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Weaning and post-weaning performance by fall-born calves weaned on different dates from endophyte-infected tall fescue pastures managed with two different rotation frequencies

K.P. Coffey [a,*], W.K. Coblentz [b], D.H. Hellwig [c], M.P. Popp [a], T.F. Smith [a], D.S. Hubbell III [a], D.A. Scarbrough [d], J.B. Humphry [e], J.E. Turner [f], Z.B. Johnson [a], C.F. Rosenkrans Jr. [a]

[a] *Division of Agriculture, University of Arkansas, Fayetteville, AR 72701, United States*
[b] *USDA-ARS, US Dairy Forage Research Center, Univ. of Wisconsin Marshfield Agric. Exp. Stn., 8396 Yellowstone Dr., Marshfield, WI 54449, United States*
[c] *Berea College, Berea, KY 40404, United States*
[d] *126 Jessie Dunn, Northwestern Oklahoma State University, Alva, OK 73717, United States*
[e] *Humphry Environmental, Inc., Fayetteville, AR 72702, United States*
[f] *Mountain Research Station, Dept. of Anim. Sci., North Carolina State University, 239 Test Farm Rd., Waynesville, NC 28786, United States*

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Abstract

A number of studies have reported performance by spring-calving cows grazing *Neotyphodium*-infected fescue [E+, *Lolium arundinaceum* (Schreb.) Darbysh.], but post-weaning calf performance from the majority of those studies is limited. Furthermore, both pre- and post-weaning information pertaining to fall-calving cows and their calves grazing E+ is particularly limited. A 3-year study was initiated in April 2000 near Batesville, AR (USA) to investigate the impact of rotational management (twice monthly vs. twice weekly) program and weaning date [mid-April (EARLY) vs. early June (LATE)] on production of fall-calving cow-calf pairs grazing E+ overseeded with ladino (*Trifolium repens* L.), and red clover (*Trifolium pretense* L), lespedeza (*Lespedeza stipulacea* Maxim.), and crabgrass (*Digitaria sanguinalis* (L.) Scop.). A secondary objective of the study was to evaluate calf performance both at weaning and after weaning until either breeding of the heifers or slaughter of the steers. Calves weaned later had greater ($P<0.05$) actual weaning weights, but weaning date × year interactions were detected ($P<0.05$) for most measurements at weaning. Weight loss during a simulated transport and sale, as well as the days required to regain the lost weight were lower ($P<0.05$) by EARLY than by LATE in 2 of 3 years, and intake (kg DM/100 kg BW) was higher by EARLY than by LATE in 2 of 3 years. Antibody titers to infectious bovine rhinotracheitis and bovine virus diarrhea measured prior to vaccination and at weaning were greater ($P<0.05$) from EARLY than from LATE. Heifer weight at breeding was greater ($P<0.05$) from LATE than from EARLY in 1 year and numerically greater ($P\geq0.11$) from LATE in the other 2 years. Initial and final feedlot BW and gain did not differ ($P\geq0.16$) among previous treatments in 2 of 3 years. Therefore, carryover effects of weaning date or rotational grazing on calves previously grazing E+ tall fescue may be mitigated during a subsequent backgrounding period such that impacts on subsequent breeding or feedlot performance is minimized.
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Keywords: Tall fescue; Endophyte; Post-weaning performance

* Corresponding author. Tel.: +1 479 575 2112; fax: +1 479 575 7294.
E-mail address: kcoffey@uark.edu (K.P. Coffey).

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1. Introduction

Cow/calf pairs (Gay et al., 1988; Peters et al., 1992; Sanson and Coombs, 2003), and stocker cattle (Thompson et al., 1993; Paterson et al., 1995) grazing *N. coenophialum*-infected tall fescue (E+) exhibited reduced BW gains, but these reductions in weight gain may not be consistent across seasons within a year (Crawford et al., 1989; Thompson et al., 1993). In our previous work, weight gain differential between steers grazing E+ and those grazing fescue with a low infection (no detectable ergovaline) with *N. coenophialum* was greater during the period between mid-May and mid-June than between mid-April and mid-May (Coffey et al., 2001), likely due to increasing ergovaline concentrations during late spring (Rottinghaus et al., 1991). Therefore, weaning fall-born calves earlier in the spring should reduce their exposure to tall fescue toxins and thereby improve their long-term performance. However, during the cow/calf phase of the present study (Coffey et al., 2005), fall-born calves weaned in early June were heavier at the June weaning date than calves weaned in mid-April and moved to non-toxic pastures, and the June-weaned calves had greater gain between the April and June weaning dates than those weaned in April. No advantage in calf weights was detected from a twice weekly compared with a twice monthly rotational grazing system. Body weight gain by calves grazing E+ pastures has been consistently lower compared with calves grazing non-toxic pastures, but the effects of grazing E+ on subsequent animal performance have been variable (Cole et al., 2001b; Hancock et al., 1988; Coffey et al., 1990; Lusby et al., 1990). Furthermore, weaning age and post-weaning management also may impact long-term calf performance (Myers et al., 1999a,b; Thrift and Thrift, 2004; Sexton et al., 2005). Our objective was to investigate the impacts of our previous management (2-cell vs. 8-cell rotational management and mid-April vs. early June weaning dates) on weaning and post-weaning performance by fall-born calves weaned from *N. coenophialum*-infected tall fescue overseeded with legumes and crabgrass.

