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Protein and glucogenic precursor supplementation: A nutritional strategy to increase reproductive and economic output[1]

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ABSTRACT: Reproductive performance in young beef cows is often compromised due to a mismatch of physiological demands and suboptimal environmental conditions. Studies conducted at the Corona Range and Livestock Research Center from 2000 to 2007 evaluated 3 postpartum supplement strategies that varied in the amount of glucogenic potential (GP) supplied. Reproductive variables, milk production, and serum metabolites were used to assess supplement effectiveness and economics associated with 2- and 3-yr-old beef cows (n = 379) grazing native range. Supplements were individually fed twice/week at 1,135 g/d (2003 to 2004) or 908 g/d (all other years) and provided 1) 327 g of CP, 109 to 118 g of RUP (CON); 2) 327 to 341 g of CP, 142 to 157 g of RUP (RUP); or 3) 327 g of CP, 151 to 173 g of RUP + 40 to 100 g of propionate salt (PS; RUP+PS). Ultimately, total GP for CON, RUP, and RUP+PS was 44 to 47, 57 to 70, and 93 to 141 g, respectively. Blood samples were collected once/week (2000) or twice/week (2001 to 2007) for progesterone analysis to estimate days to resumption of estrus. Cows were exposed to bulls for 60 d or less, and pregnancy was confirmed by rectal palpation at weaning. Days to resumption of estrus after calving decreased linearly ($P = 0.02$), resulting in an increased pregnancy rate ($P = 0.03$) with increasing GP. Milk production exhibited a quadratic ($P = 0.04$) response to increasing GP, with cows fed RUP producing the most amount of milk. However, a linear decrease ($P = 0.07$) in days from BW nadir to estrus was found with increasing GP. Total kilograms of calf weaned per cow exposed for the supplemental year and subsequent year was increased linearly ($P = 0.07$) with increased GP. The improvement in pregnancy rate by supplementing RUP+PS resulted in an increase in total revenue of 18% compared with CON-fed cows and 9.5% compared with RUP-fed cows in the subsequent year after supplementation. These data suggest feeding young cows additional GP in the form of PS allows for partitioning of nutrients away from milk production and toward reproduction, allowing for increased profitability by increasing pregnancy rates and decreasing days to resumption of estrus.

Key words: average rainfall, beef cow, glucogenic precursor, reproduction, supplementation

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INTRODUCTION

Reproductive failure is a primary limitation to production efficiency, which represents the single most important factor reducing net calf crop (Dziuk and Bellows, 1983). Decreased reproductive success in young beef cows, especially in the Southwestern United States, is largely associated with low forage quality coupled with increased energy demands of the cow (Hawkins et al., 2000). Glucose requirements, utilization, and synthesis are increased after calving due to the role of glucose in milk lactose and ruminal VFA production. This increased demand for glucose is compromised by an inadequate supply of glucogenic precursors deriving from

[1]The USDA Research Service, Northern Plains Area, is an equal opportunity/affirmative action employer. All agency services are available without discrimination. This research was conducted under a cooperative agreement between USDA-ARS and the Montana Agricultural Experimental Station. Mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA, Montana Agricultural Experimental Station, or the authors and does not imply its approval to the exclusion of other products that may also be suitable.

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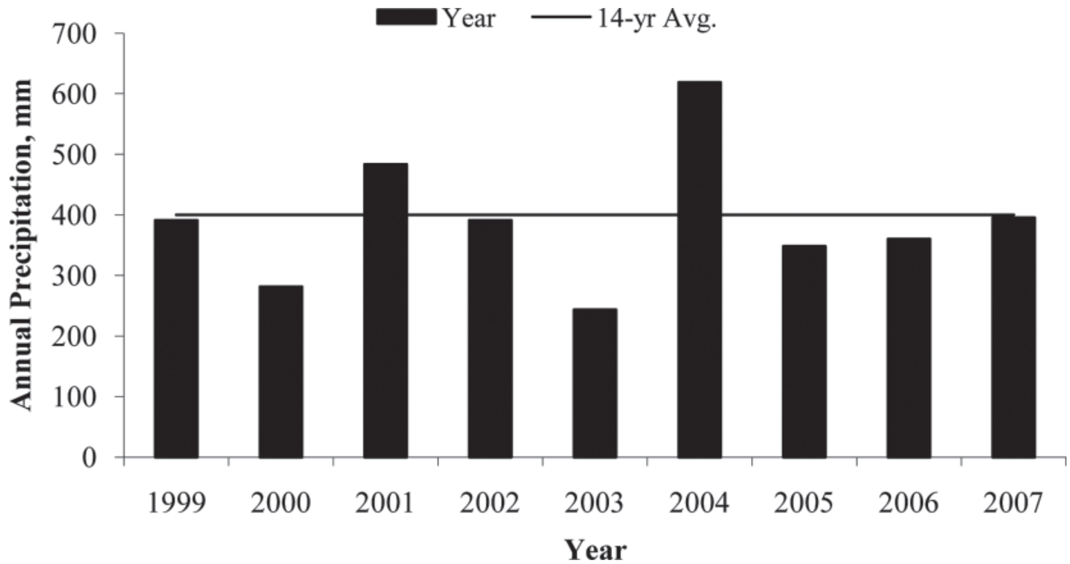

