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Relative costs and feeding strategies associated with winter/spring calving

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Abstract

Delaying calving season from late winter to late spring has been suggested as a way for producers in Wyoming and other high elevation areas of the West to reduce feeding costs. We hypothesized that shifting calving season to a later date would reduce feed costs by providing a closer match between cow nutritional requirements and nutritional quality of grazable forage. The objectives of this study were to estimate the cost of feeding a cow under 5 alternative calving month scenarios (February through June) and to identify alternative lower-cost forage practices that could replace feeding hay. Mixed integer programming models were constructed for each calving scenario with the objective of minimizing the cost of providing energy and protein to a mature cow. Objective function values from each model were compared to identify the low feed cost calving month. The ration was balanced for each month of the year, with requirements dependent on the interaction between the reproductive cycle and environmental conditions. Fat reserves were included as an alternative energy source and body condition was allowed to fluctuate. Under average weather conditions, June was the lowest feed cost calving month with a reduction in annual feed costs of \$43 cow^{-1} over February calving. The cost reduction was a result of a shift from mechanical to stock harvested forage, with the cow being maintained at a lower average body condition during the winter.

Key Words: body condition score, calving month, fat reserves, feed costs, multi-period integer programming

Resumen

La demora de la época de parición de las vacas del invierno tardío a la primavera tardía se ha sugerido como manera de reducir los costos de alimentación para los productores de Wyoming y otras áreas del Oeste de elevación alta. Hipotetizamos que la demora de la época de parición reduciría los costos de la alimentación al proveer un equilibrio más emparejado entre los requisitos nutritivos de las vacas y la calidad nutritiva del forraje apacentable. Los fines del estudio eran calcular el costo de dar de comer a una vaca bajo cinco épocas de parición distintas (de febrero a junio) e identificar prácticas de alimentación menos costosas que pudieran reemplazar dar de comer heno. Modelos programáticos de cifras variadas se construyeron para cada escenario de parición con la meta de minimizar los costos de proveer energía y proteínas a una vaca madura. Los valores objetivo-funcionales de cada modelo se compararon para identificar el mes de parición menos costoso en cuanto a alimentación. La ración se balanceó para cada mes del año, con los requerimientos ajustados a la interacción entre el ciclo reproductivo y las condiciones ambientales. Las reservas de gordura se incluyeron como fuente alternativa de energía y se permitía la fluctuación de la condición corpórea. Con normales condiciones meteorológicas, junio era el mes de parición menos costoso en cuanto a la nutrición con una reducción de \$43.00 la vaca en costos de alimentación sobre lo que costaría la parición en febrero. La reducción resultaba de un cambio de forraje cosechado mecánicamente a uno apacentado directamente por el ganado, con un mantenimiento promedial más bajo respeto a la condición corporal de las vacas durante el invierno.

Delaying calving season from late winter to late spring has been suggested as a way for producers in the high elevation areas of the West to reduce feeding costs (Clark et al. 1997, Adams et al. 1996, Grafel 1996). Calving in late spring shifts peak nutrient requirements into early summer when low-cost forage nutrients are often abundant. Late spring calving also increases the likelihood that lower winter nutritional requirements can be met with standing forage, thereby saving the costs of baling, hauling, storing, and feeding hay. For example, Clark et al. (1997) measured forage intake on an experimental herd separated into March and June calving on the Nebraska Sandhills and found that June calving reduced winter hay feeding by 1.4 metric tons cow^{-1}. Additionally, high energy requirements imposed by severe winter weather occur earlier in pregnancy when cows can better afford to lose body condition.

This study sought a better understanding of the feed cost advantages accompanying different calving month scenarios. The objectives of this study were to identify the calving month, between February and June, that would minimize

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feeding costs and to determine the optimal feeding strategy and cow body condition for each calving month scenario.

Materials and Methods

The Model

Multi-period mixed integer programming models (MIP) were constructed to estimate yearly feed costs for each calving scenario. The objective function of the MIP model was to minimize the cost of providing energy and protein to a 453-kg mature cow. The ration was balanced, on an as-fed basis, for each month of the year, with nutrient requirements dependent on the interaction between the reproductive cycle and environmental conditions. Nutrient availability was based on the forage production cycle (Younglove 1998). Objective function values from each model were compared to estimate the feed cost savings that may potentially occur.

A disadvantage of the mathematical programming approach compared to biological experiments when estimating relative feed costs is that important biological interactions are based on a synthesis of several prediction equations and are subject to the errors inherent in the estimation process. A well-designed optimization model, however, offers several advantages. Variables that cannot be controlled by researchers, such as weather conditions, can be included in the model to evaluate their importance to production and economics. Parameters and constraints can easily be adjusted to test the robustness of the results over a variety of scenarios and ranch characteristics.

