Behavioral Studies of Dairy Cow Sensitivity to AC and DC Electric Currents

Robert J. Gustafson, Thomas M. Brennan, Robert D. Appleman

MEMBER
ASAE

ABSTRACT

DAIRY cow behavioral responses to alternating and direct current were examined for three body pathways: mouth-to-all hooves, front-to-rear hooves and body-to-all hooves. For mouth-to-all hooves and front-to-rear hooves pathways, response frequency functions were obtained over a range of 0-5 mAAC and 0-6 mADC. At significant levels of response, a higher DC than AC current was needed to obtain the same response. At a 50% response rate, a 34% higher DC current than AC was needed for the front-to-rear path and 22% higher for mouth-to-all hooves.

Front-to-rear hooves response rate became statistically significant above 2.0 mAAC and 1.0 mADC. Mouth-to-all hooves response rate became significant above 2 mAAC and 4 mADC. Response rate for a body-to-all hooves pathway with currents from 0-7.5 mAAC and 0-9 mADC were inconclusive. No reliable response pattern was obtained for this body pathway.

INTRODUCTION

Recent studies have documented a condition existing in livestock facilities known as stray voltage. These voltages are generally of a low level (less than 10 V). As a result of exposure to these voltages, animals can exhibit a wide range of behavior and health problems. For dairy cows, these include uneven milkout, reluctance to drink water, increased mastitis, and extreme nervousness while in the milking parlor (Cloud et al., 1980). These symptoms could also be attributed to other factors such as animal mistreatment, disease, and nutritrional disorders. Careful evaluation of herd management practices and health, as well as electrical sources, must be conducted to identify problem causes.

In this study, dairy cow responses to alternating (AC) and direct (DC) electrical currents were examined. Three body pathways; front-to-rear hooves, mouth-to-all hooves, and body-to-all hooves were used.

These pathways were selected because animals may be exposed to front-to-rear hooves currents when they stand or walk across an area of the barn or parlor where a floor voltage gradient exists. A mouth-to-all hooves shock can occur when an animal bridges the gap between a metallic feeder or water bowl and the ground. A body-to-all hooves current can occur when an animal bridges the gap between metal pipework that is connected to the grounded neutral system and a concrete floor or earth.

Three separate experiments were conducted with dairy cows. The overall objective was to develop cow response functions for a range of AC and DC current through each of the three pathways. The first experiment was to involve front-to-rear hooves currents, 0-5 mAAC and 0-6 mADC. The second experiment was to involve mouth-to-all hooves currents, 0-5 mAAC and 0-6 mADC. The third experiment was to involve body-to-all hooves currents, 0-7.5 mAAC and 0-9 mADC.

REVIEW OF LITERATURE

The effect of a specific voltage on dairy cattle is influenced by many factors: (a) voltage magnitude and waveform, (b) the resistance of a cow's body pathway, (c) condition of concrete, soil and metallic conductors. affecting resistance to "true earth", (d) resistance of cow's contact points; (e) resistance of the electrical pathway to cow's contact points; and (f) impedance of the source (Gustafson, 1983). When combined, these factors determine the current flow through the cow's body.

Several of these factors cannot be determined in the field. Therefore current flow necessary to elicit a response is combined with resistance estimates to calculate probable voltage necessary to cause an animal to respond.

Available research data quantifying sensitivity by current level have been reviewed by Appleman and Gustafson (1984). In summary, they found three criteria have been used in judging cow responses to electric current: behavioral responses, endocrine responses, and changes in milking performance.

Endocrine Responses and Milking Performance

Lefcourt et al. (1984) summarized their studies by concluding that "any negative effects of electrical shock on milk production or mammary gland health most likely are not directly related to shock, i.e., physiological responses to shock were minimal and milk yield was generally maintained at normal levels during the shock period. However, the severe behavioral responses to shock would almost assuredly result in management problems and the degree to which milk production would be affected would depend on how dairymen deal with the abnormal behavior." Similarly, Drenkard et al. (1984) found little or no physiological response to electrical currents common in 'stray voltage'-problem herds. Thus, it appears the primary influence of stray voltage on dairy cow performance is one of behavior modification.

