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Volume 1 of 3 Volumes:
Tabs A, B

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During 1993, the U.S. Navy continued to conduct a program to monitor flora, fauna, and their ecological relationships for possible effects from electromagnetic (EM) fields produced by the Navy's Extremely Low Frequency (ELF) Communications System.

Physiological, developmental, behavioral, and ecological variables for dominant biota in upland and riverine habitats near the Naval Radio Transmitting Facility at Republic, Michigan (NRTF-Republic) have been monitored since 1982. The NRTF-Republic was intermittently energized at low amperages beginning in early 1986. Electric current and periods of energization were then gradually increased until 1989, when the transmitter became a fully operational facility. A split-plot or blocked strategy was used to examine biological variables for possible effects from EM exposure. Reports compiled in this document present the progress of these studies through 1993.

Final results and conclusions are expected after all data have been analyzed in 1994. Investigators for similar studies completed in Wisconsin concluded that there were no EM bioeffects from intermittent or full operation of the transmitter in that state.

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FOREWORD

This compendium has been prepared by IIT Research Institute (IITRI) on behalf of the Space and Naval Warfare Systems Command (SPAWAR) to document the results of studies monitoring for possible electromagnetic effects to biota from operation of the U.S. Navy's ELF Communications System.

Monitoring studies have been performed by research teams from Michigan State University, Michigan Technological University, the University of Minnesota-Duluth, the University of Wisconsin-Milwaukee, and the University of Wisconsin-Parkside under subcontract agreements with IITRI. SPAWAR funded these studies under Contracts N00039-81-C-0357, N00039-84-C-0070, N00039-88-C-0065, and N00039-93-C-0001 to IITRI. IITRI, a not-for-profit organization, managed the program and provided engineering support to ecological research teams.

Each report in this compendium (Tabs A through H) presents the results of monitoring research performed near the Naval Radio Transmitting Facility at Republic, Michigan (NRTF-Republic) over the period 1982-1993. The results and conclusions of studies conducted near the Naval Radio Transmitting Facility at Clam Lake, Wisconsin (NRTF-Clam Lake) can be found in previous compilations. Research reports have been prepared annually, and each has been reviewed by at least three scientific peers. Investigators considered and addressed peer critiques prior to providing a final copy to IITRI for compilation. Final reports were compiled without further change or editing by SPAWAR or IITRI.

As was done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Previous compilations and other program documents are listed under Tab I.

Respectfully submitted,
IIT RESEARCH INSTITUTE

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ELF Electromagnetic Compatibility Assurance

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ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM

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The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1993

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ELF Environmental Monitoring Program

Upland Flora 1993 Report

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INTRODUCTION

Background

In 1982, Michigan Technological University initiated research at the site of the Naval Radio Transmitting Facility - Republic, Michigan which would determine whether ELF electromagnetic (EM) fields cause changes in forest productivity or health. Studies initiated at analagous control, antenna and ground treatment plots have established a baseline of data that are being used to compare various aspects of these communities before and after the antenna became operational. In addition, comparisons are also made between test and control plots within a year. This is a rigorous approach for evaluating possible effects of ELF EM fields on forest ecosystems.

Studies of commercially and environmentally important tree species have been key to past ELF EM field studies at Michigan Tech. Existing stands of northern red oak, paper birch, red maple and aspen as well as young red pine plantations have been the subject of intense monitoring efforts with major emphasis on measures of productivity such as height and diameter growth and production of foliage. In addition, studies of herbaceous plants and mycorrhizal fungi have been examined as potential indicators of ELF EM field effects. On-site measurements of ambient weather, site and EM field strength (magnetic - mG, longitudinal - mV/m and transverse V/m) have been used in statistical analyses to evaluate potentially subtle ELF EM field effects on growth.

The ELF studies database at Michigan Tech contains eight years of information. The first data were gathered in 1985 with collection continuing through 1992. At the same time, antenna testing began in 1986 (6 amps) and continued in 1987 (15 amps) and 1988 (75 amps) with operational levels (150 amps) being reached in 1989 through the present. The only exception to this ocurred in May through June of the 1991 field season when the north-south antenna operated at full power while the east-west antenna was off. Prior to the start of these studies, 1.5 years were spent establishing and installing instruments on analagous plots. The additional efforts this past year during full antenna operation augments this already extensive database allowing the best possible evaluation of ELF field effects on forest productivity.

This Report examines the degree of success achieved by research efforts through the 1992 and 1993 field seasons (depending on the work element). Several field measures were made for the last time during the 1992 season including leaf water potential, starflower phenology, and analysis of litter and red oak foliar nutrients. All measurements end in Novemger of 1993. Analysis of data, however, is seldom complete in the same year as data gathering and a final synthesis of these studies will appear in the 1994 Final Report.

Objectives

Our broad objective remains to assess the impact of ELF fields on forest productivity and health. To accomplish this, more specific objectives of the work elements are to determine the impacts of ELF electromagnetic fields on:

1) growth rates of established stands, individual hardwood trees and red pine seedlings,
2) timing of selected phenological events of trees, herbs and mycorrhizal fungi,
3) numbers and kinds of indigenous mycorrhizae on red pine seedlings,
4) nutrient levels of hardwoods and red pine,
5) foliage production in hardwoods.

The ecologically significant subject of insect and disease incidence is discussed in a related project on litter decomposition. Ultimately, the question of whether ELF EM fields measurably impact forest communities will be answered by testing various hypotheses (Table 1) based on the results of long-term studies.

PROJECT DESIGN

Overview of Experimental Design

This study is based on a statistically rigorous design to separate possibly subtle ELF field effects on response variables from the existing natural variability caused by soil, stand and climatic factors. Consequently, to test our hypotheses, it has been imperative to directly measure both plant growth and important regulators of the growth process such as tree, stand, and site factors in addition to ELF fields at the sites. Our work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypothesis (Table 2). The experimental design integrates direct measures with site variables and electromagnetic field exposure and is a common thread through nearly all studies due to the field design.

Table 1. Critical hypotheses that are tested to fulfill the objectives of the ELF environmental monitoring program Upland Flora project.

I.	There is no difference in the magnitude or the pattern of seasonal diameter growth of hardwoods before and after the ELF antenna becomes activated.
II.	There is no difference in the magnitude of diameter growth of red pine seedlings before and after the ELF antenna becomes activated.
III.	There is no difference in the magnitude or rate of height growth of red pine seedlings before and after the ELF antenna becomes activated.
IV.	There is no difference in the rate of growth and phenological development of the herb, *Trientalis borealis* L., before and after the ELF antenna becomes activated.
V.	There is no difference in the number of different types of mycorrhizal root tips on red pine seedlings before and after the antenna becomes activated.
VI.	There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELF antenna becomes activated.
VII.	There is no difference in the foliar nutrient concentrations of northern red oak trees or red pine seedlings before and after the ELF antenna becomes activated.

