BIOLOGICAL EFFECTS OF ELECTRIC FIELDS ON AGRICULTURAL ANIMALS*

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ABSTRACT. The biological effects of electric fields has been intensively studied in laboratory animals. Most of the effects relating to exposure to electric fields have been observed under artificial conditions and at exceptionally intense fields (40-100 kV/meter). Few studies have been completed in agricultural animals, yet this class of animal probably receives the greatest exposure under actual field conditions. The objective of this paper was to summarize the available scientific data for agricultural animals. Based upon limited experimental data, and a number of years experience with animals under high-voltage lines, it appears that electric fields of 10 kV/m or less do not represent a biological hazard to agricultural animals.

It has been projected that as the demand for electrical energy continues to grow there will be an increasing need for greater electric energy transmission capability. By the year 2000, it is projected that ultra-high voltage transmission (UHV), that is, voltages in the one million volt and over range will be required to transmit this energy and still keep the number of transmission lines to a minimum. This demand will require UHV transmission lines in the 1100 kV class. At present, a large percentage of these energy transmission requirements are being met with the 500 and 765 kV class of lines. Since a great amount of right-of-way has to cross lands used for agricultural purposes, including livestock production, there is an ever increasing concern regarding the biological effects of induced electric fields on livestock.

Interest in the possible biological effects of transmission line electric fields developed into an environmental issue in the 1970's (1). Public interest, especially concerning electric fields, is still strong today wherever 500 kV and 765 kV transmission lines are proposed. Although most emphasis is on human health, questions are often raised about the effects on livestock and wildlife. Numerous research projects addressing biological effects of 60 Hz electric fields are continuing in the US and in other countries (2,3).

Public interest and concern continue today as evidenced by continuing media coverage. The Friday, April 12, 1984 edition of the Birmingham News carried a headline story entitled "Magnetic Fields a Danger? Feds to speed Probe". The Sierra Club continues to publish articles like the one found in the July/August, 1978 issue of their journal entitled "Health and High Voltage". The December, 1983 issue of Popular Science ran a lead article entitled "Electromagnetic Pollution, Are They Zapping You." In the last decade, the movie "OHMS" was released pitting a small group of farmers against the massive electrical power industries. Sixty-minutes has run at least two specials on this topic since 1982. In general, veterinarians and particularly rural practicing veterinarians, have little practical knowledge about this topic. Veterinary toxicologists have also had little exposure to the issues surrounding the potential biological effects of electric fields. This paper is intended to provide a summary of the existing information related to this subject.

PERSPECTIVES ON THE TOPIC

Since this subject has received such little attention by the veterinary profession, perhaps some delineation or definition of some of the more common terms would be appropriate. Please keep in mind that I claim no technical expertise in the field of electrical engineering and thus you are receiving a veterinarians's perspective.

These are several classes of high voltage lines used for the conduction of electricity. These are summarized below:

90 kV - rural transmission (service) line - 90,000 volts
135 kV - regional line - 135,000 volts
340 kV - Inter- and intra-state power lines - 340,000 volts
(Break point for the definition of extra high voltage (EHV) lines)
500 kV - Interlocking systems -used mainly for conduction of electricity between utilities - 500,000 volts
765 kV - Cross-country EHV lines now in use in some states - 765,000 volts
1200 kV - To meet increased population needs - 1.2 million volts (planned)

All of these line classifications produce an electric field beneath them. The electric field is generally described in kilivolts per meter (kV/M), which means that the induced voltage (field) is measured at one (1) meter

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from the ground generally at the lowest point of the swag of the line. The electric fields produced by the various lines described above as follows:

340 kV = 2-5 kV/meter (2000-5000 volts/meter)
500 kV = 5-8 kV/meter (5000-8000 volts/meter)
kV = 8-10 kV/meter (8000-10,000 volts/meter)
1200 kV= 12-15 kV/meter (12,000-15,000 volts/meter)

Concurrently, there have been a number of potential health hazards identified in association with these electrical fields. Some of the more common ones have been stated to be: hypertension, ulcers, abnormal growth, danger to wild animals, migratory birds and livestock, increased irritability and fatigue, noise under lines, contact shocks from objects under the line, lightning attraction, leukemia in man-recent focus.

