The Effects of High-Voltage Transmission Lines on Honey Bees

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Prepared by
Bioconcern
Chicago, Illinois

ELECTRIC POWER RESEARCH INSTITUTE

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Chicago, Illinois

ABSTRACT

Data are reported on the effect of hive height and current distribution on honey bees hived under a 765 kV line (E-field ca. 7 kV/m). Hive height was standardized with adjustable collectors to 1 meter (59 μA total hive current) or 1.5 meter (85 μA) equivalents; controls were shielded. A 1.5 meter group with completely painted supers was included. After 8 or 16 weeks of exposure there was no effect on honey moisture content or weight of young workers in any group. Worker capped brood was not affected in 1 m hives but declined significantly in 1.5 m hives after 4 weeks of exposure and this was associated with queen loss, abnormal queen cell production, and colony failure. Weight gain was depressed in all hives after 2 weeks of exposure and was dose related, with the taller hives more severely affected. Only the exposed hives propolized entrances but the amount and time of onset were not dose related. The 1.5 m hives with painted interiors behaved like the 1 m hives with unpainted interiors in all respects, although their total hive current approximated the other group of 1.5 m hives. Reversal of treatments at mid-season resulted in reversal of colony behavior, manifested most clearly with respect to hive weight, less with respect to brood. When first exposed, colonies exhibit pronounced but transient elevations in hive temperature. Bio-effects were more severe during the first period when hives had fewer bees. Total hive current was greater in wet than in dry periods. All these factors influence observed bio-effects.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

EPRI is currently supporting a project under RP934-1 to evaluate the biological effects from the electromagnetic environment beneath overhead transmission lines. This project is designed to test whether the electric fields produced by transmission lines affect the biological activities in a honeybee hive. Previous studies in this project have shown that adverse effects can occur in hives situated beneath a 765-kV line. In some cases, the effects were so pronounced that the hives failed to survive the summer. The work showed that (1) the effects were unrelated to the materials incorporated into the hive construction; i.e., it did not matter if the hive was conventionally built with metal nails (which produce local field and current distortion) or without and (2) the effects were related to the hive heights, a finding which led to the suggestion that the appropriate dosimetric parameter was total hive current.

This interim report describes field work conducted in 1979. The research team for RP934-1 consists of Bioconcern, which is the contractor of this report, and IIT Research Institute (IITRI), which supplied engineering design and support functions under RP934-2. Dr. Norman Gary of the University of California at Davis served as technical adviser for RP934-3.

The hives were placed beneath Commonwealth Edison's 765-kV line in Joliet, Illinois, and each hive was assigned to one of three dosage groups: no exposure, intermediate exposure (average hive current of 59 A), and high exposure (85 A). At midseason half of the exposed hives were shielded, half the shielded hives were exposed, and the remaining hives were maintained in their initial conditions.

The parameters investigated were reproductivity as reflected by worker capped brood count, net hive weight, individual bee weight, honey moisture content, and propilization at the hive entrance (deposition of propilis at the entrance is a manifestation of disturbance).

PROJECT OBJECTIVES

This study's aims are (1) to determine if there is a dose-effect relationship; in other words, to see if the observed effects are quantitatively related to the amount of current the hives conduct to ground and (2) to determine if the effects are reversible.

The longer-range project objective is to understand the mechanisms responsible for the observed effects so that the data might be applied to understanding field effects on higher organisms.

PROJECT RESULTS

Two of the five parameters--capped worker brood and net hive weight--showed dose-related effects. In both cases, the hives in the high-dosage group had the lowest reproductivity and the least weight gained. The responses of the intermediate exposure group fell between the highs and the controls. Hives exposed to the field in the first half of the experiment displayed the ability to recover after they were shielded, and by the same token, hives shielded during the first half of the experiment displayed the same exposure effects following removal of the shields.

Two other parameters--bee weight and honey moisture content--were unaffected by exposure, and the fifth parameter, propilization of hive entrances, was associated with exposure but appeared independent of the given current doses. Propilization was absent in shielded hives.

The results suggest that the electric field provides an inhospitable environment to the bees.

Previous studies by the IITRI engineering team suggest that unavoidable spark discharges within the hive might be responsible for diminished hive productivity. This possibility is now being addressed with studies in which the external fields and internal currents remain the same, but the spark discharge is eliminated with short circuits placed in the appropriate locations within the hives.

We believe that knowing the reasons for the effects is an important step in providing information for an analysis of environmental hazard.

Robert Kavet, Project Manager
Energy Analysis and Environment Division

ACKNOWLEDGMENTS

We thank the personnel of the EM Effects section, IIT Research Institute, Chicago, IL, for their engineering support and William Fern, Commonwealth Edison Technical Center, Maywood, IL, for data on the 765 kV transmission line used in the study. We continue to be deeply indebted to the administration of the U.S. Army Ammunition Plant at Joliet, IL, and particularly to Frank Forsythe, who have generously provided a site and a laboratory for our studies. We thank Dr. Norman Gary, Department of Entomology, University of California at Davis, for his many helpful suggestions.

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SUMMARY

Our previous studies on honey bees hived under a 765 kV transmission line have shown that abnormal propolization of hive entrances, poor hive weight gain, and decreased capped brood are due to electrical factors and not to magnetic, atmospheric, or other line phenomena. It appeared from these studies and from inconsistencies in the literature that hive height, not presence or absence of metal hive parts, is a crucial factor. Should not the nature of the hive's interior components influence the amount of total current and its path through the hive to ground as well? Our investigation in 1979 addressed both dosimetric aspects which have been virtually ignored in published work.

The field site was the same as in previous years. Fifty six conventional (metal-containing) hives, with hive chambers painted on the outside only, were placed in electromagnetically defined positions under the line. All colonies were homogeneous with respect to hive weight, level of development, and brood production. Half the hives (28) were designated 1 meter high equivalents and the other half, 1.5 meter high equivalents. Each group was further divided into tests and controls, with the latter enclosed in grounded shields. A hardware cloth extension was mounted on top of each of the exposed hives and its height was adjusted for an average total hive current of 59 μA (1 m equivalent) or 85 μA (1.5 m equivalent). Another group of seven exposed hives designated painted 1.5 m tests (painted outside and inside) was set up at the same time.

The experiment ran from June 7 until September 28. On August 2, the mid-point, treatment-reversal for half the hives took place. Among the 1.5 m group, 7 of 14 exposed hives were shielded (exposed-shielded) and 7 of 14 control hives had their shields removed (shielded-exposed); the other 7 hives of each continued the original treatment for 114 days. The 1 m hives were similarly reversed. The painted 1.5 m tests continued their exposure for the entire 114-day period.

The parameters were: worker capped brood count; net hive weight; teneral worker dry weight; honey moisture content; and amount of propolis in hive entrance.

Worker capped brood in 1 m and 1.5 m painted hives was unaffected by an exposure of 114 days. There were also no queen losses or abnormal queen cell production. In 1.5 m exposed hives capped brood was normal the first two weeks, then significantly dropped at the fourth week, the decline reaching zero in 5 of 14 hives at the eighth week. Queens were lost from 8 of those hives (57%) and queen cell production was abnormally high. After reversal, the 1.5 m shielded-exposed colonies had a definite downturn in capped brood, while in the exposed-shielded group, a small increase occurred which was soon aborted by the normal cessation of brood rearing in fall.

The trend toward depressed hive weights in all exposed hives was discernable after two weeks but did not become statistically significant until the third week (Anova test) or fourth week (Student-Newman-Keuls test) and then, only in 1.5 m hives. From the fifth week on, this group's hive weight was very significantly lower than that of controls ($p < .001$). At the end of 8 weeks, the 1 m and painted 1.5 m tests had intermediate weights which were significantly different from the control and 1.5 m groups. After reversal, there was an upturn in the weight of 1 m and 1.5 m exposed-shielded hives and a downturn in shielded-exposed ones.

Abnormal deposits of propolis were absent from shielded hives but were present in the entrances of all exposed hives. Neither the amount of propolis nor the time of its initial deposit were dose related. Average deposits from 1 m and 1.5 m hives had very similar weight (≃ 42 gm) while those from painted 1.5 m tests were lower, but not significantly so. Electrical analysis of propolis shows it to be a good insulator. Therefore, it cannot function protectively to lower the in-hive electric field intensity or short out the gaps and thereby shunt current around the bees.

Dry weight of a worker less than 24 hr of age was 18.1 to 22.6 mgm. Within this range there were no statistically significant differences between any exposed and shielded groups after exposures of 22, 50, 79 or 107 days.

Moisture content of honey ranged from 15.2 to 22.3 percent. There were no significant differences between any exposed and shielded group after 48 or 103 days of exposure.

A rapid increase to an abnormally high in-hive temperature (40°C) was demonstrated 10 of 16 times when shields were removed and total hive current was adjusted to ≃ 100 μA. Temperature usually increased within 10 min, reached a plateau in 30 min and remained elevated for 10 min to about 18 hr before slowly returning to normal. Responsivity varied between hives, in the same hive on different days, and in different places in the hive.

Total hive current to ground is probably a more meaningful measure of a hive's electric field exposure or excitation than the ambient electric field intensity. There are, however, several factors which modify the effects of hive current. The hive conductivity-weather interaction affects the total current. Hive currents increased during wet periods and decreased during dry periods (although differences between treatment groups remained the same). The path of current flow through a hive to ground depends on the relative conductivity of its parts. Painted interior surfaces are more resistive to current flow than wooden surfaces, therefore less conduction current should flow on the inside of these hives and through the bee population. This is borne out by the data. The 1.5 m hives with painted interiors had an average total current close to that of the 1.5 m unpainted group, yet they responded like the 1 m group which had much lower currents. Finally, population density modifies the internal electrical environment of the hive. A strong hive has more bees to divide up the current and there will be less current per bee to evoke adverse responses. This, too, is borne out by our observations. During the first period when colonies were less populous, bio-effects were more severe with earlier onset than in the second period when colonies were more populous.

I. INTRODUCTION

In this country, interest in possible biologic effects of extreme low frequency electromagnetic fields was stimulated by the U.S. Navy's plan to build a land-based submarine communication system, successively known as Project Sanguine, Seafarer, and ELF. The proposed electric fields of about .07 V/m and magnetic fields of up to two gauss were used in a number of laboratories to study the responses of various organisms and systems (1). Although some metabolic and behavioral effects were noted the consensus of a review committee of the National Research Council (2) was that such fields would not cause a significant and adverse biologic disturbance. Concurrently, there has been mounting interest here and abroad in the transmission line environment as another possible source of bio-effects. Interest has grown into concern as transmission lines carrying higher voltages increasingly span our environment. Although the Navy and power systems use similar frequencies, differences between them are significant. Transmission line E-fields are about three orders of magnitude greater, the vertical component is more important than the horizontal one, and the magnetic field is weaker. These differences do not allow extrapolation from the Navy studies, much less do they justify similar conclusions.

The few studies of people living or working in the transmission line environment (3,4,5,6) and laboratory studies of other vertebrates (7,8,9,10) have been of unequal scientific rigor and have sometimes lacked statistical validity and a standardized dosimetry, resulting in contradictory data and conclusions.

Among invertebrates it is not surprising that honey bees have become the subject of choice given their complex and populous society, the number of generations and quantifiable parameters, their sensitivity to earth's magnetic field (11,12) and their unambiguous responses to extremely weak currents, especially at power frequencies (13). Honey bees in hives placed under an AC transmission line at 7 to 11 kV/m became immediately hyperactive, attacking and stinging each other, and after a few days completely sealed themselves in with propolis and died (14). Wellenstein (15) observed hyperactivity and doubling of nectar collection under a 110 kV line, and increased tendency to swarm under a 220 kV line (field strengths not given): he does not mention abnormal propolization. Lecomte and Theurkauff (16) however, found no effects in hives placed under a 380 kV 50-Hz line. Under laboratory conditions, absconding began at field strength of 7.4 kV/m (17), metabolic rate progressively increased above 20 kV/m and stinging of other bees occurred above 50 kV/m (18). These are important effects but some of the studies are limited both in replication and design; in others, there are discrepant observations between field and laboratory studies, and between E-field strengths.

Our studies investigated reports of hive disturbance under actual high voltage line conditions, using controlled and quantifiable parameters with standardized dosimetry. We placed shielded and unshielded conventional (metal-containing) and metal-free hives under a 765 kV line (E-field 7 kV/m) and in a nearby control area (E-field 10 V/m) and observed abnormal propolization in unshielded hives of both types only under the line. The following occurred in exposed conventional hives only: reduced capped cell counts ($p = .01$) but normal egg and larval counts; and minimal hive weight gain ($p = .001$). Other effects in these hives, such as lower bee weight and honey moisture, were considered of doubtful significance in view of the almost complete absence of honey (19). From the start of the experiments, the conventional hives were maintained at a height of one and a half meters, whereas the metal-free hives were begun from packages and foundation in spring and reached a maximum of one meter during the experiment. In a follow-up study in 1978, using short hives of both types, no bio-effects occurred until wire mesh extensions were placed atop each hive in September, resulting only then in some abnormal propolization (20).

It appeared from these studies that hive height, not metal parts, was a crucial factor. This had been virtually ignored in previous published work although the direct relation between hive height and total induced current is patent, and such potential anti-bee factors as large voltage drops and enhanced E-fields in the intersuper spaces can then be inferred. In beekeeping, while hives are routinely painted on the outside, the interior surfaces are not painted, or are scorched to control foulbrood. This, and its possible influence on the path of current flow, is another dosimetric detail that has been largely ignored. Our study in the summer of 1979 addressed both aspects.

