Managing Herd Composition of Range Cattle:

Sale Weight and Seasonal Factors

by

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Abstract

We estimate the weight gain for range calves as a polynomial function of calf age accounting for weather, sex, lagged calf weights relative to the growth function, and compensatory gains. Birth weights plus single day weighings that occurred around 3, 8, 12, and 20 months of age are the data used to estimate our growth function. This function is then used to determine the economic trade-off between herd size and calf sale weights, for both spring and fall sale dates. In addition, we evaluate the profitability of feeding supplement by increasing the rate of gain associated with our growth function when forage and nutrients are limiting for the two grazing environments of Southeast and Central Arizona. Using prices from 1980 to 1998, results indicate that the most profitable herd mix, sale date, and feeding protocol is 450 lb. calf sales with no supplemental feeding and sales occurring in May for both regions. Although, feeding supplement was not associated with the most profitable outcome, supplement increased the average return by $45 to $70 per AUY for sale weights of 550, 650, and 750 lbs.

Key words: animal unit year, growth function, sale weight, supplement

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The tradeoff between sale weight and timing of sales is complicated by seasonal forage and price conditions along with dramatic variation in the price spread between light and heavy calves. Generally, lighter calves sell for a higher per pound price than heavier calves and calf prices in the spring are greater than in the fall, but exceptions to these generalities occur. In addition, variability in seasonal rainfall and the ability to feed supplement complicates analyzing the trade-offs between rates of gain, sale weight, herd size, and the timing of calf sales.

Some ranching regions in Arizona have adopted a rather rigid selling practice for their calves in order to take advantage of seasonal forage availability and aggregate numbers for a given sale to attract more buyers. Ranchers in the central region of the state typically sell their calves in the spring while the southeast region sells in the fall. Both regions sell mainly according to the time of year, irrespective of the weight of their calves and very few supplement calves to increase their calf weights. Because ranchers often question the economic trade-offs between sale calf weights, herd size, rates of gain or feeding supplement, and a spring versus fall sale date, our primary objective is to analyze these issues.

Data and Methods

Quantifying the future rate of gain for a calf kept on the ranch is a critical element for evaluating the profitability of selling the animal now or at a later date. Selling calves at a heavier weight generally comes with an opportunity cost of reducing the number of cows that can be maintained on the ranch or calves that can be sold.

Several studies have looked at animal performance under range conditions but mainly from a production aspect with little economic analysis (e.g., Clayton et al. 1983, Fox and Black 1977, Tess and Kolstad 1999). Notable exceptions are VanTassell , Heitschmidt, and Conner 1987 and Lambert 1989. The former study utilized six separate models representing different growth stages and examined optimal solutions under environmental uncertainty. Lambert used a discrete programming model to evaluate calf retention and production decisions over time. This paper utilizes aspects of both studies but defines the growth cycle of the calf from birth to 20 months of age and evaluates profitability of sale weight and season (i.e., mid-May or mid-November) under non-supplement and supplement range feeding scenarios.

Weight gain was estimated as a function of age, sex, rainfall, compensatory gain, and prior weight levels. Weight data was collected from the Registered Hereford herd of the San Carlos Apache Tribal Ranch, Arsenic Tubs, Arizona for the eight years of 1980, 1981, 1983 to 1986, 1988, and 1989. A birth date and calf weight at birth was recorded for each calf. In addition, weights were taken when the entire calf crop was at an average age of roughly 3, 8, 12, and 20 months of age. Weight and animal combinations are such that we have 1,368 calves and 5,862 unique calf weights. Different calving dates provide age variation around each weighing date so that we can estimate daily weight gains as a function of age. We estimate range calf weights building on the following growth function:

(1) $GF_{i,j} = \beta_0 + \beta_1 Age_{i,j} + \beta_2 Age_{i,j}^2 + ... + \beta_8 Age_{i,j}^8$

where $Age_{i,j}$ is the age in months of calf *i* at the *j*th weighing. The impact of weather or rainfall on weight gain is accounted for using