Behavioral Responses

While not directly studying behavior, researchers emphasizing physiological responses have made observations of behavior while collecting data related to endocrine response and milking performance. Drenkard, et al. (1984) used an udder-to-all-hooves pathway on four cows being milked to obtain behavioral responses at 0, 2, 4 and 6 mA. Results suggest that some cows can be expected to exhibit a behavioral response at 2 mA, and most will respond to 4 mA.

Even though many of the observed cow behavior modifications are associated with the milking process, Gustafson et al. (1983) found that the milking equipment itself is not a likely path of problem currents to the animal. The minimum resistance for the milkline-claw path under milking conditions, for a 9 kg/min flow rate, would be over 47 kohms for a high line and above 26 kohms for a low line configuration. Resistance of the milk hose, from the milkline to the machine claw, was inversely proportional to milk flow rate. Minimum resistance from the claw through the cow to the floor was 3 kohm.

A series of four experiments (Norell, 1983 and Norell et al., 1983) were designed to study the effects of AC current on dairy cow behavior. The first experiment involved a current contingent upon a muzzle-plate press by the cow. Six Holstein cows were trained to press the plate 30 times to receive a grain reward. Front-to-rear hooves currents up to 6 mA did not suppress plate pressing behavior.

Subjective signs of annoyance such as hoof movement during plate pressing were occasionally observed. The current level which suppressed plate pressing for a muzzle-to-all hooves pathway varied between cows and sessions. Four of six cows were initially suppressed by 1.0 to 2.0 mA currents. Higher currents were required during later sessions. Currents of 4.0 or 4.5 mA were required to initially suppress the other two cows.

In a second experiment, seven Holstein cows were trained to raise a front hoof to avoid a continuation of a front-to-rear hooves shock. The observed escape response level for currents between 0 and 5 mA is summarized in Fig. 1. At currents less than 2 mA, the response level was equal to that of the random response level of twenty percent.
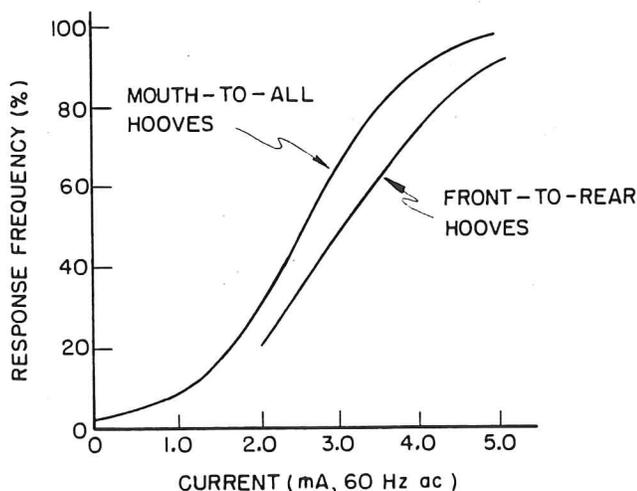
In a third experiment, an avoidance response curve for mouth-to-all hooves currents was developed. Mouth opening was a specific avoidance response, therefore, the curve shown in Fig. 1 continues to low current levels.

In the fourth experiment, 25 lactating Holstein cows were used in an experiment involving the cows walking across two electrically isolated metal grids upon leaving a preparation stall for the milking stall. Results indicated cows subjected to a 4.0 mA current required twice the time to cross the grid compared to the no current case. Two-minute milk yield, total milk yield, and machine-on ratios were not significantly influenced by experimental treatments.