II. MATERIALS AND METHODS

The site for the field study continued to be the U.S. Army Arsenal and Ammunition Plant, Will Co., Illinois, with Commonwealth Edison's 765 kV transmission line 11216 providing the experimental treatment. The line was in service 99.89% of the time from June 1 to October 15, 1979, and voltage ranged from 720 kV to 738 kV, changing hour by hour and day by day (21). Prior to placement of each hive under the line electric and magnetic field measurements were made by personnel from Illinois Institute of Technology Research Institute (IITRI). Electric field intensity was measured with Polytek FMB-100-10-46 field meter and the Y and Z components of the magnetic flux density were measured using a probe in conjunction with a HP3581A signal wave analyzer (Table 1).

Hives were medium-depth, conventional metal-containing types with nailed frames, supers, wooden bottom boards, and top and inner covers; telescoped top cover clad in sheet metal fastened with nails; and foundation, with vertical crimp wire, secured by four horizontal metal clips. All hives were painted on the exterior but the interior surfaces and edges were burned and scraped to remove all paint, except in the group designated 'painted 1.5 m tests'. One hundred hives were started April 12 with an air shipment of 3-lb packages with Starline queens (York Bee Co., Jesup, GA). The hives were initially placed several hundred meters from the test site, to minimize pretreatment exposure to the line environment. We allowed 8 weeks for them to become well established prior to the experiment and this enabled us to obtain preliminary data on brood production and hive weight for more homogeneous grouping of hives among the treatment categories (Table 2). On June 6, one day before hives were placed under the line, final brood counts and hive weights were taken and group assignments were made. Fourteen hives were assigned to each of the following groups: 1 m test; 1 m control; 1.5 m test; and 1.5 m control. On June 7, the hives were randomly distributed at pre-measured positions in three rows under the line (Figures 1 and 2). At this time a separate group of 7 hives, designated 'painted 1.5 m tests', was placed under the line. Spacing between rows and

TABLE 1.

ELECTRIC AND MAGNETIC FIELD MEASUREMENTS
AT THE HIVE SITES

Hive No.	Measurements at 1 m Height			Measurements at 1.5 m Height		
	E_{vert} (kV/m)	B_y (mG)	B_z (mG)	E_{vert} (kV/m)	B_y (mG)	B_z (mG)
2	6.3	5.4	4.8	6.8	6.8	5.4
4	6.1	4.9	4.9	6.8	2.7	5.7
6	5.6	7.2	3.0	6.1	7.3	3.1
9	6.3	2.8	4.7	6.9	2.3	5.8
10	6.5	4.4	4.9	7.3	4.3	5.7
11	6.5	3.0	4.7	7.0	2.6	5.8
13	6.8	2.8	5.0	7.2	2.6	6.0
17	7.0	4.2	5.0	7.5	4.3	6.3
19	7.0	4.4	5.2	7.6	4.7	6.4
21	5.5	7.2	3.0	6.1	7.4	3.2
23	6.5	5.7	5.3	7.2	7.3	6.6
24	6.3	5.5	5.1	6.9	6.5	5.5
25	6.7	2.7	5.0	7.3	2.8	6.1
27	6.3	2.8	5.1	7.0	3.2	6.5
30	6.9	3.9	5.1	7.5	5.3	6.6
31	6.2	2.5	4.8	6.8	6.4	5.5
32	6.5	5.5	5.0	7.2	7.6	6.0
33	6.1	4.9	4.9	6.8	2.7	5.7
34	6.8	3.9	5.0	7.6	4.5	6.3
35	6.7	3.1	4.7	7.2	2.4	5.9
37	6.4	5.2	5.0	7.0	6.5	6.0
38	6.2	2.7	4.7	6.7	2.3	5.4
39	6.3	4.1	4.7	6.8	4.5	5.7
42	6.8	4.0	4.9	7.0	4.5	5.7
43	6.5	4.1	4.8	7.2	4.3	5.8
46	5.5	7.0	3.0	6.0	7.2	3.1
47	4.5	6.3	5.1	7.2	7.1	6.4
50	6.5	2.7	4.7	6.8	2.6	5.9
51	6.7	2.5	4.9	7.2	3.2	6.6
52	6.1	5.1	4.8	6.7	6.6	5.2
53	6.6	4.2	4.9	7.2	4.4	6.1
54	6.5	5.5	5.2	7.0	7.1	5.9
56	6.5	2.8	4.8	7.0	2.4	5.6
57	6.6	4.1	5.0	7.2	4.6	5.9
58	6.5	4.1	4.7	7.0	4.4	5.5
59	6.8	3.0	5.0	7.5	3.5	6.8
60	5.5	7.2	3.0	6.1	7.4	3.1
63	6.9	7.7	4.4	5.0	5.0	6.8
64	6.5	2.9	5.0	6.9	3.0	6.2
65	6.2	5.3	5.0	6.6	6.8	5.9
66	7.0	4.3	5.5	7.5	5.1	6.9
68	6.9	4.8	5.2	8.0	5.2	6.4
69	6.8	4.3	5.3	7.8	4.7	6.6
70	6.8	2.9	5.2	7.3	3.0	6.2
72	7.2	4.5	5.0	7.7	4.5	6.6
74	6.8	2.6	4.9	7.3	2.5	6.4
75	6.2	5.3	5.0	6.8	6.8	5.6
77	6.9	7.3	3.1	5.1	3.2	6.2
78	6.5	7.3	5.9	5.2	7.5	6.1
79	6.6	7.2	5.5	5.1	6.7	6.1
80	6.8	7.2	2.7	4.9	2.8	6.6
83	5.6	7.2	3.0	6.0	7.4	3.1
85	6.6	4.4	5.5	7.7	4.9	6.6
87	7.3	4.0	5.3	7.8	5.0	6.6
88	6.5	6.4	5.1	7.2	7.0	6.4
91	6.5	6.5	5.1	7.2	6.9	6.3
92	7.0	4.5	5.1	7.6	5.0	6.7
93	6.5	5.8	5.1	7.0	7.4	6.6
94	6.2	6.4	5.2	7.0	7.6	7.1
96	6.9	3.0	5.0	7.2	3.2	6.0
98	6.8	6.4	5.3	7.3	7.8	6.6
99	6.5	2.8	5.0	7.2	3.5	6.2
100	6.8	4.9	5.1	7.3	5.0	6.5

Table 2

SUMMARY OF HIVE GROUPS[1,2]

1 m continuously shielded for 114 days

Hive	No. of capped cells	Net Wt. (kg)
58	11627	7.6
25	9266	5.5
50	10554	6.7
54	14272	7.4
32	9641	5.1
24	10449	7.5
10	9814	7.2

1 m continuously exposed for 114 days

Hive	No. of capped cells	Net Wt. (kg)
17	11660	11.1
80	9940	6.0
85	10541	5.4
64	14283	11.7
74	9673	6.9
78	10433	6.7
69	10155	5.1

1 m shielded for 57 days then exposed for 57 days

Hive	No. of capped cells	Net Wt. (kg)
66	13865	7.3
11	11760	6.4
38	10041	6.4
27	9679	5.6
31	13475	6.0
72	10685	8.8
2	10182	6.4

1 m exposed for 57 days then shielded for 57 days

Hive	No. of capped cells	Net Wt. (kg)
99	13145	7.3
94	11757	6.8
88	12472	7.4
87	9649	8.0
47	11520	6.6
30	12034	4.9
91	10189	6.9

1.5 m continuously shielded for 114 days

Hive	No. of capped cells	Net Wt. (kg)
57	12867	6.5
9	9836	7.9
92	13475	6.0
100	13150	8.8
34	8062	7.8
37	13755	6.5
77	12787	6.9

1.5 m continuously exposed for 114 days

Hive	No. of capped cells	Net Wt. (kg)
42	12821	8.1
43	10241	5.6
96	7693	7.8
75	12071	8.5
79	10749	7.3
65	14272	7.4
23	7822	7.0

1.5 m shielded for 57 days then exposed for 57 days

Hive	No. of capped cells	Net Wt. (kg)
4	12077	7.8
70	9596	6.4
35	11582	7.7
59	10779	6.8
68	11003	8.1
39	14575	14.1
51	10961	7.2

1.5 m exposed for 57 days then shielded for 57 days

Hive	No. of capped cells	Net Wt. (kg)
13	11245	10.4
19	10607	6.7
93	9506	8.8
53	7989	4.1
56	13225	5.0
98	11568	7.2
63	10600	7.0

1.5 m painted[3] hives exposed for 114 days

Hive	No. of capped cells	Net Wt. (kg)
33	10902	6.7
52	12172	7.5
46	10083	9.5
83	10117	6.9
21	14000	8.1
60	13059	7.6
6	11071	9.2

[1]Data taken one day before start of experiment. No significant differences ($p > .10$) among groups.

[2]Means of hive net weights and capped cell counts for each treatment group for the first 8 weeks of exposure were obtained from all exposed or all shielded hives from each dosimetry category.

[3]Supers with painted interiors and edges in this group only.

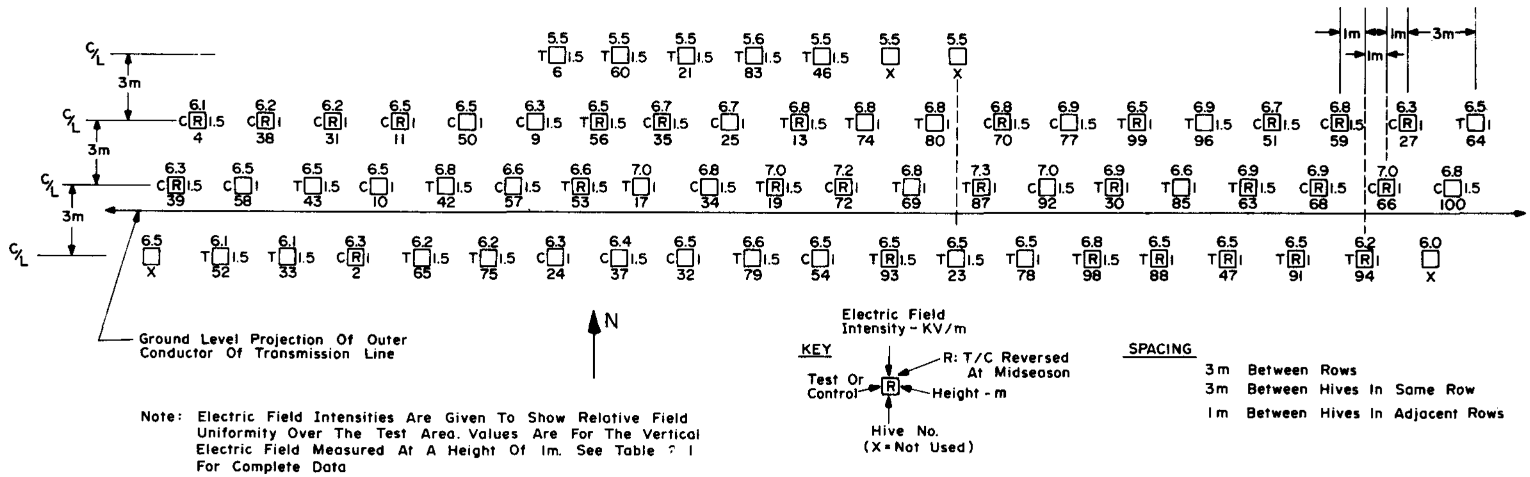

Figure 1. Deployment of Hives under 765 kV Line with Hive Number, Height, Treatment Status, and Electric Field Intensity.

Figure 2. Hives under 765 kV Transmission Line, Looking East.

between adjacent hives in the same row was three meters. Hives in adjacent rows were offset from one another by a distance of one meter to provide an uninterrupted straight line path to each hive entrance. The three-meter minimum separation between hives was adequate to minimize the perturbing effects to the electric field of one hive on another. Each control hive was immediately enclosed in a five-sided, grounded shield of hardware cloth (Figure 3a). Measurements made in previous years have shown the shields to be effective in reducing the electric field intensity by a factor of from 150 to 300, and the total hive current by a factor of about 100. Measurements made in the 1978 season indicated that the hive shields provide negligible attenuation of ambient magnetic fields (19). A hardware cloth extension was placed on top of each test hive (Figures 3b and 4) and was adjusted to give a total hive current flow of 55 μA (1 m hive equivalent) or 75 μA (1.5 m hive equivalent). All hives, including the shielded controls, were equipped with the variable height hive extensions. This was done to eliminate the possibility of any second order effect that might arise due to physical differences in the hives. The "top hat" collectors of the extensions were removed from the control hives, however, as the hive shields proved almost impossible to slip over them. This difference was justified because the collectors served no electrical function on the control hives. Each hive sat on a grounded aluminum collector sheet supported by two wooden 4" x 4"'s, under which was a one-inch thick sheet of high-density styrofoam of sufficient dimension to prevent hive contact with vegetation (Figures 3c and 4). Current was measured with an AC voltmeter (Hewlett Packard model 403B), using the voltage drop across a grounded 1000 ohm resistor connected to the hive collector sheet. The total current for the test hives was set at 55 μA or 75 μA, as required, by adjusting the height of the extensions. Initial current measurements were made using the HP3581A frequency selective voltmeter to obtain only the 60-Hz component of the current. Comparison measurements were taken with a HP403B wideband AC voltmeter, however, which showed no difference in readings from those of the narrowband HP3581A. Therefore, it was concluded that the harmonics of