Table 2. Measurements needed for testing the critical hypotheses of the ELF environmental monitoring program Upland Flora project, the objective it is related to, and the work elements addressing the necessary measurements and analyses.

Hypothesis Number	Related Objectives	Measurements	Work Elements
I	1,2	*Weekly dendrometer band readings** climatic variables, soil nutrients, tree and stand characteristics.	1,2,3
II	1	*Annual diameter growth*, terminal bud size, plant moisture stress, microsite climatic variables, number of mycorrhizae.	1,2,3,5
III	1,2	*Weekly height growth, annual height growth*, terminal bud size, plant moisture stress, number of mycorrhizae, ambient measures.	1,2,3,5
IV	2	Periodic measures of plant dimensional variables including *leaf size* and phenological stages of *flowering, fruiting,* etc., climatic variables.	1,3
V	3	*Monthly counts of mycorrhizal root tips by type*, climatic variables, tree variables.	1,2,4
VI	5	*Periodic collections of litter, nutrient analyses*, climatical variables.	1,5
VII	4	*Periodic collections of foliage, nutrient analyses*, climatic variables.	1,2,5

*Underlined print designates response variables; others listed are covariates which are also tested for independence of ELF EM field effects.

Experimental Design And Electromagnetic Exposure

At the outset of the project, it was known that the EM fields associated with the ELF system would be different at the antenna and ground locations. IITRI has measured 76 hz electric field intensities at the antenna, ground, and control sites since 1986 when antenna testing began and background 60 Hz field levels were measured at all sites in 1985. Three types of EM fields are measured: magnetic (mG), longitudinal (mV/m), and transverse (V/m) (Appendix A).

The experimental design is best described as a split plot in space and time. Each site (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two subunits (hardwood stands and red pine plantations). These stand types comprise the treatments for the second level of the design. Each stand type is replicated three times on a site (where sites represent different levels of ELF field exposure) to control variation in non-treatment factors that may affect growth or health such as soil, stand conditions and background and treatment EM field levels. The time factor in the design is the number of years that an experiment is conducted for baseline to treatment comparisons, or the number of sampling periods in one season for year-to-year comparisons. It is necessary to account for time in the experimental design since successive measurements are made on the same plots and individual trees over a long period of time without re-randomization.

Each site follows this design with one exception. There is no hardwood stand at the ground site because buffer strips required to minimize 'edge effects' on plot borders would have resulted in the stands being too distant from the ground for significant exposure to ELF fields.

Analysis of Covariance

Our experimental design directly controls error in the field through replications at the sites. Indirect, or statistical control, can also increase precision and remove potential sources of bias through the use of covariate analysis. This analysis uses covariates which are related to the variable of interest to remove the effects of an environmental source of variation that would otherwise contribute to experimental error. The covariate need not be a direct causal agent of the variate, but merely reflect some characteristic of the environment which also influences the variate.

Covariates under examination vary for different response variables (Table 2). Most analyses use ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as variables computed from these data, such as air temperature degree days, soil temperature degree days and cumulative precipitation. Depending on the response variable, microsite factors are also considered. There are also factors that are more specific to the variable; for example, covariates in the analysis of red pine height growth include bud size, seedling diameter, and total height of the seedling at the beginning of the study in addition to ambient factors.

Testing for ELF EM Field Effects

From IITRI data, it is apparent that field intensities are affected by vegetative and soil factors. Also, treatment levels have not been uniform over time because of the various testing phases prior to antenna operation. Since the antenna was activated for low level testing throughout the growing seasons of 1987 and 1988 and full power operation in late 1989, hypothesis testing examines differences in response variables between these and previous years, and differences between control, antenna and ground sites in 1987 through 1991 (or 1992 depending on the work element).

The most extensive comparisons are for yearly and site within year differences. For all hypotheses, ambient and other variables are used to explain site and year differences. Comparisons between pre- and post-operational years are made, as are comparisons of relationships between sites after antenna activation, to determine whether antenna operation has had a detectable effect on the response variables. For those elements where analysis of covariance is used, we test to insure that covariates are statistically independent of the EM fields and then examine whether fields explain differences for a particular response variable. If differences are apparent in the modelling effort, correlation is used to determine whether residuals from these analyses are related to ELF fields.

Detection Limits and Statistical Power

Since each study has been peer reviewed through the years, we feel that the biological basis of each is sound and will contribute to the overall objective aimed at determining whether forest productivity or health are affected by ELF EM fields. But because of the variability inherent in ecosystem level studies and the subtle perturbations expected from ELF EM field exposure, a quantitative assessment of the level of success and precision achieved by each of the studies in the Upland Flora project is imperative. Two different measures have been considered to make this evaluation, statistical power and detection limits.

Power is defined as the likelihood that a particular statistical test will lead to rejecting the null hypothesis if the null hypothesis is false. Exact calculation of power requires knowledge of the alpha level (Type I Error), parameters of the distribution of the variable of interest under the null hypothesis and the specification of a given alternative parameter value. In a t-test, for example, to determine power one must know the alpha level (usually 0.05 in the tests described here), the value of the test statistic under the null hypothesis (zero if the test is to determine if two means are different or not), and the degree of difference in the means which is considered biologically important (such as a ten-percent difference). The last value is the most difficult for scientists to agree upon in ecological studies because it is a matter of belief and judgement. Often, quantitative knowledge of ecological relationships is poor and scientists lack the perspective to determine whether a ten-percent difference in a parameter is ecologically significant but a five-percent difference is not. While it is possible to calculate curves showing power for a number of alternative hypotheses, one is still left with the question of how much of a difference is important. An alternative procedure which does not require the specification of this degree of difference is to do an *a posteriori* calculation of the detection limit.

The detection limit is the degree of difference which leads to 50-percent chance of correctly rejecting the null hypothesis (power) for a given alpha level. Use of the detection limit allows an individual reader or reviewer to evaluate the test in light of their own interpretation of what degree of difference is ecologically important. The calculation of detection limits is not exact since it is an *a posteriori* test; it depends on the data used in the test procedure and the procedure itself. In the tables presented in this report, the detection limits were calculated using the results from the analyses of covariance and the Student-Newman-Keuls comparison of means procedure. The detection limits are, therefore, usually conservative (larger than what may be actually detectable) since additional statistical tests which may be more sensitive to changes in system behavior, such as those utilizing models of expected behavior, are also being performed.

In summary, calculation of statistical power has the advantage of being exact, but the disadvantage for ecological studies of requiring one to specify a specific degree of change that is considered important. The calculation of detection limits has the advantage of not requiring the specification of an alternative (power is fixed at 50 percent), but the disadvantage of being an *a posteriori* calculation; therefore, it is not exact. It is our feeling that the latter quantity, the detection limit, provides information similar to statistical power, but is more suitable for ecological studies since specifications of an exact alternative hypothesis is not required.