2. Materials and methods

All animal procedures were approved by the University of Arkansas Institutional Animal Care and Use Committee Project numbers. 98010 and 01016. Pregnant cows $n=60$) of primarily Angus breeding were stratified by age and weight and allocated randomly to one of eleven pasture groups in April 2000. Groups were then allocated to one of 11 pastures with established stands of E+ that ranged between 4 and 6.5 ha in size. Additional adjacent pasture area was established to E+ in the fall of 2000 and added to the grazing area in April 2002 to produce a total of twelve 6.5-ha pastures. Additional pregnant cows of comparable age, breeding, and BW to those already grazing in the study were added to the trial in April 2002. Pasture facilities were located near Batesville, AR (USA) and all cows were mated to Gelbvieh bulls. A stocking rate of 1.0 cow/ha was maintained throughout the entire study. Pastures were allocated randomly to one of four pasture or calf management treatments in a 2×2 factorial treatment arrangement (Table 1). Treatments consisted of dividing each pasture area into either two or eight paddocks and rotating cows to a fresh paddock either twice weekly or twice monthly. Within each of the rotation schedules, calves were weaned either in mid-April (189±14.9 [SD] days of age) or early June (243±15.7 [SD] days of age). A full description of pastures, fertility, forage quality and species composition, and cow performance was reported previously (Coffey et al., 2005).

The Gelbvieh×Angus calves received vaccinations against seven *Clostridium* strains (Alpha 7™; Boehringer Ingelheim Animal Health, Inc., Missouri, USA), infectious bovine Rhinotracheitis (IBR), bovine virus diarrhea (BVD), parainfluenza (PI_3), bovine respiratory syncytial virus (BRSV), *Haemophilus somnus*, and five strains of *Leptospira* (Elite 9-HS™; Boehringer Ingelheim Animal Health, Inc.) at 28 days prior to weaning, and were re-vaccinated at 14 days prior to weaning against all but the *Clostridium* strains. Blood samples were collected at the time of the initial vaccination via jugular venipuncture into vacuum blood collection tubes for serum separation containing a gel and clot activator (Vacutainer® product no. 367985, Becton Dickinson, Inc. New Jersey, USA).

Calves were gathered beginning at approximately 0800 on their designated weaning date, separated from their dams, weighed, and then transported approximately 39 km to a local livestock auction facility. The shipping date was selected to coincide with a normal sale date at the auction facility so other cattle would be present and the cattle on the present study would be exposed to activities at the auction facility that would mimic a normal sale day. Calves were penned without feed or water until

Table 1
Treatment structure for an experiment to evaluate the effect of rotation frequency and weaning date on calf weaning and post-weaning performance and blood measurements

Weaning date	Forage management	No. of replications	Grazing duration [a]	Rest duration
mid-April	Two rotations/month	3	14 days	14 days
early June	Two rotations/month	3	14 days	14 days
mid-April	Two rotations/week	2–3 [b]	3–4 days	24–25 days
early June	Two rotations/week	3	3–4 days	24–25 days

[a] Grazing and rest durations are for paddocks within each experimental pasture.
[b] Two pasture replicates were used for the 2000 and 2001 grazing seasons, and three replicates were used in the 2002 grazing season.

approximately 2100, then were moved through the auction ring and weighed, and then returned to a pen with water but no feed. Calves were returned to the research station by 1100 the following day, weighed, treated for internal parasites with moxidectin (Cydectin®; Fort Dodge Animal Health, Iowa, USA), and blood samples were gathered via jugular venipuncture into tubes designated for trace mineral analyses (Vacutainer® product no. 369737), tubes with EDTA for whole blood hemograms (Vacutainer® product no. 366643), and tubes for serum separation containing a gel and clot activator (Vacutainer® product no. 367985). Calves were then placed in drylot pens and offered alfalfa hay ad libitum along with 0.9 kg of cracked corn for a 21-days receiving period. During this period, calves were weighed at either 3 or 4-days increments. These weights were used to calculate the number of days required for the calves to reach their original weaning weights. For the purpose of analysis and further discussion, the entire weaning period was divided into 3 phases: weaning phase 1 (Phase 1) was the period from initial separation from their dams until the calves were weighed in the evening at the auction facility, weaning phase 2 (Phase 2) was the period from when the calves were weighed at the auction facility until they were returned to the research farm, and weaning phase 3 (Phase 3) was the ensuing 21-day drylot period.

At the end of Phase 3, calves were co-mingled and placed on bermudagrass (*Cynodon dactylon* (L.) Pers.) pastures. Calves were offered no supplemental feed other than trace mineralized salt (contained 90–95% salt, and a minimum of 0.03% Mg, 0.01% K, 100 mg/kg Co, 300 mg/kg Cu, 70 mg/kg I, 6500 mg/kg Fe, 1700 mg/kg Mn, and 2000 mg/kg Zn). The steers grazed these pastures until 12 Nov, 1 Oct, or 11 Oct, in year 1 through 3 respectively. These dates were chosen based on availability of bermudagrass forage for the calves to graze. During years 1 and 3, steers were shipped approximately 1200 km to a commercial feedlot facility in western Kansas (USA) and fed a high-concentrate finishing ration for 155 and 204 days respectively. During year 2, steers were shipped approximately 322 km to Fayetteville, Arkansas (USA) and fed a growing ration for 66 days, then fed a high-concentrate finishing ration for 112 days. The growing ration was formulated to allow calves to gain approximately 0.9 kg/days. At the end of each feedlot period, steers were harvested at a commercial slaughter facility and carcass data were collected following a 24-h chill. Heifers were retained on the experimental farm and grazed bermudagrass pastures until the time of breeding in late November.

2.1. Cell-mediated immunity

Calf cell-mediated immunity was measured *in vivo* during the first 2 years starting on day 1 post-weaning. A total of 14 calves were selected randomly within each weaning date and rotational frequency combination. These calves received an intradermal injection of 150 μg of phytohemagglutinin (PHA; Sigma Chemical, Missouri, USA) in 0.1 ml of sterile phosphate buffered saline at a pH of 7.4. The injection site was immediately posterior to the scapula. The site was shaved with surgical clippers and skinfold thickness was measured twice before and 4, 8, 12, and 24 h after injection using micrometric calipers (Fisher Scientific, Texas, USA). Measurements at each time were averaged and differences were calculated by subtracting the pre-injection measurements from each post-injection measurement.

