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Effects of a High-Voltage Direct-Current Transmission Line on Beef Cattle Production

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Two herds of beef cattle were maintained beneath a ±500 kV direct-current transmission line during a 30-month period, and were compared with two similar herds maintained away from the transmission line. Exposures of animals under the line were five to 30 times greater than those of control animals, depending on the parameter of interest, with average exposure magnitudes of 5.6 kV/m, 4.1 nA/m^2, and 13 k ions/cm^3, respectively, for electric field, ion current, and density of ions. Productivity and health status of cows and calves were similar between lines and control treatments. Mean body mass of cows increased with maturity, from 438 kg in 1985 to 496 kg in 1987. Calf gain averaged 0.93 kg per head per day. No unusual sources of mortality were observed. Based on this confinement study, beef cattle permitted to graze in the vicinity of a high-voltage, direct-current transmission lines are not expected to experience any decrease in frequency of conception, calving, growth rate, or survival.

Key words: electric field, ion current, ion concentration, average daily gain, reproduction, cow, calf

INTRODUCTION

Most electrical energy is distributed as alternating current (ac); however, direct current (dc) is a more efficient way to deliver large quantities of energy over long distances. Because of recent improvements in technology, interest in high-voltage dc (HVDC) transmission has increased. Along with the expanded use of this technology has come a concern for the possibility of adverse health effects associated with the electrical environment of dc transmission lines.

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The purpose of our study was to examine the effects of a dc transmission line on beef cattle production on a scale commensurate with an operating feedlot or ranch. To accomplish this purpose, pens large enough to maintain 50 cow-calf pairs were constructed directly under the ±500-kV Pacific Intertie dc transmission line in central Oregon. We recorded breeding activity, conception rate, calving, calving interval, body mass of calves at birth, body mass at weaning, and mortality of cattle and calves exposed to dc transmission line electrical environment over a 30-month period.

The electric field at the surface of the conductors of ac and dc high-voltage transmission lines causes ionization of air molecules. In the case of dc lines, the constant field at the conductor's surface results in negative ions being repelled from the negative conductor and positive ions from the positive conductor. The electrical environment at ground level created by repulsion of ions consists of an electric field (due to the voltage on the conductors and charges on the ions), a concentration of ions, and an ionic current to ground. These three effects of the HVDC line were the exposure variables of interest in our study. The levels and polarities of these variables depend on the distance from the line and location relative to the positive and negative transmission-line conductors. Exposure estimates for the cattle in this study were based on long-term measurements of the electrical quantities and on observations of animal locations within the pens.

Environmental concerns have been raised in the past with regard to effects of dc lines on plants and animals. The Minnesota portion of the ±400-kV CU project lines met with strong opposition [Bailey et al., 1982], and at least one proposed dc line has been delayed in litigation [Lee et al., 1985]. Operating experience with existing lines, and limited biological research with dc fields and air ions, have indicated no adverse effects from HVDC lines [Lee and Burns, 1984]. However, biological and environmental data directly applicable to dc lines are limited, and few field studies on the effects of dc lines on mammals have been conducted. Griffith [1977] found fewer rodents under the ±400-kV dc Pacific Intertie than away from it. He attributed differences in rodent density to changes in plant communities resulting from line construction. Performance and reproduction records of dairy cows living on farms near a ±400-kV line in Minnesota were evaluated [Martin et al., 1986], and no observable effects by the line on production parameters were noted.

Most studies of air-ion effects have been confined to laboratory rodents, and the results of these studies are mixed [Charry, 1984, 1987]. The Minnesota Science Advisors, who were convened to review the scientific literature on possible effects of the aforementioned dc line in that state, concluded that the evidence for biological effects of air ions is inconsistent [Bailey et al., 1982]. In an update of their initial 1982 report, they stated that there was little likelihood that either chronic or acute exposures to air ions or dc fields cause adverse effects [Bailey et al., 1986]. Another recently published review of the literature on effects of air ions on people and animals concluded that reported effects of air ions are generally small in magnitude, and transient (effects were no longer present after exposure to air ions was stopped) [Charry, 1987].