MATERIALS AND METHODS

The six Holstein cows utilized for all experiments were moved individually from their home tie stall that was

Fig. 1—Dairy cow current sensitivity (Norell, et. al., 1982).
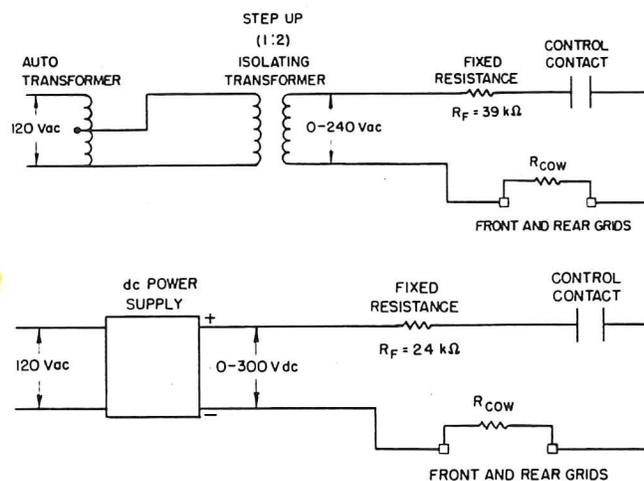
CURRENT CONTROL CIRCUIT
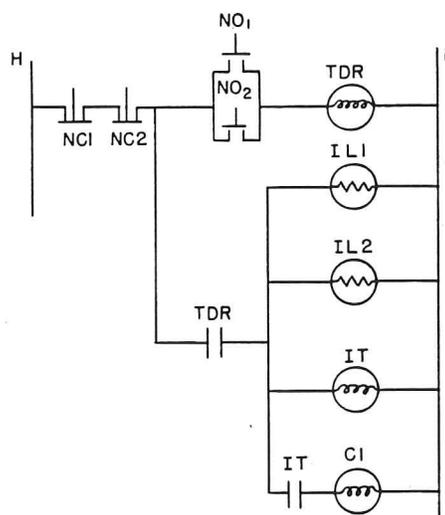
NCI, NOI START/STOP NUMBER I—OPERATOR

NC2, NO2 START/STOP NUMBER 2—OBSERVER

TDR TIME DELAY RELAY, ON OPERATE ADJUSTABLE (30 S ON)

ILI INTERVAL LIGHT NUMBER I—OPERATOR

IL2 INTERVAL LIGHT NUMBER 2—OBSERVER

IT INTERVAL TIMER, ADJUSTABLE (0.5 S ON, 0.5 S OFF)

Fig. 2—Current source and control circuits.

specially built for these experiments. The stall measured 1.2 x 3.6 m (4 x 8 ft) with a stanchion type neck hold in the front of the stall to hold the cow relatively still. On the base of the stall were two expanded metal grids. Placed under each grid and over a divider, was a continuous rubber sheet that acted as a barrier to moisture and effectively isolated the front hooves from the rear hooves. The grids were kept wet to ensure good contact. A visual barrier was constructed to shield the cow from any activity in the barn. This barrier also blocked the cows' view of the observer(s). A radio was used for background sound. In this configuration, the researchers were confident the cow was responding to the shock only and not the activity or sounds around her.

A schematic of the electrical current source circuit used for this study is shown in Fig. 2. For AC current applications, a 0-120 V autotransformer was connected to a step up (1:2) isolating transformer. A 39 kohm resistor, in series with the cow, was used as a current limiting resistance.

The current level was adjusted by varying the voltage across the 39 kohm resistor. With the circuit set up as outlined, the maximum deliverable current is 6.2 mAAC. For this study, all currents were administered for a maximum 30 s period, with each current delivered in 0.5 s "on", 0.5 s "off" pulses.

Initiation of the current is accomplished with one of the two stop/start switches in the circuit. Relays controlled not only the total period but also the on/off cycle within the period.

The design of the DC circuit was identical to that of the AC circuit, except for the substitution of a variable voltage DC power supply for the AC source and the substitution of a 20 kohm resistor for the 39 kohm resistor. The maximum deliverable current from this circuit was 15 mADC.

The six cows were divided into two groups of three, with one group receiving AC current, and the other group receiving DC current via the same pathway. Then, the current type was switched for each group so that at the end of each experiment all cows were subjected to both AC and DC current. This procedure was adhered to for each pathway.