LITERATURE REVIEW

Relatively little data are available on the physiological and behavioral responses of livestock to induced currents such as those produced by the transmission lines. Even when standing on dry ground, cattle showed no reaction when drinking water from grounded metal tanks beneath an 1100 kV line in fields of 11-12 kV/m (4). Amstutz and Miller (5) reported on electrical measurements and production performance made with livestock in close proximity to and placed on insulated surfaces underneath a kV line in Indiana. They found no effects on production performance in dairy cows, sheep, swine, and horses. Their study was a survey-type study which only evaluated general production parameters.

Several other survey-type studies (6-7) found no evidence to indicate that 500 and 765 kV lines affected livestock behavior, growth and reproduction.

Williams and Beiler (8) focused on dairy farm operations before and after construction of a 765 kV line in Ohio. The study involved 55 farms and 2,675 cows over a 4-6 year period. Personal interviews with farmers and inspection of records (retrospectively) were used to obtain data. Although the report indicated some deficiencies in the data, there was little indication of any long term effects on milk production. They were unable to reach any conclusion on reproduction effects, but they noted an increase in mean calf death loss from 3.4 percent before the line was built to 5.85 following line energization. There was an increase in the incidence of calves born with abnormalities. The dairymen, however, believed there was no evident change in the occurrence of health problems after the line was energized. Hennichs (9) also reported on a possible connection between long-term exposure of cattle to 400 kV lines and fertility changes. Cattle behavior and growth performances near a 1200 kV prototype transmission line in Oregon has also been studied (4). This line produces a 12 kV/m field. Weight gains of cattle during the study were typical for the existing pasture condition.

Phillips (10,15), Batelle Northwest Labs reported on a long-term study involving the exposure of female swine to 30 kV/m electric fields. While a number of behavioral and reproductive effects were noted, these were inconsistent and results could not be interpreted because of a serious disease outbreak. This study was designed to be a long-term (2 year), chronic (20 hours/day--seven days/week) exposure to 60-Hz electric fields (30 kV/m) on three filial generations of miniature swine. A population of 48 females (F_o) was started on exposure or sham exposure at 18 months of age. After four months of exposure these females (gilts) were bred with unexposed boars to produce offspring (F_1) that were exposed or sham exposed from conception through adulthood (30 months). At 18 months of age, the F_1, females (gilts) were bred with unexposed boars to produce an F_2 population that were exposed or sham exposed for six months. (Fig 1)

No adverse biological effects were observed in growth, development, hematology, serum chemistry, immunology, neurophysiology or mortality of exposed F_o females during the first 18 months of exposure. In one behavioral test conducted at the start of exposure, it was found that the pigs would spend more time in an area shielded from the electric field than in the electric field during the sleeping (night) period.

In the population of F_o females that was bred with unexposed boars at four months of of exposure or sham exposure and allowed to come to term, neonatal mortality among the offspring (F_1) was significantly greater among sham-exposed pigs than among exposed

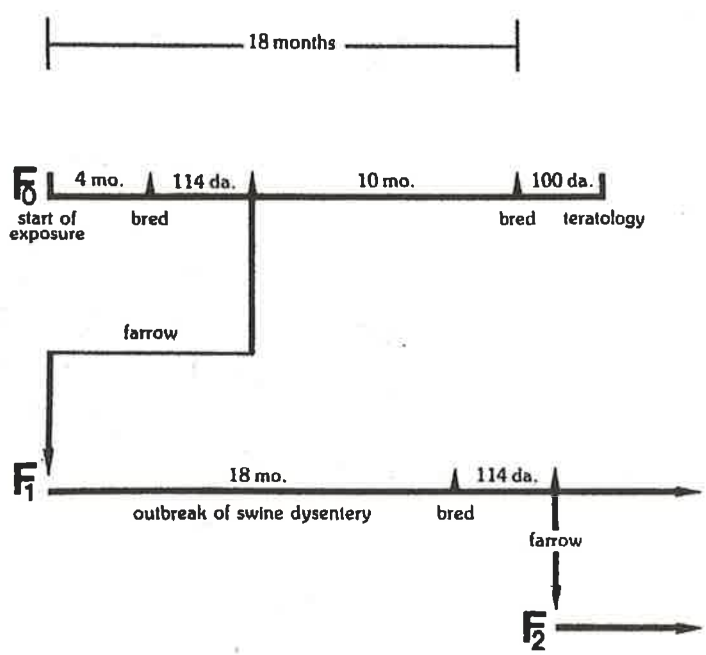

Fig 1. Design of three generations swine study by Kaune and Phillips (15).

sham-exposed off-spring than among exp... offspring. There were no significant differences between exposed and sham-exposed F0 in terms of mating performance, fertility or in numbers of offspring per litter, proportion of male and female off-spring, numbers of runts, or body weights of offspring.

