Rangeland Ecol Manage 67:219–223 | March 2014 | DOI: 10.2111/REM-D-13-00091.1

Knapweed Hay as a Nutritional Supplement for Beef Cows Fed Low-Quality Forage

David W. Bohnert,[1] Roger L. Sheley,[2] Stephanie J. Falck,[3] and Arthur A. Nyman[4]

Authors are [1]Associate Professor and [4]Ranch Foreman, Eastern Oregon Agricultural Research Center, Oregon State University, Burns, OR 97720, USA; [2]Range Research Ecologist and [3]Laboratory Technician, USDA –Agricultural Research Service, Eastern Oregon Agricultural Research Center, Burns, Oregon 97720, USA.

Abstract

Advancing our ability to use invasive plants for producing commodities is central to the agricultural industry. Our objective was to evaluate Russian knapweed (*Acroptilon repens* [L.] DC.) as a winter feed supplement for ruminant livestock. In Experiment 1, we utilized three ruminally cannulated steers in a completely randomized design to compare the ruminal degradation characteristics of alfalfa and Russian knapweed. In the second experiment, Russian knapweed and alfalfa were compared as protein supplements using 48 midgestation, beef cows (530 ± 5 kg) offered ad libitum hard fescue (*Festuca brevipila* Tracey) straw in an 84-d study. Treatments included an unsupplemented control and alfalfa or Russian knapweed provided on an iso-nitrogenous basis. In Experiment 1, the rate and effective degradability of neutral detergent fiber was greater for alfalfa compared with Russian knapweed ($P \leq 0.02$). Ruminal lag time for NDF (period before measurable disappearance began) was greater for knapweed ($P=0.03$). Soluble nitrogen, rate of N degradation, rumen degradable N, and effective degradability of N were all greater for alfalfa compared with Russian knapweed ($P < 0.01$). In Experiment 2, supplementation increased ($P < 0.01$) cow weight gain and BCS compared to the unsupplemented control with no difference between alfalfa and Russian knapweed ($P=0.47$). There was no difference ($P=0.60$) in the quantity of straw offered between the unsupplemented cows and supplemented groups, but alfalfa fed cows were offered approximately 11% more ($P=0.03$) than Russian knapweed-fed cows. Total DM offered to cows was greater ($P < 0.01$) for supplemented compared with unsupplemented cows with no difference noted between alfalfa and Russian knapweed ($P=0.79$). Russian knapweed is comparable to alfalfa as a protein supplement for beef cows consuming low-quality forage. Using Russian knapweed as a nutritional supplement can help solve two major production problems; managing an invasive weed, and providing a feedstuff that reduces an impediment in livestock production systems.

Key Words: digestible protein, invasive weeds, livestock feed, Russian knapweed

INTRODUCTION

Invasion of agricultural land by nonindigenous plants is a worldwide problem that costs producers millions of dollars each year (Radosevich et al. 2007). Substantial effort has focused on developing methods for controlling weeds and restoring invasive plant-infested rangeland. Identifying beneficial uses of invasive weeds has received some attention, especially for grazing (Landgraf et al. 1984) and for medical treatments (Efthimiadou et al. 2012). It is becoming increasingly clear that using invasive plants will be a necessary component of managing them. An ideal situation would be to use invasive weeds to fill a need while confronting an obstacle in the production of agricultural commodities.

As rangeland plants senesce during summer, livestock forage quality declines rapidly and remains low through fall and winter, creating an impediment in animal production in the Intermountain West (Adams and Short 1988). Annual winter feed costs in this region often total \$100 to \$200 per cow, representing a significant economic constraint for cow–calf producers. Winter feed costs normally include harvested forage and supplement necessary to sustain, or increase, cow body condition score (BCS) prior to calving. Feeding nutritious hay, especially alfalfa (*Medicago sativa* L.), and providing supplements to cows is often necessary to optimize conception rates and maintain a 365-d calving interval (Herd and Sprott 1986). Consequently, the ability to compete with other regions of the United States often depends on how effectively cow–calf producers in the Intermountain West can reduce winter feed costs while maintaining acceptable levels of livestock performance (Merrill et al. 2008).