Experiment 1: Front-to-Rear Current Path

For Experiment 1, it was necessary to conduct training sessions for each cow to acquaint her with the desired response to current from her front-to-rear hooves. The training sessions consisted of exposing each cow to a 5.0 mAAC or 6.0 mADC front-to-rear hooves current. A total of 50 exposures were presented. Each exposure, 0.5 s "on", 0.5 s "off" pulses, lasted for up to 30 s. If the cow gave the proper response, a front hoof raise, then the trial was terminated early. Intervals between trials varied from 30 to 90 s. A cow was considered trained if she gave the proper response 90% of the time over the last 20 trials.

The training sessions were performed 24 to 48 h before actual experimental testing took place.

An experimental session consisted of sixty AC trials, six current levels (0.0 to 5.0 mA in 1.0 mA increments) arranged randomly within ten blocks of time, or seventy DC trials; seven current levels (0.0 to 6.0 mA in 1.0 mA increments) arranged randomly within ten blocks of time. This random block design allowed for each current level to occur once within each block of time and ten

blocked replicates. Preceding the experiment trials were 10 "warmup" trials similar to the training sessions. All the cows gave the trained response at least 70% of the time, with four of the six responding at 90% or better. This indicated a retention of the learned response from the training sessions conducted earlier.

Experimental trials were presented in a single blind experiment, that is, the animal observer was unaware of the current level being administered. Trials were replicated 24 to 48 h later. As with the training sessions, if the cow raised her front hoof in less than thirty seconds, the trial was manually terminated. The interval between exposures was 30 to 90 s.

Experiment 2: Mouth-to-All Hooves Pathway

Experiment 2 used a mouth-to-all hooves pathway. The mouth contact was achieved by placing a metal bit in the cow's mouth.

For experiment 2, the stall configuration, electrical equipment, and testing methodology were identical to that in experiment 1 except the front and rear floor grids were connected. The observation wall was placed near the front of the cow so the observer could better view the cow's responses.

Cows were exposed to ten warmup trials prior to the actual experimental trials. Unlike experiment 1, no training sessions were necessary. Cows opened their mouths as a response to a current through the mouth without any prior training. All cows recorded an 80% or better positive response in these warmup trials, with both AC and DC currents. The same randomized block design and current levels used in the previous experiment were employed. Experimental trials were terminated early by the observer if the mouth opening response was detected before the thirty second duration of the current had expired.

Experiment 3: Body-to-All Hooves Pathway

The current pathway examined in this experiment was one of body-to-all hooves. The stall configuration, electrical equipment, and testing methodology were similar to those used in the previous experiments. Approximating a body-to-all hooves path was achieved through the use of a canvas belt with a metal patch attached to the belt. The belt was placed around the shoulders of the cow and secured underneath by two D-rings. Attached to the inside of the belt was a brass metallic patch, measuring 5 cm (2 in.) in width and 12 cm (5 in.) in length. This patch delivered the current to the cow's body.

The placement of the patch was critical in terms of how the cows reacted to a current of a given level. A cow could experience a body-all-hooves shock from any number of points on her body, depending on the orientation of her body to the source of the voltage. For this experiment, the patch was located on the shoulder area of a front leg. In order to ensure good contact at the cow's body, the metallic patch was coated with a conductive paste, "Liqui-Cor" ECG conductor. The hair was not shaved off.

A minimum of two training sessions were conducted for each cow for each current type. The cows were trained for a front hoof raise. All six cows exhibited initial confusion as to exactly what type of response to give. Some shook their shoulders, others developed a muscle tremor, while still others lifted one of their front

hooves. Hence, longer training sessions were required. Results from these training sessions were still below those of the other two pathways. Average cow responses were about 70% for training trials 30 through 50, as compared to over 80% for training trials 30 through 50 for the previous two pathways.