Work Elements

The various work elements of this project were established to group similar tasks and analyses. Although data from several work elements are often used to test a single hypothesis, we retain the work element format in this report to allow the reader to easily refer to details presented in past annual reports. Each of the following sections presents a synopsis of the rationale for study, measures and analyses, and progress.

Element 1: AMBIENT MONITORING

The growth and development of a forest community or an individual in the community is directly related to the environmental factors (natural and anthropogenic) which influence the physical space that the community or individual occupies. Any study which attempts to relate the development of a population to any one of these factors must also determine and screen out the effects of other independent factors. Thus, the relationship between plant growth or development and ambient vriables must be quantified .before the effect of a single and potentially subtle factor, such as the electromagnetic fields of the ELF antenna, can be quantified (National Research Council, 1977).

Given the overall importance of ambient factors to the Upland Flora Project, the objectives of this monitoring work element are to:

1. evaluate the natural ambient differences between the control site and the test sites.

2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.

3. select ambient variables which are independent of ELF system effects which can be used to (1) build models to predict community growth and development and (2) supply ambient variables as covariates for community growth and development analysis.

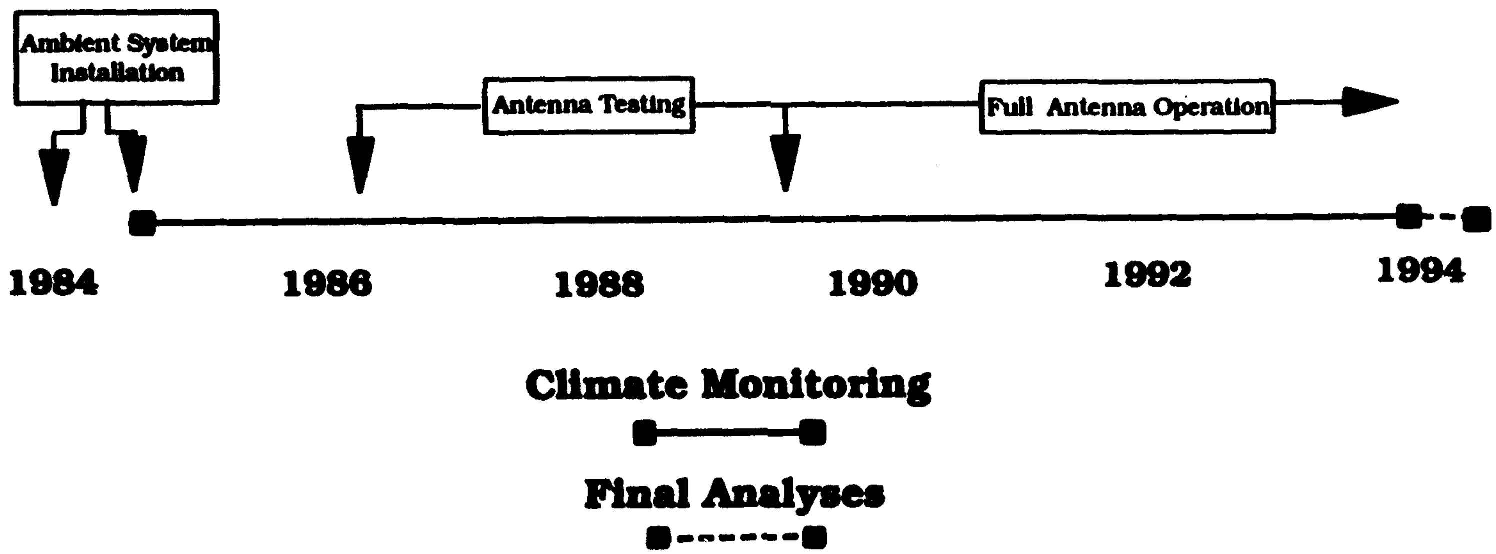
4. evaluate possible ELF system effects on non-independent ambient variables detected through the screening process in objective 3.

Accomplishing these objectives will not only document ambient differences among sites and annual changes in these conditions but also quantify ambient variables which can be employed in the growth and development modeling in the various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic and soil relationships to other study components as discussed in the design section dealing with covariate analysis. Accomplishment of the last objective will give direct measurement of any ELF system influences on such factors as solar radiation in the understory or soil nutrient status that may be affected by overstory biomass. The initiation and schedule of each phase of the objectives are presented in Figure 1.1.

Work on the Upland Flora Project during the past eight years has indicated that soil chemistry is important to the project's growth modeling efforts. Thus comparisons of soil chemical properties among sites and years are included in this element. The ambient monitoring element is separated into two

Figure 1.1

Schedule of annual ambient monitoring objectives



sections, climatic monitoring and nutrient monitoring, to reflect the two distinct monitoring activities.

Climatic Monitoring

Sampling and Data Collection

System Configuration

The climatic variables being measured in the study are air temperature (30cm and 2m above the ground), soil temperature and soil moisture at depths of 5 and 10 cm, global solar radiation, relative humidity, photosynthetically active radiation (PAR), and precipitation. The configuration and placement of the sensors at the study sites have been presented in Appendix B (Table 1) of the 1985 Herbaceous Plant Cover and Tree Studies Project annual report (Mroz et al. 1986).

Due to the location of the precipitation and global solar radiation sensors measurements of these variables are considered to be independent of possible ecological changes caused by ELF electromagnetic fields. Locations of the air temperature, soil temperature, soil moisture, air temperature (30 cm above the ground), relative humidity, and PAR (30 cm above the ground) sensors are such that they would be altered by ecological changes related to stand characteristics and thus to possible ELF electromagnetic fields effects.

Air temperature, soil temperature, PAR, and relative humidity are measured every 30 minutes by a Handar, Inc. ambient monitoring platform. Global solar radiation is measured every 60 minutes, soil moisture is sampled every 3 hours, and precipitation monitored continuously. A microprocessor on the ambient system calculates three hour averages or totals for the appropriate climatic variables. These averages and totals as well as the soil moisture and global solar radiation measurements are transmitted to the GOES East satellite every three hours and relayed to Camp Springs, Virginia. The data are transferred from Camp Springs to an IBM PC at MTU nightly.

Soil moisture subsampling procedures are performed at each site in order to more accurately measure soil moisture content over the entire area of each plot. Twenty cores are randomly taken from each plot at each site once a month. Moisture content for each depth (5 cm and 10 cm) is determined gravimetrically from a composite of the cores from a plot. These moisture contents are considered to represent the average moisture content for a given plot for the day of core sampling.

Differences between the soil moisture content calculated from the cores and measurements from the soil moisture sensors for a given plot and day of core collection are used as an adjustment for the soil moisture readings for each plot over a monthly time interval. To eliminate any abrupt changes in estimated soil moisture contents between consecutive months which would be attributed to the monthly adjustment, the weighting equation (1.1) is used to determine the actual monthly soil moisture sensor adjustments. The equation's adjustments for a given month are weighted more heavily to the month of adjustment.