Russian knapweed (*Acroptilon repens* [L.] DC.) is a rhizomatous perennial invasive plant native to Eurasia that is highly competitive and invades productive habitats (Duncan 2005). It is widely established throughout the western United States, with infestations estimated at 557 000 ha in 1998 (Whitson 1999). Also, this weed is rapidly expanding its range, with annual spread in the western United States estimated between 8% and 14% (Simmons 1985; Duncan 2005). Russian knapweed can be temporally controlled with herbicides, but rapidly reinvades once the herbicide has dissipated, especially if cool-season grasses cannot be established (Whitson 1999). Consequently, complex integrated pest management programs have been developed for restoring Russian knapweed-infested rangeland (Sheley et al. 2007). However, integrated management of Russian knapweed is very difficult and expensive (Whitson 1999). Russian knapweed can produce nearly 2 200 $kg \cdot ha^{-1}$ and has been reported to have protein values similar to alfalfa (Whitson 1999). Because it is often harvestable, Russian knapweed may have potential as a supplemental feedstuff for

Correspondence: David W. Bohnert, Eastern Oregon Agricultural Research Center, Oregon State University, Burns, OR 97720, USA. Email: dave.bohnert@oregonstate.edu

Manuscript received 11 June 2013; manuscript accepted 16 November 2013.

beef cattle consuming low-quality forages (< 6% crude protein [CP]; dry matter [DM] basis) during winter feeding. Our objective was to evaluate the potential for using Russian knapweed as a winter feed supplement for ruminant livestock. Therefore, we compared the ruminal degradation characteristics of Russian knapweed vs. alfalfa and also compared their use as protein supplements for beef cows consuming low-quality forage. Although this paper specifically discusses Russian knapweed as a feedstuff for cattle, we want to provide a caution if producers are feeding cattle and horses together. It is important that Russian knapweed not be fed to horses because of the potential for a fatal neurological disorder, equine nigeropallidal encephalomalacia or "chewing disease" (Young et al. 1970).

MATERIALS AND METHODS

Russian knapweed used in these experiments was swathed at the initiation of flowering (June), allowed to dry to about 15% moisture content, raked into a windrow, and baled. All experimental procedures used in this study were approved by the Oregon State University Institutional Animal Care and Use Committee (ACUP# 3092).

Ruminal Degradation of Alfalfa and Russian Knapweed

Experimental Design. Three ruminally cannulated Angus × Hereford steers were used in a completely randomized design to evaluate the ruminal degradation characteristics of alfalfa and Russian knapweed. Steers had ad libitum access to 6.5% (CP; DM basis) meadow hay consisting of approximately 82% meadow foxtail (*Alopecurus pratensis* L.) with the majority of the remaining vegetation being rushes (*Juncus* spp.), sedges (*Carex* spp.), and blue wild rye (*Elymus triticoides* Buckley; Wenick et al. 2008). The steers were offered the low-quality meadow hay diet for at least 90 d prior to the start of this experiment.