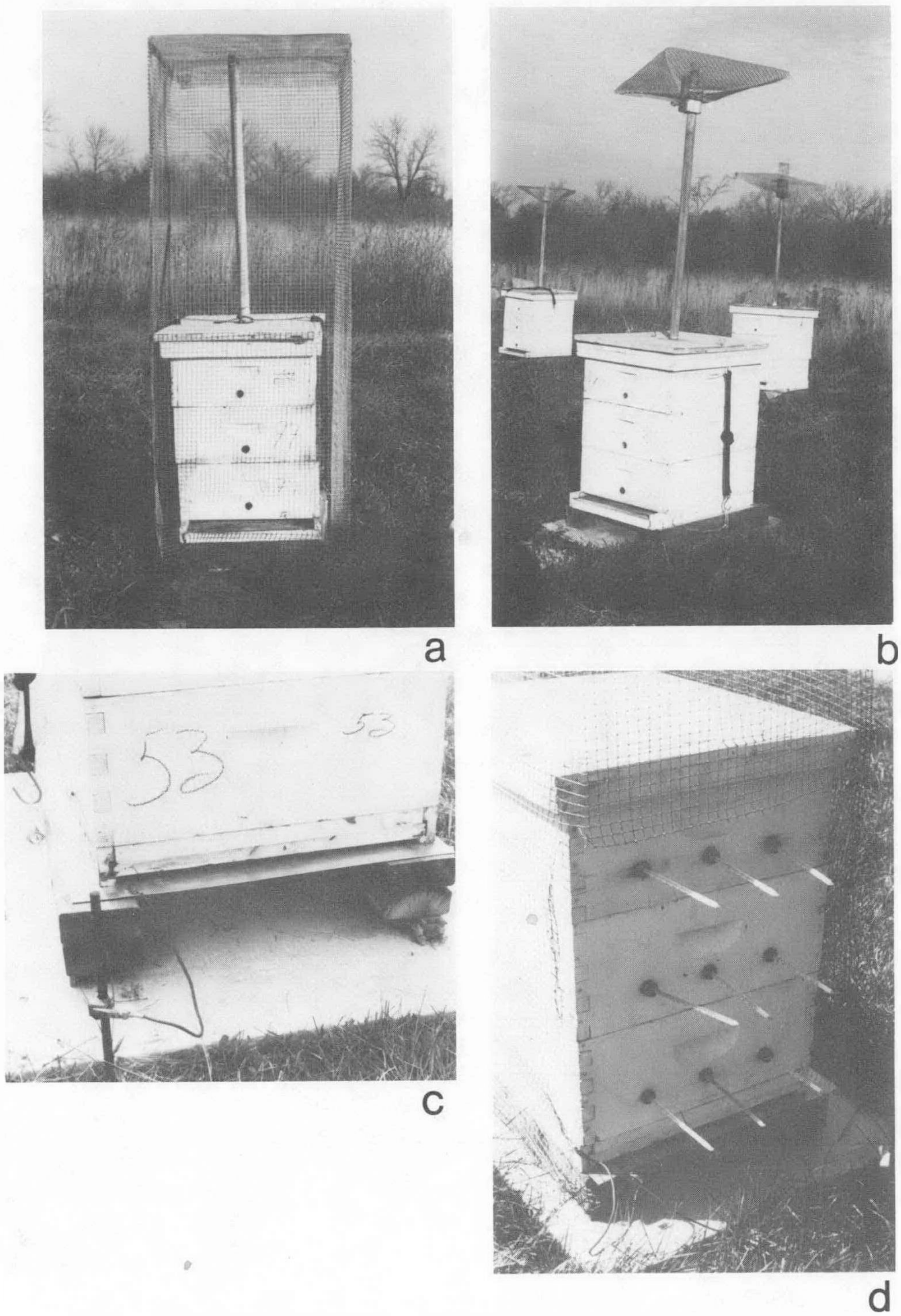

Figure 3. Hive Modifications: a. Shielded Control, Including Variable Height Extension without Collector; b. Exposed Hives with Extensions and Collectors; c. Hive Base Showing Sequence of Grounded Aluminum Collector Sheet, 4" x 4"'s, and styrofoam sheet; d. Thermometers in Rear of Shielded Hive.

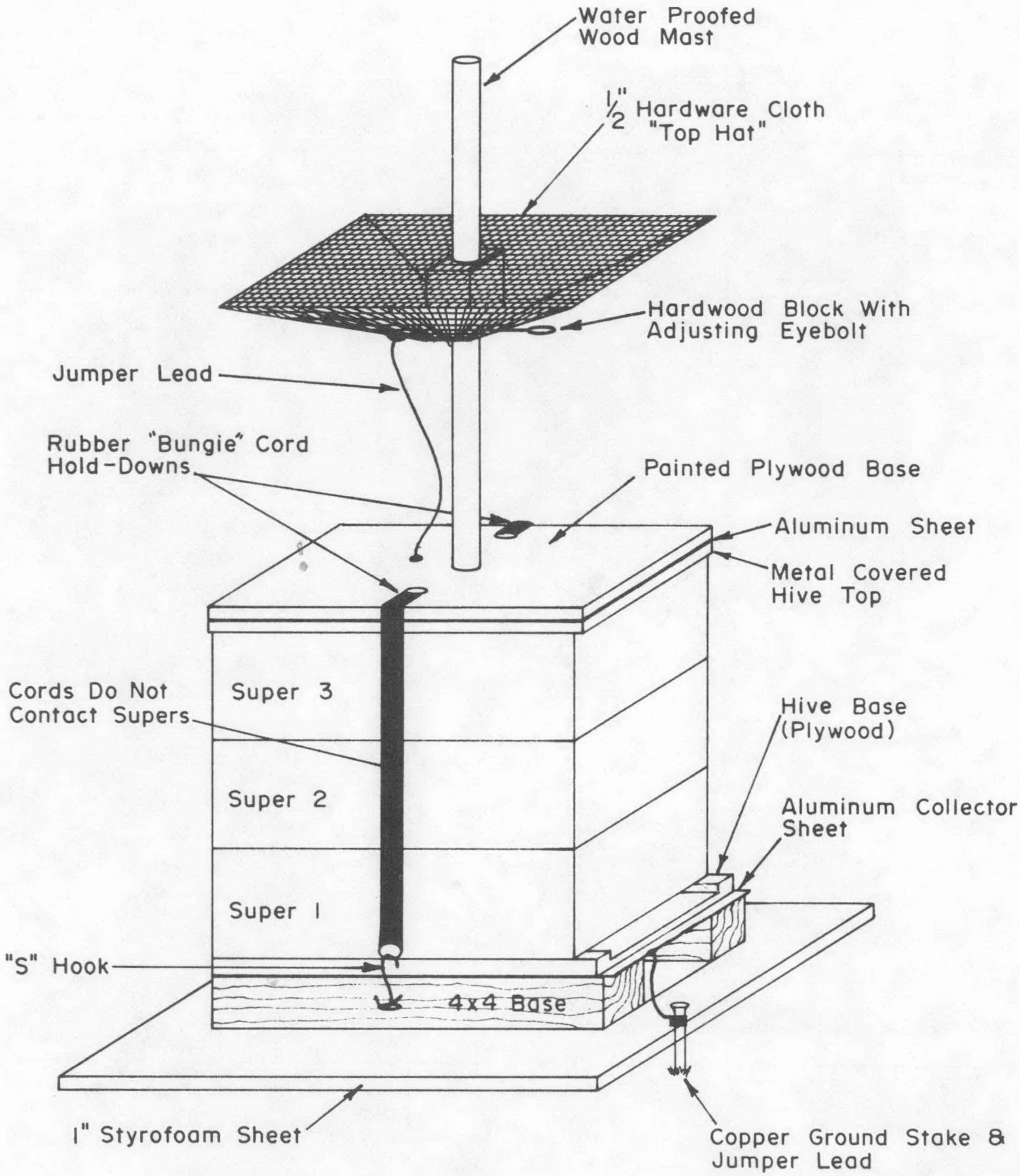

Figure 4. Hive with Variable Height Extension, Insulated Base, and Collector Sheet for Measuring Total Hive Current with Minimal Disturbance. An "S" Hook, Nylon Link, and Screw-eye Combination at the 4" x 4" End of the Straps Allow Simple Removal of the Extensions for Access to the Hives while Assuring that Current from the Extensions Is not Shunted around the Hives through the Straps.

the 60-Hz line frequency were insignificant with respect to the fundamental, and that the much simpler and more compact HP403B would be acceptable for future current measurements. On June 24, the currents of the 1.5 m hives were re-set upwards, from an average of 67 μA to 78 μA, to increase the difference between them and the 1 m equivalents to offset the weather-related dosimetry changes. During the course of the season, as the colonies developed and especially when they were supered, adjustment of the extensions was necessary to maintain uniform hive current. The greater the number of supers per hive the smaller was the hive current increase for each additional super whereas the variable height extension gave a nearly linear increase in current with height. On October 26, each hive was consolidated in preparation for wintering. Collectors were adjusted at this time, as well, attempting to maintain uniform dosimetry during winter. Hive current readings made during the course of the experiment are given in Table 3 and summarized in Figure 5. The latter also shows that hive currents increased during wet weather and decreased during dry spells.

Treatment reversal for half the hives of each group occurred on August 2. Seven of the fourteen 1.5 m exposed hives were shielded and seven shields of the 1.5 m control hives were replaced by collectors calibrated to deliver an average of about 95 μA at the collector sheet. The other seven hives of each group continued the original treatment. The 1 m hives were also reversed but the painted 1.5 m test hives were not. In summary, the treatment groups of seven hives each are as follows: 1 m and 1.5 m tests continuously exposed for 114 days; 1 m and 1.5 m controls continuously shielded for 114 days; 1 m and 1.5 m tests exposed for 57 days, then shielded for 57 days (exposed-shielded); 1 m and 1.5 m controls shielded for 57 days, then exposed for 57 days (shielded-exposed); and painted 1.5 m tests continuously exposed for 114 days.

A. <u>WORKER CAPPED CELL COUNTS</u>

Bi-weekly capped cell counts followed the baseline count on June 6, with a final count on September 28. The method of direct enumeration has been described (19) and

Table 3

MEASUREMENTS OF THE TOTAL HIVE CURRENT FOR THE 1979 FORAGING SEASON

(μA)

	Hive No.[1]		Date of Measurement															
			6/6[2]	6/12	6/15	6/18	6/19	6/21[2]	6/24[3]	6/27	7/3	7/11	8/2[1]	8/6	8/15	8/24	9/7[4]	10/26
1.0 m Equiv. Hives-Charred	30	2	56	67	-	-	-	55	54	48	69	74		80	62	61	65	69
	47	11	53	53	-	-	-	55	53	46	66	67		81	66	60	54	55
	87	27	56	55	-	-	-	55	53	46	62	65		83	66	61	57	65
	88	31	55	61	-	-	-	55	51	45	65	66		80	68	60	53	62
	91	38	54	-	-	-	-	55	46	45	67	64		80	62	59	61	61
	94	66	55	-	-	-	-	55	50	46	60	63		84	67	62	60	64
	99	72	56	60	-	-	-	55	47	45	69	70		82	71	64	60	64
	17		55	60	50	-	53	55	48	43	66	68		84	75	67	64	68
	64		56	-	-	-	-	55	45	-	58	61		82	65	60	61	53
	69		55	60	-	-	-	55	51	43	70	70		83	70	64	58	57
	77		55	60	-	42	-	55	49	43	65	66		82	73	62	58	60
	78		56	60	-	46	-	55	52	46	64	64		79	71	63	59	59
	80		55	68	-	47	-	55	54	45	66	69		82	78	70	61	65
	85		55	55	-	45	-	55	49	46	63	65		82	68	65	62	68
	Average		55	60	50	44	53	55	50	45	65	66		82	72	64	60	61
1.5 m Equiv. Hives-Charred	13	4	74	86	71	-	-	75	67/81	69	94	98		122	90	97	96	104
	19	35	75	87	68	-	-	75	71/79	66	107	107		120	93	85	93	82
	53	39	75	99	68	62	74	75	82/86	69	96	101		125	90	92	89	89
	56	51	75	85	68	56	83	75	58/70	63	111	116		130	98	96	99	-
	63	59	74	89	65	53	-	75	61/75	73	97	105		126	107	100	97	95
	93	68	74	87	-	-	-	75	71/78	65	85	96		126	101	99	97	107
	98	70	74	91	73	-	-	75	63/71	62	93	96		134	119	99	95	92
	23		76	92	67	55	-	75	57/66	58	89	96		135	105	98	100	94
	42		75	87	69	60	81	75	63/84	60	102	104		136	98	91	93	-
	43		74	76	79	-	-	75	-/-	59	89	88		126	100	96	90	-
	65		73	85	71	63	73	75	73/90	69	84	88		116	104	97	93	-
	75		74	-	66	56	77	75	69/80	68	97	107		132	102	99	94	-
	79		74	98	70	56	75	75	62/78	59	95	104		132	108	100	100	-
	96		74	84	59	-	-	75	69/77	69	103	105		125	100	94	90	-
	Average		75	88	69	58	77	75	67/78	65	96	101		129	101	96	95	95
1.5 m Equiv.Hives-Painted	6		-	-	-	-	-	-	-	60	77	87		127	94	85	90	87
	21		-	-	-	-	-	-	-	55	98	104		121	110	93	89	95
	33		-	-	-	-	-	-	-	66	82	90		121	99	84	89	86
	46		-	-	-	-	-	-	-	69	84	93		110	90	88	84	83
	52		-	-	-	-	-	-	-	74	79	89		117	102	88	91	90
	60		-	-	-	-	-	-	-	58	107	114		130	92	81	92	83
	83		-	-	-	-	-	-	-	58	81	88		107	89	88	87	87
	Average		-	-	-	-	-	-	-	63	87	95		119	97	87	89	87

[1]Seven test and seven Control hives of each height were role-reversed at midseason (8/2). The numbers of the hives which were used as Tests before and after the reversal are presented in the first and second column, respectively.

[2]On these dates the total hive currents were adjusted to the current set point values.

[3]The currents of the 1.5-meter hives were reset upward to increase the differences between the 1.0- and 1.5-meter currents. Both initial and reset values are given.

[4]- = data not taken.