The integer programming model is stated mathematically as:

Minimize Feed Cost = $\sum w_j b_j$; (1)
objective function

subject to the following major constraints:

$\sum e_{ij} b_j = k_j$; (2)
energy requirement constraint

$\sum c_{ij} b_j \geq p_i$; (3)
protein requirement constraint

$\sum t_{ij} b_j \leq r_i$; (4)
dry matter intake capacity constraint.

Equation (1) represents the objective function of minimizing the cost of feeding a cow year round, where w_j is the cost of the j^{th} feeding activity and b_j is the level the j^{th} feeding activity enters the solution. The ration was balanced on a per cow basis and each feeding alternative was available in unlimited quantities. Grazed forage alternatives within a period were considered mutually exclusive, i.e., cows were not allowed to graze different forage alternatives concurrently.

Table 1 contains a list of the forage alternatives used in the model and the months they were considered to be available. The opportunity to substitute grazed forages for hay in a late spring calving system provides an occasion to examine the feasibility of alternative winter forages. Basin wildrye (*Elymus cinerus* Scribn. and Merr.) is a tall forage that appears to be well suited for winter grazing (Majerus, 1991, 1992, USDA-SCS 1991, Jarecki 1985, Lesperance et al. 1978), and was included as an alternative forage in the model. Hay cut and raked into windrows and left in the field for winter grazing has also been suggested as a possible low-cost winter forage (Miller 1997, Simonds 1990, Turner 1987). This system was included in the model as an alternative to baled hay[1].

Energy constraints are expressed in equation (2) where e_{ij} is the net energy contribution (as-fed basis), measured in megacalories (Mcals) of net energy for maintenance (NE_m), of the j^{th} feedstuff in the i^{th} month since calving. The symbol k_i denotes the energy measured in Mcals of NE_m required in the i^{th} month.

The model was formulated to incorporate cow body condition as a decision variable and estimate the optimal pattern of seasonal condition scores for each calving system. As cows lose body condition during the winter, part of the cost of winter-feeding is deferred to the spring or summer when condition is recovered (Allison 1985). Each period included a slack and a surplus variable in the energy constraint to allow storage and depletion of energy reserves. Each Mcal of NE stored in mobilized tissue replaced 0.8 Mcal of diet NE (NRC 1996). Body condition scores (BCS) were monitored each month based on NRC estimates of energy (Mcals) mobilized in moving between condition scores.

Morrison and Castle (1997) found that cows can lose body condition during the winter and regain it prior to calving without adversely affecting calf production. Research suggests that allowing condition scores to remain below 5 at calving time can impair lactation and rebreeding (Morrison and Castle 1997, Torell and Torell 1996, Wickse et al.1995, Odde 1992). Condition scores at calving, therefore, were constrained to be 5 or higher. Cows also should be gaining or maintaining weight during the period between calving and breeding (Church 1991). Condition loss was not allowed 2 months before calving, or in the months between calving and breeding. Other limitations relating to energy reserves were that body condition could not drop below a score of 3 and cows could not lose more than 1 body score in a single month.

Maintenance energy requirements may increase as cows lose body condition during the winter. Thompson et al. (1983) reported that during winter, fleshy Angus-Hereford cows had a 6% lower maintenance requirement than thin cows. Byers and Carstens (1991) suggest NE_m requirements and body fat are directly related during warm weather periods and inversely related during cold weather. These studies compared cows at 2 narrow points on the body condition scale and did not estimate the relationship over the range of condition scores. Given the lack of data, this effect was not modeled in this study.

Shifting winter feeding programs from hay to grazing may increase NE_m requirements. Osuji (1974) found that maintenance requirements for grazing livestock were 25 to 50% higher than animals fed indoors. Havstad and Malechek (1982) concluded that heifers grazing on rangeland expended 40% more energy than stall-fed heifers. These studies compared energy requirements of grazing animals to those in a confined feeding situation. The difference in NE_m requirements between cows grazing and trailing a feedrow with grass hay would likely be less severe. The model, therefore, did not account for this effect.

Equation (3) represents protein requirement constraints, where c_{ij} represents the crude protein (CP) content of the j^{th} feed alternative in the i^{th} month since calving. The right-hand-side constraints, p_i, represents the daily crude protein requirement (kg) in the i^{th} month since calving. Because excess protein is

[1]Baled hay is defined in this application as hay packaged in 450 kg round bales.

Table 1. Forage alternatives for each month of the production cycle.

Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Native hay				X	X	X	X	X	X	X	
Alfalfa hay				X	X	X	X	X	X	X	
Windrowed hay					X	X	X	X	X		
Basin wildrye					X	X	X	X	X	X	
Native range	X	X	X	X	X	X	X	X	X	X	X
Hay aftermath				X	X	X	X	X	X		
Supplement	X	X	X	X	X	X	X	X	X	X	X
Fat reserves[1]	X	X	X	X	X	X	X	X	X	X	X

[1]Fat reserves were not allowed as a source of energy 2 months prior to and 3 months after calving.

excreted rather than stored (Church 1991), protein requirements were met each month and surpluses were not stored for later use.