(2) $R_{i,j} = D_8 \delta_{r8} \cdot Rain_{i,8}^{3\,to\,8} + D_{12} \delta_{r12} \cdot Rain_{i,12}^{8\,to\,12} + D_{20} \delta_{r20} \cdot Rain_{i,20}^{12\,to\,20}$,

where $Rain_{i,j}^{k\text{ to }j}$ is the actual monthly rainfall from the *k*th to *j*th weighing in a given year less the 30 year average rainfall for these same months and D_j is a dummy variable that is 1 if it is the *j*th weighing or 0 otherwise. The growth function after accounting for rainfall and a constant percentage weight differential between steers and heifers is defined as:

(3) $GFRS_{i,j} = (GF_{i,j} + R_{i,j})(1 - DH_i \delta_h)$

where DH_i is a dummy variable that is 1 if the *i*th animal is a heifer and 0 if a steer, and δ_h is the percentage weight difference between steers and heifers. Compensatory gain at the 20 month weighing is accounted for with

(4) $CG_{i,20} = D_{20}[(WT_{i,12} - WT_{i,8}) - (GF_{i,12} - GF_{i,8})][1 - DH_i \delta_h]$,

or the difference between the actual weight change from the 12th and 8th month weighing versus that expected from the growth function, adjusting this differential by sex. $WT_{i,j}$ is calf *i*'s weight at the *j*th weighing and other variables are as described above. Given that prior to 8 months of age a calf obtains most of its nutrients from the cow, compensatory gains for other weigh dates were not considered and rainfall effects were not considered for the 3 month weighing. Even if rainfall has been poor prior to their calving date, cows will generally pull down their body condition to provide milk for a young suckling calf. Finally, combining equations (1) through (4) with lagged weight effects results in $WT_{i,j}$ estimated as

$$\text{(5)}\quad WT_{i,j} = GFRS_{i,j} + \delta_{CG} CG_{i,20} + D_3 \delta_{wBW}[WT_{i,BW} - GFRS_{i,BW}] + D_8 \delta_{w3}[WT_{i,3} - GFRS_{i,3}]$$
$$+ D_{12} \delta_{w8}[WT_{i,8} - GFRS_{i,8}] + D_{20} \delta_{w12}[WT_{i,12} - GFRS_{i,12}] + \varepsilon_{i,j}$$

where δ_{CG} is the parameter associated with the compensatory gain of animal *i* at its 20 month weighing, δ_{wj} is the impact of the difference between the actual prior weighing with that expected after adjusting for rainfall and sex components (i.e., $GFRS_{i,j}$) and $\varepsilon_{i,j}$ is a normally distributed error term with mean 0 and variance σ^2. Equation (5) was estimated using the least squares maximum likelihood procedure in TSPv4.5.

To gain insights into the trade-off between different sale weights and dates, average real profits for two different ranching regions were simulated from 1980 through 1998 using either mid-May or mid-November sale dates for steer calves that weighed either 350, 450, 550, 650, or 750 lbs. A 350 lb. sale weight was matched with Cattle-Fax sale weight categories of 300 to 400 lb. sales and similarly for the heavier sale weights. The two regions examined have distinct seasonal forage differences. The Southeast region of Arizona is dependent upon the summer monsoon rains for warm season grass production, while Central Arizona is more dependent upon winter rains for its production of cooler season grasses and legumes like jojoba.

Table 1 shows the expected daily gains estimated for different sale weights and dates by region plus the equivalent cow numbers than can be maintained for each scenario. Rates of gain for the two regions were set up to mirror each other with the most favorable gains occurring prior to November and May sales for the Southeast and Central regions, respectively. The most favorable forage conditions under supplementation assume a growth rate of 1.77 lbs./day for weights from birth to 350 lbs. and 1.75 lbs./day for weights from 450 to 750 lbs. These rates of gain were reduced by 10% for when forage is less abundant in each region prior to the animal's sale date. To calculate the cows that could be supported on an Animal Unit Year (AUY) of forage, reductions of .5, .6, and .7 AUYs were charged for the number of days it took calves to go from 450 to 550, 550 to 650, and 650 to 750 pounds, respectively. The AUY reduction for producing calves heavier than the 450 lb. weight has the effect of reducing total cow numbers and thereby reducing the number of calves available for sale.

