ATTACHMENT R: STUDIES EVALUATING POTENTIAL IMPACTS TO LIVESTOCK FROM ELECTRIC TRANSMISSION LINES

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Exposure of Pregnant Dairy Heifer to Magnetic Fields at 60 Hz and 30 μT

J.F. Burchard,[1]* D.H. Nguyen,[2] and H.G. Monardes[1]

[1]Department of Animal Science, McGill University, Sainte-Anne de Bellevue, Que., Canada
[2]Institut de Recherche d'Hydro-Québec (IREQ), Varennes, Que., Canada

Thirty-two pregnant Holstein heifers weighing 499 ± 45 kg, at $3.1 \pm .7$ months of gestation and 21 ± 2.0 months of age were confined and exposed to 30 μT magnetic fields (MFs) and a 12 h light/12 h dark light cycle. The heifers were divided into two replicates of 16 animals. Each replicate was divided into two groups of eight animals each, one group the non-exposed and the second, the exposed group. The animals were subjected to the different treatments for 4 weeks. After 4 weeks, the animals switched treatment, the exposed group becoming the non-exposed group and vice versa. Then the treatment continued for 4 more weeks. Catheters were inserted into the jugular vein, and blood samples were collected twice a week to estimate the concentration of progesterone (P4), melatonin (MLT), prolactin (PRL), and insulin-like growth factor 1 (IGF-1). Feed consumption was measured daily. The results indicated that exposure of pregnant heifers to MF similar to those encountered underneath a 735 kV high tension electrical power line for 20 h/day during a period of 4 weeks produces slight effects. This is evidenced by statistically significant higher body weight (1.2%), higher weekly body weight gain (30%), and decreases in the concentration of PRL (15%) and IGF-1 (4%) in blood serum. The absence of abnormal clinical signs and the absolute magnitude of the significant changes detected during MF exposure, make it plausible to preclude any major animal health hazard. Bioelectromagnetics 28:471–476, 2007.

Key words: magnetic field; ELF; dairy cattle; prolactin; melatonin; progesterone; IGF-1

INTRODUCTION

Previous studies have shown that dairy cattle exposed to worst case scenario electric and magnetic fields (EMFs), as found directly under 735 kV AC power lines carrying around 2000 A, increased their feed consumption, milk yield, progesterone (P4) concentrations in blood plasma [Burchard et al., 1996] and estrous cycle length [Burchard et al., 1998b]. These EMFs have also been associated with changes in the concentrations of macro and trace elements in blood plasma [Burchard et al., 1999] and neurotransmitter metabolites in cerebrospinal fluid [Burchard et al., 1998c] and slight variations in plasma thyroxine [Burchard et al., 2006] in dairy cattle. Lactating pregnant dairy cows exposed to EMF (60 Hz, 10 kV/m, and 30 μT) had increased blood prolactin (PRL) and decreased diurnal melatonin (MLT) concentrations [Rodriguez et al., 2004]. Non-pregnant dairy cattle exposed to EMF (60 Hz, 10 kV/m, and 30 μT) during estrous cycle did not show changes in PRL and a decreasing tendency in diurnal MLT [Rodriguez et al., 2004]. Exposure of pregnant dairy cattle to a 60 Hz, 10 k/V electric field (EF) did not have any effect on MLT, P4, PRL or insulin-like growth factor I (IGF-I) [Burchard et al., 2004].

The above-mentioned research established mild effects of EMF on some physiological variables in dairy cattle. Exposure of dairy cattle to EF did not replicate these effects. The experiment reported herein is an attempt to discern if the effects observed with EMF exposure may be attributable to the magnetic field (MF) component.

MATERIALS AND METHODS

Animal Care and Exposure

All the experimental procedures comply with the good laboratory practices (GLP) recommended by the

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*Correspondence to: J.F. Burchard, Department of Animal Science, McGill University, 21111 Lakeshore Road, Sainte-Anne de Bellevue, Que. H9X 3V9, Canada.
E-mail: javier.burchard@mcgill.ca

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guide to the care and use of experimental animals of the Canadian Council on Animal Care [CCAC, 1984].

Thirty-two pregnant Holstein heifers weighing 499 ± 45 kg, at 3.1 ± .7 months of gestation and 21 ± 2.0 months of age (Table 1), obtained from commercial herds in the province of Québec, were confined to wooden metabolism cages in exposure chambers for the duration of the experiment. These chambers were designed and constructed to resemble commercial tie stall barns prevailing in the province of Québec. Further description of the MF exposure chamber can be found elsewhere [Burchard et al., 1999; Nguyen et al., 2005]. The animals were exposed to artificial light with a cycle of 12 h of light with 178 lx (PANLUX Gossen # 3C10075, Nürnberg, Germany) followed by 12 h of darkness. Every day during the study, lights in the chambers were turned on and off at 04:00 and 16:00 h, respectively.

The animals were fed twice daily, to meet NRC requirements [NRC, 2001]. Water and feed were available ad libitum. Test animals were fed a total mixed ration consisting of a mix of forages, and a commercial supplement containing 12% crude protein and required minerals and vitamins.