Excess protein intake may stimulate rumen microbial activity and increase energy absorption (Rush 1987) to effectively substitute protein for energy. This ruminant characteristic may affect the optimal feeding program by increasing the likelihood that low quality forage combined with a high-level protein supplement would enter the least cost ration. Data quantifying the relationship between protein consumption and energy absorption is limited and this relationship was not accounted for in the model.

Equation (4) represents the set of dry matter intake (DMI) constraints for each month after calving, with t_{ij} denoting the percent dry matter of the j^{th} feedstuff in the i^{th} month. Because cows have limited capacity to consume dry matter (r_i), the diet was required to be sufficiently rich in nutrients to satisfy maintenance and lactation requirements given the consumption capacity constraint.

Relative Cost Estimates of Forage Alternatives

Forage alternatives were valued at their opportunity cost as reflected by available market prices (American Agricultural Economic Association Task Force 1998). Costs used in the model are shown in Table 2 (Wyoming Department of Agriculture 1998). A $9 metric ton^{-1} charge[2] was added to the cost of feeding baled hay and a 10% hay waste adjustment was included in the model (Adams et al. 1994). Producers using windrowed hay report refuse rates similar to baled hay (May 1999).

Hay left in windrows is less costly to produce and feed than baled hay, implying windrowed hay should conceptually have a lower market value. A market price, however, is not readily observable. Windrowed hay was valued by subtracting estimated production cost savings ($11 metric ton^{-1})[3] from the price of baled hay. Parametric analysis was used to identify the relative opportunity cost that would allow windrowed hay to enter or exit the optimal solution.

Adams et al. (1994) valued forages grazed during winter at half the summer forage rate, recognizing the loss of nutritional quality after the growing season. Forage with the highest quality, though, does not necessarily have the highest economic value. Rather, seasonal forage availability is often the most important factor and a forage source that is available during short-supply periods (e.g., winter) typically is more valuable. An opportunity cost (cost of not using the forage during summer) also exists when forage is held over until winter. In addition, the cost of providing grazed forage is fairly constant in both seasons. Grazing alternatives, therefore, were valued at the Wyoming private lease rate (Wyoming Department of Agriculture 1998) regardless of the season of use. Maintenance and herding costs of $7.15 and $3.25 AUM^{-1} for range forage and hay aftermath, respectively, were added to the lease rate (Van Tassell et al. 1997). Total basin wildrye costs included annualized establishment ($33 ha^{-1}), maintenance and herding (7.15 AUM^{-1}), and opportunity lease rate ($12 AUM^{-1}).

Table 2. Relative cost of feed source alternatives contained in the integer-programming model.

Feed source	Unit	Cost ($)
Basin wildrye	Ha	33.00
Hay feeding	Metric Ton	9.00
Grass hay	Metric Ton	87.00
Alfalfa	Metric Ton	94.00
Supplement	Metric Ton	230.00
Windrowed hay	Metric Ton	68.00
Range grazing cost	AUM	7.15
Hay aftermath grazing cost	AUM	1.58
Grazing lease	AUM	12.00

Nutritional Data

Monthly nutritional requirements for a 453-kg light-milking cow (4.5 kg day^{-1}) were obtained from NRC (1996) assuming a 7-month lactation period. June calving requirements were adjusted to a 1 December weaning date, making the lactating period for the June calving scenario one month shorter than the other calving scenarios.

Nutritional requirements developed by the NRC assume thermo-neutral environmental conditions. In Wyoming, the combination of wind and cold temperatures during winter often impose cold stress on range cattle. To estimate the adjustment in energy requirements necessary to account for cold stress, daily wind and temperature data (NOAA) was obtained from 1972 through 1997 for the Laramie county area. Average daily wind chill adjusted temperatures were

[2]The hay feeding cost was estimated with the assistance of local producers, and machinery cost data collected by the ASAE and compiled by Burgener and Hewlett (1993). Assumptions include a 125 HP tractor with a grapple fork and spear capable of feeding 6 bales hr^{-1}.

[3]This value accounts for baling and stacking required for baled hay, along with portable electric fencing and herding required to utilize windrowed hay. This value was derived with the assistance of local producers and ASAE data compiled by Burgener and Hewlett (1993).

computed from a formula developed by Ames and Insley (1975). These results were aggregated to average monthly temperatures. The adjustment factor for each month was estimated using the rule suggested by Ames (1985) that for each degree the effective temperature drops below the lower critical temperature (LCT), energy requirements increase by 1%. Lower critical temperature is a characteristic of the cow and depends primarily on the hair coat and the degree of acclimation. The LCT levels used in the model were 7, 0, –12, and 0 degrees C for October, November, December through March, and April, respectively (Ames 1985).

Table 3 contains the crude protein and energy content of the feed alternatives. These values were taken from the NRC Feed Library (NRC 1996) and were verified or modified based on forage sampling to represent nutritional characteristics of grasses in southeastern Wyoming (Younglove 1998). Nutritional quality of native range was listed separately for the summer months (June through September) in the NRC feed library. April forage was assumed to be a combination of old and new growth. Nutritional quality for April forage was assigned a weighted average of winter and spring values. May range nutritional quality values were taken from the NRC feed library (NRC 1996) and Younglove (1998).

