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ESTIMATING WEATHER AND FORAGE RELATIONSHIPS

by
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Introduction

Weather variability has a large impact on range forage production and subsequently on range management and ranch income. Because of this impact, the ability to forecast weather and forage production would reduce uncertainty about production and income for California ranchers.

The relationship between weather and forage production has been studied at three range research stations. At Hopland Field Station (HFS) fall precipitation (Murphy 1970), temperature, drought and precipitation (Pitt and Heady 1978) and fall and winter precipitation, winter degree-days and winter dry periods (George et al. submitted) were shown to influence total forage yield. Duncan and Woodmansee (1975) found poor correlations between early fall precipitation and total forage yield for the San Joaquin Experimental Range (SJER). However, George et al. (submitted) showed a relationship between spring precipitation, winter evaporation, growing season degree-days and timing of winter weather and peak standing crop. Sully (1977) found a similar result in that Sierra Foothill Range Field Station (SFRFS) and HFS had a high correlation between total forage production and early season precipitation, but at SJER the relationship was too weak for further analysis.

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By including temperature and drought patterns in their regression analysis, Pitt and Heady (1978) found that correlations between forage yield and precipitation could provide reasonable estimates of forage yields throughout the growing season. Pendleton et al. (1983) developed an ecosystem model (ELMAGE) for the different components of the annual grassland ecosystem at SJER in California. George et al. (1988) found a strong relationship between accumulated degree-days and seasonal forage yield.

This paper analyzes the statistical relationships between weather and forage at three range research stations in California. In the first section, the relationships between mid-season and total forage production and weather at HFS are analyzed. Since there is insufficient data to analyze the seasonal relationships of weather and forage at other locations, seasonal weather data are used to estimate the predictability of winter and spring weather conditions based on fall weather conditions in the second section. In the last section, the ability to predict seasonal forage production from weather information is developed based on subjective knowledge.

HOPLAND FIELD STATION WEATHER AND FORAGE RELATIONSHIPS

Introduction

There are very few long-term series of monthly or seasonal forage production data. Most forage measurements are of total production, taken in late spring. However, HFS has more than 20 years of mid-season and total forage yield and daily weather data.

Procedures

Hopland Field Station has higher rainfall and cooler temperatures than rangeland in the Central Valley of California. Thus, any relationships that can be discerned between forage and weather may not be applicable to other areas of California. Forage yield data were gathered during a long-term seeding and fertilization experiment on four pastures (Murphy et al. 1986). The mid-season forage level was measured in February or March when the temperatures started to warm enough to initiate spring forage growth. The total forage growth was measured in April or May when the plants began to mature.

The relationship between forage growth and weather conditions was estimated by multiple regression. The dependent variables are the mid-season and total forage production in each of the four pastures. The independent variables include weather variables determined by the methods of George et al. (1988) and dummy variables for seeding and fertilizing:

1. The number of degree-days from a germinating rain until the weather turns cold.
2. The rainfall from (and including) the germinating rain until the weather turns cold.
3. The number of days from a germinating rain until the weather turns cold.
4. The number of days from a germinating rain to November 15.
5. Seeding: 1 in the year seeded and thereafter or 0 before seeding.
6. Fertilizing: 1 in each year when the pasture is fertilized.

Lagged independent variables are used in some of the regressions to determine if this year's production is dependent on last year's production. Interactions between variables are analyzed by taking the product of pairs of independent variables to create an interaction variable.

Untreated pastures In examining either mid-season or full season forage production in the untreated pastures, we found no regressions that acceptably explained the relationships between forage and weather variables (Appendix Table A-1).

Treated pastures For the two treated pastures, we found that mid-season forage production was not adequately explained in any regression (Appendix A-2 and A-3). While no set of variables explained mid-season forage production for the Upper Horse pasture, the variables for seeding and for the interaction between rainfall and degree-days from the germinating rain to winter have significant coefficients for the Lower Horse pasture.

The full season production on the treated pastures is explained best by the seeding and fertilizing variables; however, the adjusted R^2 is less than 0.6 in all regressions (Appendix A-4 and A-5). The weather and other combinations does not improve the adjusted R^2 for full season production.