At about this point in the study a serious outbreak of swine dysentery occurred which resulted in mortality in all groups. The animals were treated with sulfonamides and nitrofurans and continued on the study.

The F_1 females were bred at 18 months of exposure to produce an F_2 generation. 80% of the sham-exposed females mated while only 36% of the exposed females mated. Repeated attempts at mating were unsuccessful. The reason(s) for this performance in the F_1 females has not been determined. The incidence of disease and therapy are certainly considered as a compromising bias in these results.

Mahmoud and Zimmerman (11) reported that growing and finishing swine under a 345 kV line showed no effects from the electric field. Figure 2 shows the alignment of the line and swine confinement units under the line and Table 1 reflects the results of this study. No significant differences in weight gain and feed efficiency were noted.

Over 2000 chicks were subjected to various schedules of electrical stimulation, including short and long-term exposure to electrical fields varying from 40 to 80 kV/m (12). Results of short term exposure (30 minutes) had no statistically significant effect on livability, growth, or development of males or females. Relatively long-term exposure of three weeks to 40 to 80 kV/m did result in a significant but not permanent enhancement of growth in male broiler chicks (Fig 3).

A companion study to the Batelle swine project described above involved exposing hundreds of mice and rats to electric fields of 60-100 kV/m (2-3). The possible effects

Replication	Grower Period		Finisher Period		G-F Period	
	Control Group	Exposed Group	Control Group	Exposed Group	Control Group	Expose[d] Grou[p]
Average Daily Gain, lb.						
1	1.70	1.55	1.85	1.82	1.78	1..
2	1.82	1.63	1.66	1.96	1.73	1.79
3	1.79	1.89	2.02	2.01	1.91	1.95
4	1.60	1.66	1.73	1.85	1.67	1.76
5	1.53	1.55	1.62	1.78	1.59	1.68
Average	1.690	1.656	1.78	1.89	1.74	1.78
CV, %	5.6		5.3		2.9	
Average Daily Feed, lb.						
1	3.774	3.437	5.650	5.194	4.773	4.50
2	4.123	2.935	5.857	6.219	5.026	5.06
3	4.012	4.330	6.292	6.133	5.170	5.15
4	3.792	3.818	5.560	5.820	4.733	4.83
5	3.547	3.483	5.245	5.401	4.506	4.52
Average	3.851	3.800	5.643	5.754	4.841	4.82
CV, %	4.6		4.1		2.1	
Feed: Gain						
1	2.21	2.22	3.05	2.94	2.68	2.6
2	2.27	2.41	3.53	3.17	2.90	2.8
3	2.24	2.29	3.11	3.05	2.71	2.6
4	2.37	2.30	3.23	3.12	2.84	2.7
5	2.32	2.24	3.22	3.04	2.84	2.7
Average	2.28	2.29	3.23	3.06	2.79	2.7
CV, %	2.9		2.7*		1.1*	

*Feed: Gain ratios differed (P < .05) between treatments for the finisher and the G-F periods.

CV: statistical coefficient of variation.