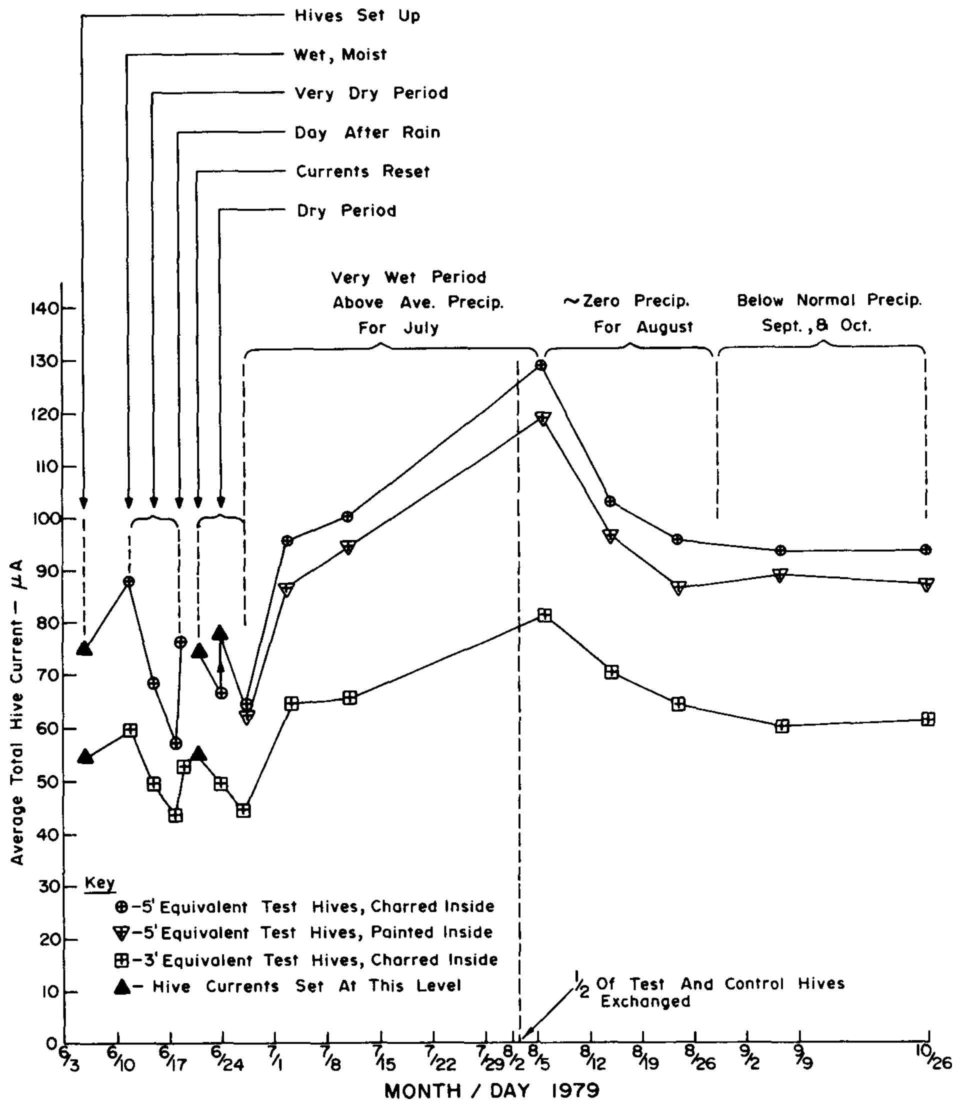

Figure 5. Moving Average of Total Hive Current in Several Treatment Groups as Modified by Weather during the Season.

periodic checks of accuracy during the season showed errors of < 3%. Hives were closed while capped comb was counted, which took no more than 5 min per frame. Queen cells were counted and destroyed.

B. HIVE WEIGHT

Each hive was weighed at weekly intervals with a bench beam scale (Accu-Weight model 300/T; error ± 0.1 lb) and net weight (gross weight minus frames with foundation, supers, top and inner covers, and bottom boards) was recorded.

C. BEE WEIGHT

Workers, less than one day old, were obtained as follows. In late afternoon, comb with mature pupae was placed in an empty super on top of the hive and separated from the rest of the hive by fiberglass screen. This permitted warmth from the hive below. Teneral adults were collected the next morning, killed with ethyl acetate, oven-dried at 70 C for 24 hr and weighed in groups of 25 with an Ainsworth balance (error ± 0.1 mg). Use of teneral bees minimized differences in gut contents normally associated with older bees. Total current in test hives was recalibrated whenever supers were added and later removed. Five hives per each treatment group were sampled on June 27, July 25, August 23, and September 20, representing exposures of 22, 50, 79 and 107 days, respectively, for 1 m and 1.5 m hives continually exposed for the entire experiment. For the reversed hives (shields exchanged), the exposure periods were 21 and 49 days, comparable to the first exposure periods.

D. HONEY REFRACTOMETRY

All hives were sampled twice for honey moisture content: on July 23 (48 days of exposure) and on September 16 (103 days of continuous exposure or 45 days after reversal). Nine samples were taken, three per capped comb from various sections of a hive, and were immediately analysed with an Atago honey refractometer, calibrated with an optical standard before each day's use.

E. IN-HIVE TEMPERATURE

Four 3-chamber hives, comparable to other experimental hives in weight and brood were placed under the line and shielded on August 6. Experiments were conducted on five dates between August 8 and September 6 on two hives with unpainted interiors (hives 103, 104) and two with painted interiors (hives 105, 106). Daigger mercury thermometers were inserted through the rear of each super, as shown in Figure 3d and previously described, and were left in position for about 3 hr and sometimes overnight. In order to eliminate the problem of variability in internal composition from hive to hive e.g. amount and location of brood and honey-processing areas, we used each hive as its own control. Hive temperatures were initially sampled with shield in place and several baseline readings were taken in the first half-hour. Shields were then removed and temperature readings were taken every ten minutes, as hive current was increased either in small increments or in a few large steps. Concurrent readings of two adjacent shielded hives provided information on normal fluctuation in internal hive temperature due to ambient temperature changes.

F. PROPOLIZATION

As in previous years, photographs of hive entrances were taken to document abnormal propolis deposits. This year, the deposits were harvested from the entrances of exposed hives after 57 days, and again after 114 days of exposure; propolis was sealed in plastic bags and weighed the following day.

G. STATISTICAL ANALYSIS

Analyses of worker capped cell counts and hive net weights were based on one-way Anova and Student-Newman-Keuls tests (SNK); log transformation of hive weight data preceded analysis (22). Analyses of honey refractometer data, propolis weight, and worker bee weight were based on one-way Anova.

III. RESULTS

A. WORKER CAPPED CELL COUNTS

The number of capped cells in 1 m hives was unaffected by exposure to the transmission line environment for 57 days or 114 days. The shorter period includes two groups: those exposed from June 7 to August 2 and then shielded until September 30, and those shielded during the first period and exposed during the second period. Normal biweekly capped cell production averaged about 12,000 per hive. Statistical comparisons of various treatment combinations and controls show no significant departures from normal during any period of the study (Figures 6 and 7). There was no queen loss and there were also no treatment-related differences in queen cell production: during the entire summer among 28 1 m hives, one control hive produced one queen cell in the fourth week and one in the fifth week and another control hive produced two queen cells in the eighth week. Among the exposed hives, one hive produced one queen cell and another hive produced two, all within the eighth week.

Painted 1.5 m hives that were continuously exposed for 114 days had normal numbers of capped cells and only slight queen cell production. There was no evidence that queens were lost.

Capped cell number in 1.5 m exposed hives was normal at two weeks but was significantly reduced at four weeks, the decline reaching zero in 5 of 14 hives by week 8 (Figures 6 and 8). Hives with zero brood were continued as test hives and were not reversed because there was no expectation of recovery, even with shielding, because of queen loss and queen failure.

Queens were lost in 8 of 14 (57%) 1.5 m exposed hives during the first 8 weeks. In some hives queen loss took place in the first two weeks, in others, after a month or two of exposure. Hive 42, an extreme case, was already queenless with 19 queen cells, at two weeks. None of the other exposed hives of this group produced queen cells until week 4, at which time 5 of 14 (36%) hives had one to four cells per hive. None appeared in the controls until week 8 and then in only two hives with consis-

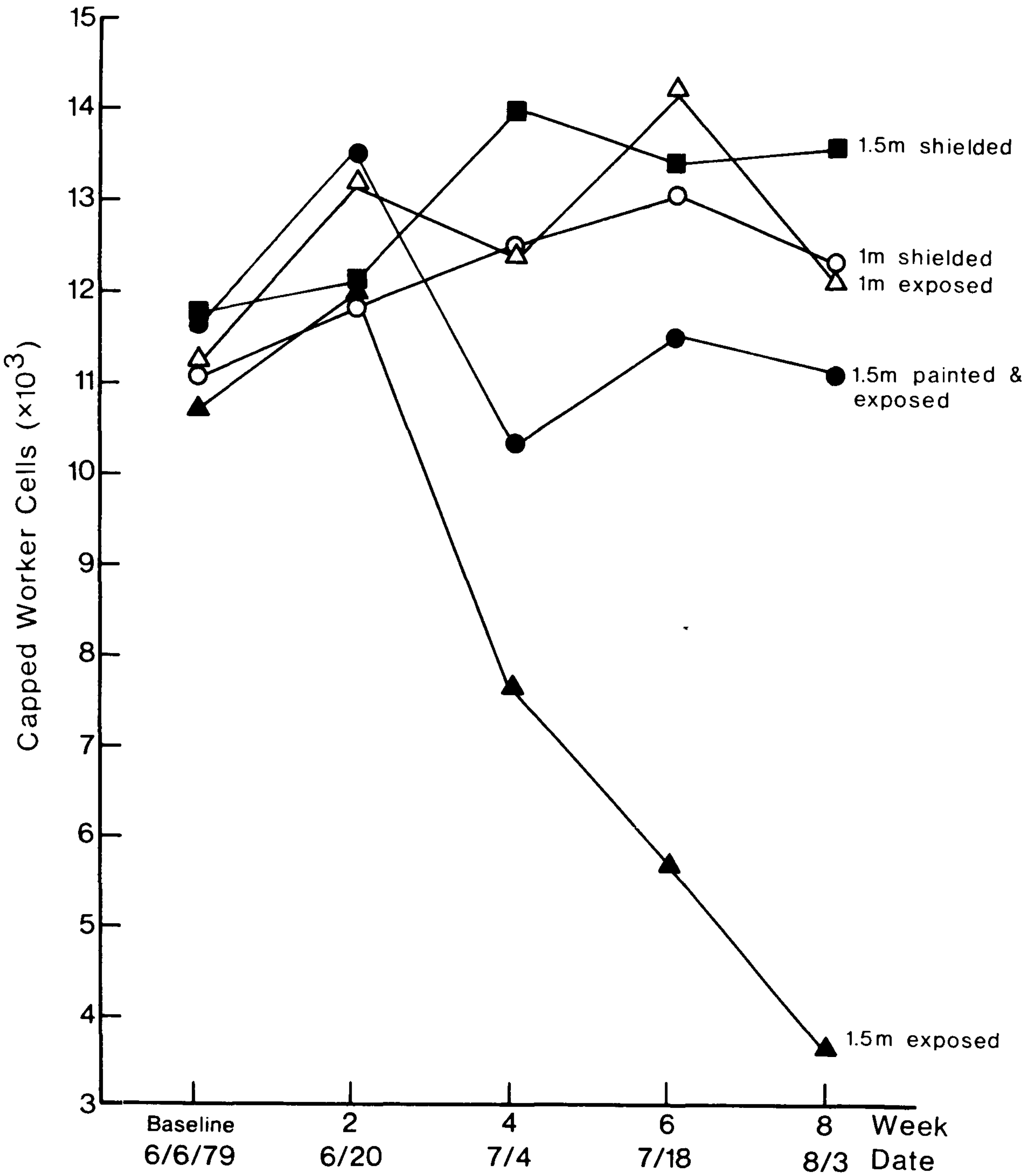

Figure 6. Average Bi-weekly Capped Worker Cells in 1 m, 1.5 m, and 1.5 m Painted Hives before Reversal.

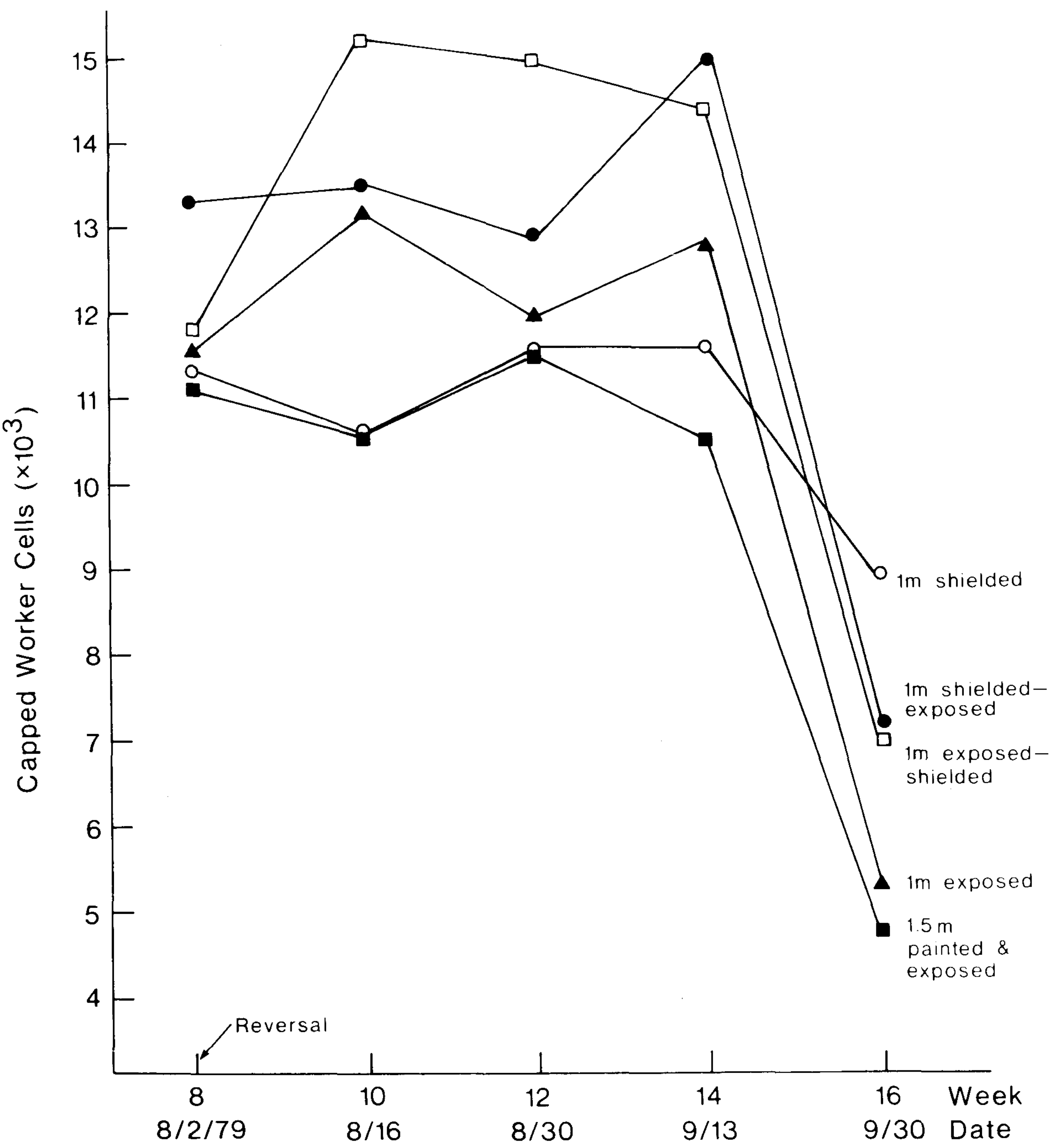

Figure 7. Average Bi-weekly Capped Worker Cells in 1 m and 1.5 m Painted Hives after Reversal.