Table 3. Nutritional quality of forages on a dry matter basis represented in the integer programming models.

	Total Digestible Nutrients	Crude Protein
Alfalfa hay	64	14.0
Grass hay	56	9.0
Windrowed hay	52	9.0
Supplement	80	20.0
Basin wildrye	50	5.5
Range April	57	8.0
Range May	61	15.0
Range June	65	13.0
Range July	62	10.5
Range Aug.	59	9.7
Range Sept.	57	8.9
Range Oct.-Nov.	53	7.5
Range Jan.-Mar.	50	5.5
Grass hay aftermath Sept.	59	11.5
Grass hay aftermath Oct.	54	8.0
Grass hay aftermath Nov.-Dec.	52	5.0
Grass hay aftermath Jan.-Mar.	50	4.0
Alfalfa aftermath Sept.-Oct.	58	10.0
Alfalfa aftermath Nov.-Dec.	53	8.0
Alfalfa aftermath Jan.-Mar.	50	4.0

Sensitivity Analysis

The MIP model required specifically defined values to represent costs, forage nutritional quality, and biological interactions. Many of these values were not well documented and may change from year to year, or across location and type of operation. Sensitivity analysis was conducted to test the robustness of the results to changes in the value of inputs. Probability distributions were assigned to cost and forage quality variables. Simulation software (Palisade 1996a) was used to randomly select values for each input based on specified distributions. The mixed integer programming (MIP) model was solved after each random selection of input values. This process was repeated for 500 iterations. The objective of this procedure was to systematically test the robustness of the results over a number of input-value combinations. Spearman rank correlation coefficients (Groebner and Shannon 1993) were calculated between estimated feed cost savings from late calving scenario and the random input variables. The absolute magnitude of the correlation coefficients identified the input variables influencing the model results. Cumulative probability distributions of feed cost cow^{-1} for each calving month scenario were estimated from the results of the simulation.

The data needed to estimate probability distribution parameters for forage nutritional yield were not available. A uniform distribution requiring only a minimum and maximum value, therefore, was assigned to the nutrient yield of each forage alternative. The lower and upper bounds of each uniform distribution were defined as 80% and 120%, respectively, of the estimate value contained in the original model. This range represents a subjective degree of uncertainty regarding the values to assign forage nutritional quality. Uniform distributions imply all values within the specified range are equally likely to occur. Seasonal nutritional values and yields of a particular forage were assigned a correlation coefficient of 1.0, implying, for example, that if a certain forage had a high summer nutritional quality, the relative winter quality would also be high.

Market price distributions were estimated from the previous 20 years of historical data (Wyoming Department of Agriculture 1998). Prices were adjusted to 1997 dollars using the GDP implicit price deflator (US Dept. of Commerce 1998). Distribution parameters were estimated using the software BestFit (Palisade 1996b) and were tested for statistical significance with the chi-square goodness-of-fit test. Uniform distributions best described alfalfa and grass hay prices ($\rho \leq 0.01$), with the maximum and minimum observed real price composing the parameters. Pearson and extreme value distributions were chosen ($\rho \leq .01$) for protein supplement and grazing lease prices, respectively.

Historical price correlations were maintained in the simulation. Correlation coefficients ranged from 0.93 between alfalfa and grass hay, to 0.55 for supplement and alfalfa hay prices. All correlation coefficients were significantly different from zero ($\rho \leq .01$).

Basin wildrye establishment cost and the estimated savings from windrowed relative to baled hay were assigned uniform distributions with minimum and maximum values ranging from 80% to 120% of the estimate contained in the original model. This range represented a subjective degree of uncertainty. Production costs associated with establishing and harvesting basin wildrye and windrowed hay were assumed to be uncorrelated with other variables.

Results

Results of the mixed integer programming (MIP) models for each calving scenario assuming average weather conditions are presented in Table 4. Feeding costs declined each month calving was delayed. June was the lowest cost calving month, with an estimated annual feed cost of \$173 cow^{-1}. May and June calving resulted in an estimated annual feed cost saving of \$39 and \$43 cow^{-1} over February calving. A distinct trend away from hay and toward grazing resources was exhibited each month calving was delayed (Table 4). Hay required by a June calving cow was 25% of the amount required by a February calving cow. The average daily ration during winter (December through March) in the February calving model was 9.0 kg hay cow^{-1} and 1.8 kg standing forage cow^{-1} on a dry matter basis. In February and March, the entire ration consisted of hay. The winter ration for a May calving cow over the same period averaged 0.5 kg supplement cow^{-1} day^{-1} and 11.5 kg grazed forage cow^{-1} day^{-1}. The percentage of protein and energy coming from grazed forage increased from 60 and 61% of protein and energy in the February calving model to 95 and 98% of protein and energy in the May calving model. There was a slight decrease in the percent of grazed nutrients coming from grazed forage as calving was shifted from May to June. June calving extended lactation requirements into fall, thereby increasing hay requirement during that period.