Figure 1. Bars show annual precipitation at the New Mexico State University Corona Range and Livestock Research Center (Corona) for the year preceding the study (1999) and the years of the study. The 14-yr average is also shown.

ruminal fermentation, specifically propionate. Therefore, the supply of glucose precursors becomes increasingly important for reproductive competence when forage quality is low (Hawkins et al., 2000). Knox (1998) reported that young cows fed protein supplements increasing in glucogenic precursors (presumably derived from glucogenic AA) coming from differing amounts of RUP had an 18% increase in pregnancy rates than cows fed a supplement low in RUP. By increasing the glucogenic potential (**GP**), we hypothesized that nutrients would be partitioned away from lactation, resulting in decreased days to resumption of estrus and improved pregnancy rates. Therefore, the objective of this experiment was to compare pregnancy rate, days to resumption of estrus, calf weight per cow exposed, and assess marginal economic returns as affected by environmental variations caused by different years and 3 postpartum supplementation strategies that differ in GP on 2- and 3-yr-old cows grazing native rangelands.

MATERIALS AND METHODS

All animal handling and experimental procedures were in accordance with guidelines set by the New Mexico State University's Institutional Animal Care and Use Committee.

Study Site

Studies were conducted over 7 yr at New Mexico State University's Corona Range and Livestock Research Center (**CRLRC**). Data were compiled from 3 independent studies that spanned from 2000 to 2007 (Endecott et al., 2005; Waterman et al., 2006; Mulliniks, 2008; Mulliniks et al., 2011) but with similar designs. Treatments were not applied during 2002 because of severe drought conditions. Average elevation for CRLRC is 1,900 m above sea level with an average rainfall of 401 mm (Figure 1), most of which occurs in July and August (Torell et al., 2008). Forages at this study site were primarily blue grama (*Bouteloua gracilis*), threeawns (*Aristida* spp.), and common wolftail (*Lycurus phleoides*).

Animals and Supplementation

Cows were 2- and 3-yr-old (n = 379) and were primarily of Angus breeding with some Hereford influence. Management before calving was similar in all years and among all cows. At least 60 d before calving, cows were fed 1.6 kg/cow of a 36% CP cube once per week. Cow/calf pairs were moved to a common pasture within 10 d of calving. In all years, cows were stratified by age and were randomly assigned to experimental treatments by calving date. Initiation of supplementation occurred approximately 10 ± 3 d after parturition for each cow. A 60-d breeding season was utilized in all years and was initiated in early or mid-May. Cows were moved to an ungrazed (in previous year) pasture before the initiation of breeding in all years. Initiation of breeding occurred on average 67 ± 2 d postpartum across all years.

On supplementation days, cows were gathered and calves were sorted and separated from cows after the morning grazing (0900 h). Duration of supplementation was dictated by the time at which cows no longer lost BW across all treatments. Cows were individually fed supplement for an average of 90 d (2000; n = 44), 100 d (2001; n = 36), 72 d (2003; n = 34), 65 d (2004; n = 26), 74 d (2005; n = 80), 120 d (2006; n = 81), and 80 d (2007; n = 78). Supplements were cubed and milled at Hi-Pro Feeds, Friona, TX (2000 to 2006) and Alderman Cave, Roswell, NM (2007). Supplements were fed at a rate of 908 g/d in 5 of the 7 yr, whereas cows were fed 1,135 g/d in 2003 and 2004. However, the amount

Table 1. Ingredients and nutrient composition of protein supplements (all units as fed) containing increasing amounts of glucogenic potential in 2000 to 2007

Item	Supplement[1]		
	CON	RUP	RUP+PS
Ingredient, %			
Cottonseed meal	56.94	24.80	18.15
Urea	1.20	0.70	1.20
Wheat middlings	21.45	42.50	40.10
Fish meal	—	—	13.00
Hydrolyzed feather meal	—	20.00	12.00
Soybean meal	10.00	—	—
NutroCal[2]	—	—	4.40
Molasses	9.00	9.00	9.00
Potassium chloride	0.95	1.70	2.00
Monocalcium phosphate	0.30	—	—
Vitamin A premix	0.08	0.08	0.08
Manganese sulfate	0.06	0.05	0.05
Trace mineral premix	0.02	0.02	0.02
Copper sulfate	0.01	<0.01	<0.01
Nutrient composition			
DM, %	87.67	88.46	88.46
Calcium, %	0.24	0.49	1.58
Phosphorus, %	1.00	1.09	1.09
Magnesium, %	0.47	0.33	0.33
Potassium, %	2.01	2.01	2.01
Sulfur, %	0.36	0.37	0.37
Sodium, %	0.09	0.38	0.38
Manganese, mg/kg	210.49	210.57	210.57
Zinc, mg/kg	109.19	199.13	199.13
Iron, mg/kg	176.43	233.46	233.46
Copper, mg/kg	49.82	50.45	50.45
Selenium, mg/kg	0.24	0.53	0.53
Cobalt, mg/kg	0.44	0.38	0.38
Iodine, mg/kg	1.23	1.25	1.25
Vitamin A, 1,000 IU/kg	33	33	33
TDN, g/d	596	590	590
CP, g/d	327	327	327
RDP, g/d	229	167	167
RUP, g/d	109	160	160
Estimated glucogenic potential, g/d	44	64	94