This study was carried out in two replicates; the first and second replicate were executed between October and December, 2001 (16 animals) and between February and March, 2004 (16 animals), respectively. The MF exposure chamber was 15 m long, 10 m wide, and 3 m high; contained eight wooden metabolism cages, each housing one animal. Measurements of the MF were performed with probes installed at three locations in the chamber and were recorded with a data acquisition system every 5 min. The field intensities obtained by the probes were relative values and were calibrated before the experiments with a commercial probe, the Holaday model 3604 (Holaday Industries, Inc., Eden, MN). The software controlling the input voltage and current for MF generation in the exposure chamber, also acquired field values every 5 min to assess the stability and uniformity of the field intensities in the exposure and control rooms. The intensity of the MF chosen for this experiment resembles the exposure encountered by animals standing continuously under a 60 Hz 735-kV power line carrying 2000 A. The control chamber had the same design as the MF exposure chamber without the coil to generate MF. A detailed description of the exposure chamber has been published elsewhere [Nguyen et al., 2005].

The animals were housed in the MF and control chambers for a 6-day-adaptation phase immediately before the initiation of treatment. Treatment exposure was conducted using a cross-over design. A total of thirty-two heifers were divided into two replicates of 16 animals each. Each replicate was divided into two groups of eight animals, one group becoming the non-exposed and the second group, the exposed group. The animals were subjected continuously to the different treatments for 4 weeks, except during the time required for cleaning, feeding and sampling. After 4 weeks of treatment, the animals switched rooms; the non-exposed group was moved to the MF exposure chamber and the exposed group was moved to the control chamber, the MF were deactivated and a period of 1 week without any treatment was allowed. Subsequently, treatments were applied for 4 additional weeks.

Blood and Feed Sampling

Catheters were inserted into the jugular vein 3 days before blood sampling. After sedation, (Rompun, Bayvet, Etobicoke, Ont., Canada), an angiocatheter (intracath IV catheter, Vialon, Becton & Dickinson cat # 3831621 Oakville, Ont., Canada) was inserted into the jugular vein and fixed to the skin and left in place for the duration of the experiment. The procedure for the installation and maintenance of the jugular catheters has been described elsewhere [Burchard et al., 2004].

Blood samples were collected on Tuesdays at 09:00 and on Thursdays at 09:00, 10:00, 11:00, and 12:00 AM for the duration of experiment. Blood samples were collected into plain vacutainer tubes, stored in the refrigerator for 12 h to allow coagulation, then centrifuged at 1000*g* for 15 min. The serum was

TABLE 1. Body Weight, Age, and Gestation Length (Mean ± Standard Deviation) of the Animals at the Beginning of the Study for Each Replicate and Treatment Group

Replicate	Group	Weight (kg)	Age (months)	Gestation (months)
1	Off–on	500.63 ± 43.30	20.25 ± .71	2.86 ± .78
	On–off	502.50 ± 44.70	20.13 ± .42	2.78 ± .82
2	Off–on	482.75 ± 49.80	20.88 ± 1.89	3.36 ± .66
	On–off	511.75 ± 49.90	20.38 ± 1.30	3.29 ± .42
Both	Off–on	491.69 ± 46.00	20.56 ± 1.41	3.11 ± .75
	On–off	507.13 ± 46.00	20.25 ± 1.88	3.03 ± .68

stored at −20 °C pending analysis. Dry matter intake, a measure of feed consumption, was measured daily and the animals were weighed weekly. Feed samples were collected on Tuesday and Thursday mornings, composited into a weekly sample and then analyzed to estimate their nutritional components.

Blood Analyses

Serum P4 concentrations were estimated using a solid phase radioimmunoassay (RIA) (Coat Count, Diagnostic Product Corporation, Los Angeles, CA). Serum MLT concentrations were estimated with a direct RIA previously validated [Fraser et al., 1983], using the Guilford antiserum from Stockgrand Ltd. (Guilford, Surrey, UK; batch g/s/704-6483) and tracer from Amersham Biosciences (Buckinghamshire, UK; TRK 798). Serum PRL was estimated with a double antibody RIA using iodinated PRL and a primary antibody (bPRL AFP-4835B; kindly donated by Dr. Parlow, NHPP, and NIDDK, Torrance, CA), validated previously [Miller et al., 1999]. Quantification of serum IGF-I was done with an immunoradiometric assay (IRMA) (DSL-2800 kit, Diagnostic Systems Laboratories, Inc., Houston, TX) previously validated [León et al., 2004].

Intra-assay and inter-assay variations for P4, MLT, PRL, and IGF-1 were 8.60 and 10.27%, 4.96 and 13.70%, 8.46 and 9.74%, and 2.97 and 12.91%, respectively.

Statistical Analysis

This experiment was carried out as a cross-over trial to remove the between-cow variation from the experimental error; hence, each treatment is compared on each cow [Ratkowsky et al., 1993]. Briefly, each cow was initially on one treatment, then half way through the experiment was changed over to the other treatment. The statistical analysis took into consideration the treatment cross-over design structure with repeated measurements. The design had two replicates of 16 animals each. For each replicate the animals were randomly split into two groups of eight animals each, initially assigned to one of the two treatments, and after 4 weeks the animals switched treatments. The statistical methodology is described in detail elsewhere [Burchard et al., 2004]. In order to normalize the estimations of P4, MLT, PRL, and IGF-1 concentrations, a log-transformation was applied.