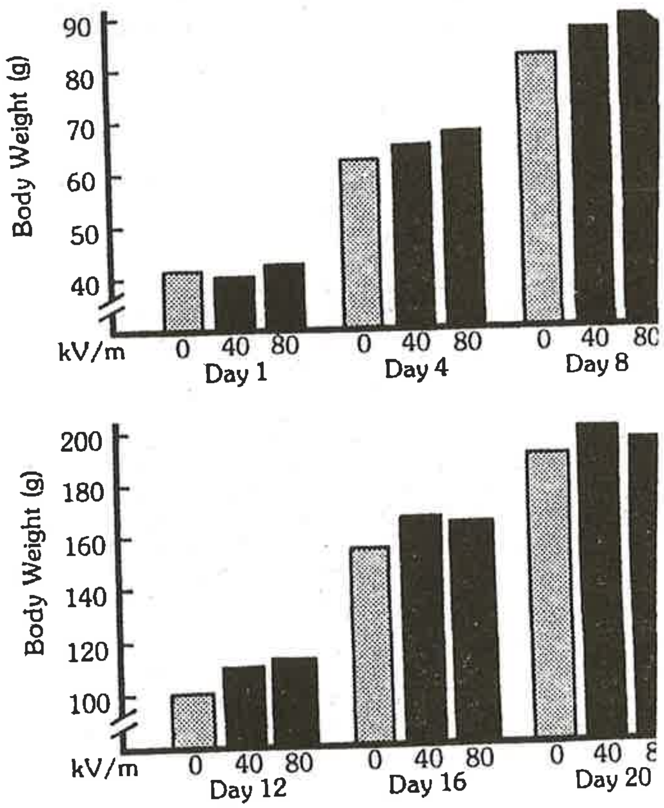

Fig 3. Growth response of male chicks exposed to 0, 40, 80 kV/m from days 1 through 20 aft[er] hatching.

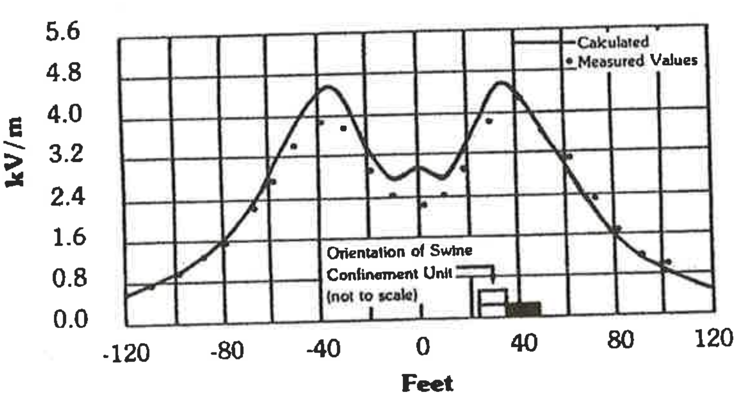

Fig 2. Comparison of measured and calculated electrical field at 6 feet above ground under the 345 kV line (11).

on reproduction reported in the swine study were generally not found in the rodent work. From these extensive studies in rodents, the following confirmed biological effects were eported:

atology
Male and female mice exposed to 100 kV/m from conception to 77 days after birth had higher leukocyte counts (all white cell types) than sham-exposed controls. Red blood cell parameters of the third generation of mice exposed in utero and for 80 days after birth had higher values than those of sham-exposed controls.

Bone Fracture and Repair
The load (force) required to deflect a previously fractured fibula 1mm is lower among juvenile rats exposed to 100 kV/m during a 14-day repair period than among sham-exposed rats. In a similar experiment with adult rats, fracture repair was retarded among exposed rats at 20 days, with recovery apparent by day 26.

Endocrinology
Rats exposed to 100 kV/m for 35 days (as weanling) and for 120 days had lower concentrations of serum testosterone than sham-exposed controls.

Neurochemistry
Melatonin content of the pineal gland of rats exposed to 60 kV/m for 30 days was significantly lower than that of sham-exposed controls during the dark period of the 14-hour light: 10-hour dark cycle.

Neurochemistry
Serotonin-N-acetyl transferase (Snat) activity was significantly lower in pineals of rats exposed to 60 kV/m for 30 days when compared to sham-exposed controls.

Synaptic Transmission
Sympathetic ganglia of rats exposed to 100 kV/m for 30 days were more excitable than those of sham-exposed rate.

Neuromuscular Function
Recovery from stimulus-induced fatigue in a slow-twitch muscle (soleus) in the rat was faster in animals exposed to 60 Hz for 30 days (100 kV/m) than in sham-exposed controls.

Behavior
Rats exposed to 75 or 100 kV/m spent more time out of the electric field than the sham-exposed controls during the 12-hour light period of a 24 hour test (12 hr light: 12 hr dark). Rats exposed to 25 and 50 kV/m spent more time in the field than sham-exposed controls during the 12-hour light period. During the 12-hr dark period the only significant effect was a perference by rats exposed to 100 kV/m to stay out of the field. ing the first hour of the test, exposed s made more traverses between the exposed and shielded regions of the shuttlebox than sham-exposed controls. Rats spent significantly more time out of a 60-Hz electric field than in it at 90 kV/m during a 45-min test. Also, exposed rats made more traverses between the exposed and unexposed regions of a shuttlebox than sham-exposed controls.