The reviews cited above generally concluded that short-term adverse effects of air ions or dc fields are unlikely. However, research on long-term effects and on actual exposures to dc lines is limited. Therefore, the present study was undertaken to investigate both these areas in the context of an agricultural feeding operation.

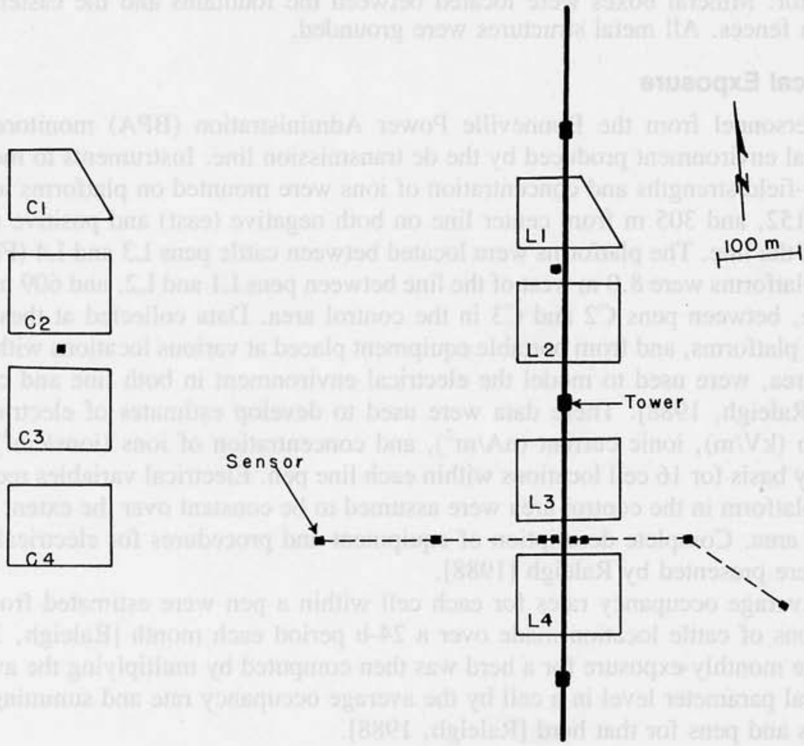

Fig. 1. Site plan of pens constructed under the transmission line, showing location of electrical monitoring sensors, transmission line, and towers. Identical pens were constructed in the control area, 615 m west of the transmission line. Feed bunks were centered under the line on the south end of the pens.

METHODS

Study Site and Facilities

The study area was in central Oregon on the Crooked River National Grassland, approximately 19 km southeast of Madras. Average annual precipitation in Madras is approximately 239 mm, and respective mean high/low temperatures for January and July are 4/−7 and 31/7 °C. Wind at this location is generally from the west.

The study was conducted under and west of the ±500-kV Pacific Intertie (Fig. 1). The transmission line was first energized at ±400 kV in 1970, but was increased to ±500 kV in 1985, prior to initiation of our study. Line and control treatments were located, respectively, directly beneath and 615 m west of the transmission line.

Two pens were established under each of two spans of the transmission line, with three 1.3-ha pens (122 × 104 m) having their long axis perpendicular to the line. The fourth pen was a trapezoid because of topographic restrictions and was 0.7 ha in area. Identical pens were constructed in the control-treatment area. Pens were constructed of railroad-tie posts 1.4 m high and galvanized iron mesh livestock panels. Feed bunks, centered on the south side of each pen, were 59 m long. Two heated, automatic water fountains were located in the center of each pen, one under each conductor. Mineral boxes were located between the fountains and the eastern and western fences. All metal structures were grounded.