Data Collection. Dacron bags (10 × 20 cm; Ankom Technology Corp, Fairport, NY) were labeled with a waterproof permanent marker, weighed, and 4 g (air equilibrated) of ground (1-mm; Wiley Mill; Model 4; Arthur H. Thomas, Philadelphia, PA) alfalfa or Russian knapweed was added and the bags sealed with an impulse sealer (TISH-200; TEW Electric Heating Equipment Co, Ltd, Taipei, Taiwan). Triplicate bags for each forage source were placed in a bucket containing warm water (39 C) and introduced into the rumen within 5 min. Bags were placed in a weighted polyester mesh bag within the rumen of each steer (0, 2, 8, 12, 24, 48, and 96 h) in reverse order, allowing all bags to be removed simultaneously. Three blank Dacron bags were incubated for 96 h and used to correct for microbial and feed contamination. Upon removal, Dacron bags were rinsed under tap water until the effluent was clear, and dried at 55 C for 24 h. The dried triplicates were allowed to air equilibrate for 24 h at room temperature, weighed for residual DM, composited by steer, time and forage type, and analyzed for neutral detergent fiber (NDF; Robertson and Van Soest 1981) using procedures modified for use in an Ankom 200 Fiber Analyzer (Ankom Technology Corp). The NDF residue was then weighed and analyzed for nitrogen (N; Leco CN-2000; Leco Corp, St. Joseph, MI). Effective degradability of DM, NDF, and N was determined as described by Hoffman et al. (1993) using a ruminal passage rate of $2\% \cdot hour^{-1}$ (Mass et al. 1999). Rumen degradable protein (RDP) was calculated as described by Ørskov and McDonald (1979) with rumen undegradable protein (RUP) calculated as 1 − RDP.

Table 1. Nutrient content (dry matter basis) of feedstuffs.

Item	Feedstuff		
	Hard fescue straw	Alfalfa	Russian knapweed
Crude protein, %	3.8	20.6	13.4
Organic matter, %	93.9	89.8	94.4
NDF, %[1]	79.7	45.5	50.1
ADF, %[2]	46.9	32.6	34.4

[1]Neutral detergent fiber.
[2]Acid detergent fiber.

Statistical Analyses. Kinetic variables for NDF and N digestibility were estimated with SAS (SAS Institute, Inc, Cary NC) using the modified nonlinear regression procedure described by Fadel (2004). Data were analyzed using the MIXED procedure of SAS. The model included hay type as the independent variable. Steer was used as random variable. Means were separated using LSD protected by a significant F-test ($P \leq 0.05$).

Cow Performance

Experimental Design. Forty-eight pregnant (approximately 120 d), 3-yr-old, primiparous, Angus × Hereford cows (530 ± 5 kg) were used in an 84-d performance study. Cows were stratified by body condition score (BCS; 1 = emaciated to 9 = obese; Herd and Sprott 1986) and weight and assigned randomly, within stratification, to one of three treatments. Treatments were an unsupplemented control, alfalfa supplementation, or Russian knapweed supplementation). Cows were then sorted by treatment and allotted randomly to 1 of 12 pens (4 $cows \cdot pen^{-1}$; 4 $pens \cdot treatment^{-1}$). A trace mineralized salt mix was available free choice (7.3% Ca, 7.2% P, 27.8% Na, 23.1% Cl, 1.5% K, 1.7% Mg, 0.5% S, 2 307 ppm Mn, 3 034 ppm Fe, 1 340 ppm Cu, 3 202 ppm Zn, 32 ppm Co, 78 ppm I, 85 ppm Se, 79 $IU \cdot kg^{-1}$ vitamin E, and 397 000 $IU \cdot kg^{-1}$ vitamin A). Cows were bunk-fed and provided ad libitum access to hard fescue (*Festuca brevipila* Tracey) seed straw (Table 1). The quantity of straw provided was noted daily but was not weighed back. Alfalfa and Russian knapweed were provided Monday, Wednesday, and Friday on an iso-nitrogenous basis (approximately 0.50 $kg \cdot head^{-1} \cdot d^{-1}$ averaged over a 7-d period). The amounts (DM basis) provided on Mondays and Wednesdays was 4.54 $kg \cdot head^{-1}$ and 6.80 $kg \cdot head^{-1}$ for alfalfa and Russian knapweed, respectively. On Fridays, alfalfa fed cows received 6.80 $kg \cdot hd^{-1}$ and Russian knapweed fed cows received 10.21 $kg \cdot head^{-1}$.