[1]Supplements were individually fed twice/week at 1,135 g/d (2003 to 2004) or 908 g/d (all other years) and provided 1) 327 g of CP, 109 to 118 g of RUP (CON); 2) 327 to 341 g of CP, 142 to 157 g of RUP (RUP); 3) 327 g of CP, 151 to 173 g of RUP + 40 to 100 g of propionate salt (RUP+PS). Total glucogenic potential for CON, RUP, and RUP+PS was 44 to 47, 57 to 70, and 93 to 141 g, respectively.

[2]Source of Ca-propionate; Kemin Industries Inc., Des Moines, IA.

of CP supplied was similar each year, regardless of differences in supplementation rate. Composition of the supplements changed slightly over the years based on commercial availability and least cost consideration of ingredients (Table 1). Supplements were designed to supply adequate RDP to ensure optimal ruminal fermentation and differed by increases in GP to provide 1) 327 g of CP, 109 to 118 g of RUP (**CON**); 2) 327 to 341 g of CP, 142 to 157 g of RUP (**RUP**); or 3) 327 g of CP, 151 to 173 g of RUP + 40 to 100 g of propionate salt (**PS**; **RUP+PS**). Ultimately, total GP for CON, RUP, and RUP+PS was 44 to 47, 57 to 70, and 93 to 141 g, respectively. Supplement RUP+PS was fed in all 7 yr, whereas CON (2000, 2001, 2005, 2006, and 2007) and RUP (2000, 2001, 2003, and 2004) were only fed 5 and 4 yr out of 7, respectively. Glucogenic potential of the supplements was calculated by the equation of Preston and Leng (1987), where 40% of the RUP is considered glucogenic (Overton et al., 1999). NutroCAL (Kemin Industries Inc., Des Moines, IA) contains 80% propionate, which has been shown to be 95% glucogenic (Steinhour and Bauman, 1988). All supplements were fortified with macro- and microminerals and vitamin A. Cows and calves had unlimited access to water and a loose salt-mineral mix that was formulated to complement available forages.

Sampling and Measurements

Blood samples (9 mL) were collected once weekly (2000; Friday) or twice weekly (2001 to 2007) on supplementation days (Monday and Friday) via coccygeal venipuncture beginning 35 to 55 d postpartum. Serum from the sample was analyzed for progesterone concen-

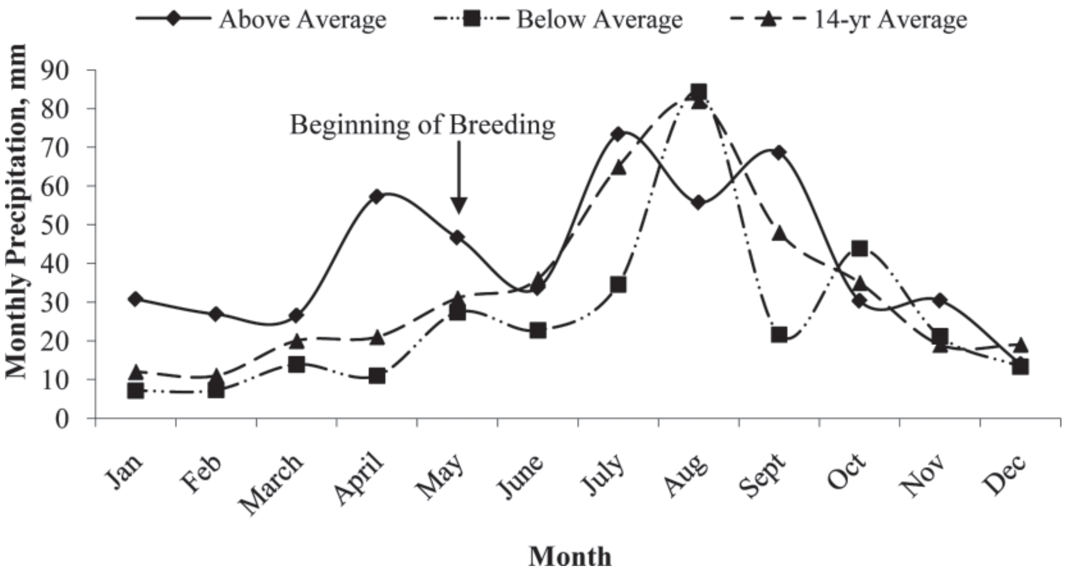

Figure 2. Monthly precipitation for above average, below average, and 14-yr average rainfall in pastures grazed by 2- and 3-yr-old cows.