Experimental trials were preceded by ten warmup trials. The response from these warmups was about 70%, as with the training sessions. The randomized block design used for the previous experiments was followed. Preliminary work had shown a higher current, via this path, was required to achieve a consistent trained response.

Therefore, the current ranges were raised to 0.0 to 7.5 mAAC and 0.0 to 9.0 mADC. The current level was stepped in 1.5 mA increments. Total number of applications remained the same. An experimental trial was terminated early if the cow expressed the trained escape response in less than thirty seconds.

ANALYSIS OF THE DATA

The data was binomial in nature, i.e. desired responses were coded as a 1 and no response was coded as a 0. Normal errors do not correspond to a zero/one response, therefore analysis of the data required the use of a transformation.

The calculation of a response function to current level using binomial data was accomplished through the use of logistic regression. The logit is the natural logarithm of the odds of success, i.e. the ratio of the probability of success to the probability of failure. The program GLIM (Baker and Nelder, 1979) was employed to perform the necessary transformations and to obtain the maximum likelihood estimates, response functions. In the analysis of data for all six experiments, both cow effects and replication effects were ignored.

Fitting a linear model in the logit scale by using the transformation, yields:

$$\text{logit } T = \ln T/(1 - T) = B_o + B_1 X \quad \dots \dots \dots [1]$$

where T is the proportion of positive responses
    X is the current level
    B_o and B_1 are regression constants
This expresses the logistic regression model as a straight line on the logit scale. Solving for T using equation [1], we arrive at:

$$T = \frac{e^{(B_o + B_1 X)}}{1 + e^{(B_o + B_1 X)}} \quad \dots \dots \dots \dots \dots [2]$$

Equation [2] expresses the model as an S-shaped curve in the original probability scale.

A straight forward means of representing the results of the logistic regression analysis is to use as an index the value of current level that is required to obtain a response 50% of the time (Weisberg, 1980). Using the equation logit $T = B_o + B_1 X$ we can find the value of X that gives $T = 0.5$, or logit $T = 0$. Hence, we must solve the equation $0 = B_o + B_1 X$ for X. The estimated response rate will be 50% when the shock level is given by $B_o/B_1 = X$.

In an attempt to establish the current level(s) at which significant responses occurred, response frequencies were compared between each 0.0 mA and current level

TABLE 1. DATA AND RESULTS OF CHI-SQUARE ANALYSIS, FRONT-TO-REAR HOOVES
AC current
Total observations = 600
Observations/current level = 100

Current, mA	Escapes, %	Number of escapes	χ^2_α, 1dof (0 - X mA)	Approx. p
0.0	27.0	27	NA	NA
1.0	31.0	31	0.22	0.66
2.0	24.0	24	0.11	0.75
3.0	62.0	62	23.40	<<0.005
4.0	66.0	66	29.02	<<0.005
5.0	84.0	84	63.48	<<0.005

DC current
Total observation = 840
Observations/current level = 120

Current, mA	Escapes %	Number of escapes	χ^2_α, 1dof (0 - X mA)	Approx. p
0.0	21.6	26	NA	NA
1.0	31.6	38	2.58	0.10
2.0	39.1	47	7.27	0.008
3.0	42.5	51	11.01	<<0.005
4.0	51.6	62	21.97	<<0.005
5.0	63.3	76	40.94	<<0.005
6.0	74.6	90	66.22	<<0.005

(i.e. 0.0 mA vs. 1.0 mA, 0.0 mA vs. 2.0 mA, etc.) with a chi-square test of proportions in two independent samples (Snedecor and Cochran, 1967). This comparison was performed through the use of 2 x 2 contingency tables, each with one degree of freedom.