Combined Regressions The data from all four pastures are stacked and analyzed for response to weather, seeding and fertilization variables. When the lagged forage variable is included, the number of observations is reduced by four to avoid the overlapping of pastures. The analysis is done for mid-season forage growth, spring growth and for the full season (Appendix A-6, A-7 and A-8, respectively).

For mid-season growth, the most important variables are last year's mid-season growth, fertilization and the interaction between degree-days on the treated pastures and rainfall in the fall (equation 16, Appendix A-6). The interaction between seeding and rainfall is significant in other equations. There is some evidence of multicollinearity in other equations. Excluding the lagged mid-season forage variable lowers the adjusted R^2 and causes the days on the treated pastures and the interaction between rainfall and fertilization to be significant (equation 22, Appendix A-6).

Spring growth and full season growth are explained better than mid-season growth. The significant variables are the same for each: days on the treated pastures, fertilization, the interaction between rainfall and fertilization, the interaction between seeding and rainfall and the lagged growth (equation 14, Appendix A-7 and equation 14, Appendix A-8). Dropping the lagged growth variable lowers the adjusted R^2.

Conclusions From these regressions, we can glean two general observations: 1) Fall weather, seeding and fertilizing do not seem to be a reliable prediction of mid-season forage production. Thus, we cannot predict the "winter plateau," that is, the amount of forage available during the winter from information available in the fall. 2) Seeding and fertilizing improve spring growth. Hence, a spring stocker operation may see a return to seeding and fertilizing, but a cow herd still is limited by the winter bottleneck. Since the Hopland Field Station has a higher rainfall than many of the other inland areas of the state, these results cannot be directly applied to drier areas.

PREDICTING WINTER AND SPRING WEATHER FROM FALL WEATHER

Procedures Since mid-season forage data is unavailable in other inland areas, rainfall and temperature data is used directly as a first step in analyzing the impact of weather on forage production. Temperatures were transformed into degree-days by the sine function method (Logan and Boyland et al. 1983). The rainfall and degree-day data were calculated for different seasons (George et al. 1988). This seasonal information is used to estimate the predictability of winter and spring weather conditions from fall weather conditions. If predictability exists, then the ability to make management decisions earlier can potentially improve income through better utilization of resources.

First, the seasons are described. The forage year begins in the fall in a Mediterranean-type climate. September 1 is a common date to start the forage year. The fall season is divided into four sub-seasons for two reasons: (1) to increase the timeliness of management information, and (2) to evaluate how well the early fall sub-seasons can predict winter and spring weather. The seasons chosen for this study are listed below.

Fall 1: September 1 through October 31
Fall 2: September 1 through November 15
Fall 3: September 1 through November 30
Fall 4: September 1 through December 31
Winter: January 1 through March 15
Spring: March 16 through May 31

The first phase of evaluating the predictability of weather is to analyze the data by multiple regression with winter and spring weather conditions as dependent variables and fall weather conditions as independent variables.

Results The hypothesis was that fall weather conditions can be used to predict winter and spring conditions. The hypothesis was rejected because the adjusted R^2s were near zero or negative except for a few cases described below. The complete table of regression results is in Appendix B.

The winter degree-days for SFRFS can be estimated with reasonable accuracy from the second fall season (Fall 2):

$$D_W = -235.8 + \underset{(7.83)}{.343}\, D_{F2} \qquad \text{adj. } R^2 = .74$$

The winter degree-days at the other two stations were not estimated at an acceptable level of accuracy. Neither winter rain nor spring degree-days were estimated with any reasonable degree of accuracy at any of the three stations. Spring rain is estimated to some degree at Hopland Field Station and the Sierra Foothill Range Field Station:

$$\text{Hopland:} \quad R_S = 2.69 + \underset{(4.60)}{.963}\, R_{F1} \qquad \text{adj. } R^2 = .43$$

$$\text{Sierra:} \quad R_S = 2.63 + \underset{(3.54)}{.679}\, R_{F1} \qquad \text{adj. } R^2 = .36$$

The winter and spring weather conditions at SJER were not explained by fall weather conditions. This result fits with the results by Duncan and Woodmansee (1975) who found no relationship between early rain and total forage production at this Station.