tration to estimate days to return of estrus (2 or more consecutive progesterone concentrations ≥1.0 ng/mL). No cows were found to have progesterone values above 2 ng/mL in the initial sample in each year. Blood was collected immediately after cows received supplement. Serum samples were cooled and subsequently centrifuged at 4°C at 2,000 × g for 30 min. Serum was harvested and stored at −20°C. Samples were analyzed for progesterone by solid-phase RIA (Coat-A-Count, Diagnostic Products Corp., Los Angeles, CA) as described by Schneider and Hallford (1996). Serum samples were composited by cow within 3 productive periods: 1) prebreeding; 2) breeding to end of supplementation; 3) end supplementation to end of breeding. Samples were also analyzed for concentrations of insulin, glucose, NEFA, and serum urea N (**SUN**) to assess nutrient status of each cow. Composited samples were analyzed using commercial kits for NEFA (Wako Chemicals, Richmond, VA), SUN (Thermo Electron Corp., Waltham, MA), and glucose (enzymatic endpoint, Thermo Electron Corp., Waltham, MA). Insulin was analyzed by solid-phase RIA (DCP kit, Diagnostic Products Corp., Los Angeles, CA). Inter- and intraassay CV were less than 10% for all serum metabolites.

A subsample of cows (n = 24 in 2000; n = 36 in 2001; n = 29 in 2003; n = 20 in 2004; n = 0 in 2005; n = 29 in 2006; and n = 24 in 2007) were individually milked with a portable milking machine at approximately 57 d postpartum on a day after supplementation using a modified weigh-suckle-weigh technique described by Appeddu et al. (1997). On the day of the milking, cows were gathered from their pasture and calves were removed. Five minutes before milking, cows were administered an intravenous injection of oxytocin (20 IU; Vedo Inc., St. Joseph, MO) to facilitate milk ejection. Cows were milked until machine pressure could not extract any additional fluid, and milk collected was subsequently discarded. After first milking, cows were kept separate from calves for 3 h and then milked a second time. Milk weight was recorded and subsamples were collected into preservative containing vials for analysis of milk components by an independent laboratory (Pioneer Dairy Laboratories, DHIA, Artesia, NM). Milk weight was calculated for a 24-h milk production.

After calving, cows were weighed once every 2 wk (2000 and 2001) or weekly (2003 to 2007) until termination of the breeding season, and at weaning. The number of days to BW nadir was calculated from the least BW after calving. Body condition scores (1 = emaciated, 9 = obese; Wagner et al., 1988) were assigned to each cow by visual observation and palpation at initiation of the study, branding, and weaning by 2 trained technicians. Calves were weighed at branding and weaning in each year. Branding weights and weaning weights were adjusted for a 55-d branding and 205-d weaning weight with no adjustments for sex of calf or age of dam. Weaning weight for the year after supplementation was not adjusted to show differences in BW caused by variation in calving date and conception date.

Economic Analysis

A hypothetical model was developed to compare the economic marginal returns due to supplementation strategy of three 100-cow herds in a 2-yr partial budget using the results from 2000 to 2007. All calves were valued at time of weaning using a base price from the New Mexico Weekly Weighted Average Feeder Cattle Report (USDA, 2009) with no value difference between steers and heifers. In the model, second-year weaning weights were adjusted for calving date by results from days to first estrus and using the weaning weight and days to first estrus for CON as the base. Therefore, weaning weights were adjusted by 0.91 kg for each day decreased in postpartum interval. Calf crop was de-

Table 2. Effect of postpartum supplementation on reproductive measurements, cow BW and BW change, BCS, milk production, and calf BW change for 2- and 3-yr-old cows grazing native range in 2000–2007

Measurement	Supplement[1]			SEM	Contrast	
	CON	RUP	RUP+PS		Linear	Quadratic
BCS						
Initial	4.6	4.7	4.7	0.3	0.34	0.38
Brand	3.9	4.1	4.0	0.1	0.23	0.16
Weaning	4.6	4.7	4.7	0.1	0.31	0.44
Cow BW, kg						
Initial	431	435	436	12	0.40	0.71
Beginning of breeding	376	374	379	10	0.39	0.71
Nadir	345	345	348	11	0.51	0.88
End of breeding	407	404	410	10	0.32	0.57
Weaning	444	439	447	12	0.31	0.48
Cow BW change, kg						
Initial to beginning of breeding	−52	−58	−54	7	0.96	0.25
Initial to nadir	−85	−89	−87	7	0.61	0.40
Initial to end of breeding	−22	−28	−23	12	0.96	0.22
Nadir to end of breeding	62	57	64	11	0.52	0.46
Nadir to weaning	99	94	100	8	0.53	0.85
Initial to weaning	14	4	13	10	0.70	0.07
Serum metabolite						
Glucose, mg/dL	51.14	51.75	53.29	1.99	0.02	0.97
Milk,[2] g/d						
24-h production	6,272	7,136	6,461	441	0.93	0.04
Protein	164	189	174	13	0.70	0.05
Fat	215	273	226	21	0.82	0.01
Lactose	313	358	321	23	0.82	0.03
Solids-not-fat	530	611	553	40	0.93	0.03
Calf BW, kg						
55-d	66	67	66	4	0.82	0.56
205-d	209	218	215	12	0.15	0.10
Kilogram weaned per cow exposed	207	188	215	25	0.17	0.32
Two-year total kilograms weaned[3]	418	410	435	40	0.07	0.58
Reproductive measurements						
Days to resumption of estrus	88	87	82	4	0.02	0.85
Days to nadir	52	54	52	8	0.99	0.59
Nadir to estrus, d	36	33	29	12	0.07	0.85
Pregnancy, %	84	88	95	—	0.03	0.43