Data Collection. Samples (approximately 200 g) of hard fescue grass seed straw, alfalfa, and Russian knapweed were collected weekly, dried at 55 C for 48 h, ground through a Wiley mill (1-

Table 2. Ruminal degradation parameters of alfalfa and Russian knapweed.

Degradation parameters	Alfalfa	Knapweed	SEM[1]	*P* value
Neutral detergent fiber				
Fractions, %[2]				
A	18.3	16.3	1.02	0.24
B	43.2	47.6	1.22	0.07
C	38.5	36.1	0.98	0.16
Kd, $\% \cdot h^{-1}$[3]	7.3	4.6	0.47	0.02
Lag, h	1.2	3.1	0.76	0.03
Effective degradability, %[4]	52.0	49.4	0.50	0.01
Nitrogen				
Fractions, %				
A	51.5	40.2	1.12	0.002
B	45.9	54.6	1.3	0.009
C	2.6	5.1	0.20	0.009
Kd, $\% \cdot h^{-1}$[3]	11.6	8.6	2.72	0.50
RDP, %[5]	95.9	91.7	0.07	< 0.001
RUP, %[6]	4.1	8.3	0.07	< 0.001
Effective degradability, %[4]	97.4	94.9	0.20	0.009

[1]SEM indicates standard error of the mean.
[2]A indicates fraction of total pool disappearing at a rate too rapid to measure; B fraction of total pool disappearing at a measurable rate; C, fraction of total pool unavailable in the rumen.
[3]Fractional rate of degradation constant.
[4]Calculated as $A + [B * (Kd \cdot [Kd+Kp]^{-1})]$, where Kp was the ruminal passage rate, which was set at $0.02 \cdot h^{-1}$ (Hoffman et al. 1993).
[5]Rumen degradable protein (% of total crude protein); calculated as described by Ørskov and McDonald (1979).
[6]Rumen undegradable protein (% of total crude protein); calculated as 1 − RDP.

mm screen; Model 4; Arthur H. Thomas), and composited by 42-d period for determination of CP, NDF, and acid detergent fiber (ADF). Feed samples were analyzed for dry matter (DM; AOAC, 1996), ADF (Goering and Van Soest 1970), and NDF (Robertson and Van Soest 1981) using procedures modified for use in an Ankom 200 Fiber Analyzer (Ankom Technology Corp), N (Leco CN-2000; Leco Corp), and organic matter [OM; AOAC 1990). Cow body weight and BCS was independently measured every 42 d following an overnight shrink (16 h) by three trained observers. The same technicians were used throughout the experiment.

Statistical Analysis. Cow performance data were analyzed as a randomized complete block design (Cochran and Cox 1957) using the MIXED procedure of SAS (SAS Institute. Inc). The model included the effects of block and treatment. Data were analyzed using pen (treatment) as the random variable. Orthogonal contrasts (unsupplemented vs. alfalfa and Russian knapweed; alfalfa vs. Russian knapweed) were used to partition specific treatment effects.

RESULTS AND DISCUSSION

A major impediment in livestock production exists in the Intermountain West because early senescing, cool-season plants lose nutritional quality early in the fall and remain low in quality throughout the fall and winter. Compounding this problem, hay production in the United States has decreased significantly in recent years. For example, the total number of hectares harvested for hay in the United States declined from 24.2 million in 2010 to 22.8 million in 2012 (Crop Production 2012 Summary; USDA National Agricultural Statistics Service 2012). As a result, total hay production decreased from 132 million metric tons to less than 108 million metric tons over the same time period. The decreased production has resulted in greater hay prices, which poses a serious economical challenge for cattle producers. The need for less expensive forages for supplementation is substantial. One such potential feedstuff might be Russian knapweed. This rhizomatous perennial invasive weed grows in dense monocultures on some of the most accessible and productive range and wild land in the West (Whitson 1999).