Birth dates and supplement requirements to meet the daily rates of gain in table 1 are described in table 2. Birth dates were calculated working backwards from the sale date and the corresponding rate of gain for each protocol. The amount of supplement required is dependent upon sale weight, sale date, and region. Respectable gains of 1.77 and 1.65 lbs. per day are viewed as attainable without feeding any supplement for 350 and 450 lb. sales in November and May for the Southeast and Central regions, respectively. Supplemental feeding ranged from 100 to 400 lbs. per Animal Unit (AU), varying in average annual cost from $10.31 to $41.23 per AU. The retail cost of a 50:50 corn meal and cottonseed meal mixture was charged for supplement. Because some ranchers may be able to obtain more of a wholesale than retail price for supplement, we did not charge additional labor or fuel expenses for distributing supplement to the cow herd. However, the distribution costs for supplement may be very noticeable, depending on the terrain of the ranch.

Another expense item that varied with different sale date and weight options was the opportunity cost of money. That is, calves sold at 450 lbs. could have been sold at 350 lbs. and so forth. The opportunity cost of funds was charged at a real annual interest rate of 4%. Except for grazing expenses, cash costs for each scenario were obtained from Economic Research Service's cow-calf production costs for the west. Cash grazing costs were calculated using the grazing fees and accompanying percentages of grazing land in Arizona owned by the State (33%), Bureau of Land Management (17%), Forest Service (40%), or Private entity (9%) as reported in Mayes and Archer. Common variable and fixed cash expenses for all sale weight and date combinations are given in tables 3a. and 3b. Gao provides more detail to the cost items incorporated.

Cull cows were assumed to weigh 1,000 lbs. when they were culled, irrespective of the herd's mix or supplementation regime. In addition, a calf crop percentage of 85% per exposed cow, calf death loss after birth of 2.5%, and a culling percentage of 16% with a 4% annual death loss for cows was applied to all scenarios. The calf crop is assumed to be a 50:50 mix of steers and heifer. Thus, 40% of all heifers or 20% of all calves are retained each year to replenish the cull cows that either die or are sold. For example, a 100 AUY ranch selling 350 lb. or 450 lb. calves would expect to sell 16.0 cows, 41.4 (i.e., 100•0.85•0.975•0.5) steer calves, and 24.9 (i.e., 100•0.85•0.975•0.3) heifer calves annually.

Results

Calf weights were estimated as a function of age, sex, climate, 20 month compensatory gain, and prior weights, as described in equation (1). Table 4 provides the parameter estimates and corresponding statistics for this model. Note that the model to estimate calf weights is constructed so that if climate, compensatory gain, and prior weight deviations are "normal," weight gain is an 8^{th} order polynomial function of calf age in months with a constant weight percentage differential between steers and heifers. Figure 1 graphically describes the polynomial growth curve for a steer calf from birth to 20 months of age and the actual calf weight data. Estimated calf weights from equation

(1) are presented in figure 2. Unlike logistical growth functions, the polynomial framework has flexibility to allow for the dip in calf weight that occurs from weaning and seasonal forage availability. An 8^{th} order polynomial was selected from polynomial orders of 3 to 10 that were estimated, applying the Schwartz criteria to calf weight estimated as only a function of calf age. On average, calf weights at the 12 month weighing were 8.47 lbs. less than at the 8 month weighing. At any given age, heifer calves were estimated to weigh 4.97% less than a steer calf.

If rainfall was above (below) the 30 year average for the months prior to their last weighing, calves would weigh more (less) than otherwise. For example, if the accumulated rainfall between the 3 and 8 month weighing was above (below) the 30 year average by 1 inch, calves would weight 11.196 lbs. more (less) than otherwise. The magnitude and statistical significance of the rainfall variable decreased as the animal increased in age. We believe that this result is because of the 20 month compensatory gain effect and the greater importance of lagged weight components as the animal increased in age. That is, these factors were able to better capture both genetic and environmental components as the calves increased in age compared to the rainfall variable.