Equation 1.1 Monthly adjustment for a specific plot

$$\frac{(CSM_{(M-1)} - PSM_{(M-1)}) + 2*(CSM_{(M)} - PSM_{(M)}) + (CSM_{(M+1)} - PSM_{(M+1)})}{4}$$

CSM = Core Soil Moisture from the plot **M** = Month of Adjustment **M+1** = Following Month

PSM = Probe Soil Moisture from the plot **M-1** = Previous Month

As stated in the 1986 Herbaceous Plant Cover and Tree Studies Annual Report, 1985 soil moisture measurements could not be used in any analyses (Mroz et al. 1987). Thus the 1992 measurements were only the seventh full year of soil moisture measurement.

System Maintenance and Performance

The performance of the climatic monitoring system in 1988 was enhanced by the installation of lightning protection equipment at the sites through a cooperative effort between MTU and IITRI. Performance of the system since the installation of this equipment has improved dramatically. Downtime of the systems have been virtually eliminated by these improvements.

Data Management

Daily averages or totals, maximums, and minimums are computed for each sensor using all 3 hour measurements (eight/day) transmitted by the platforms. If less than six transmissions are received in a day for an air temperature, relative humidity, or solar radiation sensor daily statistics for that sensor are not calculated. Due to the smaller diurnal variability in soil temperature and soil moisture the transmission limits for calculation of daily statistics for these sensors are four and two transmissions respectively. Weekly and monthly averages or totals are then computed from these summaries.

Weekly or seven day summaries comprise the basic climatic unit used by the tree productivity study (element 2). One summary generated from the climatic information is adjusted to correspond to the weekly measurements of tree diameter or height. For example if red pine height growth and hardwood tree diameter growth was determined for the seven days from May 9 through May 15, weekly ambient summaries are also calculated for these same seven days. This insures a consistent relationship between tree productivity measurements and climatic measurement summaries. Weekly averages are considered missing and not calculated if less than four daily averages are computed from a sensor for a given seven day period. Daily climatic information is summarized in the same manner to correspond to sampling periods in each of the other project elements.

Monthly averages and totals are the basic unit used for site and year comparisons in this study element. Weekly averages and totals corresponding to seven day periods in a month are calculated from the daily climatic averages and totals (Table 1.1). These weeks are used as repeated replicate samples for each plot during each month during the growing season (refer to analysis section).

Table 1.1. Example of weekly units.

Date	Week
May 1-7	1
May 8-14	2
May 15-21	3
May 22-30	4

<u>Missing Data Replacement</u>

As the result of platform and sensor downtime in the past eight years, daily climatic averages or totals are estimated for days in which specific ambient observations are missing. Four hierarchical criteria and methods are used to replace the missing data. The criteria are:

1) Daily averages missing from one or two plots from a stand type of an individual site are estimated using an average of the daily summaries from the functional plots at the same stand type and site.

2) Missing daily plot averages from adjacent sites (ground and antenna) are replaced by the stand type averages from the plantation on the adjacent site if 1) there are no significant differences between the two sites 2) there are no significant differences among plots within sites for the variable of interest. Only precipitation has met these criteria on the ground and antenna sites in the past eight years.

3) Missing daily plot averages from the ground or antenna site not estimated by the methods outlined in criteria 2 are predicted using regression equations. These equations are fitted using observed data from the missing sensor, plot, and site combination as the dependent variable and the observed average daily measurements from the plantation at the adjacent site as the independent variable.

4) Missing plot daily average air temperatures, relative humidity, and total daily precipitation at the control site are estimated from regression equations fitted to individual observed plot averages or totals and daily observations at the Crystal Falls C#200601 weather station. This weather station is located within 9 km of the control site and is operated by the Michigan Department of Natural Resources in Crystal Falls. Missing average daily soil temperatures are estimated using regression equations fitted to stand type daily averages of air temperature at the site.

Using these techniques 95% of the missing daily averages or totals can usually be replaced. Regression equations used in the data replacement along with the related regression statistics for 1985-91 have been presented in previous Herbaceous Plant Cover and Tree Studies annual reports. The 1992 equations are presented in Appendix B (Table 1) of this report. Improved performance of the ambient system in the past years has eliminated any long term use of these data replacement methods. In 1992 criteria 3 was only used to estimate 5-7 days of missing data at the antenna site during system startup in early April and May. Relative humidity and precipitation was also estimated at the control using criteria 4.

Estimates of climatic measurements obtained from criteria 1-4 are used throughout the project. Coefficients of determination as well as confidence intervals for the equations are well within acceptable limits. It is felt that the missing data replacement methods give unbiased and accurate estimates of climatic measurements and thus the variables are used in the statistical analyses in the various elements.

Data Analysis

Comparisons of site and time differences of the ambient variables generally follow a split-plot in space and time experimental design (Table 1.2). Since plot locations at one site are not related to plot locations at another site, plots are nested within sites. This nesting gives a more sensitive test of main factor effects.

The design through partitioning of variability into a number of factors (site, year, stand type etc.) and associated interactions allow a number of hypotheses to be tested. For example the site factor allows testing differences in climate between sites and year factors can quantify annual changes in climate. To determine if ELF fields are affecting ambient variables at the test sites site by year, site by stand type, and site by stand type by year interactions are used to determine if the relationship of a given ambient variable changes between the stand types or the control and test sites over time. These interaction terms can be used to quantify ELF field effects on climate by relating any temporal changes in climate to antenna preoperational and operational phases.

As mentioned previously weekly summaries are the basic unit used for statistical analysis in the element. We consider these weeks as a repeated measure on a given climatic variable. Repeated measures are multiple observations on a specific experimental unit or (in the case of climatic measurements) a specific three dimensional area. Since the observations are made on the same unit they are not independent of each other. Therefore weeks are nested in plots in the design (Table 1.2).

Comparison of ambient variables among sites, years, months, etc. were made using analysis of variance tests. Differences between specific months, years, sites, etc. were made using the Student-Newmen-Keuls (SNK) multiple range test if tests with analysis of variance indicated significant differences for the appropriate factor. Detection limits for each variable were also calculated using this multiple range test. All factors were tested at $\alpha=0.05$ for the ANOVA and SNK tests.

Analysis of ambient variables, which are only measured on a site level, year level, or on only one stand type, involved only a portion of the experimental design. Analysis of precipitation amounts involved site and year factors only because one sensor is located at each of the plantations. Since the ground site does not have a hardwood stand type associated with it, analyses were performed for the control vs. ground site and the control vs. antenna site separately with stand type dropped from the analysis for the control vs. ground site comparisons.

Progress

This year concludes the ninth full year of data collection by the ambient monitoring system (1985-1993) and the fifth year during full power operation of the ELF antenna (1989-1993). This year's report includes summaries and statistical analysis of the climatic information through 1992

Table 1.2. General analysis of variance of Element 1.