2.2. Lab analyses

Blood samples were transported on ice and stored at 2 °C for approximately 12 h. Whole blood was analyzed for total red and white blood cell counts using an Abbott Cell-Dyne 3500 instrument (Abbott, Abbott Park, IL). Serum samples were collected by centrifugation (1200 ×*g* for 25 min). Serum samples were analyzed for antibody titers against IBR, BVD, and BRSV at the Oklahoma State University College of Veterinary Medicine Diagnostic Laboratory. Serum minerals (Zn and Cu) were determined as described previously (Ratchford-Milliken et al., 2001) using an inductively-coupled plasma emission spectrophotometer (ICP, Spectro Analytical Instruments, Inc., Massachusetts, USA).

2.3. Statistical analysis

Calf data were analyzed using PROC MIXED of SAS (version 9.1, SAS Institute, Inc. North Carolina, USA). Effects of rotational frequency, weaning date, year, sex of calf, and their associated interactions were included in the model as fixed effects. Pasture was considered a random effect. Calf response to PHA injection was analyzed using similar statistical procedures except that time of measurement was considered a repeated measurement. The group of calves from each pasture was considered the experimental unit for all treatment comparisons. When rotation frequency by weaning date, or year by rotation frequency by weaning date interactions were detected ($P<0.05$), mean separations were performed using an F-protected *t*-test.

3. Results

3.1. Weaning performance

Calves weaned EARLY weighed 59 kg less ($P<0.05$) at the time of weaning than LATE, but pasture rotation frequency did not affect ($P=0.78$) actual weaning weights (Table 2). Weight loss (kg) during Phase 1 and Phase 2, and the total weight loss during the 27-h period following separation from their dams (sum of Phases 1 and 2) was not affected ($P\geq 0.59$) by rotation frequency, but a weaning date × year effect was detected ($P<0.05$) for those weight changes. Calves weaned LATE had greater ($P<0.05$) actual weight loss during Phase 1 in year 2, greater ($P<0.05$) actual weight loss during Phase 2 in years 1 and 3, greater ($P<0.05$) total weight loss (sum of Phases 1 and 2) in years 1 and 2, and tended ($P=0.06$) to have greater total weight loss in

Table 2
Actual weaning weight and performance during the weaning period by fall-born calves weaned in mid-April or early June after grazing tall fescue pastures managed in a twice weekly or twice monthly rotation schedule [a]

Item	2 rotations/month		2 rotations/week		SE	Effect [c]
	EARLY [b]	LATE	EARLY	LATE		
Actual wean weight, kg	223	267	205	279	9.7	W, Y [d]
Weight loss, kg						
Phase 1 [e]						
3-year average	11.6	13.0	10.7	13.2	0.66	W, Y, W × Y
Year 1	12.0	11.7	11.2	11.2	0.65	
Year 2	8.4	13.9	6.6	15.2		W
Year 3	14.5	13.4	14.1	13.2		
Phase 2						
3-year average	4.9	6.9	4.3	8.3	1.04	W, Y, W × Y
Year 1	2.3	7.1	1.9	7.8	0.86	W
Year 2	7.0	5.5	6.8	7.9		
Year 3	5.3	8.0	4.2	9.2		W
Total						
3-year average	16.5	19.9	14.8	21.6	1.39	W, Y, W × Y
Year 1	14.3	18.8	12.9	19.1	1.15	W
Year 2	15.4	19.4	13.3	23.1		W
Year 3	19.8	21.4	18.3	22.4		
Weight loss, %						
Phase 1						
3-year average	5.3	4.9	5.0	4.7	0.17	Y, W × Y
Year 1	5.5	4.7	5.6	4.1	0.20	W
Year 2	3.7	5.1	3.0	5.2		W
Year 3	6.7	4.9	6.5	4.8		W
Phase 2						
3-year average	2.2	2.7	2.0	3.2	0.38	Y, W × Y
Year 1	1.0	2.9	0.9	3.1	0.33	W
Year 2	3.2	2.0	3.1	2.8		
Year 3	2.5	3.1	2.0	3.6		W
Total						
3-year average	7.4	7.4	6.8	7.7	0.40	Y, W × Y
Year 1	6.5	7.5	6.3	7.1	0.36	
Year 2	6.8	6.9	5.8	7.8		W
Year 3	9.0	7.9	8.4	8.2		
Phase 3 ADG, kg						
3-year average	0.95	0.70	1.12	0.88	0.071	R, W, W × Y
Year 1	0.89	0.87	1.15	1.00	0.086	
Year 2	0.94	0.72	0.90	0.93		
Year 3	1.03	0.50	1.31	0.71		W
Hay intake, kg/100 kg BW						
3-year average	1.8	1.6	1.9	1.6	0.07	W, Y, W × Y
Year 1	1.8	2.0	2.0	1.9	0.12	
Year 2	2.0	1.6	2.0	1.6		W
Year 3	1.7	1.3	1.7	1.3		W
Total intake, kg/100 kg BW						
3-year average	2.2	2.0	2.3	1.9	0.04	W, Y, W × Y
Year 1	2.2	2.4	2.4	2.2	0.12	
Year 2	2.4	1.9	2.4	1.9		W
Year 3	2.1	1.7	2.1	1.7		W
Recovery time, days [f]						
3-year average	10.8	22.4	7.7	18.3	3.26	W, W × Y
Year 1	9.4	24.6	6.1	16.4	2.67	W
Year 2	9.8	23.3	6.7	23.3		W
Year 3	13.3	19.2	10.2	15.1		

year 3 compared with EARLY. Rotation frequency did not impact ($P \geq 0.19$) the percentage shrink, but a weaning date × year effect was detected ($P < 0.05$) for percentage shrink during Phases 1 and 2, and total shrink during the simulated transport and sale. The percentage shrink during Phase 1 was greater ($P < 0.05$) in years 1 and 3 from EARLY, but was greater ($P < 0.05$) from LATE in year 2. Shrink during Phase 2 followed a reversed trend compared with shrink during Phase 1; shrink was greater ($P < 0.05$) from LATE in years 1 and 3, but did not differ ($P = 0.13$) in year 2 between EARLY and LATE. Total shrink during Phases 1 and 2 was greater ($P < 0.05$) in year 2 and tended ($P = 0.08$) to be greater in year 1 from LATE, but did not differ ($P = 0.17$) in year 3 between EARLY and LATE.