Using the weight gains estimated above, Cattle-Fax prices for calf and cow sales, and the opportunity cost of forage described in table 1 (i.e., reduced cow numbers for heavier calf weights), the average and standard deviation of real returns for different sale dates and weights is given in table 5. With no supplemental feeding, sale weights of 450 lbs. for May are the most profitable alternative for both the Southeast and Central Arizona regions. Under this management plan, an average real return of $86.87/AUY for the Southeast and $87.52/AUY for the Central region was realized for the 19 years from 1980 to 1998. November sales of 450 lbs. are the next most profitable strategy for both regions, and this strategy has a somewhat lower standard deviation of return than the May sales of 450 lbs. It is interesting to note that cull cow sales in May rather than November account for the largest share of the $17.05 per AUY favorable revenue differential between these two months. Cull cow sales account for $9.39 or 55 percent of the revenue differential, while 450 lb. steer and heifer calf sales account for $5.22 and $2.44, respectively, of the favorable revenue for May sales.

Without feeding supplement, the growth function estimated is essentially flat after reaching 7 months of age or 450 lbs. for the next 5.5 months. Thus, the opportunity cost of lower cow numbers and lower calf prices outweigh the gains from heavier sale weights for weights beyond 450 lbs. without supplement. However, heavier weights offset lower calf prices when going from 350 to 450 lb. weights carrying the same cow numbers. No opportunity cost of fewer cows is added when going from 350 to 450 lb. weights since 450 lb. calves are weaned at about 7 months of age, which allows ample time for cows to breed back in a year-round calving system.

Supplemental feeding is able to remove the long flat period for range calves from 7 to 12.5 months of age. Given the supplement requirements and weight gains described in table 2, supplementation has a considerable impact on returns when selling heavier calves. For example, supplementation for May sales and 550 lb. calves increased the average revenues per AUY by $65.81 and $69.99 for the Southeast and Central regions, respectively. The $85.18 return associated with supplemental feeding and 550 lb. May sales for Central Arizona almost attains the $87.52 return for 450 lb. May sales and no supplemental feeding for this region.

Table 6 illustrates what the return to different sale weights and dates would be if a rancher had "extra grass" so that supplemental gains were obtainable without feeding supplement or no reduction in AUYs was charged for selling calves at heavier weights. Even when supplemental gains are available at no extra feed cost, 550 lb. sales are the most profitable except for November sales in the Southeast region. However, the difference between 550 and 750 lb. sales for this scenario is rather modest at $4.19 per AUY. In general, the opportunity cost associated with foregone calf numbers and lower prices does not outweigh the benefit of heavier calf weights, even when supplemental gains are imposed with no added feed cost. But if no AUY reduction is charged for producing heavier calves, the heaviest calf weight of 750 lbs. yields the highest return with May sales still somewhat preferred over November sales for both regions.

Conclusions

We found that the benefit of higher sale weights was not enough to overcome lower calf prices and fewer calf and cull cow sales for calf weights above 450 lbs., without feeding supplement. While feeding supplement was never the optimal strategy, supplemental feeding increased average returns by $45 to $70 per AUY for sale weights above 550 lbs. May sales were found to be more profitable than November sales, even with discounted rates of gain. More favorable market conditions for May than November sales are the main reason why May sales were often more profitable than November sales. It is also interesting to note that cull cow sales account for the largest share of the favorable revenue differential between these two months. Cull cow sales accounted for 55 percent of the favorable revenue differential, while 450 lb. steer and heifer calf sales accounted for 31 and 14 percent, respectively, of the favorable revenue for May sales in the Southeast region.

It is important to note that a more flexible sale date, weight combination, and supplemental feeding strategy could have generated more net return than the "fixed strategies" above. In addition, fertility was assumed to be high enough so that no increase in fertility was associated with feeding supplement. An increase in fertility from feeding supplement would most likely make a supplemental feeding regime as one of the most profitable strategies. But high labor and distribution costs to remote and difficult to access range sites would also make supplemental feeding less attractive than what we have expensed in our analysis. In addition, a strategy that could take advantage of market opportunities for buying replacements when they are cheap or feeding calves to a heavier weight when corn prices are high and forage is available would probably outperform the best "fixed strategy" of always producing 450 lb. calves to sell in May.