RESULTS

Initial comparison of the animals revealed no differences regarding weight and age. There was a minor difference in gestation length between replicates (Tables 1 and 2). The analysis of the power of the test for variables in the study revealed that, overall, the power of the test was adequate (Table 3). For example, in the case of MLT the difference between treatments is 6% and the power of the test is 96% with 32 animals. This means that the test would yield a significant treatment effect about 96 times out of 100 on average, when the difference between treatments is 6%. The results obtained for DMI, protein and energy intake, are in agreement with the expected intake according to the nutritional requirements for dairy cattle of the National Research Council [NRC, 2001].

The control and treated animals were exposed to a horizontal MF of $.58 \pm .01$ μT or $30.5 \pm .04$ μT for an average of $20.2 \pm .43$ h/day. During the experiment, temperature and humidity in the control and exposure rooms were $17.5 \pm .04$ °C, $42 \pm .1$%; $17.8 \pm .02$ °C and $44 \pm .1$%, respectively. Globally, exposure to MF did not affect feed consumption; however, a treatment by week interaction was detected ($P = .0013$) (Table 4, Fig. 1). On week 3 DMI was 7.5% higher ($P = .025$) during exposure; however, when applying the Bonferroni correction, to avoid type I error in a multiple testing problem, this difference became a trend ($P = .097$). Body weight increased 1.2% ($P = .01$) during exposure and there was a treatment by week interaction ($P = .0001$) (Fig. 2). The average weekly body weight gain was 30% higher ($P = .012$) during exposure (Table 4, Fig. 3). Results for MLT, P4, PRL, and IGF-1 are presented in Table 5 and are in agreement with those obtained elsewhere [Mäntysaari et al., 1999; Burchard et al., 2004; León et al., 2004; Muthurama-

TABLE 2. Two-Way ANOVA With Replicate and Group Effects on Body Weight, Age, and Gestation Length

		Weight			Age			Gestation length		
Source	df	MS	*F*-value	Pr > F	MS	*F*-value	Pr > F	MS	*F*-value	Pr > F
Replicate	1	148.78	.07	.7972	1.5313	.53	.4733	2.0503	4.32	.0470
Group	1	1906.53	.86	.3610	.7813	.27	.6077	.0528	.11	.7413
Replicate × Group	1	1471.53	.67	.4215	.2813	.10	.7577	.0003	.00	.9797
Error	28	2211.03			2.8973			.4750		
Corrected total	31									

TABLE 3. Power of the Test for the Treatment Effect With an Expected Detectable Difference between Treatments

Variable	Detectable difference (%)	Power of the test (%)
Dry matter intake	10	98
Crude protein intake	10	98
Energy intake	10	96
Body weight	2	99
Weekly weight gain	30	72
Melatonin	6	96
Progesterone	7	81
Prolactin	10	78
IGFI-1	2	86

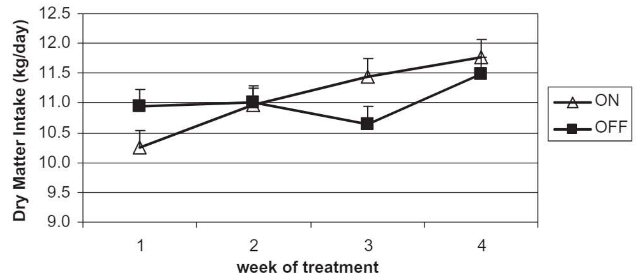

Fig. 1. Dry matter intake in pregnant dairy heifers not exposed (OFF) or exposed (ON) to 60-Hz magnetic fields (MFs).

lingam et al., 2006]. Serum concentrations of MLT and P4 did not differ between heifers exposed and not exposed to MF. Heifers exposed to MF had a 15% decrease in serum PRL (Table 5, Fig. 4). The IGF-1 ANOVA detected a MF exposure residual effect on measurements taken during the fifth experimental week (no-treatment period). Consequently, the test for treatment effect was carried out using the first 5 weeks of the experiment, where it is not possible to encounter a carry-over effect. This revealed a 4% decrease in serum IGF-1 during exposure (Table 5, Fig. 5).

DISCUSSION

The similarity of design, temperatures, humidity, and light intensity of the exposure and control rooms contributed to minimize the room factor as a confounding effect. The serum concentrations of P4 and MLT were not affected by MF exposure. Progesterone results do not agree with those obtained in similar experiments where P4 was elevated in pregnant lactating dairy cows [Burchard et al., 1996] but are in agreement with studies using non-pregnant lactating [Burchard et al., 1998b], non-pregnant non-lactating mature dairy cattle [Rodriguez et al., 2003] exposed to 10 kV/m, 30 µT EMF, and dairy heifers exposed to 10 kV/m MF [Burchard et al., 2004]. MLT has been hypothesized as the mediator of the effects caused by EMF exposure in different species [Wood et al., 1998; Takebe et al., 1999]. Mature dairy cattle exposure to EMF decreased diurnal MLT in blood plasma but did not affect nocturnal MLT. Exposure of pregnant dairy heifers to EF did not affect diurnal MLT. Simultaneous exposure to EMF resulted in increases in PRL and IGF-1 in mature cattle but not in pregnant heifers exposed only to EF [Burchard et al., 1998a, 2004; Rodriguez et al., 2004].