Source of Variation	Sum of Squares	Mean Square	F-Ratio
SI	SS(S)	MS(S)	MS(S)/MS(E_1)
PL w SI (Error 1)	SS(E_1)	MS(E_1)	MS(E_1)/MS(E_2)
WK w PL w SI (Error 2)	SS(E_2)	MS(E_2)	
YR	SS(Y)	MS(Y)	MS(Y)/MS(E_3)
YR x SI	SS(YS)	MS(YS)	MS(YS)/MS(E_3)
YR x PLwSI (Error 3)	SS(E_3)	MS(E_3)	MS(E_3)/MS(E_4)
YR x WKwPLwSI (Error 4)	SS(E_4)	MS(E_4)	
ST	SS(T)	MS(T)	MS(T)/MS(E_5)
ST x SI	SS(TS)	MS(ST)	MS(ST)/MS(E_5)
ST x PLwSI (Error 5)	SS(E_5)	MS(E_5)	MS(E_5)/MS(E_6)
ST x WKwPLwSI (Error 6)	SS(E_6)	MS(E_6)	
MO	SS(M)	MS(M)	MS(M)/MS(E_7)
MO x SI	SS(MS)	MS(MS)	MS(M_5)/MS(E_7)
MO x PLwSI (Error 7)	SS(E_7)	MS(E_7)	MS(E_7)/MS(E_8)
MO x WKwPLwSI (Error 8)	SS(E_8)	MS(E_8)	
YR x MO	SS(YM)	MS(YM)	MS(YM)/MS(E_9)
YR x MO x SI	SS(YMS)	MS(YMS)	MS(YMS)/MS(E_9)
YR x MO x PLwSI (Error 9)	SS(E_9)	MS(E_9)	MS(E_9)/MS(E_{10})
YR x MO x WKwPLwSI(Error 10)	SS(E_{10})	MS(E_{10})	
YR x ST	SS(YT)	MS(YT)	MS(YT)/MS(E_{11})
YR x ST x SI	SS(YTS)	MS(YTS)	MS(YTS)/MS(E_{11})
YR x ST x SI (Error 11)	SS(E_{11})	MS(E_{11})	MS(E_{11})/MS(E_{12})
YR x ST x SI x WKwPLwSI(Error 12)	SS(E_{12})		
ST x MO	SS(TM)	MS(TM)	MS(TM)/MS(E_{13})
ST x MO x SI	SS(TMS)	MS(TMS)	MS(TMS)/MS(E_{13})
ST x MO x PLwSI (Error 13)	SS(E_{13})	MS(E_{13})	MS(E_{13})/MS(E_{14})
ST x MO x WKwPLwSI (Error 14)	SS(E_{14})	MS(E_{14})	
YR x ST x MO x SI	SS(YTMS)	MS(YTMS)	MS(YTMS)/MS(E_{15})
YR x ST x MO x PLwSI (Error 15)	SS(E_{15})	MS(E_{15})	MS(E_{15})/MS(E_{16})
YR x ST x MO x WKwPLwSI (Error 16)		SS(E_{16})	MS(E_{16})

Site = SI, S Within=w
Stand Type = ST, T By=x
Year = YR, Y
Month = MO, M
Plot = PL

including tests to determine whether the ambient variables are related to the electromagnetic fields which have been measured at the sites during 1985-1992. The objective of this effort is to determine if ambient and climatic factors are correlated to the EM field strengths at the sites. Significant correlations between these fields and the ambient variables would suggest that either a mechanistic or coincidental relationship exists between the measured ambient variables and ELF antenna operation. Regardless of the actual cause for such a relationship, it is important to determine which variables are independent and which are either affected by or confounded with ELF antenna operation. Variables which are related to ELF fields do not meet the assumptions of independence that is necessary for inclusions as covariates in the statistical designs.

Relationships between ambient measurements and the ELF fields are determined using Pearson Product Moment Correlation Coefficients. Ambient measurements used for the correlations are the growing season averages or totals for each plot and site used for ANOVA analyses in this element. Mean maximum magnetic flux densities (76hz) for each plot are determined by integrating the point equations for this field (Appendix A, Figures 1 & 2) over the area of each plot individually for each year of measurement (Table 1). Mean longitudinal 76 hz fields (Appendix A Table 1) for each plot and year at the ground and antenna sites are determined from on site measurements and isocline maps (Appendix A, Mroz et. al. 1991). For the control site these values are determined by integrating the longitudinal field point equation (Appendix A, Figure 3) over the area of each plot (Appendix A, Table 1). The electromagnetic measurements chosen for the correlations are the 76 Hz magnetic flux and 76 Hz longitudinal electric fields during the EW leg operation.

Air Temperature (2m above the ground)

Air temperature has a substantial influence on plant physiological processes such as photosynthesis, cell division, and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1979). For any individual species given a specific period during the growing season, optimal net photosynthesis is associated with a specific range of temperatures (Waring and Schlesinger 1985). Thus differences in air temperature between the control and test sites or among study years could have significant effects on vegetation growth and development.

Site Comparisons: Average growing season air temperature during 1985-1992 was 0.7 and 0.9 ^{O}C warmer at the control plantation than at the antenna and ground plantations respectively (Table 1.3). Average air temperature during this same period was 0.8 ^{O}C warmer at the control hardwoods than at the antenna hardwoods (Table 1.3). ANOVA tests showed significantly higher temperatures at the control compared to

Table 1.3 Comparison of mean air temperature (^{o}C) 2 m above ground during the 1985-92 growing seasons (April-Oct.).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	11.4	11.5	11.9	0.5	0.4
1986	11.9	12.1	12.7	0.8	0.6
1987	12.7	12.9	13.6	0.9	0.7
1988	12.3	12.9	13.8	1.5	0.9
1989	11.8	12.1	13.2	1.4	1.1
1990	11.4	11.7	12.3	0.9	0.6
1991	12.6	12.7	13.2	0.6	0.5
1992	10.4	10.7	11.3	0.9	0.6
Ave.	11.8	12.0	12.7	0.9	0.7
			Hardwoods		
1985		11.4	12.3		0.9
1986		12.0	12.9		0.9
1987		12.7	13.5		0.8
1988		12.5	13.3		0.8
1989		11.8	12.5		0.7
1990		11.5	12.3		0.8
1991		12.5	13.1		0.6
1992		10.7	11.4		0.7
Ave.		11.9	12.7		0.8

1985-1992 MEAN DAILY AIR TEMPERATURE (C^{o})

Site Comparisons

Control	Ground
12.7 a	11.8 b

Control	Antenna
12.7 a	12.0 b

Annual Comparisons

	Control & Ground	Control & Antenna
1985	11.7 c	11.8 e
1986	12.3 b	12.4 c
1987	13.1 a	13.2 a
1988	13.1 a	13.1 a
1989	12.5 b	12.4 c
1990	11.9 c	12.0 d
1991	12.9 a	12.9 b
1992	10.8 d	11.0 f

[1]Sites or years with the same letters for a specific site combination not significantly different at p=0.05

the ground site ($p=.002$) and control compared to the antenna site ($p<.001$).