Table 4. Optimal ration and associated statistics for each calving scenario.

				Percent of nutrient from grazed forage	
Calving month	Annual feed cost	Supplement fed	Total hay fed	Crude Protein	Total Digestible Nutrients
	(\$/Cow)	(kg/cow)	(kg/Cow)	(%)	(%)
February	216	14.5	1,450	61.0	61.8
March	208	85.7	725	74.6	77.3
April	193	128.3	180	86.6	90.3
May	177	69.0	0	95.3	98.3
June	173	0.0	360	90.2	91.2

Supplement feeding increased as calving was delayed from February to April, declined sharply for May calving, and was eliminated for the June calving scenario (Table 4). Supplement feeding for the February through April calving scenarios occurred exclusively in April. April protein and energy requirements also increased as calving and lactation were shifted toward that month.

Fat reserves impacted the feeding program of all calving models. Figure 1 shows changes in total energy reserves for cows under each system. Condition scores were maintained between 4 and 6 in all models. Earlier calving systems maintained cow condition scores at a higher average throughout the year. Late calving cows gained less weight during the summer months, dropped below a body score of 5 during the winter, and returned to a body condition score of 5 before calving. Constraints preventing body condition from dropping below a score of 3, and losing more than one condition score in a single month, were non-binding in all calving models.

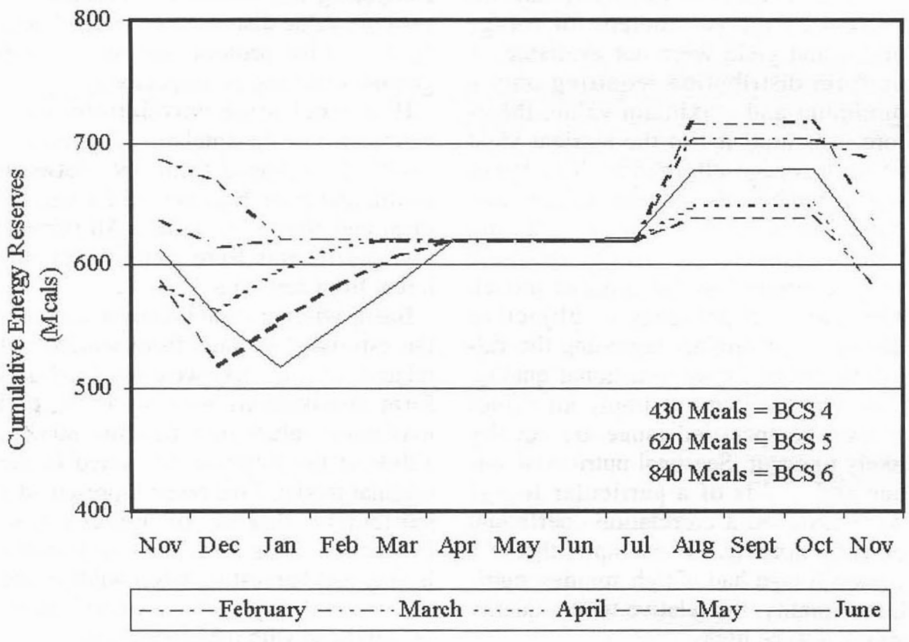

Fig. 1. Monthly body condition scores for cows in each calving scenario under least cost feeding conditions.

Modeling fat reserves was more important for late calving than early calving scenarios. To examine the impact of including fat reserves as an alternative energy source, a constraint preventing the use of fat stores was added to the model. The optimal ration under this assumption maintained a BCS of 5 throughout the year. A diet preventing condition loss during the year increased annual feed costs for a February or March calving cow by \$2. The same constraint increased annual feed costs for a May and June calving cow by \$19 and \$20 respectively.

Harsh weather conditions had a greater impact on feed costs in the early calving scenarios than in the late calving scenarios. March and May calving models were solved for mild and average winter conditions. Thermo-neutral requirements were used for the mild winter. Moving from an average to a mild winter saved \$2 in annual feed costs for a May calving cow, but saved \$19 annually for a March calving cow. As would be expected, these results suggest that feed cost savings resulting from late calving are directly related to the severity of winter weather.

The availability of range forage in the base models (Table 4) was unrestricted. The February and March calving models selected 2,150 and 2,340 AUMs of range forage to support a 400-cow herd

Table 5. Annual feed costs ($ cow^{-1}) and corresponding ranges under each calving month scenario generated by the simulation analysis.