Daily gain during Phase 3 was 0.18 kg/day greater ($P < 0.05$) for calves managed in a twice weekly compared with a twice monthly rotation regiment when averaged across the 3-year study. Weaning date effects were not consistent across years resulting in a weaning date × year interaction. Daily gains did not differ ($P \geq 0.46$) between EARLY and LATE during the first 2 years of the study but were 0.68 kg greater from EARLY in year 3. Previous rotation frequency did not impact ($P \geq 0.30$) hay and total intake or recovery time during Phase 3, but the weaning date × year interaction was significant ($P < 0.05$) for each of these measurements. Both hay and total intake (kg/100 kg BW) during Phase 3 did not differ ($P \geq 0.54$) between weaning dates in year 1 but was greater during years 2 and 3 from EARLY. Days required to regain the weight lost during Phases 1 and 2 were impacted ($P < 0.05$) by weaning date and the weaning date × year interaction. During years 1 and 2, LATE calves required 13 and 15 days longer ($P < 0.05$) to recover their lost weight than EARLY, but recovery time was not different ($P = 0.14$) in year 3 between EARLY and LATE.

3.2. Blood and immune function measurements

Total red blood cells, hemoglobin, and hematocrit differed ($P < 0.05$) between steers and heifers, but not between weaning dates ($P \geq 0.17$) or rotation frequencies ($P \geq 0.35$; Table 3). A rotation frequency × weaning date × year interaction was detected ($P < 0.05$) for mean corpuscular volume. Mean corpuscular volume was lower ($P < 0.05$) in year 1 from EARLY managed in a twice weekly rotation than from the other treatment combinations, but did not differ across treatment combinations during year 2 ($P \geq 0.25$) or 3 ($P \geq 0.10$). Mean corpuscular hemoglobin and mean corpuscular hemoglobin concentrations were impacted by interactions involving calf sex, but were not impacted by main effects of rotation frequency ($P \geq 0.43$) or weaning date ($P \geq 0.19$) or their interaction with year ($P \geq 0.16$). Platelet counts were affected by main effects of rotation frequency and weaning date as well as their 2- and 3-way interactions with year and calf sex. Platelets were higher ($P < 0.05$) from EARLY from a twice weekly rotation than from the other treatments during year 1, but did not differ among treatment combinations during year 2 ($P \geq 0.27$) or 3 ($P \geq 0.39$).

Total white blood cell concentrations at weaning did not differ between rotation frequencies ($P = 0.40$) or weaning dates ($P = 0.71$). Likewise, the percentages of neutrophils, lymphocytes, and monocytes did not differ between rotation frequencies ($P \geq 0.68$) or weaning dates ($P \geq 0.17$). The percentage of eosinophils was affected by the rotation frequency × weaning date × year interaction. During year 1, eosinophil concentrations were highest from EARLY calves managed in a twice weekly rotation. However, during years 2 and 3, LATE had higher eosinophil concentrations than EARLY within each pasture rotation regime. The weaning date × year interaction was detected ($P < 0.05$) for the proportion of basophils; LATE had higher ($P < 0.05$) basophil concentrations in year 3, but not in the other years ($P \geq 0.15$). The neutrophil to lymphocyte ratio did not differ between rotation frequencies ($P = 0.80$) or weaning dates ($P = 0.48$).

Serum concentrations of Cu and Zn were affected ($P < 0.05$) by the weaning date × year interaction but not ($P \geq 0.66$) by pasture rotation frequency (Table 4).

Notes to Table 2:

[a] At weaning, calves were removed from their dams, transported directly to a local auction facility and held without feed or water, weighed at approximately 2100 h, held overnight in pens with water, and transported back to the research station.

[b] EARLY = calves weaned in mid-April (average of 189 ± 14.9 [SD] days of age), LATE = calves weaned in early June (average of 243 ± 15.7 [SD] days of age).

[c] W = weaning date effect ($P < 0.05$); R = rotation effect ($P < 0.05$); Y = year effect ($P < 0.05$).

[d] These data were reported previously (Coffey et al., 2005).

[e] Phase 1 was the period from initial separation of calves from their dams until the calves were weighed in the evening at the auction facility, Phase 2 was the period from when the calves were weighed at the auction facility until they were returned to the research farm, and Phase 3 was the ensuing 21-day drylot period.

[f] The number of days required for calves to regain their original weaning weight.

Table 3
Hemogram measurements at weaning from fall-born calves weaned in mid-April or early June after grazing tall fescue pastures managed in a twice weekly or twice monthly rotation schedule [a]