PRL and IGF-1 have been associated with DMI and milk production increases in dairy cattle [Petitclerc et al., 1983; Dominique et al., 1992; Dahl et al., 2000] and PRL and IGF-1 are positively correlated in dairy cattle [Nosbush et al., 1996]. Even though exposure to MF did not globally affect DMI, there was an increase of 1.2% of body weight and 30% weekly body weight gain in exposed animals. The fact that the effect of MF was not uniform during different weeks, evidenced by the treatment by week interaction, might contribute to explain this MF effect on body weight and weekly body weight gain. Simultaneous application of EF and MF increased DMI [Burchard et al., 1996; Rodriguez et al., 2002; Burchard et al., 2003] and weight gain [Rodriguez et al., 2002] in dairy cattle. Conversely, exposure to 10 kV/m EFs does not affect DMI in dairy heifers [Burchard et al., 2004]. Increases in bovine body

TABLE 4. Least-Squares Means ± Standard Error (SE) for Dry Matter Intake (DMI), Crude Protein (CP), and Energy (NeG) Consumption; Body Weight (BW) and Weekly Body Weight Gain (WBWG) in pregnant Dairy Heifers not Exposed (OFF) or Exposed (ON) to 60-Hz Magnetic Fields (MFs), and the Associated Probability Value (*P*)

Variable	MF on	MF off	*P*
DMI (kg/day)	11.11 ± .25	11.02 ± .25	.7458
CP (kg/day)	1.83 ± .04	1.81 ± .04	.7070
NeG (Mcal/day)	15.72 ± .34	15.58 ± .34	.8560
BW (kg)	561.37 ± 7.93	554.73 ± 7.93	.0102
WBWG (kg)	11.95 ± .73	9.18 ± .74	.0122

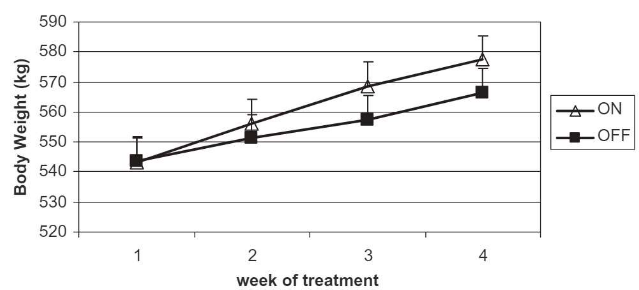

Fig. 2. Body weight in pregnant dairy heifers not exposed (OFF) or exposed (ON) to 60-Hz magnetic fields (MFs).

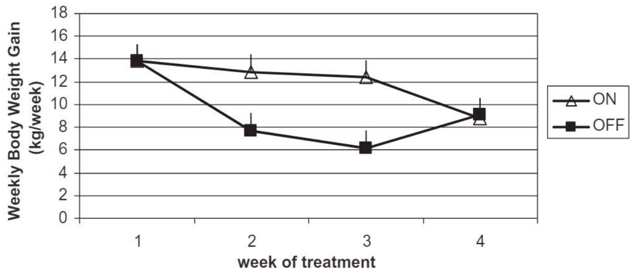

Fig. 3. Weekly body weight gain in pregnant dairy heifers not exposed (OFF) or exposed (ON) to 60-Hz magnetic fields (MFs).

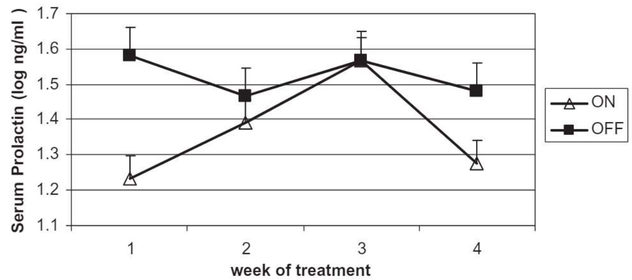

Fig. 4. Serum prolactin in pregnant dairy heifers not exposed (OFF) or exposed (ON) to 60-Hz magnetic fields (MFs).

weight are associated with increases in IGF-1 when compared to animals with restricted diets [Nosbush et al., 1996; León et al., 2004]. In the present experiment, the animals in both groups were fed normal diets and were growing normally during the whole experiment. Exposure to MF resulted in slight decreases in IGF-1 and PRL, and increases in body weight and weekly body weight gain when compared to control animals. In a similar experiment with lactating pregnant cows, EMF exposure resulted in a 4.2% greater body weight, and 9% and 31% increases in IGF-1 and PRL concentrations, respectively, compared to control animals [Rodriguez et al., 2002, 2004]. It is possible that the relatively small decreases in IGF-1 and PRL concentrations during MF exposure throughout the experimental period of time, are not enough to override the predominant effect of MF exposure on body weight observed in previous experiments. Body weight losses of 15–18% over a period of 60 days under restricted diets are associated with 50–70% reductions in IGF-1 blood concentrations [León et al., 2004]. Reductions of 17% of daily weight gain were associated with decreases of 16% and 13% in blood PRL and IGF-1, respectively in prepubertal dairy heifers [Nosbush et al., 1996]. The fact that the statistical analysis revealed a carry-over effect in the case of IGF-1 implies that the MF exposure produces some residual effects. A similar situation was suggested elsewhere in relation to PRL in EMF exposed animals [Rodriguez et al., 2004]. The duration of this residual effect cannot be determined from the data collected in this experiment. Exposure to 10 kV/m EF did not cause any change in body weight or weekly weight gain [Burchard et al., 2004]. It might be possible that the summation or interaction of the EF and MF components is necessary to elicit the responses observed in previous trials. Furthermore, the trials cited for comparison were slightly different with respect to the age, production status and reproduction condition of the cattle used, and light regime [Burchard et al., 1996, 2003; Rodriguez et al., 2002].