	Calving month				
	June	May	Apr	Mar	Feb
Minimum	105	107	109	117	130
Maximum	442	448	405	424	471
Mean	204	206	210	222	242
Standard Deviation	59	59	52	52	58

for 1 year. April, May, and June calving models selected 3,050, 3,360, and 2,960 AUMs. Restricting rangeland availability at the optimal amount selected by the February calving scenario while maintaining a 400 head cowherd increased feed costs in the May and June calving models by $25 and $16 cow^{-1}. The benefit of calving in May and June relative to calving in February, therefore, was reduced to $25 and $38. Limited rangeland resources forced the model to reduce winter grazing and increase hay feeding relative to the optimal level selected by the unrestricted rangeland model.

Establishing basin wildrye on rangeland was included as a winter forage alternative in the model. Relative dry matter and nutritional yields between basin wildrye and native grasses have not been well documented. Basin wildrye establishment costs were incurred on a hectare^{-1} basis, with cost AUM^{-1} dependent on the yield. The protein and energy content of standing basin wildrye was assumed to be similar to winter range estimates contained in the NRC feed library. Estimated establishment costs were $380 ha^{-1}, or $33 ha^{-1} year^{-1} when amortized over 15 years at a 7% interest rate. At these costs, basin wildrye was required to out-yield native range by a ratio of 4.25 or greater before being economically justified. This yield increase could be a result of increased forage production or accessibility to the forage during heavy snow periods.

Windrowed hay was included in the model as a possible low-cost alternative to baled hay. Experimental research evaluating relative nutritional quality suggests that protein levels in windrowed hay are maintained similar to baled hay (Turner 1987, Streeter et al. 1965). Holding the price of hay and grazed forage constant (Table 2), the price of windrowed hay would have to be $61 and $58 metric ton^{-1} in the March and May calving models, respectively, before windrowed hay would enter the least cost solution. This price would be $23 to $30 metric ton^{-1} less than baled hay. Enterprise budget estimates place the production cost savings of windrowed hay near $8 to $11 metric ton^{-1}. Because windrowed hay and range forage could not be utilized simultaneously, standing range forage supplemented with baled hay was a lower cost alternative to grazing windrowed hay in all calving models.

The mean, range and standard deviation of annual feed and feeding costs from the simulation analysis are shown in Table 5 for each calving month. Minimum and mean costs decreased steadily each month that calving was delayed. May and June calving scenarios had higher maximum costs than March and April scenarios. The standard deviation, however, was lowest for March and April calving. Late calving resulted in higher feeding costs when low range nutritional quality coincided with low hay costs. Low range forage quality required supplement during late summer to meet higher lactating requirements for the May calving system. Late summer and fall forage nutritional quality, therefore, was identified as an important factor in the success of a late calving program.

The cost and nutritional quality input variables that were correlated ($\rho \leq 0.05$) with feed costs under each calving system are presented in Table 6. Native range forage quality carried the greatest impact on annual feed and feeding costs in all calving models. Its importance, however, appears to increase each month calving season is delayed. Spearman rank correlation coefficients range from –0.841 in the June calving model to –0.574 in the February calving model. The nutritional quality of grass hay carried a significant negative correlation ($\rho \leq 0.05$) with annual feed costs in the February and March calving models but was not significant for the April, May, and June calving scenarios. Both fee and non-fee grazing costs carried a significant positive ($\rho \leq 0.05$) correlation with annual feed costs for all calving months. The correlation between grazing costs and total annual feed costs appears to decline each month calving season is delayed as the correlation coefficient for February and March calving is significantly higher ($\rho \leq 0.05$) than May and June calving.

Figure 2 displays the cumulative probability of incurring specified levels of annual feed costs for each calving month. Distributions lying to the left are dominant to those on the right. February and March calving were clearly high cost calving months. Feed costs were less than $200 approximately 35% and 40% percent of the time for February and March calving, respectively, and 60% of the time for May and June calving.

Sensitivity results revealed that the cost nutrient^{-1} for supplementary and non-supplementary[4] nutrient sources was negatively and positively correlat-

Table 6. Spearman rank correlation coefficients between selected input variables and yearly feed costs for each calving month.

	Calving Month				
Variable	June	May	Apr	Mar	Feb
Range nutritional Quality	-0.84a[1]	-0.85a	-0.81ab	-0.72b	-0.57
Grass hay nutritional quality	-0.05e[2]	-0.07e	-0.136	-0.24	-0.36
Alfalfa nutritional quality	0.08e	0.06e	-0.01e	-0.06e	-0.13
Grazing Lease	0.28a	0.29a	0.34ab	0.41bc	0.45c
Supplement cost	0.33a	0.34ab	0.38abc	0.43bc	0.45c
Grass hay cost	0.30a	0.32ab	0.40	0.49b	0.56b
Alfalfa hay cost	0.28a	0.31ab	0.37bc	0.46cd	0.52d
Non-fee grazing costs	0.30a	0.31a	0.29ab	0.25b	0.22b

[1]Within rows, coefficients with the same letter are not significantly different from each other.
[2]The letter e denotes correlation coefficients not significantly different from zero ($\rho \leq 0.05$).