Conclusions The regression results do not provide very much information except that winter and spring weather cannot be estimated from fall weather. However, the historical record cannot be denied. In the final section, a subjective process of estimating forage production based on extensive field experience is described.

SUBJECTIVE WEATHER AND FORAGE RELATIONSHIPS

George et al. (1985) discuss the impacts of weather on range production and estimate seasonal production patterns based on field experience. The probability of these seasonal forage production patterns can be estimated from analysis of existing weather data. George et al. (1988) and Olson et al. (1987) use weather data to estimate historical probabilities and field experience to develop subjective relationships between weather conditions and forage growth.

Seasonal rainfall and accumulated degree-days were classified as average, above average or below average. Average rainfall levels and degree-day accumulations are defined as being what occurs 50 percent of the time (Connor et al. 1983). The weather is classified as cold or dry if the measurement falls below the defined average range and warm or wet if it falls above average. The seasons were defined using the criteria described by George et al. 1988. The historical probabilities in each degree-day and rainfall category are calculated for the Sierra Foothill Range Field Station for the fall, winter and spring seasons (Table 1).

Assuming independence, the joint probabilities of rainfall and degree-day conditions can be calculated from historical data (Table 2). Two examples demonstrate the interpretation of these joint probabilities. At SFRFS, five percent of the winters have been both wet and warm. In only 29 percent of the years have rainfall and degree-days been average in the fall.

Forage production is the crucial variable in the rancher's decision process. Having the probabilities of weather alone is not sufficient for managers to make informed decisions. These probabilities do not provide the needed information relating weather to forage production. However, we do not have a database sufficient to estimate this relationship statistically. To fill this gap in our knowledge, we evaluated the types of weather conditions and their joint events, and we formulated a relationship between weather and forage production based on extensive experimental and field knowledge. These relationships are summarized in Table 3.

For each season both dry and cold conditions can be detrimental to forage growth. Either of these two conditions could cause below-average forage growth; they do not have to occur jointly. Average forage growth is usually expected when average degree-day conditions coincide with average or above average moisture conditions and high forage production is expected when warm degree-day conditions coincide with average or above average moisture conditions.

Using these subjective evaluations (Table 3) and the joint probabilities for degree-days and rainfall (Table 2), the joint probabilities for forage production are estimated for each season (Table 4). The levels of forage production under different weather conditions are estimated by George, et al. (1985) and adapted for this analysis (Table 4).

These are subjective evaluations, but they may be the best information that is currently available. Much of this is intuitively known by experienced ranchers, but is less apparent to new managers. This information can be used to incorporate weather into stocking rate decisions.

SUMMARY

The relationships between weather and forage production have been discussed and analyzed in this paper. Previous studies (Duncan and Woodmansee 1975, Murphy 1970, Pitt and Heady 1978 and Sully 1977) found a relationship between total forage production and weather during the season. However, the results of this study did not show a statistically significant relationship between mid-season forage production and weather conditions or between fall weather conditions and winter and spring conditions. To provide management information to ranchers, the process of developing subjective relationships between weather and forage production is described and exemplified by using data from the Sierra Foothill Range Field Station.

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Table 1. Historical probabilities of dry, average and wet and cold, average and wet conditions for each season at Sierra Foothill Range Field Station (George et al. 1988).

	Fall	Winter	Spring
Dry	35	26	26
Average	43	52	52
Wet	22	22	22
Cold	18	22	26
Average	68	57	52
Warm	14	22	22

Table 2. Joint probabilities of each combination of rainfall and degree-day (ADD) categories by season for the Sierra Foothill Range Field Station.

	ADD Category		
Rainfall Category	Cold	Average	Warm
Fall Season			
Dry	6	24	5
Average	8	29	6
Wet	4	15	3
Winter Season			
Dry	6	15	6
Average	11	30	11
Wet	5	13	5
Spring Season			
Dry	7	14	6
Average	14	27	11
Wet	6	11	5

Table 3. Expected relationship between forage production levels, accumulated degree-day (ADD) rainfall categories by season for Sierra Foothill Range Field Station.