TABLE 5. Least-Squares Mean ± Standard Error of the Log Transformation for Melatonin (MLT), Progesterone (P4), Insulin Growth Factor 1 (IGF-1), and Prolactin (PRL) in n Pregnant Dairy Heifers not Exposed (OFF) or Exposed (ON) to 60-Hz Magnetic Fields (MFs) and the Associated Probability Value (*P*)

Variable	MF on	MF off	*P*
Melatonin (pg/ml)	3.33 ± .06	3.35 ± .06	.6757
Progesterone (ng/ml)	1.42 ± .05	1.46 ± .05	.8773
IGF-1 (ng/ml)	5.61 ± .065	5.87 ± .065	.0001
Prolactin (ng/ml)	1.37 ± .06	1.52 ± .06	.0057

CONCLUSIONS

Exposure of pregnant Holstein heifers for 20 h/day to a 30 μT MF during a period of 4 weeks produced slight effects. This is evidenced by statistically significant increases in body weight, weekly body weight gain, and decreases in the concentration of PRL and IGF-1 in blood serum. The effect of exposure was found to be residual in the case of IGF-1. Under the experimental conditions described herein, the absence of abnormal clinical signs and the absolute magnitude of the changes detected during MF exposure, make it plausible to preclude any major animal health hazard.

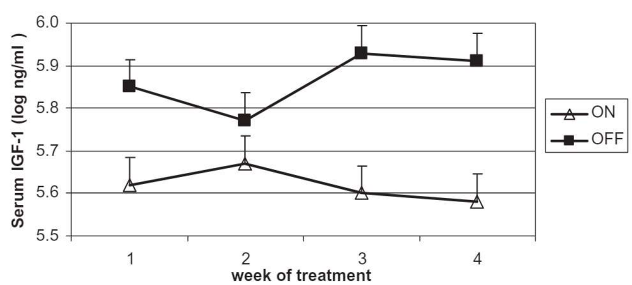

Fig. 5. Serum IGF-1 in pregnant dairy heifers not exposed (OFF) or exposed (ON) to 60-Hz magnetic fields (MFs). Due to carry-over effect only the first 5 weeks of treatment are considered.

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EFFECT OF ELECTRICAL FIELDS, IONS AND NOISE ASSOCIATED WITH HIGH VOLTAGE DC TRANSMISSION LINES ON NEARBY CATTLE AND CROPS

R. Raleigh, F. Crowe, M. Schott, and D. Bracken
Eastern Oregon Agricultural Research Center,
Oregon State University,
Burns, Oregon
Central Oregon Experiment Station, O.S.U.,
Redmond, OR
Beak Consultants, Inc.,
Portland, OR
T. Dan Bracken, Inc.,
Portland, OR

ABSTRACT

A three-year study was conducted in central Oregon to determine the possible effects of a ±500-kV direct-current (d-c) transmission line on cattle and crops. Two herds totalling 100 beef cows and six bulls were confined in pens beneath the d-c line. The cows were paired and the other members of the pairs were maintained in two herds in control pens 2,000 ft west of the line. The management facilities under the power line were duplicated in the control area. There were no significant differences in consumption of feed, minerals or water between the line and control herds. Also, no effects were found on breeding, conception, calving, calf birth date, calving interval, average daily gain, adjusted mwaning weight, cow weight, condition, carcass weight, and mortality. Differences were found between years for calf birth date, average daily gain, adjusted weaning weight, and cow weight. These differences were attributed to condition and age of the cows entering the study and their adjustment to pen confinement.

Alfalfa hay and winter wheat were produced for two years near two span midpoints of the d-c line. Crops were raised in strips extending in both directions beneath and perpendicular to the line. An identical set of control plots were placed 2,000 ft from the line. Analysis of data from line vs control plots showed no consistent statistical differences for production, seasonal growth stages or heights, hay or grain quality, or infectious disease. Wheat heights were slightly shorter among line plots than among control plots, although this was not clearly a response to the d-c

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line. There was limited evidence of slightly increased but biologically insignificant tipburn on wheat directly beneath the d-c line. Wheat plants were exposed to a d-c electric field in a laboratory test to establish corona onset levels. Based on this lab test, plants beneath the line experienced frequent daytime corona, but this could not be visualized in the field.

Data from four separate efforts were integrated to provide exposure estimates for cattle and crops. The Bonneville Power Administration provided measurements of d-c electric fields and air ions at ten fixed and one mobile station. The mobile station measured electric field, ion current, and space charge density at 25 locations in the cattle pens and crop area for 1 to 2-week periods.