[4]Supplementary nutrient sources are defined as feedstuffs whose nutritional values exceed requirements. Non-supplementary sources are defined as feedstuffs whose nutrtional values are less than requirements.

Table 7. Calf production required under different calf prices to offset additional feed costs incurred by calving earlier than June.

Calving month	Calf price ($/kg)		
	1.65	1.85	2.05
	----- kg of calf production -----		
February	26	23	21
March	21	19	17
April	12	11	10
May	4	3	3

ed, respectively, with the cost benefit of late calving. Increasing the price of hay, therefore, increases the benefit of late calving while increasing the cost of winter grazing decreases the benefit of late calving.

Windrowed hay nutritional quality was the input variable carrying the most impact on the viability of windrowed hay in the winter feeding program for both the March and May calving models. This suggests more research is needed to ascertain relative nutrient yields when hay is baled, left in windrows, or when the forage is left standing.

A major factor influencing the profitability of late calving that was excluded from this study is the relative calf production generated by each calving system. For late calving to be economically feasible, feed cost reductions must be greater than any adverse effects on the value of calf production. Table 7 shows the increase in weaned calf cow^{-1} required to offset additional feed costs resulting from calving earlier than June under 3 price scenarios. At the 1992–1996 average price for a 180 to 225 kg steer calf ($1.85 kg^{-1}), an average weaned calf cow^{-1} would need to be 19 kg heavier for a March calving cow to offset the increased feed cost of $35 cow^{-1} over a June calving cow.

Discussion and Conclusion

Results of the mixed integer programming and simulation models are consistent with the findings of the biological studies conducted by Clark et al. (1997). These results suggest hay feeding and subsequent feed costs can be reduced if calving is delayed into late spring. In addition, late calving appears to reduce the risk of higher feeding costs imposed by severe winter weather. Sensitivity analysis revealed the magnitude of the cost reduction depends on winter weather conditions, forage nutritional quality, and costs.

Energy reserve fluctuations recommended in this modeling study represent a contrast between achieving optimal monthly body condition score (BCS) and managing to maintain a constant BCS throughout the year. Managing to meet the optimal body condition each month is not very practical when cows graze freely under varying range conditions. Another limitation of this model is that it does not address long-term cow health and productivity implications associated with fluctuating body condition throughout the year. Results, however, provide useful insights into the relationship between calving date and impact of fat reserves as a management tool in the overall grazing/feeding program.

Reduced feed costs for the later calving scenarios was obtained by extending grazing into the winter months. Acquiring additional grazing resources may not be realistic for many producers. The tradeoffs between forage resources, size of cowherd, and alternative production systems (e.g., retained ownership of calves) may best be examined using a profit maximization model that includes the number of AUs as a decision variable. This maximizing model could also consider differences in expected conception rates and weaning weights for alternative calving dates. Though this type of model would require additional data that are not currently available, a more accurate assessment of the relative profitability of late and early calving and the allocation of grazing resources to their optimal use may be obtained.

Specific feeding alternatives selected by the cost-minimizing model might not be realistic for all producers. For example, late summer supplementation to compensate for a protein deficiency in August and September for a June calving scenario may not be feasible. The impact on milk production and conception rates from not meeting NRC requirements during this period is unclear. Lardy et al. (1998) found that cows on a summer calving cycle lost weight on native range during the September–October breeding season, yet maintained a conception rate similar to summer calving cows grazing subirrigated meadow and gaining weight during breeding. If late summer nutrient deficiencies adversely impact the calf growth or conception rates of May/June calving scenarios, the value of lost production may or may not offset the expected feed cost benefits of late calving. While this study was not able to compare this trade-off, supplementation costs could be interpreted as an approximation of the value of lost production resulting from nutrient deficiencies in this situation.