RESULTS AND DISCUSSION

Experiment 1: Front-to-Rear Hooves Pathway

Table 1 contains base data and results of the chi-square analysis for both AC and DC currents through the front-to-rear hooves pathway. Response frequencies were not significantly different from 0.0 mA for AC current levels at 1.0 and 2.0 mA. However, at the 3.0 mA level, response rate difference becomes significant ($p<0.005$). Response frequencies were not significantly different from 0.0 mA for a DC current level of 1.0 mA, but a significant difference ($p<0.008$) occurred at the 2.0 mA level. At current levels of 1.0 mA and less for AC and DC, there is a base level of activity evident. This can be attributed to random front hoof movement, rather than an attempt to escape a shock (Norell, 1983). At the maximum current levels of 5.0 mAAC and 6.0 mADC, the cattle were expressing the escape response 84% and 74.6% of the time, respectively. These results were consistent with the ten "warmup" trials.

Escape functions were calculated using logit regression analysis (Fig. 3). Individual cow escape percentages for all AC and DC current levels were used in the analysis. If we assume an average pathway resistance of 744 ohms (Norell, 1983), we can calculate the average floor voltage gradient that would have to be present to evoke a certain response. For example, at a 50% response rate (2.6 mAAC, 3.5 mADC) a voltage of 1.9 VAC and 2.6 VDC is indicated.

Experiment 2: Mouth-to-All Hooves Pathway

Table 2 contains base data and results of the chi-square analysis for the mouth-to-all hooves pathway. Response frequencies were not significantly different from 0.0 mA for AC current levels of 1.0 and 2.0 mA. However, a significant difference ($p<< 0.005$) in
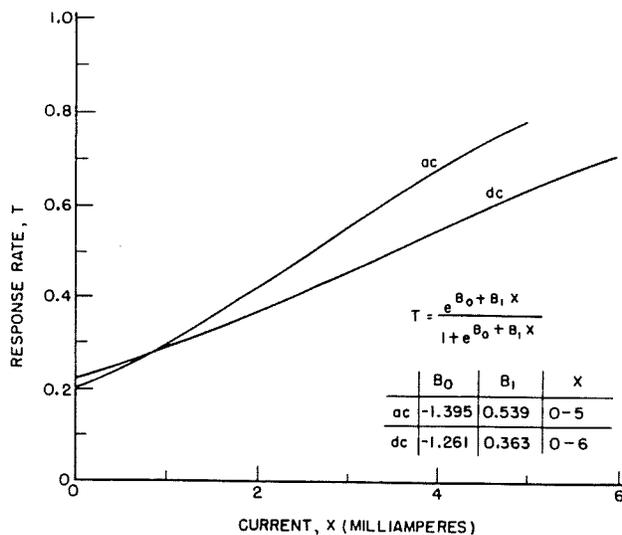
$$T = \frac{e^{B_0 + B_1 X}}{1 + e^{B_0 + B_1 X}}$$

	B_0	B_1	X
ac	-1.395	0.539	0-5
dc	-1.261	0.363	0-6

Fig. 3—Response rate vs. current, front-to-rear hooves pathway.

$$T = \frac{e^{B_0 + B_1 X}}{1 + e^{B_0 + B_1 X}}$$

	B_0	B_1	X
ac	-2.518	0.657	0-5
dc	-2.252	0.481	0-6

Fig. 4—Response rate vs. current, mouth-to-all hooves pathway.

response rate occurred at the 3.0 mA level. Significant differences in response rates for DC currents were markedly different. Response frequencies from 1.0 to 4.0 mA did not exhibit a significant difference ($p \ll 0.005$) from the response frequency at 0.0 mA. Between 4.0 and 5.0 mA, a significant difference in response rate did occur. At the higher current levels of 5.0 mA and 6.0 mADC, the cow response rates were quite similar, 74.1% and 69.1%. However, this was lower than the response rates in the ten warmup trials, where the average response rate was 85% or greater.

There was an unexpected level of response of 0.0 mA and 1.0 mA levels. Norell (1983) observed that mouth opening was a shock elicited response only. However, in this experiment, perhaps due to physical discomfort from the bit, the cows showed a distinct base level of activity at zero current.

A response function to a mouth-to-all hooves shock (Fig. 4) was calculated by logistic regression for AC and DC current. Assuming an average mouth-to-all hooves pathway resistance of 360 ohms (Norell, 1983), the calculated voltages for 50% response (3.8 mAAC, 4.7 mADC) are 1.4 VAC and 1.7 VDC.