Annual Comparisons: Mean average air temperatures during the growing seasons of 1987 and 1988 were warmer than in any other year of the study. Average air temperature during 1992 were 2.0 to 2.1 degrees cooler than in 1987 or 1988. ANOVA tests showed significant differences in average growing season air temperatures among years for the control-ground comparisons ($p<.001$) and the control-antenna comparisons ($p<.001$). Multiple range tests ranked annual growing season air temperatures for the control and ground as follows (Table 1.3): 1988=1987=1991>1989=1986>1990=1985>1992. Ranking of the temperatures at the control and antenna sites were as follows (Table 1.3):1988=1987>1991>1989=1986>1990>1985>1991.

Site by Year Comparisons: ANOVA test again in 1992 indicated significant site by year interactions for the control vs. ground ($p=0.045$) comparisons but not the control vs. antenna comparisons ($p=0.377$). Figure 1.2 shows the mean air temperature at the control and ground plantations and the differences in air temperature between these two plantations during the 1985-1992 growing seasons. Differences in air temperature between the two sites increased from a low in 1985 of 0.5 ^{o}C to a high of 1.5 ^{o}C in 1988. Starting in 1989 these differences have been decreasing and in 1991 the control plantation was only 0.6^{o}C warmer than the ground plantation (Table 1.3). Differences in air temperature at the control and antenna plantations show a similar trend (Figure 1.3 & Table 1.3) during these years but the magnitude of the changes were less than those observed for the control and ground plantation comparison. Differences in air temperature between the control and antenna hardwoods in contrast to the plantations have remained extremely stable (0.6^{o} and 0.9^{o}C) during the eight year study period (Figure 1.4). However, site by stand type by year interactions have not been found to significantly differ ($p=.260$) for the control antenna comparison.

Comparisons of the average air temperature in the plantation and hardwoods at the control and antenna sites, during 1985-1992, revealed that differences in air temperatures between these two stand types increased beginning in 1987 (Figure 1.5). Differences in temperatures between the two stand types were significant ($p\leq.05$) in 1988 and 1989 with the plantations being warmer than the hardwoods but by 1990 differences again were not significant. In previous reports (Mroz et al. 1990, Mroz et al. 1991, Mroz et al. 1992) the increased temperatures of the plantations compared to the hardwood stands and the increased temperatures of the control plantation compared to the test plantations have been shown to be a related to the height growth of the red pine in the plantations. As the canopy of the red pine approachedthe