Electrical Exposure

Personnel from the Bonneville Power Administration (BPA) monitored the electrical environment produced by the dc transmission line. Instruments to measure electric-field strengths and concentration of ions were mounted on platforms located 8, 23, 152, and 305 m from center line on both negative (east) and positive (west) sides of the line. The platforms were located between cattle pens L3 and L4 (Fig. 1). Other platforms were 8.0 m west of the line between pens L1 and L2, and 609 m from the line, between pens C2 and C3 in the control area. Data collected at these permanent platforms, and from portable equipment placed at various locations within the study area, were used to model the electrical environment in both line and control areas [Raleigh, 1988]. These data were used to develop estimates of electric-field strength (kV/m), ionic current (nA/m^2), and concentration of ions ($ions/cm^3$) on a monthly basis for 16 cell locations within each line pen. Electrical variables recorded at the platform in the control area were assumed to be constant over the extent of the control area. Complete description of equipment and procedures for electrical analyses were presented by Raleigh [1988].

Average occupancy rates for each cell within a pen were estimated from observations of cattle location made over a 24-h period each month [Raleigh, 1988]. Average monthly exposure for a herd was then computed by multiplying the average electrical parameter level in a cell by the average occupancy rate and summing over all cells and pens for that herd [Raleigh, 1988].

Cattle

Two-hundred-five cow-calf pairs were purchased from one ranch for the study. The cows were cross-bred (Hereford × Angus × Charlois) range cattle, varying in age from 2 to 7 years. Cows were paired on the basis of age, body mass, condition score, breed, birth date of calves, and sex of calves. Members of each pair were randomly assigned either to the line or control treatment, providing 100 animals per treatment. Within each treatment herd of 100 cows, the 50 youngest animals were designated as Herd A, while the 50 oldest cows were assigned to Herd B. Each herd was maintained in a separate pen, and herds were in matching pens for both treatments; i.e., if line-treatment Herd A cattle were in pen L1, control Herd A was maintained in pen C1. Herds were rotated among the four pens in each respective treatment about every second month.

Cattle were fed a basic chopped-hay ration of alfalfa (20 percent protein) and bluegrass straw (6 percent protein), with the alfalfa:straw ratio adjusted to meet nutritional requirements of the animals at each stage of production. Feed was distributed in bunks twice daily, and excess feed was weighed back weekly. Mineral mixture was available at all times.

Breeding was by 12 half-sibling Shorthorn bulls; six bulls were randomly assigned to each treatment. Bulls were tested for semen motility prior to, midway through, and at the end of the breeding season. Two bulls were placed with each herd during breeding, and they were rotated biweekly with two rested bulls from their respective treatments. Frequency and date of estrus were recorded by visual observation throughout the breeding period. Bulls were kept in an empty pen in their respective treatment condition when not with the cows. Conception rate was determined by pregnancy testing approximately 45 days after breeding.

Production

Calves were born before initiation of our study in 1985, so initial body masses of cows and calves were recorded when the cattle first arrived on the site. Thereafter, body mass of cows and calves was recorded at 28-day intervals, except during, and just after, calving. Cow and calf body mass was measured within 24 h after parturition, and again 20 days post partum for cows. Body mass of all cattle was measured at weaning in October. Weaning percentage of calves is reported as number of calves weaned divided by number of cows exposed to bulls. Average daily gain (ADG; kg/day) was computed by determining body mass change between birth and weaning, and dividing by days of age. Since body mass at birth was not known in 1985, ADG was reported as simply weaning mass divided by days of age. Adjusted weaning mass (AWM) was calculated to place animals of an equivalent-age basis, and to place heifer growth rate on an equivalent basis with bull calves [Raleigh, 1988].

All animals that died during the course of the study were examined at necropsy to determine causes of death. If necessary, tissue samples of various organs were collected and examined in the Oregon State University Veterinary Diagnostic Laboratory. At the end of the study, line and control herds were mixed and rated for body condition by a standard 1-to-9 condition rating scale [Beverly, 1981]. Cows were then slaughtered, carcasses were weighed, and evaluation was performed by USDA inspectors and the project veterinarian in accord with standard USDA procedures.