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Table 1. Weight gain (lbs./day) and equivalent cow numbers[a]

	No Supplemental Feeding			
Calf Weight	**Southeast Arizona**		**Central Arizona**	
(lbs./head)	May Sales	Nov. Sales	May Sales	Nov. Sales
Birth to 350	1.593	1.770	1.770	1.593
	(1.000)	(1.000)	(1.000)	(1.000)
350 to 450	1.485	1.650	1.650	1.485
	(1.000)	(1.000)	(1.000)	(1.000)
450 to 550	0.396	0.440	0.440	0.396
	(0.743)	(0.763)	(0.763)	(0.743)
550 to 650	1.530	1.700	1.700	1.530
	(0.688)	(0.710)	(0.710)	(0.688)
650 to 750	0.981	1.090	1.090	0.981
	(0.606)	(0.631)	(0.631)	(0.606)
	Supplemental Feeding			
450 to 550	1.575	1.750	1.750	1.575
	(0.920)	(0.927)	(0.927)	(0.920)
550 to 650	1.575	1.750	1.750	1.575
	(0.839)	(0.853)	(0.853)	(0.839)
650 to 750	1.575	1.750	1.750	1.575
	(0.762)	(0.780)	(0.780)	(0.762)

[a] Equivalent cow numbers were obtained by reducing available Animal Unit Years for cows by 0.5, 0.6, and 0.7 for the number of days it took calves to go from 450 lbs. to 550 lbs., 550 lbs. to 650 lbs., and 650 lbs. to 750 lbs., respectively. No distinction was made for weights less than 450 lbs. since these calves always reached their weight before 8 months of age, within the normal bounds of a one-year breeding and calving cycle.

Table 2. Supplement requirements and birth dates by sale date, sale weight, and location

Calving Date			**Supplement Required**	
SE AZ	**Central AZ**		50:50 Corn & Cottonseed Meal Ration	
May Sales	Nov. Sales	Sale Weight (lbs.)	Calf (lbs.)	Calf/Cow (lbs.)
Nov. 27	May 30	350	--	--
Sept. 21	Mar. 24	450	--	--
July 19	Jan. 19	550	200	0
May 17	Nov. 17	650	250	50
Mar. 14	Sept. 14	750	300	100
Nov. Sales	May Sales			
June 16	Dec. 14	350	--	--
April 16	Oct. 14	450	--	--
Feb. 18	Aug. 18	550	0	100
Dec. 23	June 22	650	0	200
Oct. 27	April 26	750	0	300

Table 3a. Common real ($1999 dollars) variable and fixed cash expenses for each Animal Unit Year, 1980-1989

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Variable Cash Expenses										
Grazing Fees	62.15	56.66	46.12	36.29	35.34	34.03	30.58	28.81	32.96	35.97
Protein Supplement	23.80	20.55	19.84	17.36	18.12	15.54	15.80	15.37	17.27	17.53
Salt & Minerals	2.93	2.98	2.99	2.93	2.78	2.81	2.82	2.76	2.66	2.67
Vet & Medicine	9.91	10.02	10.42	10.31	10.39	10.14	10.14	10.03	9.95	10.29
Livestock Hauling	4.04	4.15	4.34	4.22	4.16	4.17	3.94	3.84	3.78	3.87
Custom Rates/Operation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marketing	5.49	5.54	5.81	5.75	5.77	5.80	5.76	5.71	5.86	5.94
Hired Labor	36.62	35.83	35.00	34.43	33.56	33.08	33.70	31.73	32.21	32.29
Fuel, Lube, Electricity	29.77	30.83	28.06	25.67	20.78	19.81	15.90	15.66	15.67	17.20
Machinery & Bld. Repairs	28.42	28.90	30.29	30.78	28.86	29.15	28.86	28.16	28.46	28.35
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Variable Cash Exp.	203.13	195.45	182.87	167.74	159.75	154.54	147.51	142.06	148.83	154.12
Fixed Cash Expenses										
General Farm Overhead	43.67	37.76	34.53	31.18	38.48	33.55	42.96	55.42	34.90	35.29
Taxes & Insurance	32.05	25.16	24.66	23.91	20.54	19.26	25.13	33.93	35.19	35.62
Interest	94.55	81.93	80.57	72.78	74.19	66.25	58.58	60.04	69.58	64.30
Total Fixed Cash Exp.	170.26	144.85	139.76	127.87	133.20	119.06	126.66	149.40	139.67	135.22
Total Cash Expenses	373.39	340.30	322.63	295.61	292.95	273.60	274.17	291.46	288.50	289.33