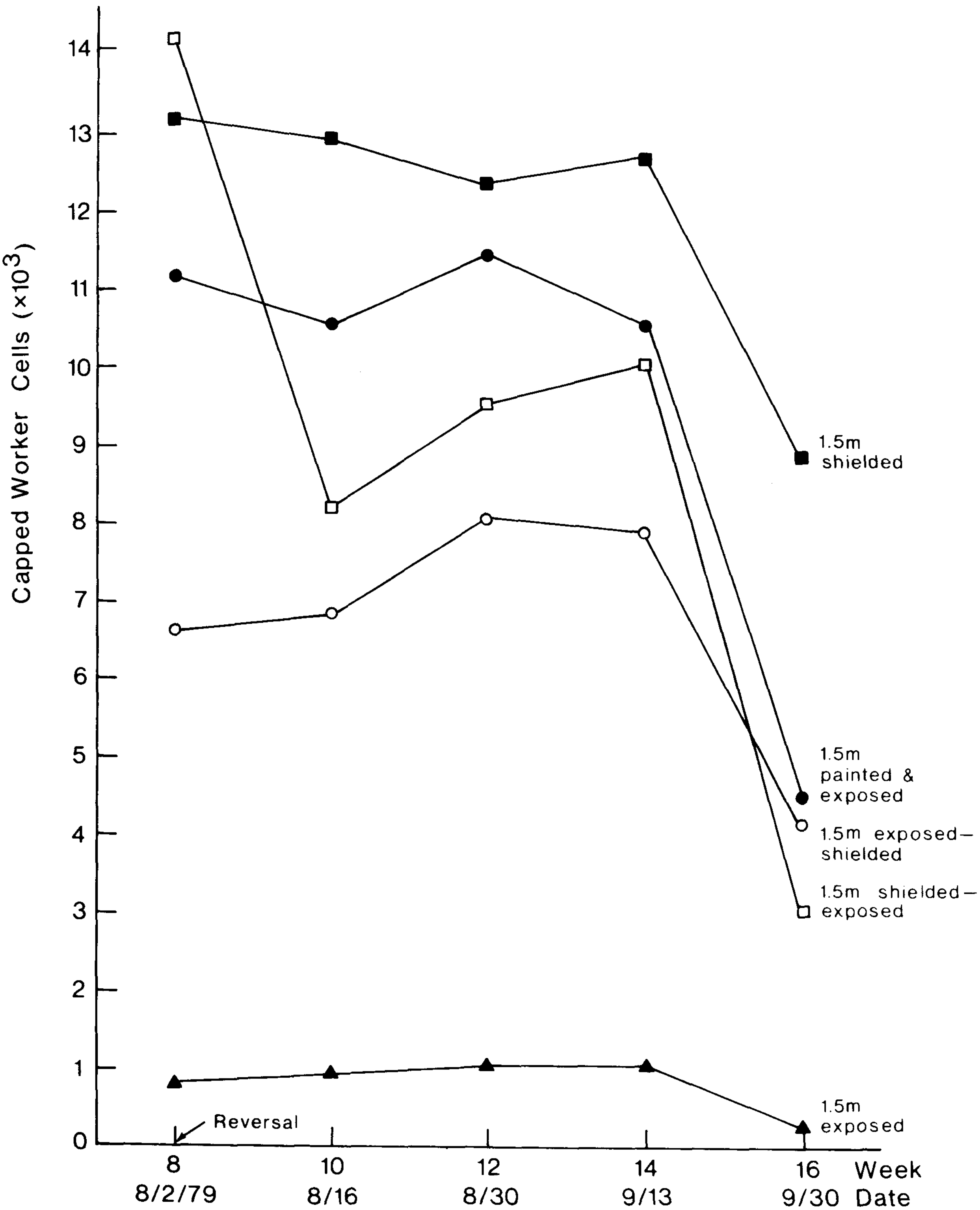

Figure 8. Average Bi-weekly Capped Worker Cells in 1.5 m and Painted 1.5 m Hives after Reversal.

tently subnormal capped cell counts (≃ 8,000) which might have been symptomatic of supersedure. Among the seven hives which were exposed for 114 days only hive 23 maintained brood production, albeit reduced, during the entire period; the others had drone brood from laying workers or none at all. The hives which were exposed during the last 8 weeks only were less affected than those exposed during the first 8 weeks, with only one queen loss (14%), with no significant capped cell reduction until the eighth week ($p < .001$), and with no queen cell production.

B. HIVE WEIGHT

All treatment groups (1 m, 1.5 m, painted 1.5 m, shielded, exposed, and reversed) satisfied the pre-treatment requirement of statistical uniformity in hive weight ($p > .10$) and capped cell production ($p > .10$) at the time the hives were placed under the line. After two weeks of exposure the trend toward lower hive weights was discernable but did not become statistically significant until the third week (Anova test) or fourth week (SNK test) and only in the 1.5 m hives (Figure 9). From the fifth week on, this group's hive weight was very significantly lower than that of the controls ($p < .001$). The 1 m exposed group and 1.5 m painted group had intermediate weights which, though graphically evident, were not always significantly different from either the controls or the 1.5 m tests.

At the culmination of eight weeks of exposure, rigorous SNK analysis ($p = .01$ or less) reveals that only the 1.5 m exposed group is significantly different from the controls. However, less rigorous SNK analysis ($p = .05$) shows that the intermediate groups are significantly different from both the control and 1.5 m exposed groups.

The reversal sub-groups were activated at the end of the eighth week. At time of reversal, there were no significant differences in hive weight between control and test groups due to smaller group size (7 instead of 14) and variability. Initiation of reversal with groups that were not significantly different was an important aspect of the study. In taking a conservative stance, we chose to continue or initiate exposure to the E-fields with the heavier of each 1.5 m sub-group, giving

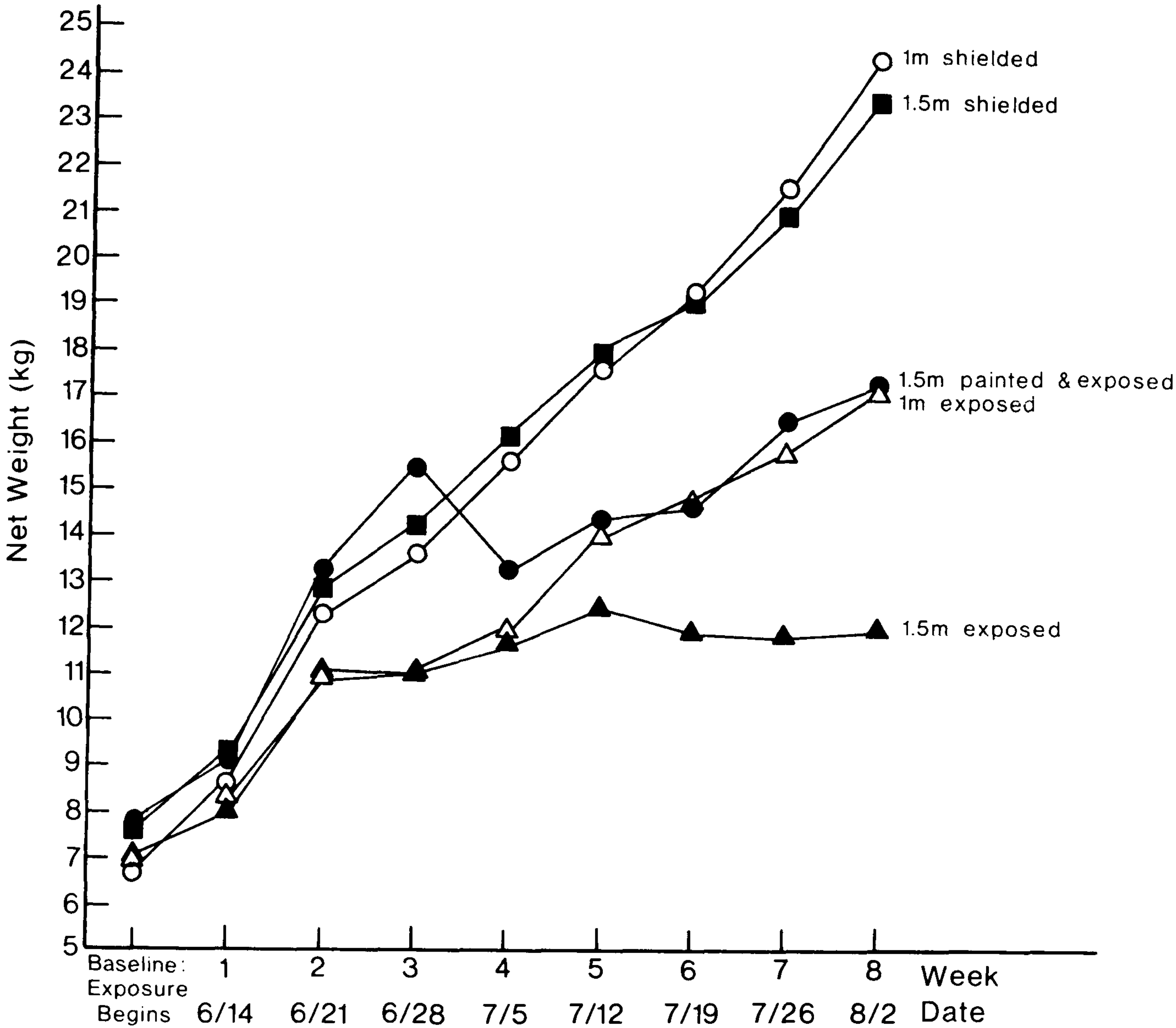

Figure 9. Mean Net Weight Gain of Hive Treatment Groups before Reversal.

the advantage of established or retained strength to the exposed hives. The 1.5 m continuously exposed sub-group began to significantly differ from controls ($p < .05$) during week 10 and remained so ($p < .01$) after the twelfth week. The 1.5 m shielded-exposed group strongly declined compared with the continuously shielded controls, as Figure 10 shows, though it did not reach a statistically significant level by week 16. The 1.5 m exposed-shielded group began to recover after week 12 but even by week 16 it still belonged more to the continously exposed group than it did to the continuously shielded controls ($p = .01$).

Significant differences among 1 m sub-groups did not occur during the final period. It is noteworthy that the sub-group exposed for 16 weeks had the lowest final weight and on this basis appears to have been affected. By the same criterion, the exposed-shielded group appears to have been recovering (Figure 11).

During the last 8 weeks, as they had done before, 1.5 m continously exposed painted hives continued to respond like the 1 m continously exposed hives.

C. BEE WEIGHT

Dry weight per teneral worker was 18.1 to 22.6 mgm. Within this range there were no statistically significant differences between exposed and shielded groups after 21 and 49 days (reversed groups), or after 22, 50, 79 and 107 days of exposure. This holds for the 1 m, 1.5 m, and painted 1.5 m hives. There is a general tailing off of bee weight towards fall which is not treatment related (Table 4).

D. HONEY REFRACTOMETRY

Moisture content of honey ranged from 15.2 to 22.3 percent, sometimes with as much variability within one hive as between hives in different treatment groups. There were no significant differences between any exposed group and controls as a result of exposures of 48 days and 103 days (Table 5).