	ADD Category		
Rainfall Category	Cold	Average	Warm
Fall Season			
Dry	Poor	Poor	Poor
Average	Poor	Average	High
Wet	Poor	Average	High
Winter Season			
Dry	Poor	Poor	Poor
Average	Poor	Average	High
Wet	Poor	Average	High
Spring Season			
Dry	Poor	Poor	Poor
Average	Poor	Average	High
Wet	Poor	Average	High

Table 4. Forage yield (lbs/a) and probabilities by season for the Sierra Foothill Range Field Station.

Forage	----Fall-----		---Winter----		---Spring----	
Production	lbs/a	Prob.	lbs/a	Prob.	lbs/a	Prob.
Poor	100	(47)	100	(43)	1000	(47)
Average	500	(44)	300	(43)	2000	(38)
High	1000	(9)	500	(16)	2500	(16)

Appendix A

Hopland Pasture Regressions

This data comes from 4 pastures with 23 years of midseason forage production data. This results in 92 observations. The pastures were part of a fertilizing and seeding experiment. Two pastures received treatments (Upper and Lower Horse) and two did not (Figtree and Cattleguard).

The variables are defined as follows:

G1: Midseason growth for all four pastures at HFS, 1959-1982
Dw: Days from germinating rainfall to beginning of winter
Dg: Degree-days from germinating rainfall to beginning of winter
Dn: Days from germinating rainfall to November 15
DNH: DN for Upper and Lower Horse pastures, otherwise 0
Rg: Rainfall counting germinating rain to beginning of winter
S: Dummy variable: 1 in year of seeding and thereafter, 0 otherwise
F: Dummy variable: 1 in each year when the pasture is fertilized
DDn: Product of S and DN
SRg: Product of S and Rg
RgF: Product of Rg and F
RgDg: Product of Rg and Dg
FS: Product of F and S
DNHRG: Product of DNH and RG
TRND: Time trend 1959-60 = 1, ... 1981-82 = 23

The T subscript is used to denote current year (T) or lagged one year (T-1).

Table A-1. Regression coefficients and their t-statistics for midseason and full season forage production on the Cattleguard and Fig Tree pastures at the Hopland Field Station.

Equation	Adj. R2	Intercept	Dw	Dg	Rg	RgDw
			Cattleguard Pasture			
Midseason forage production						
1	-.015	7.81	-.023 -.826			
2	.008	7.89		-.002 -1.087		
3	-.059	7.97	-.019 -.634		-.040 -.355	
4	-.058	9.20	-.046 -1.142		-.281 -1.062	.005 1.006
Full season forage production						
5	-.104	18.00	.002 .037		.205 .521	-.0010 -.1434
6	-.050	18.26	-.004 -.080		.154 .944	
7	.000	18.18			.150 1.002	
8	-.044	18.89	.011 .267			
9	-.044	19.55		-.001 -.279		
			Figtree Pasture			
Midseason forage production						
1	-.019	11.481	-.031 -.763			
2	-.042	10.878		-.054 -.350		
3	-.070	11.543	-.030 -.666	-.015 -.091		
4	-.080	13.178	-.065 -1.094	-.336 -.853	.007 .900	
Full season forage production						
1	-.120	23.323	.007 .079	.205 .369	-.001 -.064	
2	-.064	23.488	.003 .049	.173 .750		
3	-.014	23.556		.177 .839		
4	-.042	24.203	.019 .335			

Table A-2. Regressions, coefficients, and their t-statistics for the midseason forage production on the Upper Horse pasture at the Hopland Field Station.