[1]Supplements were individually fed twice/week at 1,135 g/d (2003 to 2004) or 908 g/d (all other years) and provided 1) 327 g of CP, 109 to 118 g of RUP (CON); 2) 327 to 341 g of CP, 142 to 157 g of RUP (RUP); and 3) 327 g of CP, 151 to 173 g of RUP + 40 to 100 g of propionate salt (RUP+PS). Total glucogenic potential for CON, RUP, and RUP+PS was 44 to 47, 57 to 70, and 93 to 141 g, respectively.

[2]Milk production measured ~d 57 postpartum.

[3]Total kilograms weaned for supplemental year and subsequent year.

termined using the average calf loss according to the SW Cow-Calf Standardized Performance Analysis data (McGrann et al., 2000).

Statistical Analysis

Years were characterized as being either above or below a 14-yr average rainfall for CRLRC (Figure 2). Consequently, year served as the experimental unit for rainfall. Within each year, there were either 2 or 3 supplemental treatments fed. A mixed model accounted for correlations within year and supplement group within year and allowed for appropriate comparison of supplements even though some supplements did not appear every year. Normality of data distribution was evaluated using PROC UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). Data were analyzed as a completely randomized design with cow as the experimental unit using the Kenward-Roger degrees of freedom method. The MIXED procedure of SAS was used to analyze the mixed model with cow as the experimental unit and with the fixed effects of supplement, rain, and supplement × rain. Year within rain and year within rain × supplement were used as the random effects. No year within rain × supplement interactions ($P > 0.10$) were found to be significant for any variables. Two preplanned contrast statements were used to test for linear and quadratic effects of increasing amounts of GP. The coefficients of the contrasts were adjusted for the unequal spacing of GP of treatments using the Interactive Matrix Language (IML) procedures of SAS. Differences in pregnancy rates were analyzed using logistic regression (PROC GENMOD of SAS) utilizing a model that included the fixed effects of treatment, rain, and their interactions. Means for statistically significant categorical data were evaluated by generating frequency table using PROC FREQ of SAS. Serum metabolite concentrations were analyzed with productive period as the repeated factor and cow as the subject with compound symmetry as the covariance structure. The model included supplement, rain, period of measurement, and their interactions. Significance was determined at $P \leq 0.10$.

RESULTS AND DISCUSSION

Supplementation Effects

Body weight or BCS change, or both, are considered functional indicators of energy status and reproductive performance after calving (Randel, 1990). Rutter and Randel (1984) suggested that reproductive success was dependent on postpartum BW change. Cow BW and BCS were similar across all treatments at all measurement times ($P \geq 0.16$; Table 2). Treatments did not affect BW change; thus any improvement in reproduction was not associated with a difference in BW gain. Cows reached BW nadir at similar ($P = 0.59$) days postpartum in all supplement groups. However, a linear decrease ($P = 0.07$) in days from BW nadir to resumption of estrus was found. As GP increased, days from BW nadir to resumption of estrus was reduced. This may be explained by an improved efficiency of nutrient utilization or energy metabolism when feeding young cows increasing GP by increasing glucose clearance rate (Waterman et al., 2006) and acetate clearance rate (Mulliniks, 2008).

Serum concentration of glucose increased ($P = 0.02$) linearly with increasing GP in the diet and also decreased ($P < 0.01$; 55.25, 53.47, 47.45 ± 1.91 for prebreeding, breeding to end of supplementation, end supplementation to end of breeding, respectively) with advancing physiological periods coinciding with improved forage quality (associated with the onset of monsoonal rainfall). An increase in serum glucose with increasing GP was unexpected due to tight regulation associated with glucose concentrations (Kaneko, 1989). This increase in glucose concentration suggests that more glucose was available for entry into tissues when RUP and RUP+PS were fed. In contrast, multiple studies have reported a decrease or no increase in serum glucose with feeding increasing quantities of glucogenic precursors (Cronjé et al., 1991; Vanhatalo et al., 2003).