Table 3b. Common real ($1999 dollars) variable and fixed cash expenses for each Animal Unit Year, 1990-1998 [a]

	1990	1991	1992	1993	1994	1995	1996	1997	1998	AVG.
Variable Cash Expenses										
Grazing Fees	34.04	35.31	34.16	33.04	33.82	30.47	31.36	30.08	30.47	36.40
Protein Supplement	22.93	21.93	22.47	22.01	23.46	21.83	10.04	9.78	0.00	17.66
Salt & Minerals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
Vet & Medicine	14.30	12.51	14.98	18.44	18.90	18.39	26.56	27.28	35.33	15.17
Livestock Hauling	4.21	5.27	5.08	6.02	0.00	0.00	0.00	0.00	0.00	3.22
Custom Rates/Operation	0.00	0.00	0.00	0.00	0.00	0.00	43.94	45.13	55.17	7.59
Marketing	6.75	6.39	3.36	3.78	3.87	3.77	6.14	6.31	4.59	5.39
Hired Labor	43.95	43.58	44.65	42.16	40.64	41.65	62.17	64.63	15.39	38.80
Fuel, Lube, Electricity	19.27	19.70	17.53	17.88	0.00	0.00	0.00	0.00	22.44	16.64
Machinery & Bld. Repairs	22.98	23.14	23.05	23.02	23.35	24.39	22.94	23.44	18.74	26.07
Other	4.56	4.49	4.50	4.28	0.00	0.00	0.00	0.00	0.00	0.94
Total Variable Cash Exp.	173.00	172.32	169.77	170.63	144.03	140.51	203.16	206.65	182.12	169.38
Fixed Cash Expenses										
General Farm Overhead	47.28	36.70	36.14	47.40	45.06	46.40	39.09	45.09	50.57	41.13
Taxes & Insurance	21.35	18.07	17.86	22.36	21.89	21.93	17.34	17.07	30.49	24.41
Interest	75.25	60.40	51.33	59.38	52.71	59.09	58.58	35.17	12.62	62.49
Total Fixed Cash Exp.	143.88	115.17	105.33	129.14	119.66	127.42	115.01	97.33	93.69	128.03
Total Cash Expenses	316.88	287.49	275.10	299.76	263.70	267.93	318.16	303.99	275.81	297.41

[a] Changes in USDA reporting classifications occurred from 1994 to 1998 and account for the large dollar changes in several categories from one year to the next. See the 1982-1998 Cow-Calf Production Cash Costs and Returns report for more detail on these changes.