Experiment 3: Body-to-All Hooves Pathway

Table 3 contains the base data and results of the 2 x 2 contingency tables and chi-square analysis of the body-to-all hooves pathway. A significant difference ($p \ll 0.005$) in response frequency, from 0.0 mA, occurs between 4.5 and 6.0 mAAC. For the DC current application, a significant difference ($p < 0.008$) in response frequency from 0.0 mA was not detected until the current interval between 4.5 and 6.0 mA. However, the response frequencies for each current level from 3.0 to 9.0 mA showed very little differences between one another. The range of the observed frequency responses over these current levels varied by only 11.8%. In addition, the observed response frequencies at the maximum current levels are lower than those obtained in the training sessions and in the warmup trials, where in both these cases the response rate was 70% of better.

The response functions generated by logistic

TABLE 2. DATA AND RESULTS OF CHI-SQUARE ANALYSIS, MOUTH-TO-ALL HOOVES
AC current
Total observations = 720
Observations/current level = 120

Current, mA	Escapes, %	Number of escapes	χ^2_α, 1dof (0 - X mA)	Approx. p
0.0	8.3	10	NA	NA
1.0	6.6	8	0.06	0.083
2.0	18.3	22	4.36	0.040
3.0	41.6	50	33.80	$\ll 0.005$
4.0	60.0	72	68.93	$\ll 0.005$
5.0	74.1	89	104.60	$\ll 0.005$

DC current
Total observation = 840
Observations/current level = 120

Current, mA	Escapes %	Number of escapes	χ^2_α, 1dof (0 - X mA)	Approx. p
0.0	15.8	19	NA	NA
1.0	18.3	22	0.12	0.50
2.0	20.0	24	0.45	0.50
3.0	25.0	30	2.56	0.10
4.0	28.3	34	4.75	0.03
5.0	57.5	69	43.08	$\ll 0.005$
6.0	69.1	83	67.67	$\ll 0.005$

TABLE 3. DATA AND RESULTS OF CHI-SQUARE ANALYSIS, BODY-TO-ALL HOOVES
AC current
Total observations = 720
Observations/current level = 120

Current, mA	Escapes, %	Number of escapes	χ^2_α, 1dof (0 - X mA)	Approx. p
0.0	25.8	31	NA	NA
1.5	30.0	36	0.75	0.44
3.0	43.3	52	6.93	2.01
4.5	39.1	47	4.27	0.40
6.0	49.1	59	12.96	$\ll 0.005$
7.5	64.1	77	34.10	$\ll 0.005$

DC current
Total observation = 770
Observations/current level = 120

Current, mA	Escapes %	Number of escapes	χ^2_α, 1dof (0 - X mA)	Approx. p
0.0	34.5	38	NA	NA
1.5	33.6	37	0	0
3.0	45.4	50	2.29	0.10
4.5	44.5	49	1.91	0.17
6.0	53.6	59	7.38	0.008
7.5	43.6	48	1.55	0.20
9.0	55.4	61	8.89	< 0.005

$$T = \frac{e^{B_0 + B_1 x}}{1 + e^{B_0 + B_1 x}}$$

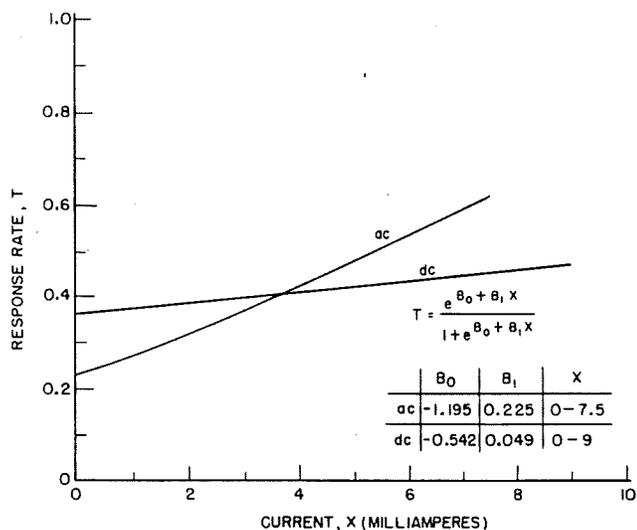|	B_0	B_1	X
ac	-1.195	0.225	0-7.5
dc	-0.542	0.049	0-9