A supplement × physiological period interaction ($P \leq 0.01$; Figure 3) occurred for serum insulin, NEFA, and SUN. Serum insulin concentrations were greater for cows fed RUP+PS than cows fed CON and RUP before breeding season and early in the breeding season. Increased serum glucose and insulin concentrations may have had a positive effect on the restoration of LH pulse frequency as reported by Chagas (2003), who observed decreased days to first estrus and increased pregnancy rates in grazing dairy cows with supplementation of glucogenic precursors. Serum NEFA were greater in the first 2 physiological periods (prebreeding and breeding) and decreased in the last period for CON and RUP+PS supplemented cows, which follows the same trend of BW loss of cows after calving. The decrease in serum NEFA may have been caused by exhaustion of labile fat depots or from the provision of greater quality forage. However, serum NEFA concentrations were not differ-

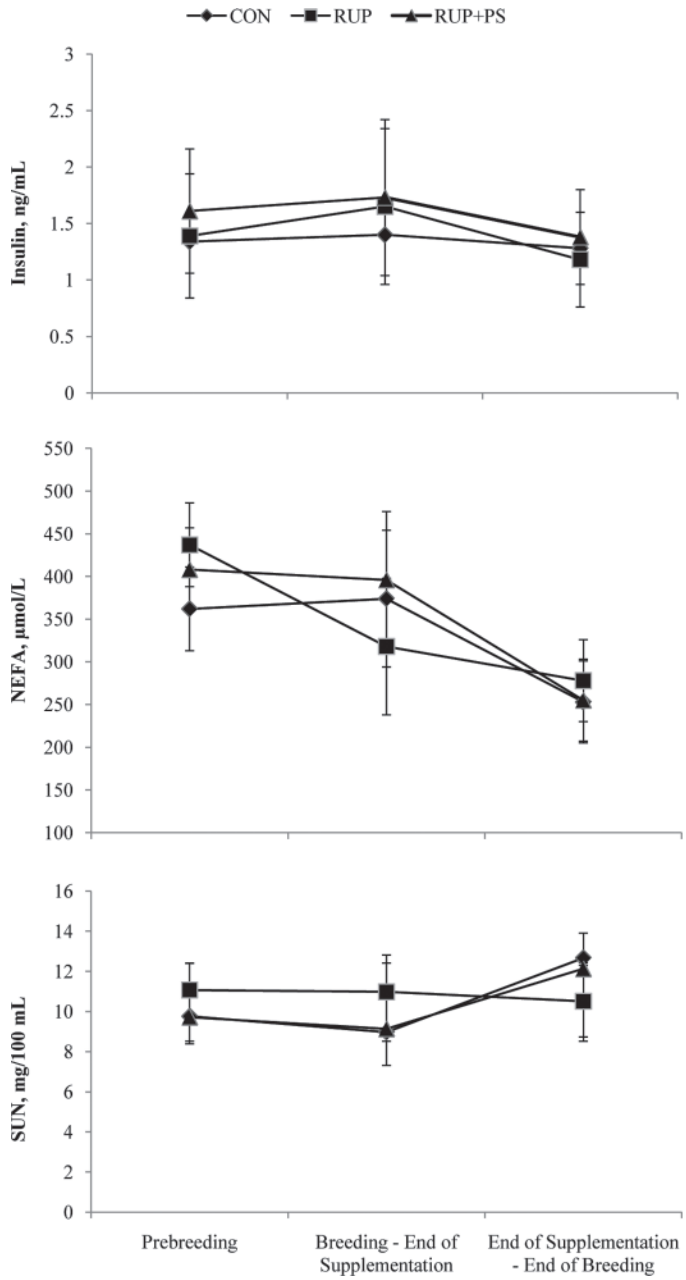

Figure 3. Supplement × physiological period interactions ($P \leq 0.01$) for serum insulin, NEFA, and serum urea N (SUN) of 2- and 3-yr-old postpartum cows grazing native range and fed supplement increasing in glucogenic potential in 2000 to 2007. The treatments were CON = 327 g of CP, 109 to 118 g of RUP; RUP = 327 to 341 g of CP, 142 to 157 g of RUP (RUP); and RUP+PS = 327 g of CP, 151 to 173 g of RUP + 40 to 100 g of propionate salt. Total glucogenic potential for CON, RUP, and RUP+PS was 44 to 47, 57 to 70, and 93 to 141 g, respectively.

Table 3. Effect of annual precipitation on reproductive measurements, cow BW and BW change, BCS, milk production, calf BW change, and serum metabolites for 2- and 3-yr-old cows grazing native range in 2000 to 2007