E. IN-HIVE TEMPERATURE

A rapid increase to an abnormally high temperature (40°C) was demonstrated 10 of 16 (62.5%) times when total hive current was increased to a median of $\sim 100\ \mu A$ (range 85 to 174 μA). Typically, temperature increases occurred within 10 min,

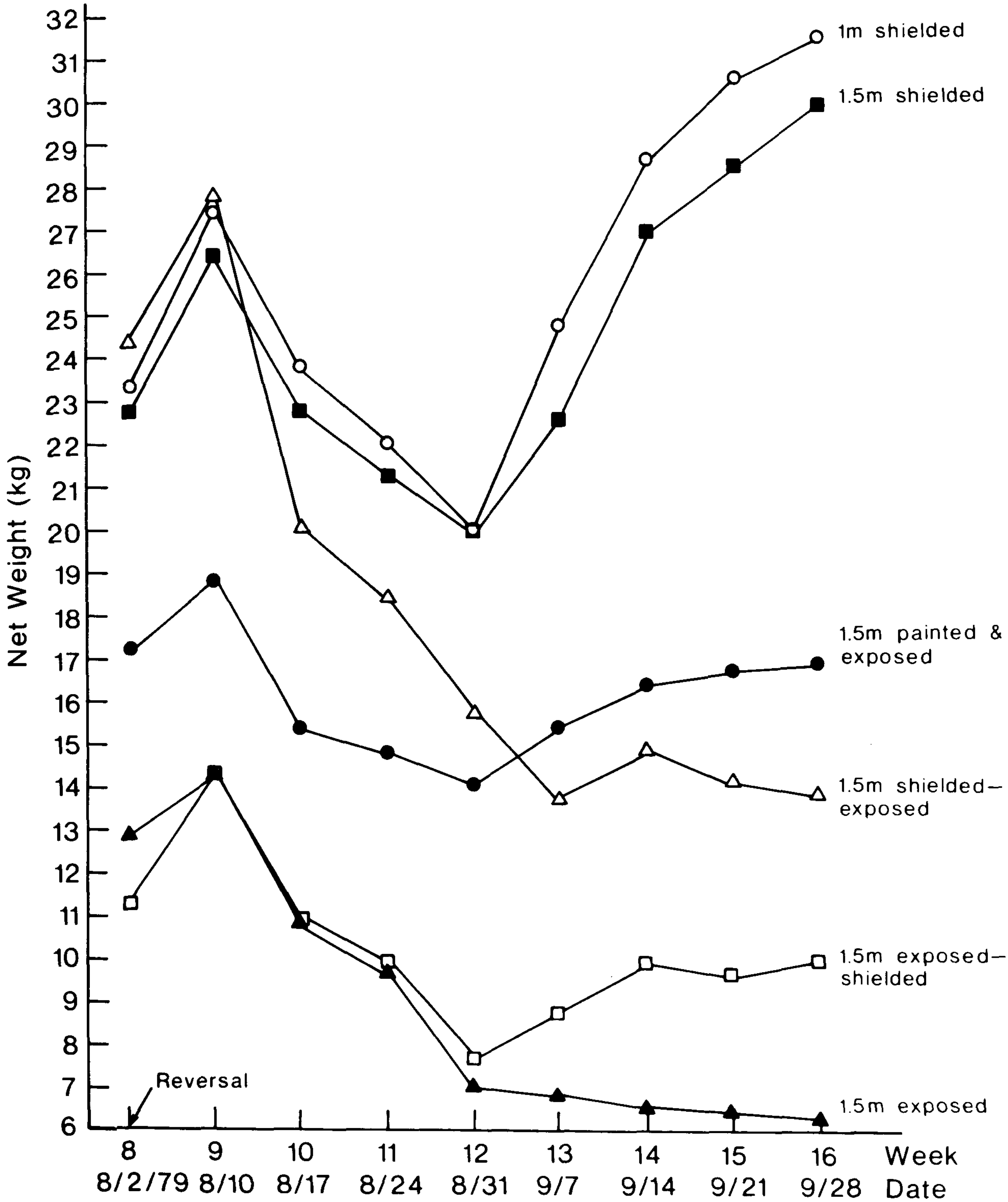

Figure 10. Mean Net Weight Gain of 1.5 m Hives after Reversal. 1 m Shielded and 1.5 m Painted Hives are Included for Comparison.

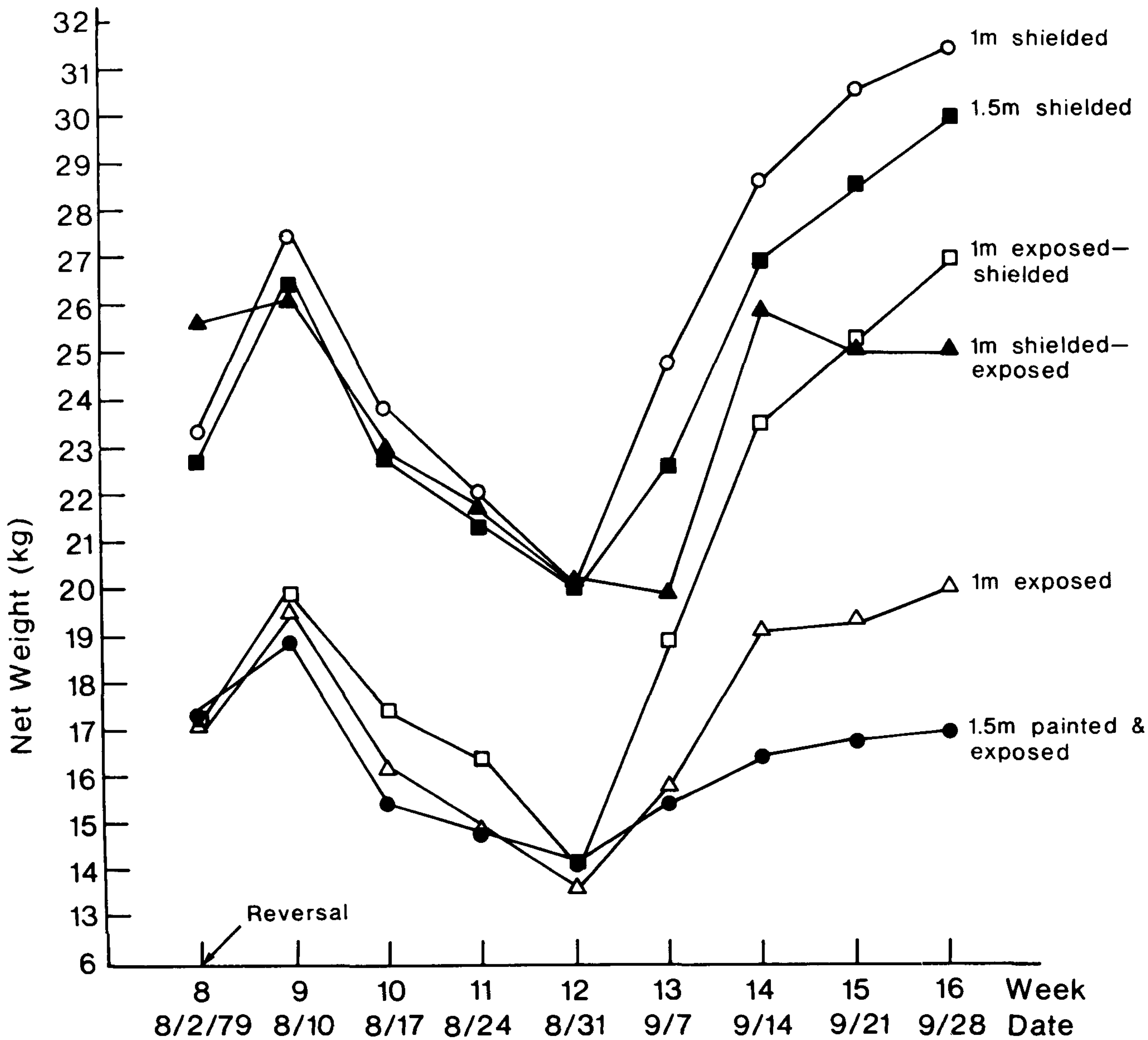

Figure 11. Mean Net Weight Gain of 1 m Hives after Reversal. 1.5 m and Painted Hives Included for Comparison.

Table 4

MEAN DRY WEIGHT PER TENERAL ADULT WORKER
BASED ON TWO SAMPLES OF 25 BEES PER
HIVE, FIVE HIVES PER TREATMENT GROUP

Date and Exposure Period	Treatment	Mean Bee Wt. (gm) ± 1 s.d.
6/27/79 [Day 22]	1 m Shielded	0.0220 ± 0.0018
	1 m Exposed	0.0194 ± 0.0005
	1.5 m Shielded	0.0209 ± 0.0015
	1.5 m Exposed	0.0225 ± 0.0029
	1.5 m Painted and Exposed	0.0213 ± 0.0015
7/25/79 [Day 50]	1 m Shielded	0.0226 ± 0.0011
	1 m Exposed	0.0210 ± 0.0015
	1.5 m Shielded	0.0212 ± 0.0020
	1.5 m Exposed	0.0189 ± 0.0021
	1.5 m Painted and Exposed	0.0207 ± 0.0013
8/23/79 [Day 79 or 21]	1 m Shielded	0.0202 ± 0.0016
	1 m Exposed	0.0203 ± 0.0017
	1 m Shielded-Exposed	0.0200 ± 0.0012
	1 m Exposed-Shielded	0.0181 ± 0.0009
	1.5 m Shielded	0.0189 ± 0.0013
	1.5 m Exposed	- -*
	1.5 m Shielded-Exposed	0.0183 ± 0.0018
	1.5 m Exposed-Shielded	0.0182 ± 0.0010
	1.5 m Painted and Exposed	0.0207 ± 0.0013
9/20/79 [Day 107 or 49]	1 m Shielded	0.0184 ± 0.0018
	1 m Exposed	0.0193 ± 0.0020
	1 m Shielded-Exposed	0.0201 ± 0.0016
	1 m Exposed-Shielded	0.0195 ± 0.0007
	1.5 m Shielded	0.0182 ± 0.0008
	1.5 m Exposed	- -*
	1.5 m Shielded-Exposed	0.0183 ± 0.0012
	1.5 m Exposed-Shielded	0.0181 ± 0.0016
	1.5 m Painted and Exposed	0.0190 ± 0.0018

* Teneral adults not available.

Table 5

MOISTURE CONTENT OF RECENTLY CAPPED HONEY.
N = NUMBER OF HIVES SAMPLED

Date and Exposure Period	Treatment	N	Mean % Moisture (± 1 s.d.)
7/23/79 [Day 48]	1 m Shielded	14	17.64 ± 0.73
	1 m Exposed	14	17.89 ± 0.97
	1.5 m Shielded	14	18.11 ± 0.92
	1.5 m Exposed	14	18.14 ± 0.88
	1.5 m Painted and Exposed	7	17.76 ± 1.10
9/16/79 [Day 103 or 45 after reversal]	1 m Shielded	7	17.96 ± 1.39
	1 m Exposed	7	18.87 ± 0.79
	1 m Shielded-Exposed	7	17.59 ± 0.42
	1 m Exposed-Shielded	7	18.06 ± 1.07
	1.5 m Shielded	7	18.67 ± 0.73
	1.5 m Exposed	3	18.30 ± 0.53
	1.5 m Shielded-Exposed	6	18.03 ± 1.03
	1.5 m Exposed-Shielded	6	18.67 ± 0.79
	1.5 m Painted and Exposed	7	17.97 ± 0.76

reached a plateau in about 30 min, and remained elevated for 10 min to about 18 hr before slowly returning to normal. Shielding of the hive accelerated recovery, which was especially rapid during the first 10 min (Figure 12). Responsivity varied between hives and in the same hive on different days. Thus, hive 103 responded 4 of 4 times; hives 104 and 105, 3 of 4 times each; and hive 106 responded only once with a small increase (2.9°C in 40 min). In two hives on different days, there was no temperature elevation, despite hive currents of 205 and 216 μA. Hive responses are summarized in Table 6.

Maximum temperature increases generally occurred in hive areas with empty comb (or foundation) and with few bees initially, e.g. top super (4 of 10), bottom super (4 of 10), and middle super (2 of 10).

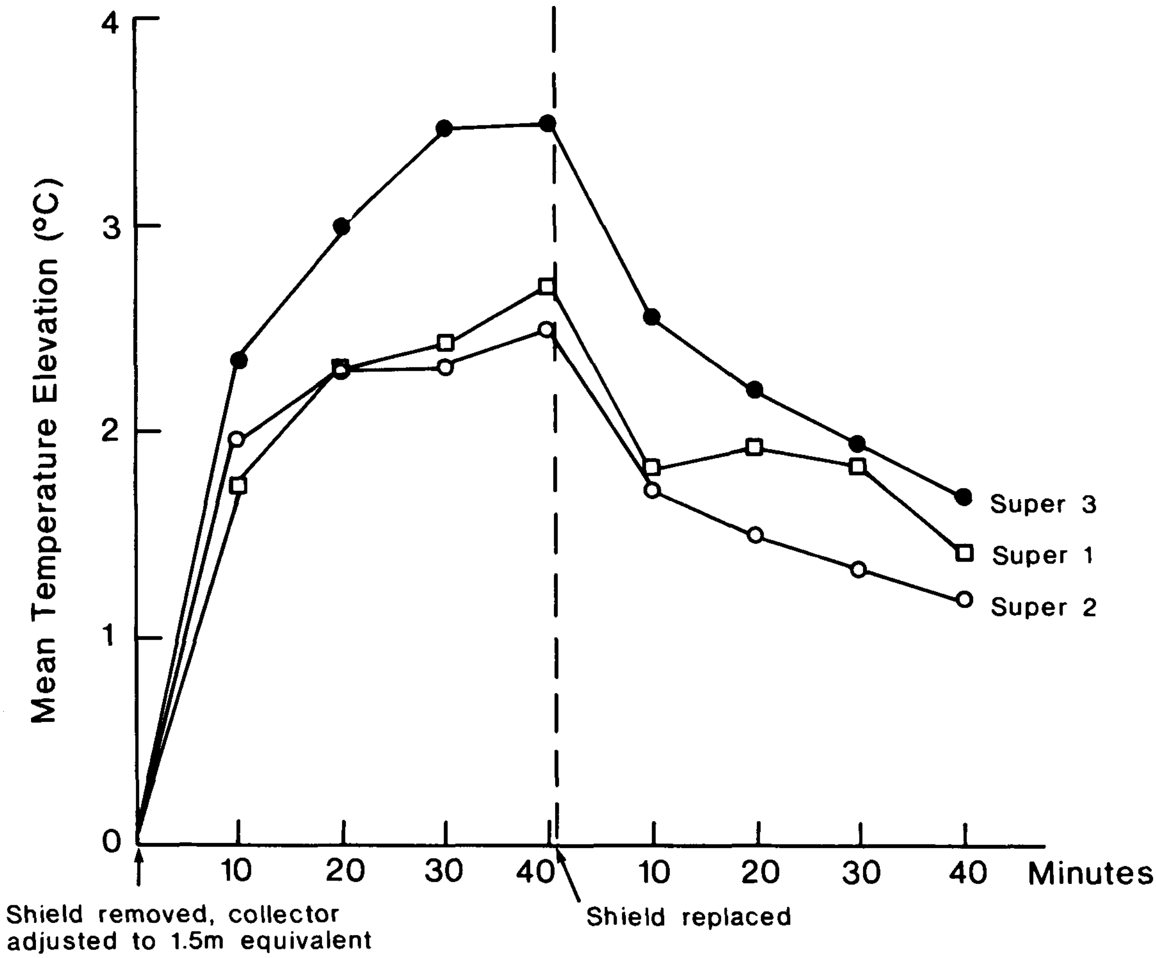

Figure 12. Typical Short-term Temperature Response in a Hive Exposed to Electric Fields under 765 kV Line. Total Hive Current, 90 μA.