Figure 1.2

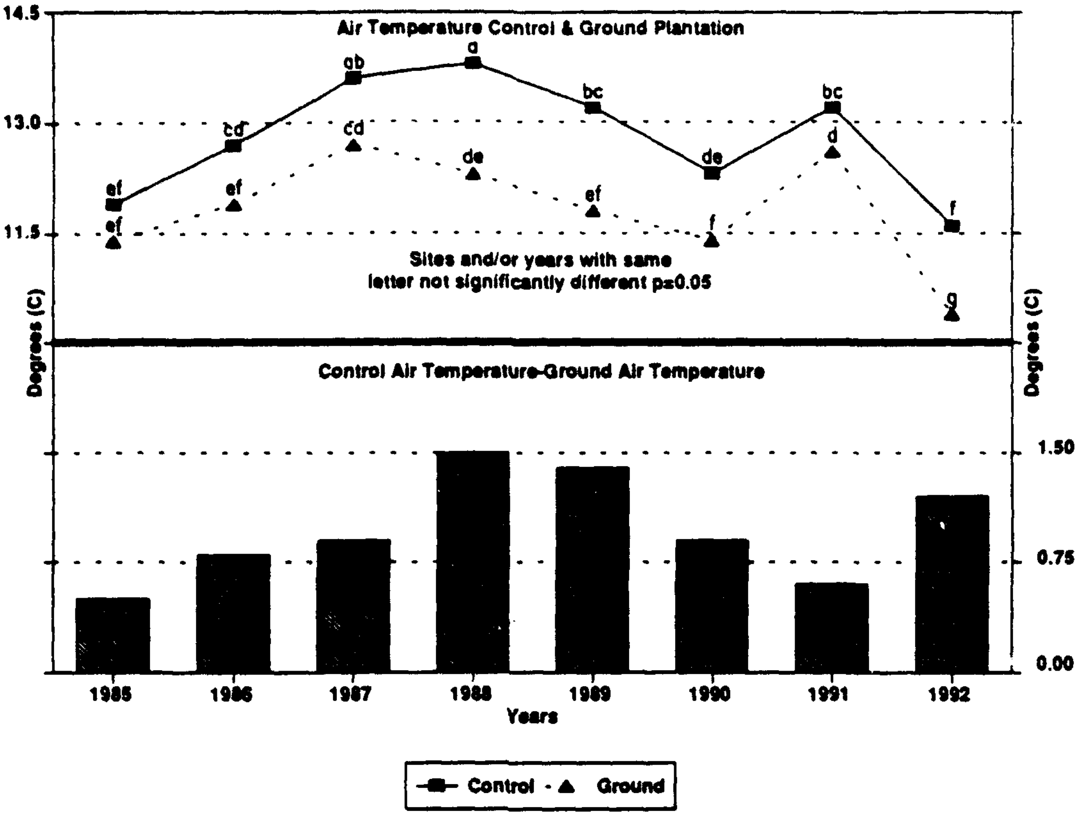


Figure 1.3

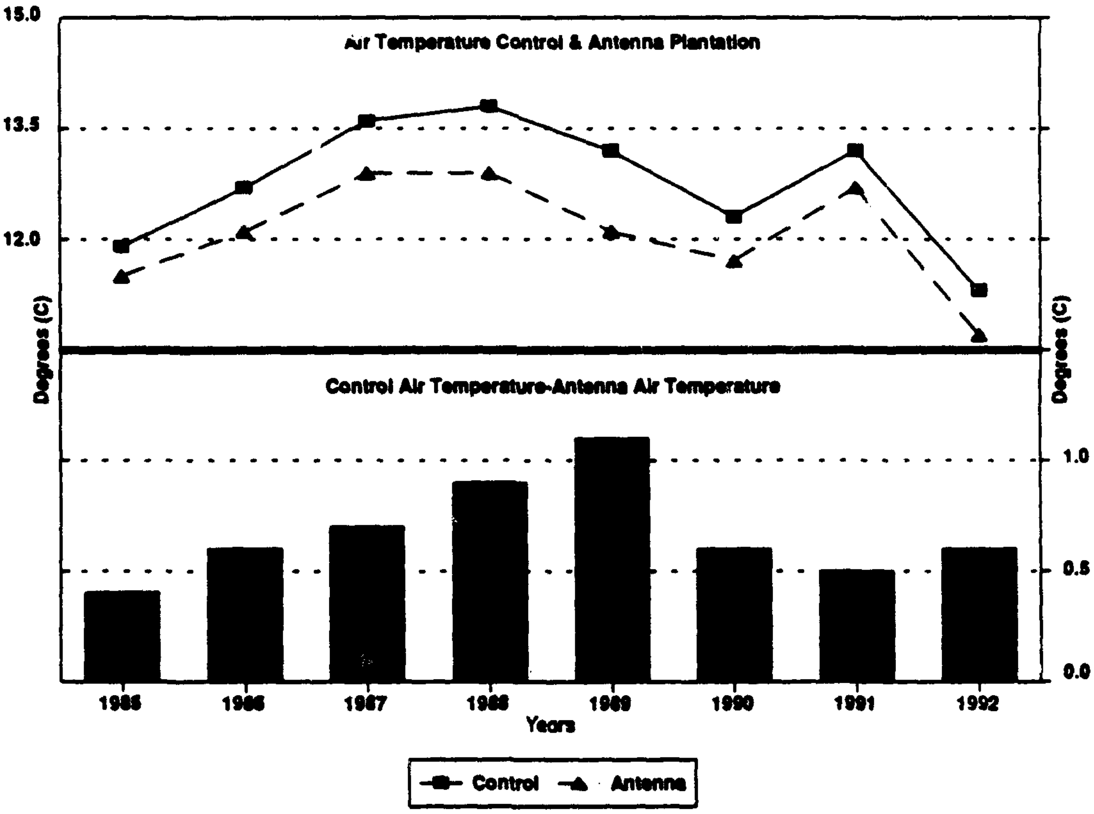


Figure 1.4

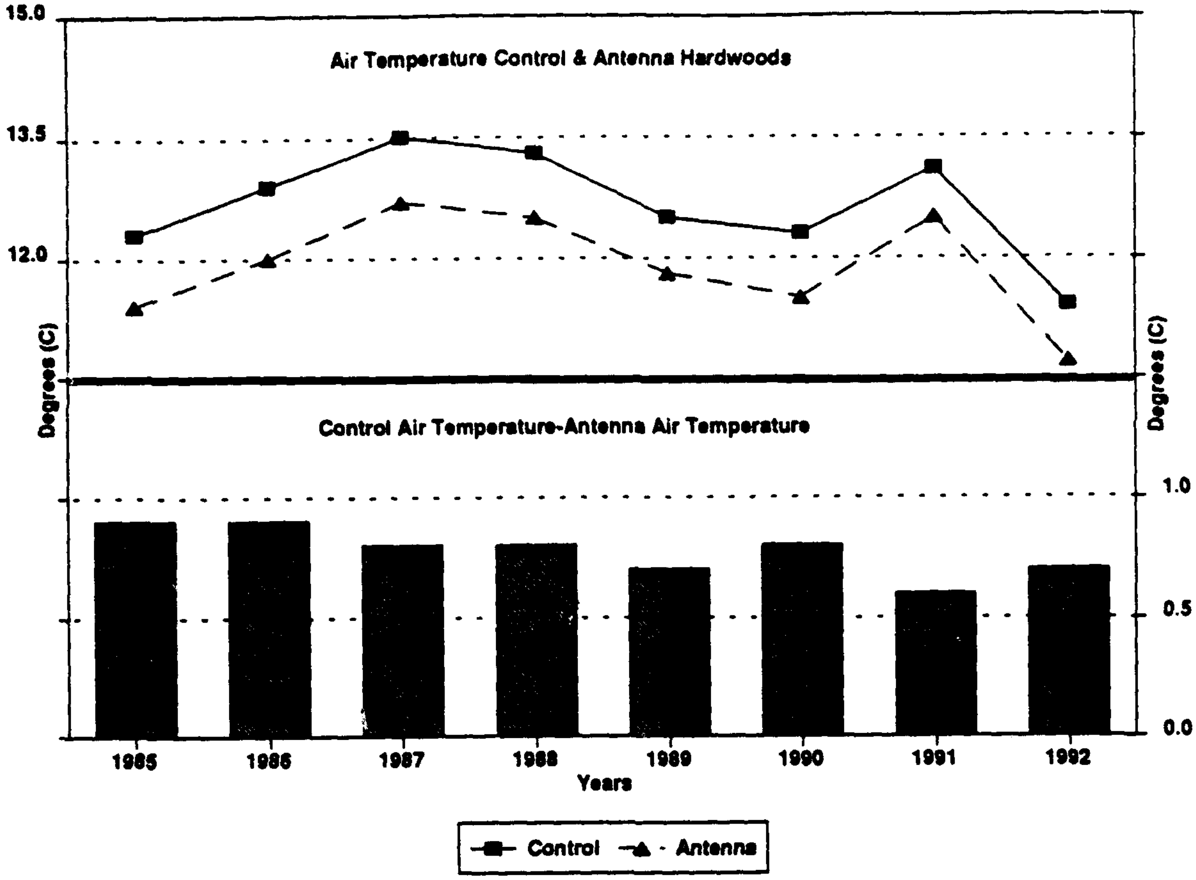
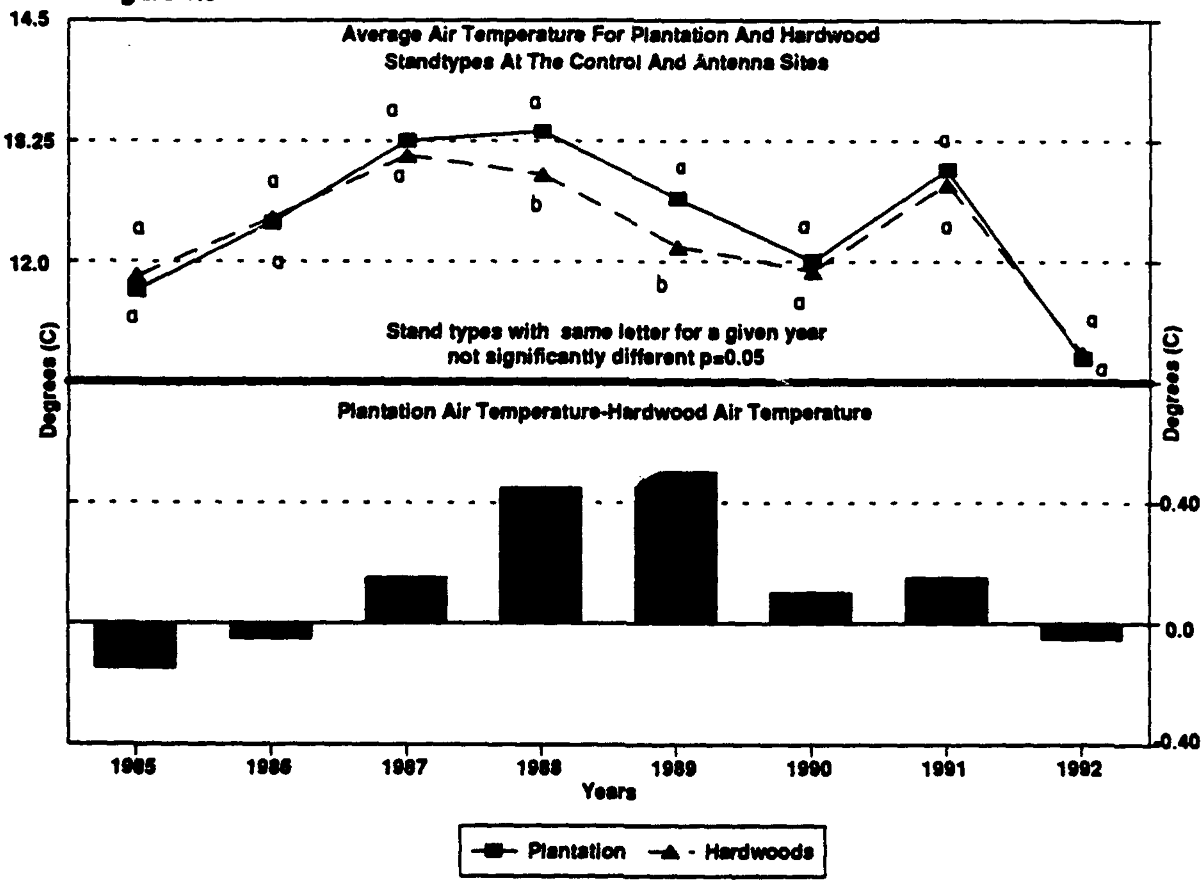