Hay Quality

The nutritional quality of the hard fescue seed straw, alfalfa, and Russian knapweed is provided in Table 1. Hard fescue hay was poor quality. Russian knapweed hay was of fair quality, and alfalfa was premium quality.

Ruminal Degradation of Alfalfa and Russian Knapweed

We noted no difference ($P \geq 0.07$) between alfalfa and Russian knapweed for the A (soluble fraction; total pool disappearing at a rate too rapid to measure), B (degradable pool that disappeared at a measureable rate), and C (undegradeable pool) fractions of NDF (Table 2). However, the rate of NDF disappearance was almost 60% greater for alfalfa ($P < 0.05$) and the lag time (period until disappearance of NDF began) was almost 2 h less for alfalfa ($P < 0.05$), compared with Russian knapweed.

The soluble N pool was greater for alfalfa ($P = 0.002$), with Russian knapweed having greater degradable (B fraction) and undegradable (C fraction) N pools ($P < 0.010$). However, the rate of ruminal N degradation was not influenced by forage source ($P = 0.50$). In addition, alfalfa had greater RDP and effective N degradability ($P < 0.01$) while Russian knapweed had more RUP ($P < 0.001$).

Many of the ruminal degradation parameters of NDF and N in alfalfa and Russian knapweed are similar. Also, the first consideration when balancing a diet for mature beef cattle consuming low-quality forages is normally to address a deficiency of RDP (NRC 2000). This is to maximize ruminal fermentation and production of microbial protein, the primary source of N flowing to the small intestine of grazing ruminants (Hannah et al. 1991; Köster et al. 1996; Bohnert et al. 2002a). Consequently, even though alfalfa had greater RDP and effective degradability of N compared with Russian knapweed, both forges would make excellent protein supplements for beef cattle. For example, in our study, the RDP content of alfalfa and Russian knapweed was 96% and 92%, respectively. The RDP of some commonly used protein supplements for beef cattle consuming low-quality forages are 66% (soybean meal), 48% (dried distillers grains), 57% (cottonseed meal), and 68% (canola meal) based in information from NRC (2000). Cool-season forages have shown to have increased RDP over warm-season forages and this might explain the high RDP of both knapweed and alfalfa (Bohnert et al. 2011). Therefore, Russian

Table 3. Effects of alfalfa and Russian knapweed supplementation of low-quality, hard fescue straw offered to midgestation beef cows.

Item	Treatment[1]			SEM[2]	*P* value	
	Control	Alfalfa	Knapweed		Control vs. Supplemented	Alfalfa vs. Knapweed
Initial wt., kg	500	512	506	8.8	0.41	0.70
Final wt., kg	481	555	548	5.9	< 0.001	0.47
Wt. change, kg	−19	43	42	6.28	< 0.001	0.87
Initial BCS[3]	5.3	5.3	5.4	0.06	0.72	0.74
Final BCS	4.2	5.6	5.6	0.81	< 0.001	0.47
BCS change	−1.1	0.3	0.2	0.07	< 0.001	0.28
Hard fescue straw offered, $kg \cdot d^{-1}$	10.2	11.0	9.8	0.32	0.60	0.03
Alfalfa or knapweed offered, $kg \cdot d^{-1}$	0.00	2.27	3.42			
Total DM[3] offered, $kg \cdot d^{-1}$	10.2	13.3	13.2	0.32	< 0.001	0.79

[1]Control = hard fescue straw provided ad libitum; Alfalfa = Control + 2.27 $kg \cdot d^{-1}$ alfalfa; Knapweed = Control + 3.42 $kg \cdot d^{-1}$ Russian knapweed. All hard fescue straw, alfalfa, and Russian knapweed values are expressed as average daily $DM \cdot cow^{-1}$.
[2]SEM indicates standard error of the mean, $n = 4$.
[3]BCS indicates body condition score; DM, dry matter.

knapweed is potentially an excellent source of RDP for beef cattle.