Item [b]	2 rotations/month		2 rotations/week		SE	Effect [d]
	EARLY [c]	LATE	EARLY	LATE		
RBC, 10^6/μL	10.9	10.8	11.2	11.2	0.30	S × Y
Hemoglobin, g/dL	14.2	14.3	14.2	14.6	0.23	S
HCT, %	38.6	39.0	38.5	40.0	0.62	S
MCV, fL	35.5	36.3	34.8	35.9	0.62	R × S, R × W × Y, S × Y, W × S × Y
Year 1	35.7 [e]	36.3 [e]	32.9 [f]	36.1 [e]	0.80	
Year 2	35.5	36.2	35.7	36.7		
Year 3	35.3	36.5	35.9	34.8		
MCH, pg	13.1	13.3	12.8	13.1	0.26	S × Y, R × S × Y, W × S × Y
MCHC, g/dL	36.8	36.6	36.8	36.6	0.15	Y, S × Y
Platelets, 10^3/μL	564	506	768	537	42.1	R, W, S^x, Y^x
Year 1	583 [f]	491 [f]	1242 [e]	576 [f]	68.6	
Year 2	568	463	450	469		
Year 3	542	565	613	566		
Total white blood cell, 10^3/μL	9.7	9.5	9.3	9.1	0.46	Y
% of white blood cells						
Neutrophils	49.1	45.9	50.1	46.4	2.54	
Lymphocytes	42.0	45.6	40.6	44.7	2.51	
Monocytes	7.6	7.0	7.7	6.9	0.49	R × S, Y
Eosinophils	0.5	1.0	1.0	1.1	0.14	R, R × S, W × S, R × Y, W × Y, R × W × Y
Year 1	0.5 [f]	0.5 [f]	2.3 [e]	0.6 [f]	0.23	
Year 2	0.5 [f]	1.3 [e]	0.4 [f]	1.6 [e]		
Year 3	0.6 [f]	1.1 [e]	0.5 [f]	1.2 [e]		
Basophils	0.8	0.6	0.6	0.8	0.29	W × Y
Year 1	0.9	0.5	0.4	0.4	0.47	
Year 2	1.0	0.3	0.9	0.2		
Year 3	0.6	0.9	0.6	1.9		W
Neutrophil: Lymphocyte	1.3	1.5	1.4	1.7	0.35	

[a] Measurements were taken upon arrival at the research station following removal from their dams, transport directly to a local auction facility and held without feed or water until approximately 2100 h, held overnight in pens with water until the following morning, then transported back to the research station.

[b] RBC = red blood cells; HCT = hematocrit; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration.

[c] EARLY = calves weaned in mid-April (average of 189 ± 14.9 [SD] days of age), LATE = calves weaned in early June (average of 243 ± 15.7 [SD] days of age).

[d] W = weaning date effect ($P<0.05$); R = rotation effect ($P<0.05$); Y = year effect ($P<0.05$); S = sex of calf effect; S^x = main effect and all interactions involving calf sex were significant ($P<0.05$); Y^x = main effect and all interactions involving year were significant ($P<0.05$).

[e,f] Means within a row without a common superscript letter differ ($P<0.05$).

Serum Cu concentrations were greater ($P<0.05$) from EARLY than from LATE in year 3, but not in year 1 or 2 ($P \geq 0.13$). Serum concentrations of Zn did not follow a consistent pattern. Serum Zn concentrations were greater ($P<0.05$) in year 1 from LATE than from EARLY, were lower ($P<0.05$) from LATE than from EARLY in year 2, and did not differ ($P=0.33$) between weaning dates in year 3.

Antibody titers to IBR on day 0 were higher ($P<0.05$) from EARLY than from LATE, but rotation frequency did not affect ($P=0.41$) antibody titers to IBR. Antibody titers to IBR at 28 days after vaccination remained higher ($P<0.05$) from EARLY compared with LATE, but the change in IBR titers following vaccination was greater ($P<0.05$) from LATE. Antibody titers to BVD on day 0 were likewise greater ($P<0.05$) from EARLY compared with LATE. Antibody titers for BVD on day 28 following vaccination were affected by the rotation frequency × weaning date × year interaction ($P<0.05$), but the change in titers between day 0 and 28 after vaccination only tended ($P<0.10$) to be affected by the same interaction. Antibody titers to BVD measured at 28 days after vaccination were highest ($P<0.05$) in year 1 from EARLY calves managed in a twice weekly rotation. Early-weaned calves from a twice monthly rotation had greater ($P<0.05$) BVD titers

at 28 days than LATE from a twice weekly rotation but did not differ ($P=0.22$) from that of LATE managed in a twice monthly rotation. In years 2 and 3, EARLY had greater ($P<0.05$) antibody titers to BVD than LATE.

A measuring time effect was detected ($P<0.05$), but no measuring time by treatment interactions were detected ($P\geq 0.48$) for cell-mediated immune response measured as the change in skinfold thickness following an injection with PHA. Therefore these values were averaged across sampling times. The change in skinfold thickness was greatest ($P<0.05$) from LATE managed in a twice weekly rotation schedule than from the other treatment combinations, which did not differ ($P\geq 0.53$).

3.3. Post-weaning performance

Previous rotation frequency did not impact ($P=0.79$) heifer weight at breeding, but the weaning date × year interaction was detected ($P<0.05$) for this measurement (Table 5). Late-weaned heifers were heavier ($P<0.05$) at breeding in year 1 and were numerically heavier in year 2 ($P=0.11$) and year 3 ($P=0.58$). Pregnancy rate did not follow the trend of heifer weight at breeding and tended ($P<0.10$) to be greater from heifers rotated twice monthly compared with those rotated twice weekly, but weaning date did not impact ($P=0.83$) heifer pregnancy rate.

Initial and final feedlot weight and feedlot gain (Table 6) were impacted by the rotation frequency × weaning date × year interaction ($P<0.05$). The majority of this impact occurred during year 1 in which LATE from a twice weekly rotation had heavier ($P<0.05$) initial feedlot weight than EARLY from either rotation frequency, and EARLY steers from the twice weekly rotation had the lowest ($P<0.05$) final feedlot weight. Feedlot gains were greater ($P<0.05$) from EARLY steers from a twice monthly rotation compared with EARLY or LATE steers from the twice weekly rotation. These trends were not observed in year 2 or 3 ($P\geq 0.15$).