The electrical measurements provided the data base for modeling the electrical environment in the entire study area. Monthly average levels of electric field, ion current density and ion density were estimated for locations within the cattle pens and along the crop plantings. Estimates of variation for the electrical parameters were also included in the models developed by T. Dan Bracken, Inc.

Observations of cattle location in study pens were used to develop estimates of time spent by the cattle at various distances from the d-c line. Location data for calves were also collected to permit estimates of their distribution. The estimated levels for electrical parameters were combined with the location data to yield a monthly time-integrated exposure for the average cow.

To translate the electrical environment measurements to a dose-related quantity, ion currents were collected with a full-scale cow model under the d-c line. Measurements were made at several locations in unshielded and shielded situations. These measurements were related to laboratory measurements using the simple geometric model. The exposure model measurements and dosimetry analyses were performed by Battelle Pacific Northwest Laboratories.

The following is a summary of a 450 page report, which contains details of the research site, experimental methods and results, plus a literature review. The full final report may be ordered as follows: "Joint HVDC Agricultural Study: Final Report", U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon.

INTRODUCTION

Background. There are various phenomena associated with high voltage (hv) direct-current (d-c) transmission lines which theoretically could affect plants or animals. These include 1. electric fields, 2. the quantity, electrical features and chemical nature of ions produced by corona at the surface of line conductors, and 3. noise. The chemical nature of ions produced in this study was not determined. With d-c power transmission, ozone and magnetic fields are infinitesimal, and limited data collected in this study confirmed their insignificance.

In contrast to alternating current (a-c) lines, d-c line conductors generate many charged ions that get into the environment. Ion movement is influenced by the wind, so the electrical environment around the transmission lines frequently changes.

The following terms may be helpful in reading this summary:

a) Voltage on the transmission line is expressed as kV = thousands of volts. A plus sign (+) indicates voltage traveling in one direction, a minus sign (-) indicates voltage traveling in the opposite direction. For paired transmission line conductors, each carrying 500 kV, this is described as ±500 kV for the line.

b) Corona is electrical discharge which occurs when molecules of air, water, dust, insect and other objects ionize on the surface of line conductors. It is accompanied by noise and light. The intensity of corona varies with the line voltage and environmental conditions. The light usually is too faint to see.

c) Electrical fields are expressed as kV/m, which is thousands of volts per meter. There may be contributions from both the static electric field around line conductors and electric field contributed by charged ions.

d) The amount of current carried by ions is expressed as nA/m^2, or billionths of amperes per square meter.

e) The numbers of ions found at different locations is expressed as ion density = $k\text{-ions}/cm^3$, which is thousands of ions per square centimeter.

Interest in the possible environmental effects of high voltage d-c (HVDC) transmission lines developed as a result of public controversy over the need for a ±400-kV d-c line in Minnesota. Surveys conducted after the line was energized in 1978 indicated that some people believed the line had adversely affected people, wildlife, and livestock.

However, a scientific committee formed by the State of Minnesota concluded that the survey was inadequate and inconclusive.

A majority of the Minnesota committee also concluded that there was no scientific evidence to indicate that short-term exposure to the d-c line posed a risk to human health. One committee member, however, concluded that the air ions produced by the line represented a potentially significant hazard. All of the committee concluded there was virtually no information on the possible long-term effects of exposure to elevated air ion concentrations. Among their recommendations was that there was need for studies of crops and livestock raised near a d-c line.

A study of dairy cattle in Minnesota was subsequently conducted (1). Dairy cattle production was assessed by examining Dairy Herd Improvement Association records from before and after the d-c line was energized. Other than general estimates of distances of herds from the d-c line, no information on electric field or air ion exposures were developed. The study found no chronic or acute effects attributable to the line on milk production, reproductive problems, or incidence of abortions. The researchers added, however, "If, in fact, substantial exposure to air ions and electric fields is present on a few farms, then this study could not have observed power line effects".

No studies of crop growth near the d-c line in Minnesota have been reported. Wheat growing at various distances from the D-C Intertie in Oregon was studied when the intertie was operated at ±400-kV. At harvest time, no significant differences were found in plant height, or in quantity, number, or germination of seeds that were related to the d-c line.

The studies discussed above are the only previously published field studies on the possible effects of commercial HVDC lines on animals and plants. There is a large and controversial body of literature involving laboratory studies of people, animals, and plants exposed to d-c electric fields and air ions. Most of this research, however, was not specifically done to assess the possible effects of d-c power lines.

Other reviews of the literature on effects of air ions on people and animals was published in 1987 (2, 3). This review 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).

The reviews monitored above generally concluded that short-term adverse effects of air ions or d-c fields are unlikely. Research on possible long-term effects, however, is limited. Only three previous studies of animals and plants living near an HVDC line have been published and both involved ±400-kV d-c lines (4, 5, 6). For these reasons, the present study was developed to examine possible long-term effects of air ions and d-c fields produced by the first commercial ±500-kV d-c transmission line in North America. Beef cattle, wheat, and alfalfa were selected for study because they are commonly raised along the D-C Intertie Line in Oregon.