Cow Performance

Supplementation with protein has been shown to increase cow weight gain and BCS (Clanton and Zimmerman 1970; Bohnert et al. 2002b), forage intake and digestibility (Kartchner 1980, Köster et al. 1996), and can improve reproductive performance (Sasser et al. 1988; Wiley et al. 1991). The results of the current study agree with the studies of Clanton and Zimmerman (1970) and Bohnert et al. (2002b) that protein supplementation of low-quality forage (< 6% CP; DM basis) increases cow BCS and weight gain compared with unsupplemented controls. Final body weight of the cows was improved with supplementation ($P < 0.001$; Table 3) whereas no difference was noted between alfalfa- and Russian knapweed-supplemented cows ($P = 0.47$). The alfalfa- and Russian knapweed-supplemented cows each gained approximately 40 kg during the feeding period compared with a loss of 19 kg by the control cows ($P < 0.001$; Table 3). No difference was noted between alfalfa and Russian knapweed ($P = 0.87$). Likewise, final BCS of cows fed alfalfa or Russian knapweed increased 0.3 and 0.2, respectively, whereas unsupplemented cows lost 1.1 BCS ($P < 0.001$). Consequently, supplemented cows had the same BCS (5.6) at the end of the 84-d feeding period ($P = 0.47$) which was greater than those not supplemented (4.2; $P < 0.001$). Although this is the first study aimed at evaluating Russian knapweed as a feedstuff, the improved cow performance agrees with previous work that has demonstrated increased cow BCS and weight change with alfalfa supplementation of low-quality forages (Horney et al. 1996; Weder et al. 1999).

The quantity of hard fescue straw offered was not affected by supplementation ($P = 0.60$; Table 3); however, the quantity offered to the cows fed alfalfa was 1.2 $kg \cdot d^{-1}$ greater than that offered to cows fed Russian knapweed ($P = 0.03$). This was probably the result of the greater quantity of supplement DM (1.2 $kg \cdot d^{-1}$) provided by Russian knapweed, to account for the lower CP% compared with alfalfa, which substituted for the hard fescue straw. This was verified when the total DM offered was compared. There was no difference between alfalfa and Russian knapweed ($P = 0.79$; 13.2 $kg \cdot d^{-1}$ for each); but supplemented cows had more total DM offered than the unsupplemented control cows ($P < 0.001$). Horney et al. (1996) reported comparable results when comparing alfalfa and vegetative tall fescue hay as protein supplements to cattle consuming 4% CP tall fescue straw. They noted no supplementation effect on straw intake but reported an increase in total DM intake with supplementation. Also, they reported that fescue straw intake by steers was greater with alfalfa supplementation compared with those steers receiving tall fescue hay. The tall fescue hay had a lower CP concentration than the alfalfa (12% vs. 19%), which resulted in a substitution effect similar to that observed in the current study for Russian knapweed. It is worth noting that cows readily consumed Russian knapweed and seemed to find it highly palatable, especially compared to the basal diet (hard fescue grass seed straw). This contrasts with reports that nonharvested Russian knapweed will not be consumed by livestock because of its bitter flavor (Whitson 1999).

MANAGEMENT IMPLICATIONS

Invasive plant management will necessarily require advancing our ability to use invaders in creative ways that support the production of agricultural commodities. In addition to targeted grazing, some invasive plants might be useful as a winter feedstuff to supplement livestock fed low-quality hay. Russian knapweed hay can be safely used as a nutritional supplement for mature beef cattle consuming low-quality forages, with results similar to supplementing alfalfa when provided on an iso-nitrogenous basis. Using Russian knapweed as a nutritional supplement solves two very serious production problems by lessening the negative impacts of an invasive weed and helping to remove an impediment in livestock production systems.

LITERATURE CITED

AOAC. 1990. Official methods of analysis. 15th ed. Arlington, VA, USA: Association of Official Analytical Chemists. 1230 p.