Table 4
Serum copper, zinc, and antibody titers, and inflammatory response of fall-born calves weaned in mid-April or early June after grazing tall fescue pastures managed in a twice weekly or twice monthly rotation schedule [a]

Item	2 rotations/month		2 rotations/week		SE	Effect [c]
	EARLY [b]	LATE	EARLY	LATE		
Serum Cu, mg/L	0.6	0.5	0.6	0.5	0.03	W, W × Y
Year 1	0.5	0.5	0.6	0.6	0.04	
Year 2	0.6	0.6	0.6	0.5		
Year 3	0.7	0.5	0.7	0.4		W
Serum Zn, mg/L	1.2	1.0	1.1	1.0	0.07	Y, W × Y, R × W × S
Year 1	0.7	0.9	0.5	0.9	0.08	W
Year 2	1.4	0.9	1.4	1.0		W
Year 3	1.4	1.3	1.3	1.3		
IBR titers, $\log_2$						
Days 0	1.8	1.3	2.0	1.4	0.16	W, Y
Days 28	1.7	1.5	1.8	1.4	0.12	W, Y
Days 28–days 0	−0.0	0.2	−0.2	0.1	0.10	W
BVD titers, $\log_2$						
Days 0	5.3	4.2	6.3	4.0	0.31	W
Days 28	4.7	3.2	5.5	3.2	0.31	W, R × W × Y
Year 1	4.7 [e]	3.9 [ef]	7.0 [d]	3.0 [f]	0.49	
Year 2	4.7 [d]	2.9 [e]	4.9 [d]	3.2 [e]		
Year 3	4.8 [d]	2.8 [e]	4.6 [d]	3.3 [e]		
Days 28–days 0	−0.6	−1.1	−0.8	−0.9	0.17	
Skinfold difference after PHA, mm [g]						
Average across times	2.8 [e]	2.9 [e]	2.9 [e]	3.7 [d]	0.13	R, W, R × W, T

[a] Serum Cu, Zn, antibody titers (day 28) and inflammatory response measurements were taken upon arrival at the research station following removal from their dams, transport directly to a local auction facility and held without feed or water until approximately 2100 h, held overnight in pens with water until the following morning, then transported back to the research station. Initial antibody titers were measured 28 days prior to weaning (day 0) immediately prior to initial vaccinations.

[b] EARLY = calves weaned in mid-April (average of 189 ± 14.9 [SD] days of age), LATE = calves weaned in early June (average of 243 ± 15.7 [SD] days of age).

[c] W = weaning date effect ($P<0.05$); R = rotation effect ($P<0.05$); Y = year effect ($P<0.05$); S = sex of calf ($P<0.05$); T = measuring time effect ($P<0.05$).

[d,e,f] Means within a row without a common superscript letter differ ($P<0.05$).

[g] Inflammatory response was measured as the change in skinfold thickness following an intradermal injection of 150 μg of phytohemagglutinin.

Table 5
Breeding weight and pregnancy rate of heifers that had been weaned in mid-April or early June after grazing tall fescue pastures managed in a twice weekly or twice monthly rotation schedule

Item	2 rotations/month		2 rotations/week		SE	Effect [b]
	EARLY [a]	LATE	EARLY	LATE		
Number of heifers exposed	21	19	20	22		
Heifer breeding weight, kg	277	305	269	306	12.9	W, Y, W × Y
Year 1	271	338	268	322	11.8	W
Year 2	302	317	281	323	12.4	
Year 3	258	263	258	273	11.4	
Pregnancy rate, % [c]	52.4	63.2	40.0	36.4		

[a] EARLY = calves weaned in mid-April (average of 189 ± 14.9 [SD] days of age), LATE = calves weaned in early June (average of 243 ± 15.7 [SD] days of age).
[b] W = weaning date effect ($P<0.05$); Y = year effect ($P<0.05$).
[c] Pregnancy rate was analyzed using chi-square analysis.

The rotation frequency × weaning date × year interaction was detected ($P<0.05$) for hot carcass weight and dressing percentage (Table 7). Similar to that of feedlot weights and gain, differences in hot carcass weights and dressing percentage among previous treatment combinations was observed during year 1 but not in the other years. During year 1, both hot carcass weight and dressing percentage were lower ($P<0.05$) from EARLY steers managed with a twice weekly rotation. Rib fat and kidney, heart, and pelvic fat were not affected ($P\geq 0.56$) by weaning date, but steers from a twice weekly rotation had greater ($P<0.05$) rib fat in year 2 than steers from a twice monthly rotation. Longissimus area did not differ ($P\geq 0.36$) across treatment combinations in year 1, but was lower ($P<0.05$) from EARLY managed previously with a twice weekly rotation than from the other treatment combinations in year 2. These differences in longissimus area were negated ($P\geq 0.39$) when they were expressed on a kg of hot carcass weight basis. Marbling score varied across years ($P<0.05$), but was not affected by previous rotation frequency ($P=0.88$) or weaning date ($P=0.80$). The weaning date × year interaction tended ($P<0.10$) to affect USDA quality grades,

Table 6
Feedlot gain by steers that had been weaned in mid-April or early June after grazing tall fescue pastures managed in a twice weekly or twice monthly rotation schedule

Item	2 rotations/month		2 rotations/week		SE	Effect [b]
	EARLY [a]	LATE	EARLY	LATE		
Initial feedlot weight, kg	261	275	239	292	10.5	W, Y, W × Y, R × W × Y
Year 1	267 [d]	291 [cd]	203 [d]	321 [c]	12.7	
Year 2	286	286	278	300		
Year 3	230	248	237	254		
Final feedlot weight, kg	586	587	536	602	17.3	R × W × Y
Year 1	595 [c]	594 [c]	463 [d]	615 [c]	20.5	
Year 2	589	558	553	596		
Year 3	573	610	592	596		
Feedlot gain, kg	324	312	297	310	9.0	Y, R × W × Y
Year 1	328 [c]	304 [cd]	264 [d]	292 [d]	11.7	
Year 2	302	273	273	296		
Year 3	343	358	354	341		
Feedlot gain, kg/day	1.80	1.72	1.64	1.71	0.193	Y, R × W × Y
Year 1	2.10 [c]	1.95 [cd]	1.71 [d]	1.87 [d]	0.062	
Year 2	1.62	1.46	1.46	1.58		
Year 3	1.69	1.76	1.75	1.68		

[a] EARLY = calves weaned in mid-April (average of 189 ± 14.9 [SD] days of age), LATE = calves weaned in early June (average of 243 ± 15.7 [SD] days of age).
[b] W = weaning date effect ($P<0.05$); R = rotation effect ($P<0.05$); Y = year effect ($P<0.05$).
[c,d] Means within a row without a common superscript letter differ ($P<0.05$).

