies. However, the weak relationships based on precipitation accumulated by 31 January, 28 February, and 31 March (Table 3) may be sufficiently timely to be of some help:

$$Y = 1600 + 4.2\,X_1 \ (r^2{=}0.22) \quad (3)$$

$$Y = 1600 + 3.3\,X_2 \ (r^2{=}0.22) \quad (4)$$

$$Y = 1400 + 3.0\,X_3 \ (r^2{=}0.32) \quad (5)$$

where X_1 = precipitation (mm) through January 31
X_2 = precipitation (mm) through February 28
X_3 = precipitation (mm) through March 31

Using the unique methodology of George et al. (1988) to give greater emphasis to the timing and length of the fall, winter, and spring seasons that comprise the growing season, this study has improved the predictability of functions relating peak standing crop to weather patterns. Collection of weather and yield data at the same sites and improved monitoring of drought within the growing season should strengthen these relationships and identify additional useful relationships.

Literature Cited

Bentley, J.R., and M.W. Talbot. 1948. Annual-plant vegetation of the California foothills as related to range management. Ecology 29:72-79.

Bentley, J.R., and M.W. Talbot. 1951. Efficient use of annual plants on cattle ranges in the California foothills. USDA Circ. 870.

Bootsma, A. 1984. Forage crop maturity zonation in the Atlantic Region using growing degree-days. Can. J. Plant Sci. 64:329-338.

Chang, Jen-Hu. 1968. Climate and agriculture, an ecological survey. Aldine Publishing Co., Chicago.

Dixon, W.J. (ed.). 1983. BMDP Statistical Software. Univ. of Calif. Press. Berkeley, Calif.

Duncan, D.A., and R.G. Woodmansee. 1975. Forecasting forage yield from precipitation in California's annual rangeland. J. Range Manage. 28:327-329.

Fitzpatrick, E.A., and H.A. Nix. 1970. The climatic factor in Australian grassland ecology. p. 8-11. *In:* Moore, M.R. 1970. Australian Grasslands. Australian Nat. Univ. Press, Canberra.

George, M.R., W.J. Clawson, J. Menke, and J. Bartolome. 1985. Annual range forage productivity. Rangelands 7:17-19.

George, M.R., K. Olson, and J.W. Menke. 1988. Range weather: a comparison at three California range research stations. Calif. Agr. 42:30-32.

George, Melvin R., Charles A. Raguse, W. James Clawson, Charles B. Wilson, Robert L. Willoughby, Neil K. McDougald, Don A. Duncan and Alfred H. Murphy. 1988. Correlation of degree-days with annual herbage yields and livestock gains. J. Range Manage. 41:193-197.

Heady, H.F. 1956. Evaluation and measurement of the California annual type. J. Range Manage. 9:25-27.

Heady, H.F. 1958. Vegetational changes in the California annual type. Ecology 39:402-415.

Hooper, J.F., and H.F. Heady. 1970. An economic analysis of optimum rates of grazing in the California annual type grassland. J. Range Manage. 23:307-311.

Jones, M.B., C.M. McKell, and S.S. Winans. 1963. Effect of soil temperature and nitrogen fertilization on the growth of soft chess *(Bromus mollis)* at two elevations. Agron. J. 55:44-46.

Logan, S.H., and P.B. Boyland. 1983. Calculating heat units via a sine function. J. Amer. Soc. Hort. Sci. 108:977-980.

Murphy, A.H. 1970. Predicted forage yield based on fall precipitation in California annual grasslands. J. Range Manage. 23:363-365.

Pendleton, D.F., J.W. Menke, W.A. Williams, and R.G. Woodmansee. 1983. Annual grassland ecosystem model. Hilgardia 51:1-44.

Pitt, M.D., and H.F. Heady. 1978. Responses of annual vegetation to temperature and rainfall patterns in California. Ecology. 59:336-350.

Sherwood, B.I., R.D. Jackson, and R.J. Reginato. 1978. Extending the "degree-day" concept to plant phenological development to include water stress effects. Ecology 59:431-433.

Talbot, M.W., H.H. Biswell, and A.L. Hormay. 1939. Fluctuations in the annual vegetation of California. Ecology 20:394:402.

Talbot, M.W., and H.H. Biswell. 1942. The San Joaquin Experimental Range: The forage crop and its management. Calif. Agr. Exp. Sta. Bull. 663.

Williams, W.A., C.O. Qualset, and S. Geng. 1979. Ridge regression for extracting soybean yield factors. Crop Science 19:869-873.

Young, J.A., R.A. Evans, and B.L. Kay. 1973. Temperature requirements for seed germination in an annual-type rangeland community. Agron. J. 65:656-659.

Young, J.A., R.A. Evans, and B.L. Kay. 1975a. Dispersal and germination dynamics of broadleaf filaree, *Erodium botrys* (Cav.) Bertol. Agron. J. 67:54-57.

Young, J.A., R.A. Evans, and B.L. Kay. 1975b. Germination of Italian ryegrass seeds. Agron. J. 67:386-389.