Objectives and Design. The Bonneville Power Administration (BPA) determined that both environmental and electrical monitoring studies would be done when the Pacific DC Intertie was upgraded from ±400-kV to ±500-kV in 1985. Nine other utility organizations from the United States and Canada joined with BPA in sponsoring an agricultural study involving the line. The project was conducted from 1985 to 1988 by researchers from Oregon State University and the Agricultural Research Service, USDA.

Research objectives were to determine the potential effects of a ±500-kV d-c transmission line on production and reproduction of beef cattle and on crop growth, health, and reproduction.

Overall, the study assessed whether operation of the ±500-kV d-c transmission line resulted in any detectable effects (beneficial or detrimental) on livestock or crops, under controlled simulated ranching and farming conditions. Livestock and crops were located on the transmission line right-of-way and received long-term exposure to maximum electric field and air ion concentrations. The study was designed to provide data on end points and parameters of primary interest in commercial ranching and farming operations.

This study simulated a "worst case" condition in terms of exposure to the d-c line. In farming, crops are grown directly under the power line, whereas, in livestock operations, the animals generally are managed on various size pastures with the power line transecting them. In this study, 100 cows and six bulls were confined in pens directly under and extending 200-ft on either side of the transmission line center. One hundred cows and six bulls in identical control pens were located 2,000-ft from the d-c line.

The study area was typical, with respect to climate, topography, and vegetation of most of the land under the Celilo-Sylmar d-c line across Oregon and much of California. The site was in central Oregon near Madras on the Crooked River National Grassland.

METHODS

One hundred cows with their calves were managed directly under the line with a corresponding group in the control area for three production and reproduction cycles. Parameters compared between line and control groups were conception, calving difficulties, calving interval, calf and cow weights, nutrient intake, health, behavior, and slaughter characteristics.

For the plant study 60 wheat and 60 alfalfa plots were established in 400-ft strips transecting the power line with corresponding plots in the control area for two growth and production cycles. Parameters compared between the line and control areas included: phenology and other growth characteristics, yield on both crops, the quality measures of protein and fiber for the alfalfa, and protein and germination of the wheat.

The electrical study conducted by BPA, while not directly part of the OSU contract, was an integral part of the combined Grizzly Mountain HVDC Research Facility. The electrical study was designed and in place before the agricultural study began. A coordinated program was developed to minimize potential areas of conflict between the two studies.

Measurements of electrical parameters were taken at fixed locations at distances of 26, 75, 500 and 1,000-ft from the center of the line on both positive and negative sides of the line. In addition, a portable monitor was used to measure electrical parameters at selected locations within the pens. Meteorological variables were recorded on a continuous basis.

In a field study which investigated the possible effects of an operating transmission line on biological systems, there was a need to identify and quantify the exposure of the study subjects to the electrical environment. Documentation of exposures can provide information for dose-response analyses and on thresholds for effects. Exposure quantification can also provide the basis for comparison of exposures in this study to exposures in laboratory studies and to actual exposures received from this and other d-c transmission lines.

The principal electrical exposure parameters in this study were the d-c electric field, the ion current density and the ion density. Because these parameters are dependent on transmission line and meteorological factors, they are highly variable and are best characterized by measured levels whether in the short term or the long term.

The principal electrical exposure parameters at the Grizzly site were measured almost continuously at five locations within the treatment area near the line and at one location in the control area. In addition, measurements were made at various locations within the study area using a portable measurement system. From the measurements at the five permanent locations in the treatment area, the electrical environment over the entire treatment area encompassing four cattle pens under two spans was modeled to produce a quantitative description of the fields, ion currents and ion density to which the cattle and crops were exposed.

Average cattle exposures were estimated based on the field (or other parameter) levels at a location and the time the cattle spent at that specific location. Cattle location distributions were estimated from monthly observations. Thus, in an analogous fashion to exposure models for air pollution and 60-Hz electric fields, time, location and level data were combined to produce an estimate of monthly and total time-integrated exposure for the average cow. Monthly means of electrical parameters provided a direct estimate of exposure levels for the plants; since the crops are stationary, averaging over different locations is not required.

There is no identified mechanism of interaction which produces effects on biological systems for any of the three principal electrical parameters. Therefore, a meaningful exposure metric to characterize interactions between electrical quantities and biological systems cannot be established. For this study time-integrated average exposures over a month or longer were selected as the exposure metric, because they were considered indicative of long-term exposures. In the event that a more biologically significant or appropriate method of expressing exposure is identified in the future, the collected data are available in a form that can probably accommodate any particular metric.

The average monthly levels of electrical parameters which were used to express exposure levels say nothing about dosimetry (i.e., what dose of field or ions an animal actually receives). Questions of dosimetry such as the effects of animal shape, size, and posture were addressed in a study by Battelle Pacific Northwest Laboratories, performed under a subcontract to Oregon State University.

RESULTS

Livestock Parameters. The livestock study included three production and reproduction cycles (1985, 1986, and 1987). No statistically significant differences occurred between line and control groups for any of the production or reproduction parameters. Conception rates for line and control herds were 86 and 82, 100 and 100, and 98 and 100 percent, respectively, for the three breeding seasons. Average daily weight gains for calves in each year were 1.64 and 1.56, 2.15 and 2.08, and 1.94 and 2.04 lb for line and control groups, respectively. There were ten deaths in the line group and ten in the control group during the entire study. The animals went on feed readily and at no time in the study period was there any significant difference in nutrient intake between line and control animals. The live animal condition scores, carcass condition ratings and antemortem examinations showed no significant differences between line and control animals.