Table 7
Carcass measurements from steers that had been weaned in mid-April or early June after grazing tall fescue pastures managed in a twice weekly or twice monthly rotation schedule

Item	2 rotations/month		2 rotations/week		SE	Effect [b]
	EARLY [a]	LATE	EARLY	LATE		
Hot carcass weight, kg	379	380	337	387	12.4	Y, R × Y, W × Y, R × W × Y
Year 1	384 [b]	381 [b]	275 [c]	394 [b]	15.73	
Year 2	382	359	353	384		
Year 3	370	399	382	383		
Dressing %	62.1	62.1	60.1	61.6	0.46	R, Y, R × W × Y
Year 1	62.0 [c]	61.5 [c]	57.4 [d]	61.4 [c]	0.68	
Year 2	62.3	61.9	60.9	61.9		
Year 3	62.1	62.8	61.9	61.5		
Rib fat, cm	1.1	1.2	1.1	1.3	0.16	R × Y
Year 1	1.3	1.4	0.7	1.4	0.23	
Year 2	1.0	0.9	1.8	1.3		R
Year 3	1.0	1.2	0.9	1.1		
KPH, %	2.2	2.2	2.1	2.1	0.15	
Longissimus area, cm^2	91.4	92.0	84.5	90.5	3.07	R × W × Y
Year 1	97.8	96.5	85.8	94.4	5.04	
Year 2	91.9 [c]	88.3 [c]	73.1 [d]	90.1 [c]		
Year 3	84.4	91.1	94.5	87.0		
Longissimus area, cm^2/100 kg carc. weight	24.3	24.3	25.5	23.7	0.98	Y
Marbling score [e]	372	382	371	374	26.01	Y
USDA quality grade [f]	8.2	8.3	8.9	8.2	0.50	Y
USDA yield grade	2.3	2.4	2.0	2.6	0.15	

[a] EARLY = calves weaned in mid-April (average of 189 ± 14.9 [SD] days of age), LATE = calves weaned in early June (average of 243 ± 15.7 [SD] days of age).
[b] W = weaning date effect ($P<0.05$); R = rotation effect ($P<0.05$); Y = year effect ($P<0.05$).
[c,d] Means within a row without a common superscript letter differ ($P<0.05$).
[e] 300 = $Slight^0$, 400 = $Small^0$, 500 = $Modest^0$, etc.
[f] $Select^0$ = 8.0, $Select^+$ = 9.0, etc.

and USDA yield grade tended ($P<0.10$) to be greater from LATE compared with EARLY steers.

4. Discussion

Our overall objective in this study was to investigate the impacts of our pre-weaning management (2-cell vs. 8-cell rotational management and mid-April vs. early June weaning dates) of fall-born calves weaned from *N. coenophialum*-infected fescue on various measurements taken at weaning and during the post-weaning period until either breeding of heifers or harvest of steers. Numerous years by main effect interactions were detected, thereby complicating the evaluation of these pre-weaning management techniques. However, numerous trends were apparent throughout the experiment, which serve as focal points for subsequent discussion.

While it is apparent that grazing E+ pastures has significant negative impacts on calf weaning weights (Peters et al., 1992; Schmidt and Osborn, 1993; Sanson and Coombs, 2003), published research reporting other measurements at weaning, and during the post-weaning period is limited. Brown et al. (1999) reported that post-weaning grazing and feedlot performance was not different between spring-born calves weaned from E+ pastures compared with those weaned from bermudagrass pastures. In the present study, all calves were exposed to E+ pastures, but different management strategies were imposed to reduce exposure to tall fescue toxins. One such strategy, increasing the rotation frequency, was used in an attempt to increase the persisence of other non-toxic forages to dilute the E+ toxins; however, this strategy did not alter species composition (Coffey et al., 2005). Based on both actual measurements of plant concentrations of ergovaline, a potentially toxic chemical (Rottinghaus et al., 1991), and seasonal animal performance in response to toxin loads in tall fescue (Crawford et al., 1989; Thompson et al., 1993; Coffey et al., 2001), a second strategy was employed in which calves were weaned in mid-April with the goal of reducing their exposure to tall fescue toxins relative to calves grazing tall fescue through late May.

Total weight loss during transport to a local auction facility was greater from the heavier calves (LATE) in 2 of the 3 years, but this differential was negated when expressed as a percentage of body weight in the third year. Others reported inconsistent weight loss during

transport of calves exposed to varied levels of E+ toxins (Cole et al., 2001b). Daily gain during the receiving period (Phase 3) was greater from EARLY compared with LATE during the third year and total intake during the receiving period was greater from EARLY compared with LATE during the second and third years. In previous studies, calves moved from E+ pastures to non-toxic pastures had reduced intake for at least 10 days (Stuedemann et al., 1989), but animal gains during initial periods in a feedlot environment following removal from E+ pastures has been variable (Lusby et al., 1990; Cole et al., 2001b). In the present study, calves weaned LATE required more days to regain their weight lost during the transport and simulated auction in 2 of 3 years. This extended recovery time is likely a function of a number of variables. Although daily gain differed only during year 3, LATE calves generally lost more total weight consumed less hay during the receiving period, thereby indicating they were likely under more stress during the weaning process.