Table 4. Weight and corresponding growth function estimate for range calves

Variables	Description	Corresponding Parameters	Parameter Estimates	t-values
Constant	(birth weight estimate)	β_0	81.873	52.287
$Age_{i,j}$	(age of calf *i* in months at the *j*th weighing and corresponding component of the polynomial growth function)	β_1	215.830	13.425
$Age_{i,j}^2$		β_2	-147.709	-9.718
$Age_{i,j}^3$	.	β_3	50.824	9.639
$Age_{i,j}^4$	.	β_4	-8.613	-9.407
$Age_{i,j}^5$	.	β_5	0.785	8.913
$Age_{i,j}^6$		β_6	-0.03945	-8.271
$Age_{i,j}^7$	(order of polynomial associated with the growth function was determined applying the Schwartz criteria to estimating $WT_{i,j}$ as a function of just $GF_{i,j}$)	β_7	.001031	7.583
$Age_{i,j}^8$		β_8	-.110E-04	-6.907
DH_i	(Dummy variable that is 1 if heifer and 0 if steer)	δ_h	-0.0497	-10.344
$WT_{i,BW}$	(birth weight of animal *i*)	δ_{wBW}	0.524	2.082
$WT_{i,3}$	(animal *i*'s weight at 3 month weighing)	δ_{w3}	0.0271	1.819
$WT_{i,8}$	(animal *i*'s weight at 8 month weighing)	δ_{w8}	0.460	28.306
$WT_{i,12}$	(animal *i*'s weight at 12 month weighing)	δ_{w12}	0.765	35.957
$CG_{i,20}$	(compensatory gain at the 20 month weighing for animal *i*)	δ_{CG}	-0.115	-6.195
$Rain_{i,8}^{3\text{ to }8}$	(inches of rainfall from 3 mo. to 8 mo. weighing in a given year less 30 year average rainfall for these same months)	δ_{r8}	11.196	17.111
$Rain_{i,12}^{8\text{ to }12}$	. . .	δ_{r12}	4.096	11.441
$Rain_{i,20}^{12\text{ to }20}$	(inches of rainfall from 12 mo. to 20 mo. weighing in a given year less 30 year average rainfall for these same months)	δ_{r20}	0.258	0.282
D_j	(Dummy variable that is 1 if it is the *j*th weighing or 0 otherwise)			

Adj. R-squared of model was 0.9571 and standard errors were calculated using the Robust White procedure, using TSP v4.5.

Model:

$$WT_{i,j} = GFRS_{i,j} + \delta_{CG}CG_{i,20} + D_3\delta_{wBW}[WT_{i,BW} - GFRS_{i,BW}] + D_8\delta_{w3}[WT_{i,3} - GFRS_{i,3}]$$
$$+ D_{12}\delta_{w8}[WT_{i,8} - GFRS_{i,8}] + D_{20}\delta_{w12}[WT_{i,12} - GFRS_{i,12}] + \varepsilon_{i,j}$$

where

$$GF_{i,j} = \beta_0 + \beta_1 Age_{i,j} + \beta_2 Age_{i,j}^2 + ... + \beta_8 Age_{i,j}^8$$
$$R_{i,j} = D_8\delta_{r8}Rain_{i,8}^{3\,to\,8} + D_{12}\delta_{r12}Rain_{i,12}^{8\,to\,12} + D_{20}\delta_{r20}Rain_{i,20}^{12\,to\,20}$$
$$GFRS_{i,j} = (GF_{i,j} + R_{i,j})(1 - DH_i\delta_h) \text{ and}$$
$$CG_{i,20} = D_{20}[(WT_{i,12} - WT_{i,8}) - (GF_{i,12} - GF_{i,8})][1 - DH_i\delta_h].$$

Table 5. Average real return and standard deviation[a] of returns ($ / Animal Unit Year), 1980-98

	No Supplemental Feeding			
Sale Weight	**Southeast Arizona**		**Central Arizona**	
(lbs./steer)	May Sales	Nov. Sales	May Sales	Nov. Sales
350	36.15	23.66	36.49	23.32
	(61.78)	(57.58)	(61.85)	(57.52)
450	86.87	70.60	87.52	69.97
	(67.70)	(63.90)	(67.82)	(63.79)
550	4.72	2.30	15.19	-7.79
	(50.84)	(50.34)	(52.67)	(48.54)
650	1.00	6.91	13.75	-5.55
	(49.18)	(51.40)	(51.38)	(49.11)
750	-20.71	-17.77	-5.08	-32.83
	(46.01)	(63.14)	(48.68)	(60.20)
	Supplemental Feeding			
550	70.53	69.29	85.18	54.91
	(66.10)	(64.57)	(66.97)	(63.78)
650	50.57	60.51	68.81	42.52
	(63.10)	(65.41)	(64.62)	(63.97)
750	28.55	52.70	50.23	13.35
	(61.55)	(84.79)	(63.70)	(79.38)

[a] The sample standard deviation of returns is in parentheses below the average of annual real returns.