Measurement	Rainfall[1] High	Rainfall[1] Low	SEM	*P*-value
BCS				
Initial	4.4	4.9	0.3	0.20
Brand	3.9	4.1	0.2	0.59
Weaning	4.6	4.8	0.1	0.07
Cow BW, kg				
Initial	444	424	17	0.38
Beginning of breeding	387	366	13	0.27
Nadir	359	333	16	0.27
End of breeding	404	410	12	0.71
Weaning	439	448	17	0.69
Cow BW change, kg				
Initial to beginning of breeding	−57	−51	10	0.66
Initial to nadir	−85	−88	10	0.85
Initial to end of breeding	−41	−8	17	0.20
Nadir to end of breeding	45	78	16	0.19
Nadir to weaning	80	115	12	0.07
Initial to weaning	−6	26	14	0.13
Blood metabolites				
Glucose, mg/dL	52.65	51.46	2.56	0.76
Insulin, ng/mL	1.37	1.52	0.74	0.89
NEFA, mmol/L	339	346	76	0.96
SUN,[2] mg/100 mL	12.94	8.16	1.77	0.13
Milk,[3] g/d				
24-h production	6,997	6,249	507	0.36
Protein	190	162	15	0.26
Fat	261	214	24	0.23
Lactose	350	311	27	0.37
Solids-not-fat	603	527	46	0.32
Calf BW, kg				
55-d	62	71	5	0.22
205-d	224	204	17	0.43
Kilograms weaned per cow exposed	202	205	30	0.95
Two-year total weaned calf[4]	424	418	56	0.94
Reproductive measurements				
Days to first estrus	94	77	13	0.37
Days to nadir	48	58	12	0.55
Nadir to estrus, d	46	20	18	0.31
Pregnancy, %	92	90	—	0.56

[1]Years were characterized as being either above or below a 14-yr average rainfall for Corona Range and Livestock Research Center, Corona, NM.

[2]SUN = serum urea N.

[3]Milk production measured ~d 57 postpartum.

[4]Total kilograms weaned for supplemental year and subsequent year.

ent during the last 2 physiological periods in cows fed RUP. Cows fed RUP had greater SUN concentrations in the first 2 physiological periods. In the last period, concentrations of SUN increased from the second to the last period in cows fed CON and RUP+PS, but not in cows fed RUP, resulting in less SUN in RUP than CON or RUP+PS. We speculate that the greater supply of MP supplied by RUP compared with CON was removed from circulation by the liver; deaminated (as reflected by SUN) and keto acids were used for gluconeogenesis. However, MP was spared (as reflected by decreased SUN values) from deamination in cows fed RUP+PS, despite the fact that RUP and RUP+PS supplied similar quantities of MP. This may have been due to the improved glucose supply provided by PS that may allow for excess AA to be used for other protein needs (Waterman et al., 2006). In general, average SUN concentrations were at or below the optimum concentration of 10 to 12 mg/100 mL suggested by Hammond et al. (1993) for all 3 supplements.

Twenty-four-hour milk production exhibited a quadratic ($P = 0.04$; Table 2) response to increasing consumption of GP. A quadratic response was also observed for milk protein, lactose, solids nonfat, and butterfat ($P \leq 0.05$). The additional GP in the RUP supplement appeared to increase milk nutrients compared with CON and RUP+PS. Supplement RUP+PS contained the same amount of RUP as the RUP supplement, but cows fed RUP+PS incorporated a lesser quantity of nutrients into milk production, which may have improved the supply for realimentation and reproduction. Appeddu et al. (1997) and Sawyer (2000) reported an increase in 24-h milk production in the RUP-supplemented cows compared with cows fed a low RUP supplement. In contrast, Hunter and Magner (1988) reported that RUP supplements may repartition nutrients away from lactation and toward maternal body growth. The quadratic response on milk production may be explained by the fact that cows fed RUP in our study may not have received enough GP to overcome the effects of insulin insensitivity and passively partitioned nutrients toward lactation. Although milk nutrients differed due to RUP, calf BW at 55 d of age was not influenced by treatment ($P = 0.56$). Calf 205-d weight exhibited a quadratic response ($P = 0.10$) with RUP cows having the heaviest weaning weight, which may have been a result of increased nutrients from the RUP-fed cows.

Cows fed RUP+PS returned to estrus 5 to 6 d earlier over the 7 yr than cows fed the other supplements. A linear decrease ($P = 0.02$) in days to resumption of estrus was found with increasing amounts of GP (Table 2). This earlier return to estrus increases the probability that conception will occur earlier in the breeding season (Randel, 1990), which can result in older and heavier calves the next year at weaning. Along with calving earlier the next year, cows will have an increased opportunity to remain in the herd by becoming reproductively competent sooner and cycling before the initiation of the breeding season. Pregnancy rates increased linearly ($P = 0.03$) with increasing supply of GP in the supplements.