Equation	Adj. R2	Intercept	Rg	Dw	Dn	Dg	Ft-1	St-1	Rg*St-1	Rg*Ft-1	S1	F1	RgDg
1	.004	13.047	.170 1.042										
2	.002	12.838		.044 1.023									
3	.053	12.352			.074 1.494								
4	-.029	13.517				.002 .611							
5	.050	11.336	.155 .971		.071 1.424								
6	.038	12.862				.001 .425	3.419 1.572						
7	.076	13.329					3.537 1.673						
8	-.036	11.365	.136 .765	.028 .583				1.710 .842					
9	-.036	12.659	-.067 -.248	.033 .701				-.749 -.236	.340 1.006				
10	.029	12.250	.014 .073	.049 1.018							2.286 1.022	-4.448 -1.695	
11	.131	11.656	.046 .282		.094 1.812						1.721 .800	-4.854 -1.963	
12	.007	11.417	.071 .370		.061 1.160		2.532 .861	.176 .074					
13	-.020	11.752	-.034 -.134		.082 1.462		-3.185 -.577	.962 .262	-.378 -.540	.821 1.075			
14	.018	12.273	.062 .352			.002 .913					2.391 1.067	-4.516 -1.685	
15	-.059	12.189	.075 .377			.001 .374	2.631 .866	.632 .260					
16	-.134	12.664	-.024 -.089			.002 .553	-1.555 -.272	.918 .237	-.190 -.262	.555 .713			
17	-.106	16.078	-.723 -1.121			-.002 -.514	-1.226 -.217	-.454 -.113	-.075 -.104	.650 .840			.001 1.189

Table A-3. Regressions, coefficients and their t-statistics for the midseason forage production on the Lower Horse pasture at the Hopland Field Station.

Equation	Adj. R2	Intercept	Rg	Dw	Dn	Dg	St-1	Ft-1	Rg*St-1	Rg*Ft-1	S2	F2	RgDg	Gt-1
1	-.013	10.294	.159 .852											
2	.002	9.820		.050 1.022										
3	.058	9.209			.086 1.537									
4	-.013	10.270				.002 .850								
5	.248	7.962		.041 .963			5.482 2.808							
6	.251	9.221					5.623 2.894							
7	.237	7.318	.145 .837	.028 .598			5.613 2.845							
8	.312	8.567	-.100 -.463	.045 1.010			1.587 .535		.567 1.750					
9	.177	7.712	.078 .410	.030 .602							6.195 2.602	-2.785 -.850		
10	.201	7.335	.101 .577		.053 .951						5.824 2.442	-3.090 -.951		
11	.296	7.594	.040 .220		.060 1.197		2.952 1.158	4.816 1.397						
12	.249	8.170	-.044 -.211		.062 1.164		1.688 .291	1.083 .136	.334 .162	.114 .054				
13	.173	7.791	.109 .610			.001 .512					6.164 2.579	-2.742 -.833		
14	.268	8.045	.035 .185			.002 .835	3.186 1.226	5.023 1.395						
15	.212	8.652	-.041 -.189			.002 .741	1.590 .267	2.065 .254	.499 .236	-.091 -.042				
16	.365	12.554	-.927 -2.077			-.003 -.915	.605 .113	3.624 .495	.586 .308	-.082 -.042			.001 2.202	
17	.289	4.676		.040 .844			4.178 1.849							.347 1.421
18	.300	6.017					4.569 2.082							.319 1.330
19	.198	3.523		.058 1.177										.561 2.458

Table A-4. Regressions coefficients and their t-statistics for the full season forage production on the Upper Horse pasture at the Hopland Field Station.

Equation	Adj. R2	Intercept	S1	F1	Gt-1	Ft-1	St-1	Rg	Dw	Dg	Ft-1*St-1
1	.375	30.100	15.340 3.689								
2	-.050	40.519		.148 .026							
3	.433	30.100	18.522 4.247	-7.956 -1.744							
4	.109	22.007		-3.474 -.636	.497 2.140						
5	.447	29.244				10.148 2.131	6.397 1.486		.149 1.598		
6	.432	31.092				12.646 2.274	5.028 1.058	-.187 -.494		.010 1.730	
7	.499	16.552			.431 1.811	14.090 2.667	-1.700 -.293	-.033 -.089		.011 2.001	
8	.353	36.300									15.617 3.529
9	.411	32.023							.166 1.729		13.100 2.934

Table A-5. Regressions coefficients and their t-statistics for the full season forage production on the Lower Horse pasture at the Hopland Field Station.