Analysis

Body mass and performance data were analyzed by analysis of variance (ANOVA) by using a general linear models procedure [SAS Institute Inc., 1988], with Herds A and B considered to be blocks. Years and line and control conditions were treatments [Steele and Torrie, 1980]. When ANOVAs indicated significance, means were separated by Least Significant Difference tests. Weaning percentage differences between line and control herds were analyzed by paired t, with pairs being Herds A and B. Conception data were analyzed by Chi-square tests [SAS Institute Inc., 1988].

RESULTS AND DISCUSSION

Electrical Exposure

Estimated total exposures for an average cow in line Herds A and B and the control herd are presented in Table 1. Electric-field ion-current, and ion-density exposure were greatest in late spring and summer, during the breeding period. During this study, negative-polarity exposures were of greater magnitude than were positive-polarity exposures. Lowest-exposure magnitudes occurred during November 1985 and October 1986 when maintenance was performed on the dc system, resulting in periods of low or zero voltage on the line.

The ratio of line-to-control-treatment electric-field exposure was about 33:1 for the magnitude of the field, and about 10:1 for the positive field. Total accumulated electric-field exposures for line A and B Herds differed by less than 3%.

Total accumulated ion-current magnitude exposure of about 3,700 (nA/m^2) days

TABLE 1. Average Total Electrical Exposures for the Line and Control Treatments for Both the A and B Herds: April 1985 to September 1987 (913 Days)

	Herd A			Herd B			Control
Parameter	Magnitude	Positive	Negative	Magnitude	Positive	Negative	Site[a]
Electric-field (kV/m)days	5,068	+1,531	−3,537	4,964	+1,531	−3,432	153
Ion-current (nA/m^2)days	3,760	+845	−2,915	3,671	+821	−2,845	—[b]
Ion-density (k $ions/cm^3$)days	12,051	+4,534	−7,517	11,886	+4,528	−7,357	445

[a]Electrical parameters were recorded at one platform in the control area and were assumed to be constant over the extent of the control area.
[b]Ion currents in control area were too low to measure reliably.

corresponds to exposure at an average magnitude of about 4.1 nA/m^2 for the entire project. Total accumulated ion-density magnitude of about 12,000 (k $ions/cm^3$) days corresponds to exposure at an average magnitude of about 13-k $ions/cm^3$ over the entire time period of the study.

Most exposures occurred in the negative-ion environment and in the south half of the pens near feed bunks. Depending on the parameter under consideration, exposures in the line area were five to 30 times greater than exposures in the control area. Ion-current exposure during the study, scaled to body mass, was estimated at 1.8 (nAh)/g for line cattle, compared with 0.25 to 21 (nAh)/g for laboratory animal studies [Raleigh, 1988].

Body Mass of Cows

The mean mass of cows at calf weaning did not differ between treatments ($F = 0.49$, $P = .61$, df = 1,1) (Table 2). However, year effects were significant ($F = 11.18$, $P = .08$, df = 1,2) because cows in both line and control treatments had significantly lower body mass in 1985 than in 1986 or 1987. The observed increase over time is attributed to two causes. First, cows in the A Herds were 2 and 3 years of age in 1985, and were still growing; and second, the physical condition of all cattle improved in 1986 and 1987, because of the consistently high quality of the diet received during the study.

Calf Production

Pregnancy rate of line and control cattle did not differ ($\chi^2 = 0.043$, $P = .8$, df = 1), averaging 94.3 percent during the study. Averages for line and control herds were 95 and 94 percent, respectively. In 1985, pregnancy rates were 86 and 82 percent, respectively, for line and control herds. Conception rate for both treatments was 100 percent in 1986, and in 1987 line and control herds reached 98 and 100 percent, respectively. Three sets of twins were born in 1986, two in line herds and one in control. Four sets of twins were conceived in 1987, two in each treatment condition.