A productivity of a ranch can be described as kilograms of calf weaned per exposed female (Ramsey et al., 2005). Efficiently increasing total weight of calf weaned per cow exposed to a bull is a crucial criterion for beef cattle producers and is primarily controlled by reproductive efficiency and calf death loss. Feeding young lactating beef cows the RUP+PS supplement decreased days to resumption of estrus and increased

Table 4. A model results comparing cost and net revenue for 3 postpartum supplementation strategies for three 100-cow herds for 2 consecutive years[1,2]

Item	CON	RUP	RUP+PS
Year 1			
No. of cows	100	100	100
Cost of supplement, $/t	351	424	523
Days of postpartum supplementation	70	70	70
Cost of supplement/d	0.318	0.385	0.474
Postpartum supplement cost/cow	22.26	26.95	33.18
Weaning weight, kg	209	218	215
Price of calves, $/45.4 kg	124	124	124
Weaned calf value, $	569.16	595.20	586.52
Minus feed cost, $	546.90	568.25	553.34
Net revenue/100 animals, $	54,690	56,825	55,334
Difference from CON, $	—	2,135	644
Pregnancy rates, %	84	88	95
Calving death loss based on exposed females, %	2.8	2.8	2.8
Calf crop, %	81.2	85.2	92.3
Year 2			
No. of cows	81	85	92
Estimated calving interval, d	365	364	359
Cost of supplement, $/t	351	424	523
Days of postpartum supplementation	70	70	70
Cost of supplement/d	0.318	0.385	0.474
Postpartum supplement cost/cow	22.26	26.95	33.18
Adjusted weaning weight for calving date, kg	209	219	220
Price of calves, $/45.4 kg	124	124	124
Weaned calf value, $	569.16	597.68	601.4
Minus feed cost, $	546.90	570.73	568.22
Net revenue/cow herd, $	44,298.90	48,512.05	52,276.24
Difference from CON, $	—	4,213.15	7,977.34

[1]Data from 2- and 3-yr-old cow postpartum supplementation studies (2000 to 2007) at the New Mexico State University Corona Range and Livestock Research Center (Corona, NM) were used to construct the 2-yr partial budget.

[2]Supplements were individually fed twice/week at 1,135 g/d (2003 to 2004) or 908 g/d (all other years) and provided 1) 327 g of CP, 109 to 118 g of RUP (CON); 2) 327 to 341 g of CP, 142 to 157 g of RUP (RUP); and 3) 327 g of CP, 151 to 173 g of RUP + 40 to 100 g of propionate salt (RUP+PS). Total glucogenic potential for CON, RUP, and RUP+PS was 44 to 47, 57 to 70, and 93 to 141 g, respectively.

pregnancy rates, providing the opportunity to wean more older and heavier calves the following year. Total weight of calf weaned for the supplemental year and the subsequent year linearly increased ($P = 0.07$; Table 2) with increasing amount of GP fed.

Rainfall Effects

Yearly rainfall above average or below average did not influence pregnancy rates ($P = 0.56$; Table 3), days to resumption of estrus ($P = 0.37$), days to BW nadir ($P = 0.55$), or cow BW ($P = 0.27$). However, cows in the below-average rainfall years did gain more BW from BW nadir to weaning ($P = 0.07$) compared with cows in the above-average years. Cows in the below-average years had a greater BCS at weaning than cows in the above-average years ($P = 0.07$). This increase in BW gain and fat deposition in the below-average years may have contributed to the similar reproductive performance between the 2 different rainfall patterns. Calf 55-d and 205-d weights and 24-h milk production and milk components were not different among the 2 levels of rainfall ($P \geq 0.22$). Serum metabolites (glucose, insulin, NEFA, and SUN) were not influenced by amount of rainfall ($P \geq 0.13$). The lack of detectable differences between the 2 rainfall amounts for reproduction and serum metabolites may be due to the lack of major differences observed with year (Figure 1) and across year (Figure 2).

Economic Analysis

An evaluation of potential revenue from three 100-cow herds was conducted with a 2-yr partial budget of the 3 postpartum supplements using the results from 2000 to 2007 (Table 4). Total feed costs for the supplemental period were $22.26, $26.95, and $33.18/cow for CON, RUP, and RUP+PS, respectively. In yr 1, net revenue was $21.35 and $6.44 per cow more for RUP and RUP+PS, respectively, compared with CON. The increase in net revenue in yr 1 was due to an increase in calf weaning weight in the RUP and RUP+PS cow herds. Pregnancy rates across the 7 yr averaged for the supplement year (yr 1) were 84, 88, and 95% for CON, RUP, and RUP+PS, respectively. Consequently, cows fed RUP+PS in yr 1 had an increase in net revenue in yr 2 of 18% compared with CON-fed cows and 9.5% compared with RUP-fed cows. This increase in revenue is the sum of an increase in pregnancy rates and to a lesser extent a decrease in days to first estrus, which offset the greater postpartum feed costs for the year. The increase in revenue did not account for income from cull cows or the cost of developing additional heifers to replace culled open cows. A sensitivity analysis was conducted on the second year of the economic data. With the given production assumption, costs of supplement can increase up to $1.09 and $1.71/cow/d for RUP and RUP+PS, respectively, and still generate the same revenue as the CON supplement.

In conclusion, an increase in pregnancy rates for cows fed PS offset the greater cost of the supplement by increasing calf crop the following year, which increased marginal revenue compared with predicted net revenues derived from cows fed the other supplements in this study. Furthermore, cow longevity may also be improved by decreasing days to first estrus, resulting in increased percentage of young cows pregnant earlier in the breeding season, while maintaining a yearly calving interval.

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