ADAMS, D. C., AND R. E. SHORT. 1988. The role of animal nutrition on productivity in a range environment. *In:* R. S. White and R. E. Short [EDS.]. Achieving efficient use of rangeland resources. Bozeman, MT, USA: Montana Agricultural Experiment Station. p. 37–43.

BOHNERT, D. W., T. DELCURTO, A. A. CLARK, M. L. MERRILL, S. J. FALCK, AND D. L. HARMON. 2011. Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: differences in intake and digestibility. *Journal of Animal Science* 89:3707–3717.

BOHNERT, D. W., C. S. SCHAUER, M. L. BAUER, AND T. DELCURTO. 2002a. Influence of rumen protein degradability and supplementation frequency on steers consuming low-quality forage: I. Site of digestion and microbial efficiency. *Journal of Animal Science* 80:2967–2977.

BOHNERT, D. W., C. S. SCHAUER, AND T. DELCURTO. 2002b. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: cow performance and efficiency of nitrogen use in wethers. *Journal of Animal Science* 80:1629–1637.

CLANTON, D. C., AND D. R. ZIMMERMAN. 1970. Symposium on pasture methods for maximum production of beef cattle: protein and energy requirements for female beef cattle. *Journal of Animal Science* 30:122–132.

COCHRAN, W. G., AND G. M. COX. 1957. Completely randomized, randomized block, and Latin square designs. *In:* R. A. Bradley, J. S. Hunter, D. G. Kendall, and G. S. Watson, [EDS.]. Experimental designs. 2nd ed. New York, NY, USA: John Wiley & Sons. p. 95–147.

DUNCAN, C. L. 2005. Russian knapweed. *In:* C. L. Duncan and J. K. Clark [EDS.]. Invasive plants of range and wildlands and their environmental, economic, and societal impacts. Lawrence, KS, USA: Weed Sci. Soc. America. p. 8–15.

EFTHIMIADOU, A., A. KARKANIS, D. BILALIS, AND N. KATSENIOS. 2012. Cultivation of cow cockle (*Vaccaria hispanica* (Mill.) Rauschert): an industrial-medicinal weed. *Industrial Crops and Products* 40:307–311.

FADEL, J. G. 2004. Technical note: Estimating parameters of nonlinear segmented models. *Journal of Dairy Science* 87:169–173.

GOERING, H. K., AND P. J. VAN SOEST. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). Agric. Handbook No. 379. Washington, DC, USA: ARS, USDA. 20 p.

HANNAH, S. M., R. C. COCHRAN, E. S. VANZANT, AND D. L. HARMON. 1991. Influence of protein supplementation on site and extent of digestion, forage intake, and nutrient flow characteristics in steers consuming dormant bluestem-range forage. *Journal of Animal Science* 69:2624–2633.

HERD, D. B., AND L. R. SPROTT. 1986. Body condition, nutrition and reproduction of beef cows. Texas Agric. Ext. Serv. Bull. 1526 11 p.

HOFFMAN, P. C., S. J. SIEVERT, R. D. SHAVER, D. A. WELCH, AND D. K. COMBS. 1993. In situ dry matter, protein, and fiber degradation of perennial forages. *Journal of Dairy Science* 76:2632–2643.

HORNEY, M. R., T. DELCURTO, M. M. STAMM, R. K. BAILEY, AND S. D. BRANDYBERRY. 1996. Early-vegetative tall fescue hay vs. alfalfa hay as a supplement for cattle consuming low-quality roughages. *Journal of Animal Science* 74:1959–1966.

KARTCHNER, R. J. 1980. Effects of protein and energy supplementation of cows grazing native winter range on intake and digestibility. *Journal of Animal Science* 51:432–438.