Oliver et al. (2000) reported reduced mean corpuscular volume, mean corpuscular hemoglobin, and concentrations of eosinophils from calves grazing E+ compared with those grazing non-toxic pastures. In the present study, concentrations of eosinophils were greater from EARLY calves rotated twice weekly in year 1, but greater from LATE in years 2 and 3 compared with EARLY. Increased concentrations of eosinophils are associated normally with response to allergic reactions and parasitism, but may also be elevated in response to chronic infections or during recovery from acute infections (Voigt, 2000). Conversely, Oliver et al. (2000) postulated that reduced concentrations of eosinophils from steers grazing E+ pastures resulted from suppressed immune function in those steers. This was apparently not the case in the present study since concentrations of eosinophils were greater from calves with prolonged exposure to E+ (LATE) compared with EARLY in years 2 and 3. Other blood cellular measurements were affected only minimally by rotation frequency or weaning date in the present study, likely because these management options had minimal impacts on forage species composition (Coffey et al., 2005). Serum Cu concentrations at weaning in the present study were low in all instances (McDowell, 2003). Others have reported declining concentrations of serum Cu (Coffey et al., 1992; Saker et al., 1998; Oliver et al., 2000), plasma Cu (Stoszek et al., 1979; Saker et al., 1998), or ceruloplasmin (Coffey et al., 1992; Saker et al., 1998) from cattle grazing E+ pastures. The differences in serum Cu between EARLY and LATE observed in year 3 could be the culmination of continued exposure of the cows to tall fescue throughout the 3-year study, and/or the prolonged exposure of LATE during the grazing season of year 3. Oliver et al. (2000) reported no effect of grazing E+ on serum Zn concentrations, but Cole et al. (2001a) reported reduced serum Zn from calves grazing E+ compared with those grazing bermudagrass pastures. In the present study, it is apparent that simply removing calves earlier in the grazing season did not provide sufficient reduction in exposure to E+ toxins for differences in serum Cu and Zn to occur.

A number of studies have addressed the impact of E+ on immune function of cattle. Saker et al. (1998, 2001) reported reduced monocyte immune cell function of cattle grazing E+ compared with those grazing non-toxic forages. However, Rice et al. (1997) reported that calves grazing E+ pastures had similar to increased humoral immune responses to intramuscular injections with concanavalin A and sheep red blood cells than calves grazing non-toxic pastures. Filipov et al. (1999) reported enhanced sensitivity to an intravenous injection of lipopolysaccharide from calves grazing E+ pastures compared with those grazing non-toxic pastures. Also, Cole et al. (2001a) reported similar IBR antibody titers from calves grazing E+ pastures compared with those grazing non-toxic pastures. In the present study, antibody titers to IBR and BVD prior to vaccination declined with delayed weaning, likely because of advanced age of the calves rather than because of continued exposure to fescue toxins for the 2 months between weaning dates. Inflammatory response to PHA injection also was inconsistent in that LATE calves managed using a twice weekly rotation had greater inflammatory response than the other treatment combinations, and there were no differences among the other treatment combinations. Therefore, it is unlikely that rotational management or earlier weaning to reduce calf exposure to tall fescue toxins impacted immune function of the calves in this study.

For the majority of the cow-calf producers in the Ozark Highlands, the most important measurement economically is calf weight at weaning; however post-weaning animal performance ultimately has additional direct or indirect economic implications for these cow-calf producers. The perception that calves weaned from E+ pastures will also exhibit carryover effects during subsequent production phases often reduces the price that buyers are willing to pay for these calves. Numerous studies have evaluated feedlot performance following a grazing period on E+ fescue. Generally, cattle that previously grazed E+ pastures showed improved gain during a subsequent feedlot period (Coffey et al., 1990;

Lusby et al., 1990; Allen et al., 2001; Cole et al., 2001b), but some studies have reported no improvement (Hancock et al., 1987) in feedlot gain or even reduced feedlot gain (Hancock et al., 1988) by calves that grazed E+ pastures previously. However, each of these studies used yearling cattle during post-weaning evaluations on E+ or other non-toxic forages. In the present study, calves had access to E+ pastures only during the pre-weaning period and half of the calves (EARLY) also were weaned early, further reducing their exposure to E+. In a study using spring-calving cows (Brown et al., 1999), calves weaned following grazing E+ gained more during the winter while grazing either wheat pasture or native range than calves weaned from bermudagrass pastures. However, animal weights at the end of the feedlot period or at the end of the winter backgrounding period were still less generally for calves exposed to E+, although their backgrounding or feedlot growth was greater than that of calves that grazed non-toxic forages previously. In the present study, heifer weight at breeding was greater from LATE in only 1 of the 3 years, and did not differ between weaning dates in the other 2 years. Furthermore, steer weight at the time of feedlot placement was affected by the rotation frequency × weaning date interaction in 1 year and did not differ among treatments during the other 2 years. This indicates that the increased exposure to E+ resulting from a later weaning date did not cause long-term negative impacts on animal weights.

Since increased exposure to E+ was likely not a significant factor affecting post-weaning animal performance, it is possible that weaning age influenced subsequent animal gains by steers and heifers in the present experiment. In a previous study, calves weaned at 7 months of age had greater gains during a 14-days weaning period as well as during the first 28 days in a feedlot facility compared with calves weaned at 4 months of age (Smith et al., 2003). Story et al. (2000) also reported higher feedlot gains by calves weaned at an average of 270 days of age compared with those weaned at 210 or 150 days of age. Conversely, Myers et al. (1999a,b) reported higher feedlot gains by early-weaned calves compared with those weaned at a more conventional age (213 to 231 days of age). The discrepancy in these studies may rest on the post-weaning management, which may impact long-term calf performance (Myers et al., 1999a,b; Thrift and Thrift, 2004; Sexton et al., 2005).

5. Conclusions

Calving season may have considerable implications for post-weaning calf performance, as spring-born calves would be weaned normally in the fall when ambient temperatures would be cooler compared with weaning fall-born calves during periods of increasing ambient temperature. In most instances, limited information is available pertaining to post-weaning performance by calves weaned from fall-calving cows. Numerous decisions must also be considered for cattle grazing endophyte-infected tall fescue. Weaning fall-born calves from endophyte-infected tall fescue at 189 days appears to provide some benefits to the calf at the time of weaning, such as higher antibody titers prior to vaccination and reduced transportation shrink compared with weaning at a later age, but long-term implications of early weaning may not be manifested in improved body weight of those calves at times subsequent to weaning.

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