Calving was normal for the two calf crops born on the site, with no unusual problems. In 1986 one cow in the line treatment needed minor assistance. In 1987,

TABLE 2. Average Mass (kg), at the Time of Calf Weaning, for Cows Maintained Under, and Away From, a ±500-kV dc Transmission Line Over a 30-Month Period

	Line			Control		
	N	kg	SD	N	kg	SD
Herd A—1985	50	417	43.0	50	413	42.3
Herd A—1986	50	511	58.0	49	499	51.4
Herd A—1987	49	483	61.3	48	501	54.9
Herd B—1985	50	462	50.4	50	459	48.2
Herd B—1986	50	518	61.7	49	505	50.0
Herd B—1987	49	496	64.5	49	500	51.0
		M = 482			M = 480	

one control animal had a breech birth, two cows in the line treatment needed minor assistance with single births, and one line-treatment cow had poorly positioned twins.

Calves conceived in 1985 and 1986 were weaned in 1986 and 1987, respectively. Weaning percentages averaged 90 percent those years and did not differ between treatments (t = 1.4142, P = .25, df = 3). Weaning percentages were 99, 84, and 96 percent, respectively, in 1985, 1986, and 1987. The 1986 percentage reflects the number of non-pregnant cattle in 1985. The high weaning percentages observed here probably resulted from intensive animal management.

Average date of birth (ADB) across years was March 31. ADB did not differ between line or control treatment herds (F = 0.62, P = .5, df = 1,1); however, ADB differed among years (F = 73.18, P = .01, df = 1,2). Calf ADB was April 4, April 21, and March 6 in 1985, 1986, and 1987, respectively, with differences each year resulting from changes in starting date of the breeding season. Breeding in 1985 began on June 15, after cows were allotted to treatments. In 1986, breeding began on April 21, 25 days after the first calf was born. Cows on both treatment conditions exhibited estrus soon after calving, and no differences were observed in behavior of bulls, with an average of 1.9 and 2.0 services per head in respective line and control herds.

Adjusted weaning masses (AWM) of calves increased between 1985 and 1987 (F = 11.8, P = .08, df = 1,2), from 190 to 243 kg, respectively (Table 3). Calf AWM did not differ between line and control treatments (F = 0.28, P = .69, df = 1,1). Across years, respective line and control AWM were 213 and 214 kg. The yearly increases in weaning mass were expected because improvement in calf performance generally occurs as younger dams become more mature [Neumann and Snapp, 1969]. The average daily gain (ADG) by calves was 0.9 kg/head/day, and did not differ between line and control treatments (F = 0.01, P = .94) (Table 4). Calf ADG varied less than 0.2 kg/day across all herds. In terms of total mass of beef weaned during the study, line and control herds produced, respectively, 56,018 and 54,628 kg of saleable product.

Herd Health

Mortality during the study was 0.73, 0.79, and 3.36 percent in 1985, 1986, and 1987, respectively. One bull, five cows, and 14 calves died during the study, and mortality was evenly distributed between line and control herds (Table 5). The bull

TABLE 3. Adjusted Weaning Mass (AWM) (kg) of Calves Raised Under, and Away From, a ±500-kV dc Transmission Line

	Line			Control		
	N	AWM	SD	N	AWM	SD
Herd A—1985	45	182	31.3	50	177	28.1
Herd A—1986	39	208	18.0	38	208	16.3
Herd A—1987	47	245	21.7	44	250	18.8
Herd B—1985	49	202	27.9	49	198	21.5
Herd B—1986	47	212	16.8	42	203	15.5
Herd B—1987	42	230	25.0	46	245	18.9
		M = 213			M = 214	

TABLE 4. Average Daily Gain (ADG) of Calves (kg/Day) Raised to Weaning Under, and Away From, a ±500-kV dc Transmission Line. ADG Was Calculated as Mass Gained per Day From Birth to Weaning, Except in 1985, When the Mass at Birth Was Unknown

	Line			Control		
	N	ADG	SD	N	ADG	SD
Herd A—1985	45	0.88	0.15	50	0.85	0.15
Herd A—1986	39	0.97	0.10	38	0.96	0.11
Herd A—1987	47	0.92	0.11	44	0.93	0.10
Herd B—1985	49	0.97	0.11	49	0.96	0.12
Herd B—1986	47	0.99	0.10	42	0.93	0.10
Herd B—1987	42	0.84	0.11	46	0.93	0.10
		M = 0.93			M = 0.93	

died because ingested metal perforated his stomach lining. No consistent cause of mortality was apparent for cows. Diarrhea was the single greatest cause of calf mortality. Wetter and colder weather during calving in 1987 contributed to increased health problems in calves that year, with equal losses on both treatments. Typical calf mortality prior to weaning is about 5 percent [Neumann and Snapp, 1969].