Table 6

TOTAL HIVE CURRENT AND ABNORMAL TEMPERATURE (C°) RESPONSES

	Hive Number			
Date	103	104	105	106
8/8/79	146 μA 40° max.	127 μA 40.3° max, + 4.5° in 15 min. in left middle corner	114 μA 40° max, 154 μA 41° max.	160 μA no effect
8/9	174 μA 40° max. + 11° in 30 min. in left top corner	control	control	216 μA no effect
8/15	90 μA + 6.7° in 10 min. in right bottom corner	85 μA + 11.1° in 10 min. in center middle super	94 μA + 8.3° in 10 min. left top corner	98 μA + 2.9° in 40 min. in right top corner
8/23	111 μA + 6.4° in 26 min. in right top corner	205 μA no effect	120 μA no effect	105 μA no effect
9/6	control	93 μA + 4° in 20 min. in right bottom super	92 μA + 7.8° in 20 min. right bottom super	control

F. PROPOLIZATION

Abnormal deposits of propolis were absent from shielded hives but were present on the front underside of the bottom chamber of exposed hives: 1 m, 1.5 m, and 1.5 m painted (Figures 13 and 14). The average weight of propolis harvested from 1 m hives was 40.85 gm and 45.81 gm after the first and second 57-day exposure periods, respectively. Those initially shielded and then exposed yielded an average of 48.59 gm. Average propolis yield from 1.5 m hives after the first 57-day period was 42.81 gm; the failure of many of these hives during the second period precluded further comparison. The reversed 1.5 m hives yielded an average of 48.11 gm per hive. During the first and second periods, 1.5 m painted hives produced 23.7 and 32.1 gm, respectively (Table 7). Although these figures are somewhat lower than those for hives with unpainted interiors they are not at a level of statistical significance; we looked for abnormal desposits in other parts of these hives but there were none. Neither amount nor time of onset of propolization were dose related, which typically began in the first week (Figure 15).

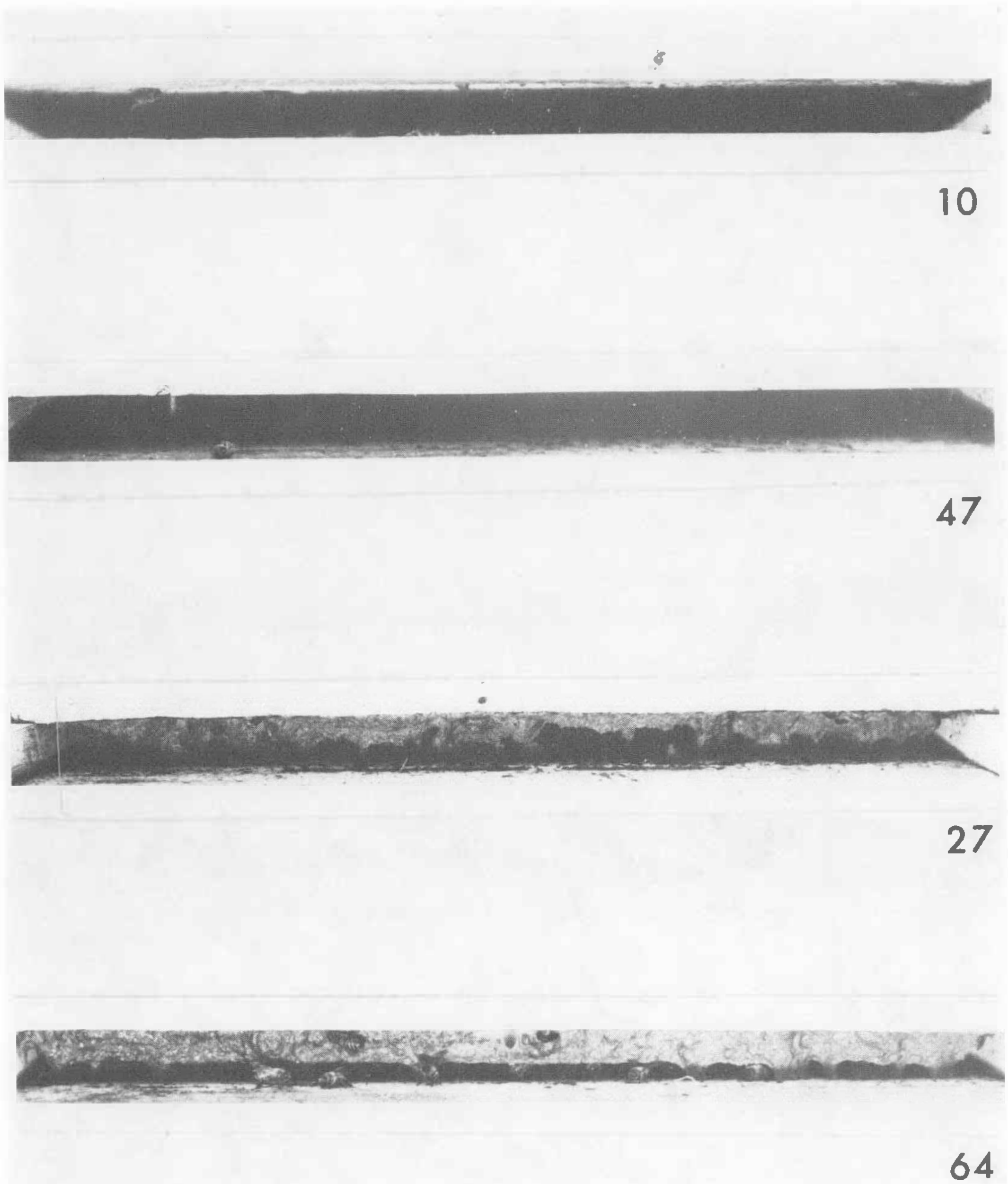

Figure 13. Typical Entrances of 1 m Hives after Last Eight Weeks of Experiment: #10-Shielded; #47-Exposed-shielded; #27-Shielded-exposed; #64-Exposed.

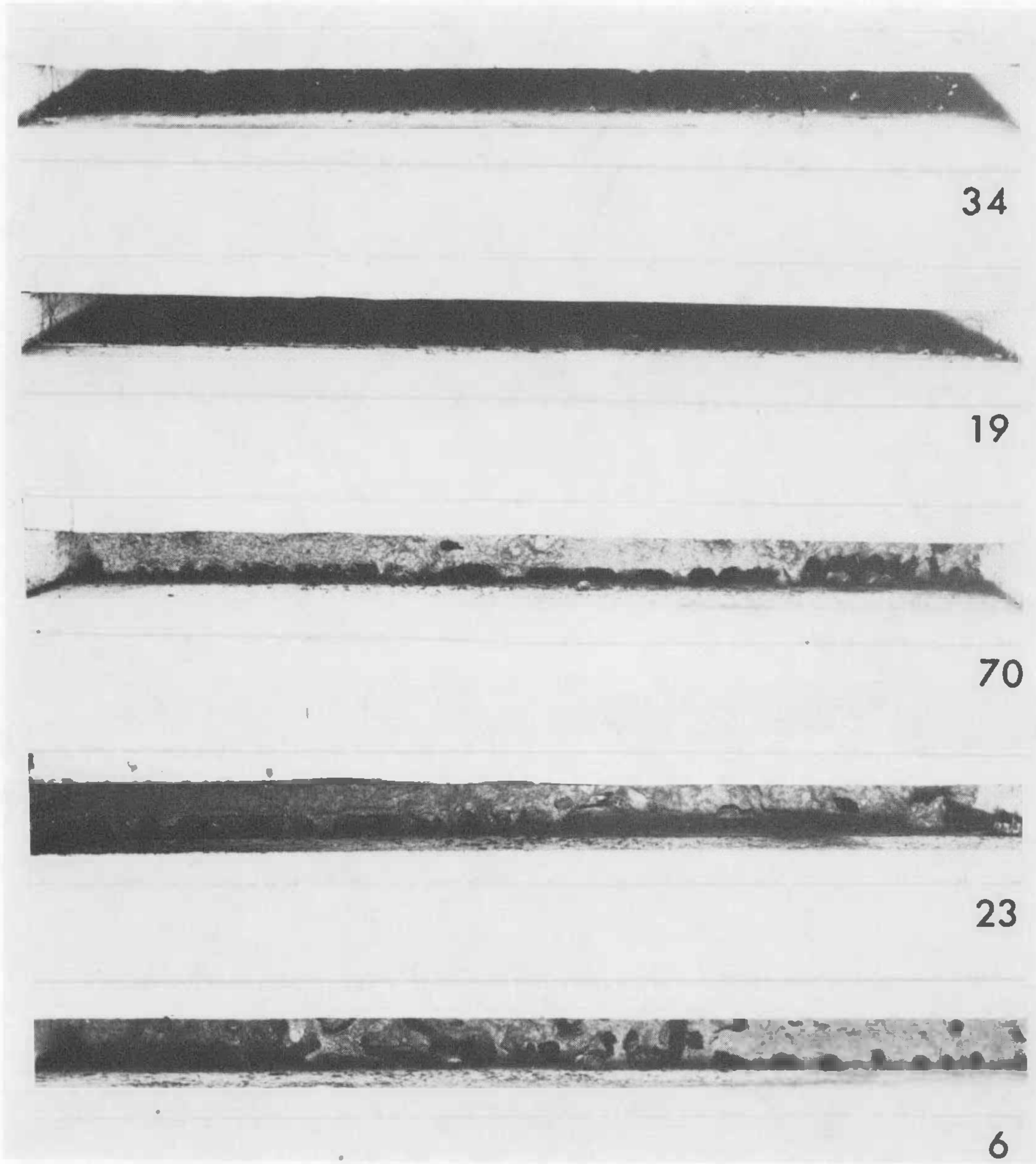

Figure 14. Typical Entrances of 1.5 m Hives after Last Eight Weeks of Experiment: #34-Shielded; #19-Exposed-shielded; #70-Shielded-exposed; #23-Exposed; #6-Painted and Exposed.

Table 7

WEIGHT OF PROPOLIS DEPOSITED IN HIVE ENTRANCES.
N = NUMBER OF HIVES SAMPLED

Date and Exposure Period	Treatment	N	Mean Wt. (gm) (± 1 s.d.)	Range
8/1/79 [Day 57]	1 m Exposed	14	40.85 ± 18.5	(16.1 - 66.1)
	1.5 m Exposed	14	42.81 ± 17.5	(10.9 - 72.8)
	1.5 m Painted and Exposed	7	23.66 ± 20.3	(1.9 - 59.4)
10/5/79 [Day 114]	1 m Exposed	7	45.81 ± 27.3	(5.8 - 68.6)
	1 m Shielded-Exposed	7	48.59 ± 15.5	(28.5 - 67.7)
	1.5 m Exposed	7	25.3 ± 31.6	(0 - 76.1)
	1.5 m Shielded-Exposed	7	48.11 ± 29.99	(5.4 - 77.7)
	1.5 m Painted and Exposed	7	32.1 ± 19.8	(4.5 - 66.3)

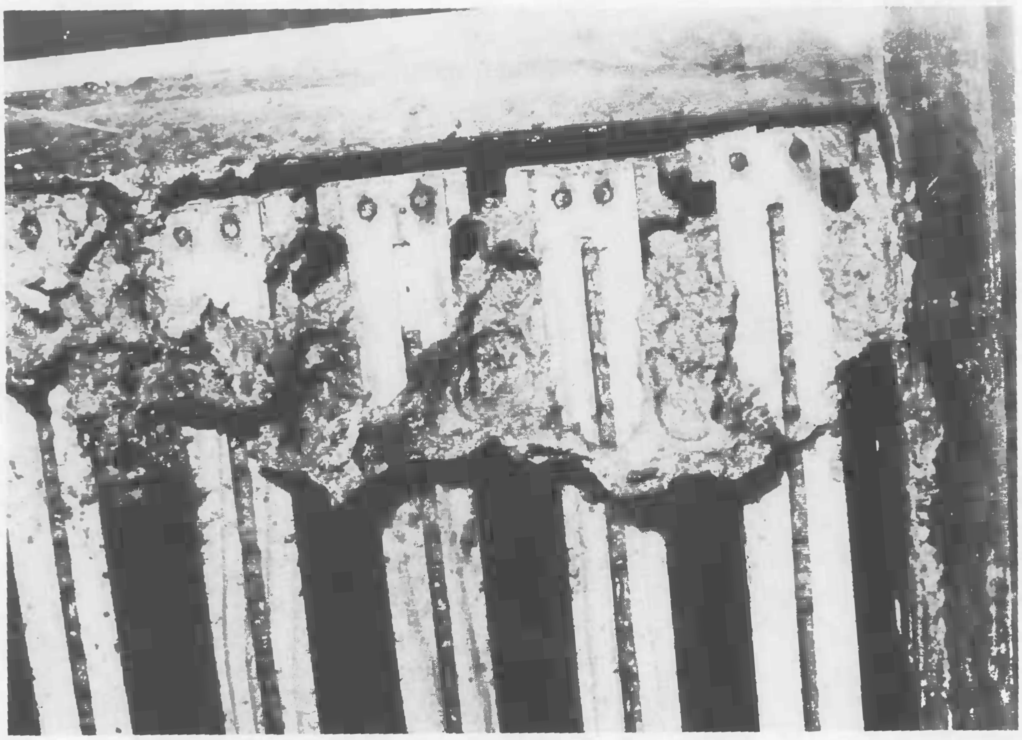

Figure 15. Lower Front Surface of Bottom Chamber Showing Abnormal deposits of propolis on Frames Near Hive Entrance.