Equation	Adj. R2	Intercept	S2	F2	Dw	Gt-1	St-1	Ft-1	Rg	Dg	Ft-1*St-1
1	.566	23.325	19.795 5.324								
2	.157	29.628		14.822 2.217							
3	.546	23.325	18.908 4.261	2.217 .387							
4	.569	20.848	18.780 4.910		.098 1.069						
5	.188	21.350		12.008 1.740		.286 1.324					
6	.105	19.975				.401 1.863					
7	.415	21.194			.152 1.448		13.783 5.373	5.144 6.767			
8	.365	21.110					15.133 2.288	3.030 .345	.289 .607	.005 .751	
9	.360	27.885				-.269 -.931	19.435 2.403	4.793 .531	.221 .457	.005 .718	
10	.177	29.500									15.525 2.350
11	.243	23.744			.195 1.658						14.977 2.361

Table A-6. Regressions coefficients and their t-statistics for the midseason forage production on all four pastures at the Hopland Field Station.

Equation	Adj. R2	Intercept	DN	DNH	SDN	RG	SRG	F(t-1)	DNH*RG	RG*F(t-1)	TRND	GI(t-1)
1	.417	6.362		.060 2.229			.415 3.576				-.101 -1.408	.383 4.057
2	.410	4.922		.056 2.077			.365 3.286					.415 4.487
3	.402	6.858			.055 1.678		.417 3.371				-.121 -1.612	.384 3.985
4	.396	6.681	.011 .381		.049 1.336		.426 3.363				-.131 -1.644	.390 3.976
5	.390	6.040	.028 1.067		.515 4.757						-.117 -1.480	.421 4.392
6	.389	6.346					.520 4.804				-.083 -1.148	.414 4.331
7	.382	4.785	.012 .515				.462 4.491					.446 4.700
8	.387	5.139					.473 4.724					.439 4.695
9	.382	4.785	.012 .515				.462 4.491					.446 4.700
10	.406	5.410	-.018 -.670	.067 2.112			.360 3.218					.399 4.172
11	.416	5.874	-.009 -.336	.043 .917		-.110 -1.170	-.110 -.367	2.554 .769	.006 1.313	.271 .664		.407 4.250
12	.423	5.672		.036 .864		-.117 -1.277	-.109 -.367	2.609 .791	.007 1.395	.269 .662		.414 4.479
13	.429	5.643		.030 .788		-.112 -1.247		2.878 .900	.006 1.374	.155 .594		.414 4.497
14	.433	5.540		.022 .624		-.110 -1.223		4.562 3.093	.007 1.723			.423 4.678
15	.437	5.763				-.134 -1.677		4.622 3.151	.009 3.063			.426 4.743
16	.425	4.807						4.549 3.070	.007 2.551			.446 4.955
17	.292	10.490	-.037 -1.250	.081 1.608		-.126 -1.216	-.087 -.263	.729 .201	.006 1.128	.433 .967		
18	.300	10.500	-.038 -1.262	.085 1.801		-.126 -1.230	-.102 -.319		.006 1.116	.498 1.629		
19	.308	10.466	-.038 -1.267	.080 1.800		-.123 -1.208			.005 1.088	.410 3.088		
20	.306	10.165	-.043 -1.467	.115 3.682		-.059 -.709				.464 3.757		
21	.310	9.830	-.046 -1.613	.118 3.814						.430 3.789		
22	.297	8.991		.092 3.449						.448 3.926		

Table A-7. Regressions coefficients and their t-statistics for the spring season forage production on all four pastures at the Hopland Field Station.