Behavior of cattle was quantified by monitoring their locations at feed bunks and their distribution and activity in 16 subdivisions of the pens during afternoon loafing periods, night bedding periods, and 24-hr watches. No disparities of biological significance were detected in cattle activities or in their selection of feeding locations. Statistically significant relationships were detected in the distribution data. These suggested one to four percent fewer cattle remained in areas under the d-c line conductors than in corresponding areas of control pens. This finding did not appear to be correlated with either the electric field or the audible noise produced by the d-c line.

Plant Parameters. No line vs control differences were found for the primary production parameters of wheat and alfalfa fields, and quality of wheat grain and alfalfa hay. Similarly, few if any differences were found for the primary production parameters when side of the line or distance treatments away from the line were considered. A difference in wheat height might be related to the electrical environment, but plot-to-plot variation and effects from factors other than the transmission line were equally likely to have been responsible for these differences.

Control area plots were intended to provide relatively uniform data away from the d-c line. However, control plots varied as much or more than line plots. This reduced our ability to determine significant differences between line and control area plots. Influences other than presence of the transmission line may have resulted in occasional patterns of crop response in both line and control plots. This was most apparent with occasional exceptional center plot responses in comparison to all other plots, but there were several measurements in which significant trends were seen with distance from the midpoint of blocks. It is also possible that the elongated block design caused a differential plant growth away from the midpoint of the blocks. However, we do not believe that these negate the importance of our findings. Within the limits of design and management capabilities, no commercially important differences were detected above normal variation.

Leaf tip and awn damage on wheat growing beneath the d-c line was not easily detected by plant specialists. These effects appeared to be no greater than natural tip burn that occurs in the region. Theoretical crop losses from such tip burn would be so small that no detectable production responses would result. Laboratory data for corona on wheat leaves and awns, in conjunction with measured and calculated field and ion levels near the transmission line, support the contention that corona probably does occur at times on sharp plant parts protruding above the ground plane beneath the conductors. However, no corona was observed on crops using an image intensifier due to several possible factors. These include the fact that most intense corona would occur during daylight hours when it would be impossible to visualize. At night, corona might occur, but would be faint enough to be obscured by high ambient star light levels.

Dust did not accumulate differently on crop foliage near or away from the transmission line. No infectious disease problems occurred during the two-year study. Measurable animal damage was limited to rodents. Where this damage was abundant, crop yields were corrected for rodent damage.

Exposure Estimates. Exposures of the cattle and crops to electrical fields were quantified, using data from the electrical measurements program and the cattle location observations. The principal electrical parameters in this study were the d-c electric field, the ion current density, and the ion density.

Electrical parameters at the study site were measured almost continuously at five locations near the line and at one location in the control area. In addition, measurements were made at various locations within the study area, using a portable measurement system. From these measurements, the electrical environment over the entire line and control areas was modeled to produce a quantitative description of exposure. Cattle exposures were estimated based on the field (or other parameter) levels at a location and on the time the cattle spent at that specific location. Since the crops were stationary, averaging over different locations was not required.

The total accumulated electric field exposure was approximately 5,000 (kV/m) days for an average cow in the line group. This corresponded to exposure to an average electrical field of 5.5 kV/m over the duration of the project. The total accumulated ion current exposure in the line group was about 3,700 (nA/m^2) days for an average cow. This corresponds to exposure at an average ion current of about 4.1 nA/m^2 for the entire project. The total accumulated ion density exposure was about 12,000 (k-ions/cm^3) days for an average cow in the line group. This level corresponds to exposure at an average of about 13 k-ions/cm^3 over the duration of the project. Depending on the parameter under consideration, exposures in the line area were five to 30 times greater than exposures in the control area.

The exposure levels experienced by the study cattle were related to that received by rodents in other recent laboratory studies. A series of measurements at the study site of the ion current collected by various animal models was compared to the exposure levels in the study and to those of the three EPRI-sponsored air ion research projects. Relative dose for an animal was expressed as the product of the collected ion current and the duration of exposure divided by the weight of the animal. Using this exposure metric, the relative exposures ranged from 21 to 0.25 for the laboratory studies and 1.8 for the study of cattle.

Maximum exposures for the crops occurred directly under the d-c line. The maximum average electric field exposures were approximately +9 and -16 kV/m. The maximum levels in line plots exceeded minimum levels by four to 30 times, depending on the parameter. The maximum exposures in the line plots exceeded exposures in the control plots by a factor of 30 to 100 depending on the parameter. Similar differences were seen for ion current density and ion density.

CONCLUSIONS

This experimental study found no evidence that continuous exposure to a ±500-kV d-c transmission line affected the production of beef cattle, wheat, or alfalfa. Extensive electrical monitoring indicated that electric field and air ion exposures received by cattle and crops raised near the line, were substantially greater than exposures in the control area. For cattle, these exposures were greater than would typically occur because the animals were confined beneath the line. This further decreases the likelihood that effects would occur to livestock normally exposed to a d-c transmission line.

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