Results suggest establishing tall grass species such as basin wildrye for winter

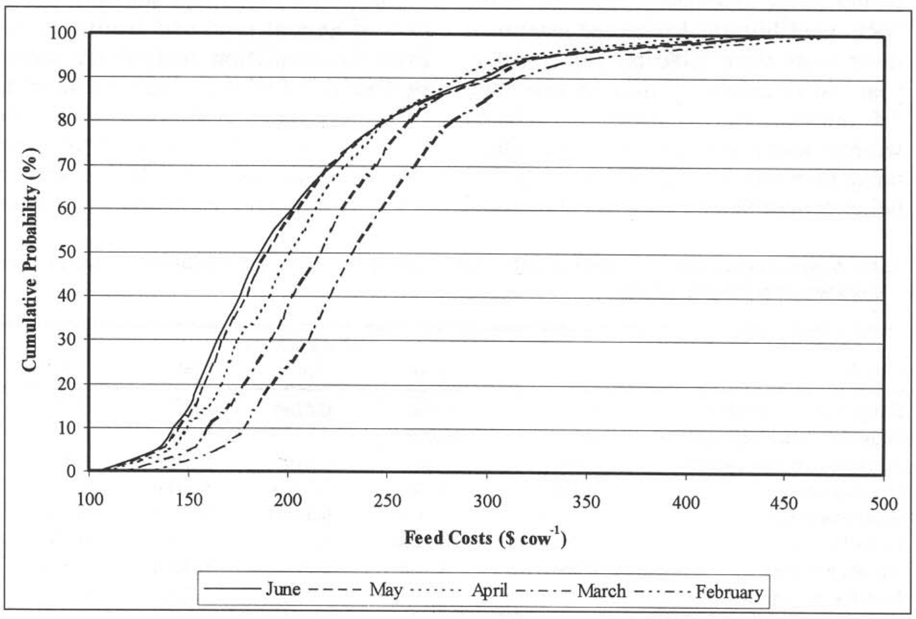

Fig. 2. Cumulative distribution of yearly feed costs cow^{-1} for each calving month scenario.

grazing would increase profitability only if existing forages are typically inaccessible during the winter, or significant increases in forage yields are obtained. The opportunity cost associated with committing land to basin wildrye is the value of non-winter forage production displaced. Based on Natural Resource Conservation Service (USDA-SCS 1988) estimates of relative forage production on sites where basin wildrye could potentially be established, it is unlikely that a yield increase would be sufficient to justify the costs of establishment, even in heavy snow areas where winter forage is typically inaccessible.

Parametric analysis showed windrowed hay carried more value in an early calving than a late calving system contrary to a priori expectations. An important advantage of baled hay over windrowed hay is that it can be rationed and used as a supplement while grazing relatively low cost/quality standing forage. Hay left in windrows must be used as the primary feed in the diet. Windrowed hay, therefore, has a difficult time competing economically with a forage combination of baled hay and standing forage. Windrowed hay, though, may be a low-cost alternative to baled hay on operations where limited winter range requires the use of hay as the primary feed source during the winter.

Other Factors Affecting the Optimal Calving Season

This study was not intended to be an exhaustive evaluation of late calving. Factors not included in this study but which impact the optimal timing of the reproductive cycle have been identified through interviews with producers experienced with late calving (May 1999). These variables include calf mortality, weaning weights, conception rates, and seasonal calf prices. The benefit of lower feed costs resulting from late calving must be measured with these additional advantages and disadvantages of late calving.

An expected advantage of late calving is reduced stress on newborn calves (May 1999), resulting in fewer health problems. In Wyoming, February and March born calves are frequently born in a concentrated environment under adverse weather conditions where infectious illnesses can easily spread. Conversely, cows calving in May and June are typically on green grass and are widely dispersed. Proponents of late calving contend dispersed calves lower the risk of scours and other calfhood illnesses and reduce mothering problems (May 1999). Research directly measuring relative calf health between summer and spring calving is limited. Cow productivity, measured in weaned calf per cow, accounts for calf mortality and growth rates, which are closely related to newborn calf health. Deutscher et al. (1991) compared cow and calf productivity between March and April calving herds. Weaning weights and cow productivity between calving herds were similar when calves were weaned at a similar age. This study, however, did not measure the costs of maintaining equivalent productivity.

Conception rates are an important consideration in determining the optimal calving season. March and April calving cows are bred in June and July when forage quality is at its peak, May and June calving cows are breeding in August and September when the protein content of native range forage is declining. Protein and energy deficiencies at breeding could impair conception and milk production. Moving late calving cows to hay aftermath or irrigated meadow may be a viable alternative if the crude protein levels of September range forage drops below the minimum required to support lactation and conception. April would likely be the least-cost calving month for an operation without forage of sufficient quality to maintain conception rates of cows bred in late summer.

Calving dates exert a major influence over weaning and selling decisions. Calf prices and marketing objectives are important variables when considering the optimal calving season. Some experimental research suggests June born calves are smaller than spring calves, even when weaned at a similar age. Lardy et al. (1998) compared weaning weights on summer and spring born calves. Summer born calves were evaluated under 1 November and 10 January weaning treatments while spring born calves were weaned 10 October. Average weaning weights of early and late weaned summer born calves were 45 kg and 16 kg lower than spring born calves. The adverse effect lighter calves may have on profitability may be mitigated by the fact that smaller calves receive a higher price in the market (Bastian 1997).

Seasonal calf prices also may exert a major influence on the optimal calving date. Wyoming calf prices typically bottom in mid-fall (Bastian 1997). December and January weaned calves, then, would typically receive a higher price kg^{-1} than October and November weaned calves. Based on average eastern Wyoming calf prices observed between 1992 and 1996, revenue generated by a calf sold in January was approximately equivalent to a 16 kg heavier spring born calf sold in October.

Maximum profitability can only be reached by considering all aspects of a ranching operation in a systems approach. Many of the producers in Wyoming that have switched to a later calving system have simultaneously integrated a yearling retention program to minimize the adverse effects of reduced weaning weights (May 1999). This system allows ranchers to shift hay land from cow production to yearling stocker production. Further research examining the relative resource values for these uses is needed.

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