Equation	Adj. R2	Intercept	DN	DNH	SDN	RG	F(t-1)	DNH*RG	RG*F(t-1)	SRG	TRND	GI(t-1)
1	.611	9.577		.189 4.524						.706 4.229	.147 1.413	.189 2.164
2	.606	10.738		.186 4.444						.752 4.565		.223 2.642
3	.621	11.556	.006 .154		.240 4.235					.591 3.356	.040 .358	.466 1.826
4	.625	11.664			.244 4.945					.586 3.408	.047 .458	.162 1.864
5	.629	12.072			.248 5.106					.594 3.490		.169 1.994
6	.578	11.000			.317 6.697						.083 .767	.202 2.209
7	.580	11.713			.325 7.069							.216 2.422
8	.549	8.078	.091 2.561							.937 5.574		.354 4.255
9	.603	10.257	.021 .541	.173 3.525						.758 4.570		.230 2.682
10	.606	10.738		.186 4.444						.752 4.565		.223 2.642
11	.630	9.191	.006 .164	.170 2.386		.219 1.613	8.270 1.771	-.009 -1.297	-1.480 -2.598	1.733 4.126		.221 2.239
12	.635	9.308		.176 2.769		.223 1.682	8.271 1.782	-.009 -1.361	-1.479 -2.613	1.732 4.151		.219 2.251
13	.631	9.381		.118 2.486		.142 1.192	9.258 2.009		-1.616 -2.887	1.673 4.010		.248 2.606
14	.629	11.079		.130 2.794			8.897 1.929		-1.455 -2.671	1.639 3.927		.198 2.312
15	.617	10.477		.149 3.235					-.714 -1.819	1.439 3.502		.241 2.875
16	.606	10.738		.186 4.444						.752 4.565		.223 2.642
17	.612	13.132	-.005 -.124	.239 3.631		.141 1.045	9.962 2.109	-.013 -1.847	-1.407 -2.414	1.779 4.138		
18	.616	13.069		.236 4.006		.137 1.050	9.973 2.125	-.013 -1.864	-1.406 -2.429	1.779 4.165		
19	.616	13.976		.216 3.873			9.791 2.086	-.009 -1.539	-1.332 -2.317	1.721 4.061		
20	.610	13.924		.165 3.650			11.701 2.564		-1.586 -2.854	1.702 3.985		

Table A-8. Regressions coefficients and their t-statistics for the full season forage production on all four pastures at the Hopland Field Station.

Equation	Adj. R2	Intercept	DN	DNH	SDN	RG	F(t-1)	DNH*RG	RG*F(t-1)	SRG	TRND	GI(t-1)
1	.642	15.584		.230						1.093	-.006	.306
				4.240						4.895	-.047	3.771
2	.647	15.522		.230						1.090		.306
				4.267						5.059		3.806
3	.637	17.407	.030		.254					1.009	-.151	.305
			.546		3.380					4.214	-1.022	3.539
4	.640	18.003			.274					.985	-.122	.293
					4.157					4.202	-.889	3.533
5	.641	16.673			.259					.958		.292
					4.068					4.127		3.530
6	.563	16.589	-.012		.400						-.037	.344
			-.205		5.472						-.232	3.659
7	.568	16.331			.393						-.048	.349
					6.057						-.321	3.901
8	.573	15.820			.386							.348
					6.345							3.914
9	.592	11.971	.100							1.338		.426
			2.146							6.099		5.264
10	.642	15.489	.001	.229						1.090		.307
			.024	3.570						5.025		3.695
11	.639	14.411	-.005	.192		.140	9.692	-.001	-1.203	1.608		.316
			-.087	2.011		.760	1.534	-.123	-1.540	2.797		3.463
12	.643	14.306		.188		.137	9.697	-.001	-1.204	1.608		.317
				2.253		.762	1.544	-.109	-1.551	2.815		3.577
13	.648	14.333		.182		.127	9.828		-1.219	1.602		.319
				2.895		.820	1.604		-1.606	2.835		3.650
14	.649	15.823		.191			9.127		-1.054	1.567		.293
				3.077			1.507		-1.443	2.787		3.604
15	.644	15.827		.235			2.975			.914		.297
				4.305			.688			2.726		3.640
16	.589	23.622	-.042	.321		.015	10.690	-.007	-.974	1.692		
			-.760	3.414		.078	1.588	-.689	-1.173	2.762		
17	.594	23.703	-.041	.318			10.674	-.006	-.966	1.686		
			-.767	3.689			1.596	-.787	-1.179	2.790		
18	.596	22.952		.292			10.815	-.006	-.981	1.705		
				3.692			1.622	-.755	-1.201	2.831		
19	.598	22.916		.257			12.147	-1.158		1.691		
				4.045			1.894	-1.482		2.817		
20	.593	22.933		.306			5.431			.975		
				5.617			1.187			2.719		
21	.591	22.948		.302						1.308		
				5.538						5.848		