KÖSTER, H. H., R. C. COCHRAN, E. C. TITGEMEYER, E. S. VANZANT, I. ABDELGADIR, AND G. ST-JEAN. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prarie forage by beef cows. *Journal of Animal Science* 74:2473–2481.

LANDGRAF, B. K., P. L. FAY, AND K. M. HAVSTAD. 1984. Utilization of leafy spurge (*Euphorbia esula*) by sheep. *Weed Science* 32: 348–352.

MASS, R. A., G. P. LARDY, R. J. GRANT, AND T. J. KLOPFENSTEIN. 1999. In situ neutral detergent insoluble nitrogen as a method for measuring forage protein degradability. *Journal of Animal Science* 77:1565–1571.

MERRILL, M. L., D. W. BOHNERT, D. C. GANSKOPP, D. D. JOHNSON, AND S. J. FALCK. 2008. Effects of early weaning on cow performance, grazing behavior and winter feed costs in the Intermountain West. *The Professional Animal Scientist* 24:29–34.

NRC. 2000. Nutrient requirements of beef cattle. 7th ed. Update 2000. Washington, DC, USA: National Academy Press. 232 p.

ØRSKOV, E. R., AND I. MCDONALD. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *Journal of Agricultural Science* 92:499–503.

RADOSEVICH, S. R., J. S. HOLT, AND C. M. GHERSA. 2007. Weed ecology: implications for management. 3rd ed. New York, NY, USA: John Wiley & Sons. 589 p.

ROBERTSON, J. B., AND P. J. VAN SOEST. 1981. The detergent system of analyses and its application to human foods. *In:* W. P.T. James and O. Theander [EDS.]. The analysis of dietary fiber. New York, NY, USA: Marcell Dekker. p. 123–158.

SASSER, R. G., R. J. WILLIAMS, R. C. BULL, C. A. RUDER, AND D. G. FALK. 1988. Postpartum reproductive performance in crude protein-restricted beef cows: return to estrus and conception. *Journal of Animal Science* 66:3033–3039.

SHELEY, R. L., S. M. LAUFENBERG, J. S. JACOBS, AND J. BORKOWSKI. 2007. Restoring species richness and diversity in a Russian knapweed (*Acroptilon repens*)-infested riparian plant community using herbicides. *Weed Science* 55:311–318.

SIMMONS, R. G. 1985. Northwest area noxious weed control program—environmental impact statement. Portland, OR, USA: US Department of Interior, Bureau of Land Management. 157 p.

USDA NATIONAL AGRICULTURAL STATISTICS SERVICE. 2012. Crop Production Summary. Washington, DC, USA: United States Department of Agriculture, National Agricultural Statistics Service. 95 p.

WEDER, C. E., T. DELCURTO, T. SVEJCAR, J. R. JAEGER, AND R. K. BAILEY. 1999. Influence of supplemental alfalfa quality on the intake, use, and subsequent performance of beef cattle consuming low-quality roughages. *Journal of Animal Science* 77:1266–1276.

WENICK, J. J., T., SVEJCAR, AND R. ANGELL. 2008. The effect of grazing duration on forage quality and production of meadow foxtail. *Canadian Journal of Plant Science* 88:85–92.

WILEY, J. S., M. K. PETERSEN, R. P. ANSOTEGUI, AND R. A. BELLOWS. 1991. Production from first-calf beef heifers fed a maintenance or low level of prepartum nutrition and ruminally undegradable or degradable protein postpartum. *Journal of Animal Science* 69:4279–4293.

WHITSON, T. D. 1999. Russian knapweed. *In:* R. L. Sheley and J. K. Petroff [EDS.]. Biology and management of noxious rangeland weeds. Corvallis, OR, USA: Oregon State University Press. p. 315–322.

YOUNG, S., B. KLINGER, AND W. W. BROWN. 1970. Nigropallidal encephalomalacia in horses fed Russian knapweed (*Centaurea repens* L.). *American Journal of Veterinary Research* 31:1393–1404.