Table 6. Average real return and standard deviation[a] of returns ($ / Animal Unit Year) for extra grass year scenarios, 1980-98

	Supplemental Gains at No Supplement Cost			
Sale Weight	**Southeast Arizona**		**Central Arizona**	
(lbs./steer)	May Sales	Nov. Sales	May Sales	Nov. Sales
550	91.42	79.63	95.63	75.59
	(66.31)	(64.63)	(67.08)	(63.87)
650	81.96	81.22	89.75	73.62
	(63.46)	(65.44)	(64.87)	(63.99)
750	70.47	83.82	81.69	54.90
	(62.07)	(84.03)	(64.10)	(78.34)
	Non-Supplemental Gains with No AUY Reduction			
550	116.09	101.04	118.08	99.10
	(70.86)	(68.81)	(71.23)	(68.46)
650	147.05	139.61	149.42	137.29
	(75.36)	(77.01)	(75.80)	(76.59)
750	178.59	161.28	181.64	158.28
	(82.20)	(103.80)	(82.75)	(103.42)

[a] The sample standard deviation of returns is in parentheses below the average of annual real returns.

Figure 1. Calf weight data and estimated growth function

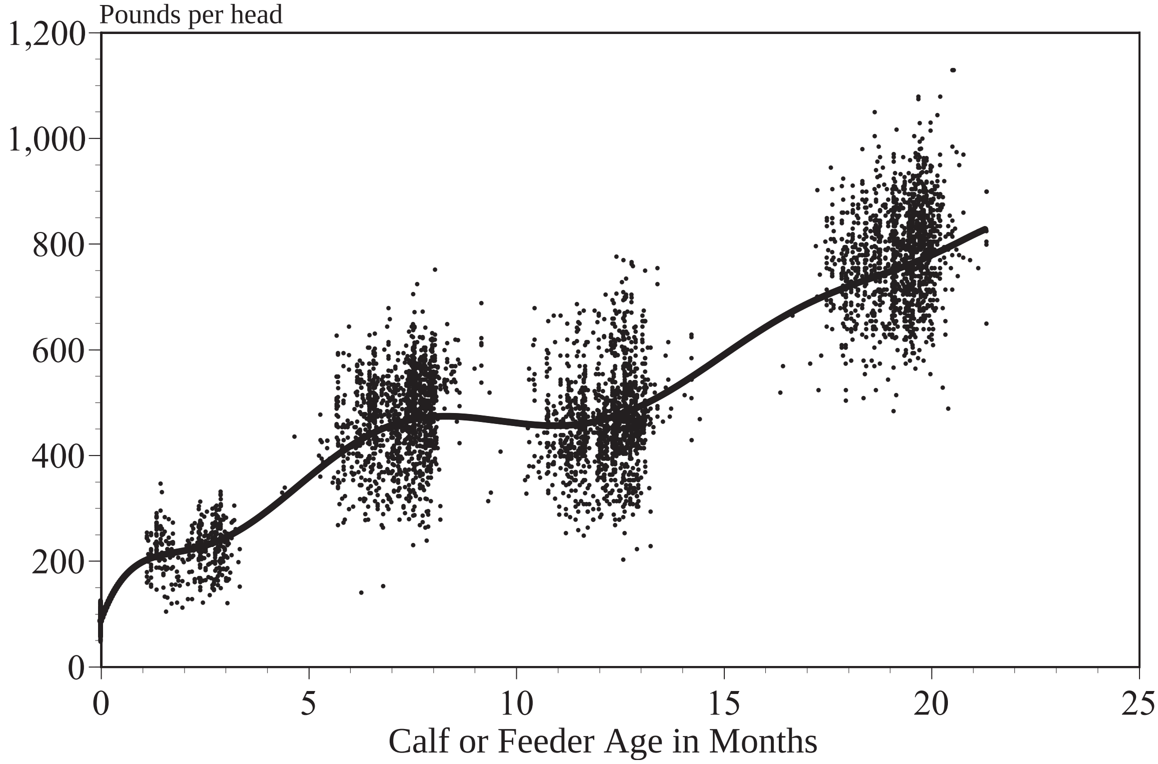

Figure 2. Calf weight estimates based on growth function, rainfall, compensatory gain, prior calf weights, and sex