Fig. 5—Response rate vs. current, body-to-all hooves pathway.

regression were generally inconclusive (Fig. 5). The lines are positively sloped but show little if any of the expected S-shape that is characteristic of this type of exponential transformation. There is very little distribution of response throughout the range of current levels.

Several possible reasons exist for this lack of consistency in the response frequencies: (a) a training period that was too short; (b) confusion on the part of the cows as to what response to give to a current, despite the training sessions; (c) the utilization of current levels that were not high enough to evoke a consistent response from a majority of the cattle; or (d) inadequate technique of body contact. Any of these could have contributed in part to the inconsistencies in the data. Although two training sessions were conducted for each cow, for each current type prior to the beginning of the experimental sessions, the trained response might have been an unnatural one for a current of this type. Three of the six cows exhibited a tendency to raise a front hoof upon experiencing the training current levels of 7.5 mAAC and 9.0 mADC, while the other three cows gave varying responses including muscle contractions, startled jerks, and shoulder shakes.

Better response frequencies may have been obtained if the training sessions were longer or made allowances for these varying responses among cattle.

The only conclusive information from this particular pathway/current combination was that it seems a higher threshold current level is necessary to elicit a response from cattle than was the case with the previous two pathways. It is not possible to assign any values for the response voltages based on the results from this experiment.

References

1. Appleman, R. D. and R. J. Gustafson. 1984. Sources of stray voltage and effect on cow health and performance. Symposium on Environmental Effects on Cow Health and Performance. J. Dairy Science (Accepted for Publication).

2. Baker, R. J. and J. A. Nelder. 1978. The GLIM System. Release 3. Generalised linear interactive modelling. Numerical Algorithms Group. Oxford, United Kingdom.

3. Cloud, H. A., R. D. Appleman, and R. J. Gustafson. 1980. Stray voltage problems with dairy cows. North Central Regional Extension Publication No. 125. Agricultural Extension Service. University of Minnesota.

4. Gustafson, R. J. 1983. Stray voltage: Detection and diagnostic procedures guide for rural electric systems. NRECA Res. Proj. 80-1. National Rural Electric Cooperative Association, Washington, DC.

5. Gustafson, R. J., G. S. Christiansen, and R. D. Appleman. 1983. Electrical resistance of milking system components. TRANSACTIONS of the ASAE 26(4):1218-1221.

6. Henke-Drenkard, D. V., R. C. Gorewit, N. R. Scott, and R. Sagi. 1984. Milk production, health, and endocrine responses of cow's Exposed to electrical currents during milking. Journal of Dairy Science. (Submitted for Publication.)

7. Lefcourt, A. M., R. M. Akers, R. H. Miller, and B. Weinland. 1984. Effects of intermittent electrical shock on responses related to milk ejection. Journal of Dairy Science. (Accepted for publication.)

8. Norell, R. J., R. J. Gustafson, R. D. Appleman. 1982. Behavioral studies of dairy cattle sensitivity to electrical currents. ASAE Paper No. 82-3530. ASAE, St. Joseph, MI 49085.

9. Norell, R. J. 1983. Dairy cattle sensitivity to electrical shocks as determined with behavioral indices. Ph.D. Thesis. University of Minnesota.

10. Snedecor, G. W. and W. G. Cochran. 1967. Statistical methods. Sixth Ed. Iowa State University Press. Ames, Iowa.

11. Weisberg, S. 1980. Applied linear regression. 2nd edition. John Wiley and Sons. New York.