At termination of the study, cows were rated for body condition. Average condition of all cattle was 6.1 (Table 6), which is in the moderate-to-good range. Condition varied less than one point among the four herds. A condition score between 5 and 6 is desireable for breeding cattle, and indicates milk production and breeding should be satisfactory.

After condition scoring and slaughter, carcass evaluation was performed. One line cow was condemned because of adenocarcinoma, metastatic to pulmonary lymph nodes, which is rare in cattle [Sigmund, 1973]. It was not possible to tell when the condition originated in the animal. On inspection, 54 and 53 livers were condemned from control and line animals, respectively. The USDA inspector indicated that rate (55 percent) was not atypical for range livestock. These cattle had grazed wet meadows prior to the study, which may have increased the level of infestation by flukes [O'Mary and Dyer, 1974]. Scars caused by liver flukes were the most common cause of condemnation; however, no living flukes were found in any livers, indicating that the condition developed prior to the study. No other problems were noted by the

TABLE 5. Sources of Mortality of Three Classes of Beef Cattle During 1985, 1986, and 1987 When Maintained Under, and Away From, a ±500-kV dc Transmission Line

	No. of animals						
	1985		1986		1987		Class
Cause of death	Line	Control	Line	Control	Line	Control	total
Bulls							1
Traumatis reticulitis*	1						
Cows							5
Traumatis reticulitis				1			
Hemorrhagic enteritis				1			
Brisket disease			1				
Kidney infection						1	
Injuries from ther cattle					1		
Calves							14
Viral pneumonia		1					
Bloat	1						
BVD in dam					2		
Intestinal rupture during delivery					1		
Breech delivery						1	
Hair ball impaction						2	
Diarrhea					3	3	

*Traumatis reticulitis occurs when cattle ingest small pieces of metal which can later migrate through the stomach wall and cause peritonitis.

TABLE 6. Mean Body Condition Rating of Mature Beef Cows, Based on a Nine-Point Scale (1 = Low, 9 = High)*

	Line			Control		
	N	Score	SD	N	Score	SD
Herd A	50	6.18	0.86	48	5.90	0.81
Herd B	49	5.86	1.02	49	6.49	0.89
		M = 6.02			M = 6.20	

*Line cattle were maintained in pens beneath a ±500-kV dc transmission line for 30 months. Control cattle were mantained in similar pens 615 m from the lines.

inspectors. Carcass mass of line and control animals averaged, respectively, 233 (SE = 12) and 234 (SE = 10.7) kg.

CONCLUSIONS

Exposure levels experienced by animals under the line were five to 30 times greater than that of animals maintained in pens away from the line. Ion-current exposure levels per unit mass were estimated at about 1.8 (nAh)/g, assuming a 450-kg animal, and were considered similar to exposure of animals in other laboratory studies.

Results of this field study, covering 3 years of production, do not indicate any deleterious effects on beef cattle production or health attributable to HVDC exposure. Differences were observed for calf performance across years; however, the differences were similar between treatments. Differences in cow and calf performance can be attributed to nutrition and increasing maturity of dams.

Mortality of animals was not greater than expected for beef cattle, and no trends in causes of mortality developed for either treatment. This study was designed as a "worst case" in that cattle were maintained directly beneath a ±500-kV transmission line continuously for 30 months, from June 1985 to September 1987. It indicates that free-ranging livestock, not confined to the vicinity of a transmission line right of way, would not likely experience any decrease in production.

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