IV. DISCUSSION

The total current collected and conducted to ground by a hive immersed in the ambient electromagnetic field of a HV power transmission line is dependent upon the electric field intensity produced by the line and upon the electrical characteristics of the hive and its contents. The electric field intensity in internal cavities of the hive is a function of the induced current on and in the hive, the electrical characteristics of the hive materials, and the geometry of the hive's internal structure. The total hive current can also provide an upper bound for the value of current which a bee can conduct when in contact with hive surfaces. As such, the total hive current to ground is probably a more meaningful measure of a hive's electric field exposure or excitation than is the parameter of the ambient electric field intensity itself. To facilitate this measurement with minimal disturbance to the hives, special bases were installed as described earlier. The aluminum collecting sheet was mounted between the four-by-four standoffs and the hive bottom board instead of directly on the styrofoam sheet. This was done to eliminate any effect on the total hive current due to changes in the moisture content of the untreated wooden four-by-four's and assured that any changes in hive current would be due to changes in the hives only. At the start of the season it was believed that the hive conductivities were sufficiently high and their impedance-to-ground was low enough that the hive currents to ground would be relatively stable and not vary significantly with ambient moisture conditions. This did not prove to be the case. At the end of the first week of exposure, current measurements indicated that almost all hive currents had increased by about 10 percent. It was noted that the hive currents had been set during relatively dry weather, while the second measurements were taken in wet conditions following a period of precipitation. Experimentally soaking only the hive extension had no effect on the hive current, nor did application of water between the extension base and hive top. Lightly misting the sides of the hive, however, caused a 25 percent increase in hive current; these results were repeatable.

The reversal design of the experiment was constrained by the realities of the field situation. During the first period flowers were more abundant, therefore foraging was better for the bees. We compensated for the dearth early in September with supplemental feeding of all hives with 1:1 syrup placed around the bee yard. Had there been better foraging some of the reversal trends might possibly have attained statistical significance. Nevertheless, an upturn in hive weight is evident in 1 m and 1.5 m exposed-shielded hives while there is a downturn in the shielded-exposed hives. With respect to brood production in 1 m hives there are no reversal trends because there was no effect. The 1.5 m shielded-exposed hives showed a definite downturn while, in the exposed-shielded group, the slight increase in capped cells was soon aborted by the normal cessation of brood rearing in fall.

The hive conductivity-weather interaction influences the amount of total current and its path through a hive to ground. We have seen that despite a relatively stable E-field during the season (line voltage 720 to 738 kV), the total hive current varied up to two-fold as it tracked moisture conditions (Figure 5). The 1.5 m hives with painted interiors had currents which approximated those of the 1.5 m unpainted group, yet they behaved like the 1 m exposed group with respect to hive weight gain and brood. Painted interior surfaces are more resistive to current flow than scorched wooden surfaces, therefore less conduction current will flow on the inside of these hives and through the bee population. The conduction current is actually enhanced by the wood surfaces and by the conductive bees which mill around in the high E-fields (ca. 30 kV/m) in the inter-super gaps (23).

Population density also modifies the internal electrical environment of the hive. Let us examine the 1.5 m reversal groups. The shielded groups that were exposed in the second period starting August 2 had had two additional months in which to build up their populations compared with the groups exposed from early June until August. Consequently, there were more bees later in the season to divide up the current and therefore less current per bee to elicit adverse reactions. The outcome was a more severe reaction with earlier onset in the first period, expressed in a sharper decline in capped brood, and a higher incidence of queen cells and queen loss. For example, hives exposed during the first eight weeks had a 57% rate of queen loss, while those exposed only during the last eight weeks had a 14% rate of queen loss. Because abnormal propolization was not dose-related and was quantitatively equal in 1 m and 1.5 m hives, the heavier deposits in the second period probably reflected greater foraging capacity in these colonies.

Propolis, the honey bees' multi-purpose sealant of plant origin, serves as an early indicator of electrical disturbance when it is deposited in the hive entrance. Given the bees' awesome behavioral repertoire, one is tempted to assume that these deposits have special properties which mitigate the adverse electrical effects. This could possibly happen by lowering the electric field intensity or, by effectively "shorting out" the gaps, shunting current around the bees. Gauger of IITRI investigated the electrical properties of propolis and compared them with available data on other relevant materials (Table 8).

Table 8

COMPARISON OF THE ELECTRICAL CHARACTERISTICS OF PROPOLIS WITH VARIOUS MATERIALS

	Dielectric Constant, K, @			Dissipation Factor, D, @			ρ (ohm-cm)
	60 Hz	1 kHz	1 MHz	60 Hz	1 kHz	1 MHz	@ DC, 25°C
Propolis	4.6	4.23	-	0.28	0.055	-	1.16×10^{13}
Beeswax*	2.76	2.66	2.53	0.49**	0.0140	0.0092	$1.1 \rightarrow 8.5 \times 10^{13}$**
Plexiglass* (polyethylmethacrylate))	-	2.75	2.55	-	0.0294	0.0090	-
Styrofoam (foamed polystyrene)	1.03	1.03	1.03	<0.0002	<0.0001	<0.0002	-
Neoprene Rubber*	6.7	6.6	6.26	0.018	0.011	0.038	8×10^{12}
Wood (fir, across* gain, dry)	2.05	2.00	1.93	0.004	0.008	0.26	-
Distilled Water*	-	-	78.2	-	-	0.040	10^{6}
Polystyrene*	2.56	2.56	2.56	<0.00005	<0.00005	<0.00007	10^{18}
Teflon*	2.1	2.1	2.1	<0.0005	<0.0003	<0.0002	10^{17}

* (24,25) ** (26)

From Table 8 it can be deduced that propolis is a fairly good dielectric material with low loss characteristics. Restated, propolis, when hardened, is a good insulator. Its texture is similar to a light-colored bakelite. As an insulator its properties are similar to those of beeswax and neoprene rubber. It has substantially more loss, however, than the low-loss plastics such as plexiglass, polystyrene, and teflon. At 60 Hz, the characteristics of propolis are essentially those of capacitive materials. This analysis is based on older propolis but it has since been shown that fresh material has the same characteristics. The values for wood also show it to be a surprisingly good insulator. However, wood can absorb significant amounts of water. Even distilled water, which is free of materials which enhance conductivity, has a resistivity seven orders of magnitude lower than propolis and beeswax. Thus, the conductivity of wood will be controlled by its moisture content, and in an outdoor environment will be much more conductive than propolis or beeswax. It appears from the analysis that the hardened propolis is not much better a conductor than the air gaps in the inter-super spaces and at the bottom of the hive. As such, the gap impedance will remain primarily capacitive, with propolis bridges and the air forming parallel capacitances. From the viewpoint of bee behavior, propolization is a generalized response to an inimical factor. It is an inherited trait, much more common among Caucasian than Italian bees. Our hives were stocked with Italian queens. Propolis deposits in the area of the hive entrance suggest that the bees experience the worst current flows here. This is consistent with calculated expectations of the highest available current flow in this area. It is further borne out by the removal of energetically expensive comb by the bees from the entrance-end of a full frame which had been left in the lower super of an exposed hive for several weeks. Wax removal occurred above the heavy propolis deposits in the entrance. Abnormal propolization in the environment of the transmission line is too recent to have evolutionary significance; besides, as we have seen, propolis has no conductive properties to ameliorate the plight of the bees. It is a stereotyped and futile response aimed at reducing hive vulnerability against pervasive electric effects within the hive.

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ADDENDUM

All viable hives were wrapped with roofing paper in early December and were weighed on December 28, 1979 and on February 23, 1980. Overwintering survival was determined on the latter date, with the results given in the accompanying table.

Hive category	Mean Number of Frames Covered by Bee Clusters on 10/13/79 (±1 S.D.)	Mean Hive Net Wt (kg) 12/28/79 (±1 S.D.)	N*	% Survival, original sub-group	Mean Honey Consumption (kg) (±1 S.D.)
1 m Shielded	14.1(7.3)	30.9(14.1)	5	71.4	6.4(3.1)
1 m Exposed	12.1(5.3)	17.3(9.4)	6	14.3	3.6(2.7)
1 m Shielded-exposed	15 (8.0)	18.4(4.3)	7	28.6	2.9(2.1)
1 m Exposed-shielded	13.6(3.9)	20 (12.1)	7	100	3.5(1.7)
1.5 m Shielded	13 (6.6)	26.5(13.5)	6	71.4	4.3(1.8)
1.5 m Exposed	0 -	-	0	0	0 -
1.5 m Shielded-exposed	9.3(8.0)	14.1(9.9)	4	0	2.6(1.1)
1.5 m Exposed-shielded	9.2(5.9)	15.1(9.2)	4	28.6	3.3(1.5)
1.5 m Painted & exposed	5.9(3.5)	15.7(5.1)	4	0	2.6(1.9)

*Number of viable colonies December 28, 1979.

The failure of all 1.5 m exposed hives confirms our results of 1977 (19) when all such hives also failed. The high losses among exposed-shielded hives occurred because treatment reversal came too late for these colonies to make up for poor honey and brood production in preparation for winter. The poor survival of the 1 m exposed groups was contraindicated by the summer's experience when none failed during sixteen weeks of exposure. They were expected to survive given adequate adult densities and low rate of honey depletion. The fact that they did not survive indicates ongoing deleterious electrical effects. This confirms our observations of overwintering of shorter hives kept under the same line in winter 1977-78 when, despite normal numbers of bees and adequate honey stores, seven of the nine colonies

(78%) failed, compared with 9 to 14% failure in three types of controls.

Given a mild winter between December 28, 1979 and February 23, 1980 surviving colonies consumed an average of only 4.9 kg of honey. Exposed hives which failed had generally low honey consumption and with much honey uneaten and easily accessible; thus, bees did not starve. There were no significant differences in honey consumption between exposed and shielded colonies but this cannot be used as indirect evidence that metabolic rates were unaffected because adult population size varied between hives. A possible explanation for these hive failures is disturbance of normal bee clustering behavior by the currents, voltage drops, and E-field.

Following are supplemental analyses of data to accompany Figures 6 to 11 in the text.

Figure 6. Average Bi-weekly Capped Worker Cells in 1 m, 1.5 m, and 1.5 m Painted Hives before Reversal. Analysis at Week 4 when 1.5 m Exposed Hives First Show Significant Effect ($p < .001$, Anova).

Treatment	$\bar{X}$ (capped cells)	±S.E.M.
1.5 m Exposed	7650.6	942.3
1 m Exposed	12393.5	336.5
1 m Shielded	12513.1	569.5
1.5 m Exposed	13863.9	664.8
1.5 m Painted and Exposed	10341.1	966.1

Figures 7 and 8. Average Bi-Weekly Capped Worker Cells in 1 m, 1.5 m, and Painted 1.5 m Hives after Reversal. Analysis at Terminal Week 16.

Treatment	$\bar{X}$ (capped cells)	±S.E.M.
1 m Shielded	8918.7	1256.1
1.5 m Shielded	8891.7	1196.2
1 m Shielded-Exposed	7069.3	1376.7
1 m Exposed-Shielded	6891.1	872.1
1 m Exposed	5292.3	590.3
1.5 m Painted and Exposed	4748.1	751.5
1.5 m Exposed-Shielded	4151.3	1594.4
1.5 m Shielded-Exposed	3089.0	809.0
1.5 m Exposed	324.9	324.9

Figure 9. Mean Net Weight Gain of Hive Treatment Groups before Reversal. Analysis at Week 3 when 1 m and 1.5 m Exposed Hives First Show Significant Effect (p = .05, Anova).

Treatment	$\bar{X}$ (kg)	±S.E.M.
1.5 m Exposed	11.02	.37
1 m Exposed	11.13	.35
1 m Shielded	13.61	.34
1.5 m Shielded	14.21	.38
1.5 m Painted and Exposed	15.47	.44

Figures 10 and 11. Mean Net Weight Gain of 1.5 m, Painted 1.5 m, and 1 m Hives after Reversal. Analysis at Terminal Week 16.

Treatment	$\bar{X}$ (kg)	±S.E.M.
1.5 m Exposed	6.36	.58
1.5 m Exposed-Shielded	9.95	.93
1.5 m Shielded-Exposed	13.86	.86
1.5 m Painted and Exposed	16.88	.55
1 m Exposed	20.09	.58
1 m Shielded-Exposed	25.22	.50
1 m Exposed-Shielded	26.99	.57
1.5 m Shielded	29.91	.63
1 m Shielded	31.49	.65

In designing the experiment we considered the pros and cons of moving hives a short distance from a preliminary control site to the test site, or of starting the hives at the test site. We chose the former although all hives probably lost some foragers which were disoriented by the short-range move. Catch hives at the original hive location picked up many of these bees, but drifting at the new location under the line was not a problem. This method had the advantage of enabling us to start with a larger number of hives from which to select homogeneous experimental groups than would otherwise have been possible if we had started the hives under the 765 kV line, given its space constraints. Removal of a hive shield from a hive started under the line would probably have led to loss of fewer bees than the short-range move, but the smaller number of hives per group, with increased variance of hive net weights and capped cell counts, might possibly have swamped subtle line effects.