Growth and Developement
A smaller percentage of rats exposed from conception to 8 days after birth exhibited the righting reflex and a higher percentage showed motile behaviors than sham-exposed rats at 14 days of age. Three generations of offspring (F_1, F_2, and F_3) in a 4 generation mouse study (conceived, born and raised in a field) exhibited a retardation in tooth eruption compared to sham-exposed controls.

While these biological effects have been statistically confirmed in laboratory rodents in well-designed and controlled experiments, it is extremely important to recognize the difference between "biological effects" and "biological hazards". Further, one must be completely aware of the very high (40-100 kV/m) exposure rates over lengthy periods. As scientists, we can never over-look a commonly utilized principle of toxicology; that being the expectancy that drugs, chemicals, and physical agents react in most biological systems to the time honored and proven concepts of dose-response. In this particular field of toxicology, there appears to be great difficulty in defining the spectrum of the dose-response curve between "no effects" and "confirmed biological effects".

WHAT IS THE CONCERN OF THE VETERINARIAN?

There has been and continues to be some major confusion between induced electric fields, as one might encounter under a EHV line, and "stray" voltage which is commonly encountered by veterinarians. "Stray" voltage in dairy barns has been studied extensively. There is no question that electricity in low voltage amounts from a direct source (such as faulty wiring and malfunctioning equipment) in a dairy barn can cause considerable problems in the dairy cow (13-14). Many of these effects have been well documented and include such clinical signs as increased mastitis, 20-30% losses in milk production, increased nervousness in cows, and cows refusing to enter milking parlor.

In my experience, this source of electricity is often confused with potential electrical current that can be generated beneath high voltage lines. I have briefly summarized and defined the three major types of electrical current veterinarians might encounter:
Lightning - causes instant death, usually in range of 1 million volts - 30,000 AMPs.
"Stray" voltage - direct source electricity in dairy/swine barns; 3-10 volts yielding 2-9 milliamperes (mA) of current. (The Bovine sensing threshold has been determined to be 1-2-mA.)

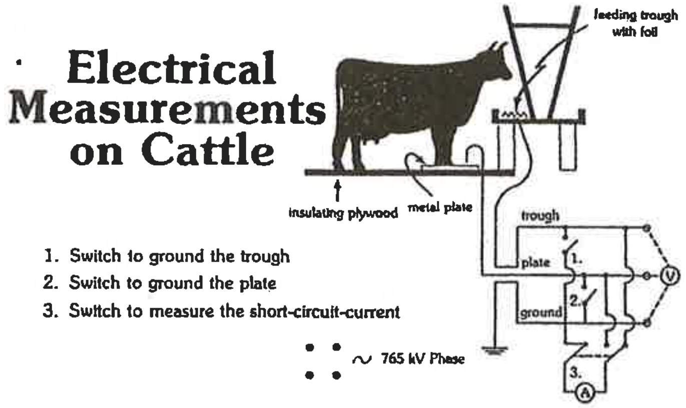

Fig 4. Device used to make electrical measurement exposures on cattle (5).

Indirect (electric fields) - 760 kV line yields 0.3-0.5 mA of electrical current and requires a special collecting device (see Fig 4). (The human threshold has been determined to be about 5 mA which is the equivalent of a carpet shock.)

SUMMARY

Electric fields are produced beneath extra high voltage lines in amounts that are definitely measurable. Induced electric fields are not the same as direct electrical current and "stray" voltage problems must be differentiated from electric fields. Existing literature and a number of disclosures provided in legal encounters have not revealed any solid scientific evidence to support the fact that a biological hazard might exist beneath high voltage lines that produce electric fields of 10 kV/m or less. There is no question that if extra high voltage lines in the class of 1200 kV and above are required in the next century, considerable long-term research needs to done in agricultural animals at realistic exposure rates. The greatest potential for adverse biological effects to occur in agricultural animals would appear to be in the area of the neuroendocrine axis or perhaps the immune response systems.

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