Appendix B

Regressions of Winter and Spring Weather from Fall Weather

The following tables report the results of regression of degree-days and rainfall during the winter and spring seasons on the fall degree-days and rainfall, respectively, from three range research stations. The fall season is divided into four sub-seasons as specified in the text.

Table B-1. Regressions of degree-days in the winter and spring on the degree-days determined four four definitions of the fall season at three range research stations.

Season	Adj. R^2	Inter-cept	Fall: 1	Fall: 2	Fall: 3	Fall:4
			Hopland Field Station Fall Season			
Winter						
C-1	.13	13.6	.182 (2.28)			
C-2	.18	-26.3		.18 (2.64)		
C-3	.22	-44.1			.192 (2.93)	
C-4	.28	-57.5				.199 (3.36)
Spring						
C-5	-.01	442.1	.144 (.84)			
C-6	-.02	469.5		.103 (.69)		
C-7	-.03	482.5			.087 (.58)	
C-8	-.03	496.3				.07 (.50)
			Sierra Foothill Range Field Station			
Winter						
C-9	.69	-257.0	.393 (6.90)			
C-10	.74	-235.8		.343 (7.83)		
C-11	.76	-219.9			.32 (8.26)	
C-12	.70	-184.0				.279 (7.14)
Spring						
C-13	.12	-235.0	.435 (1.94)			
C-14	.10	288.1		.353 (1.85)		
C-15	.11	303.5			.331 (1.89)	
C-16	.07	376.2				.258 (1.59)
			San Joaquin Experimental Range			
Winter						
C-17	.03	11.5	.123 (1.55)			
C-18	.06	-27.5		.146 (2.09)		
C-19	.07	-21.9			.136 (2.09)	
C-20	.13	-58.1				.16 (2.79)
Spring						
C-21	-.02	746.2	-.002 (-.008)			
C-22	-.02	803.9		-.05 (-.25)		
C-23	-.02	713.6			.02 (.14)	
C-24	-.02	706.				.03 (.18)

Table B-2. Regressions of precipitation in the winter and spring on the precipitation received during four definitions of the fall season at three range research stations.

Season	Adj. R^2	Inter-cept	Fall: 1	Fall: 2	Fall: 3	Fall:4
			Hopland Field Station Fall Season			
Winter						
C-25	-.01	14.8	.526 (.92)			
C-26	-.04	16.3		-.013 (-.38)		
C-27	-.03	17.1			-.105 (-.38)	
C-28	-.03	14.7				.102 (.54)
Spring						
C-29	.43	2.7	.963 (4.60)			
C-30	.25	2.5		.525 (3.18)		
C-31	.30	2.2			.389 (3.56)	
C-32	.09	2.9				.163 (1.87)
			Sierra Foothill Range Field Station			
Winter						
C-33	-.05	11.2	-.03 (-.06)			
C-34	-.05	10.7		.09 (.23)		
C-35	-.04	10.4			.11 (.36)	
C-36	-.05	11.0				.01 (.05)
Spring						
C-37	.36	2.6	.679 (3.54)			
C-38	.26	2.0		.49 (2.87)		
C-39	.32	1.3			.437 (3.28)	
C-40	.17	1.2				.268 (2.31)
			San Joaquin Experimental Range			
Winter						
C-41	-.02	7.1	.4 (.55)			
C-42	-.02	7.7		-.08 (-.16)		
C-43	-.01	8.4			-.29 (-.75)	
C-44	-.02	7.6				-.01 (-.05)
Spring						
C-45	-.01	2.9	.25 (.63)			
C-46	-.01	2.8		.22 (.79)		
C-47	-.02	3.3			-.05 (-.23)	
C-48	-.01	2.6				.11 (.88)