Figure 1.5



height of the air temperature sensors in the plantations, air temperatures were found to increase in the plantations relative to the hardwood stands (Figure 1.5). Air temperature at the control plantation, which has had the greatest height growth, increased to a greater extent than the air temperature at the test plantations. The decreased differences in the temperature between the two stand types (Figure 1.5) and the decreased differences in the temperatures between the control and test plantations from 1990 to 1992 suggests that either, 1) the canopies of the red pine at the control site are beginning to grow above the sensor level and thus their impact on air temperature in relation to 1988 and 1989 plantation conditions has been minimized and/or, 2) the height of the canopy at the test plantations has increased to such an extent that at this time effects of the test plantation canopies on air temperature are similar to the effects of the control plantation canopies on air temperature.

Comparisons of air temperature at the control plantation and hardwoods, shows that at least at this site the effect of the red pine canopy on air temperature has diminished since 1989 (Figure 1.6) and may not be altering the temperature at the plantation as of 1992. This can be seen by comparing the average growing season temperature in the control plantation and hardwoods. During 1985-1986 average air temperature was greater in the hardwoods than the plantation (Figure 1.6). In the years from 1987 to 1991 air temperature in the plantation was greater or equal to the air temperatures observed in the hardwoods. However in 1992 average air temperature was again greater in the hardwoods than in the plantation.

In order to further evaluate the effects of the red pine canopy on plantation temperatures, the average air temperature difference between the control and each test plantation was computed using the 1985 and 1986 observations. This was considered to be the normal difference in air temperature (NDAT) among sites before the alteration by the planted trees. A departure from this normal air temperature difference (DNDAT) was then computed by subtracting the NDAT from the observed air temperature differences (Table 1.3) for each year of the study. The percentage of permanently marked red pine with total heights between 1.25 and 2.75 m (Element 2) were then determined for the plantation of each site and year of the study. This height interval was considered to be the tree height at which the canopy would have its greatest effect on air temperature at the 2 m sensor height. Differences between the percentage of the permanently marked trees in this height interval (DPMT%) for control and each test site (ex. Control-Ground) were determined. The DNDAT and DPMT% were plotted for each year of the study.

These values for the control and ground sites (Figure 1.7) show a direct relationship between the differences in air temperature and differences in the percentage of trees in the designated height class. In 1988 and 1989 DNDAT averaged approximately 0.8 ^{o}C and the DPMT% was between 25 and 30%. The reduction in the differences in air temperature between

Figure 1.6

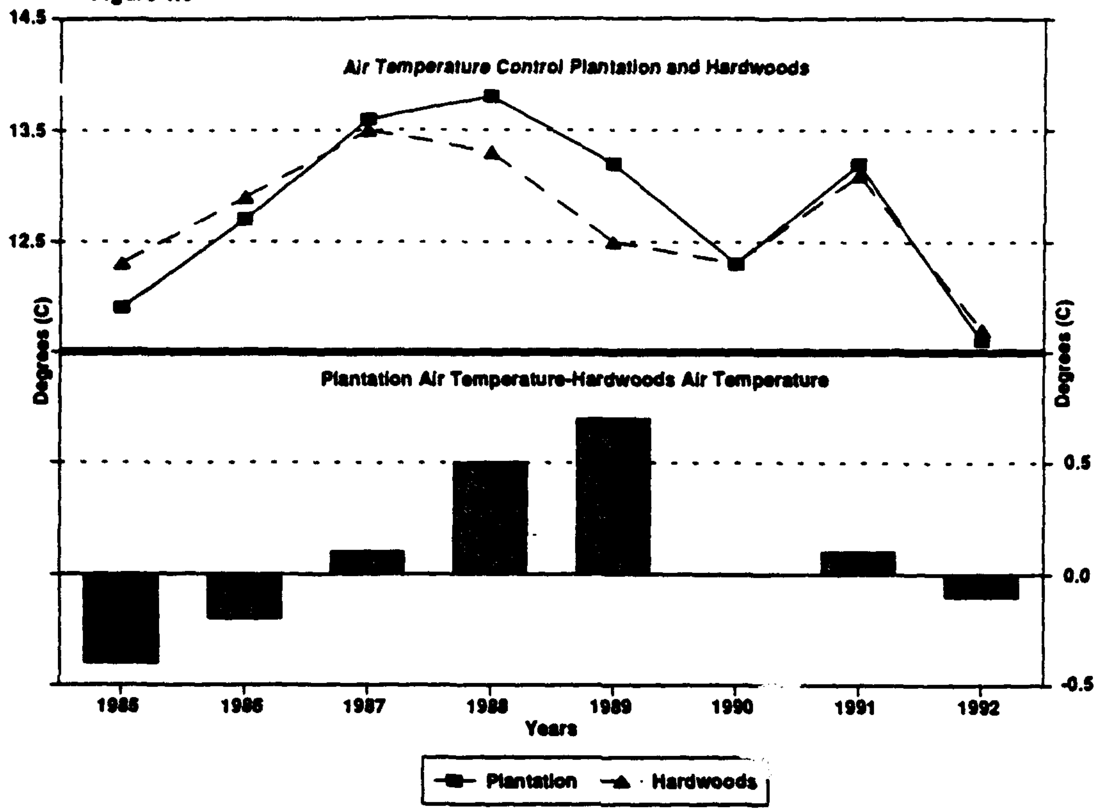
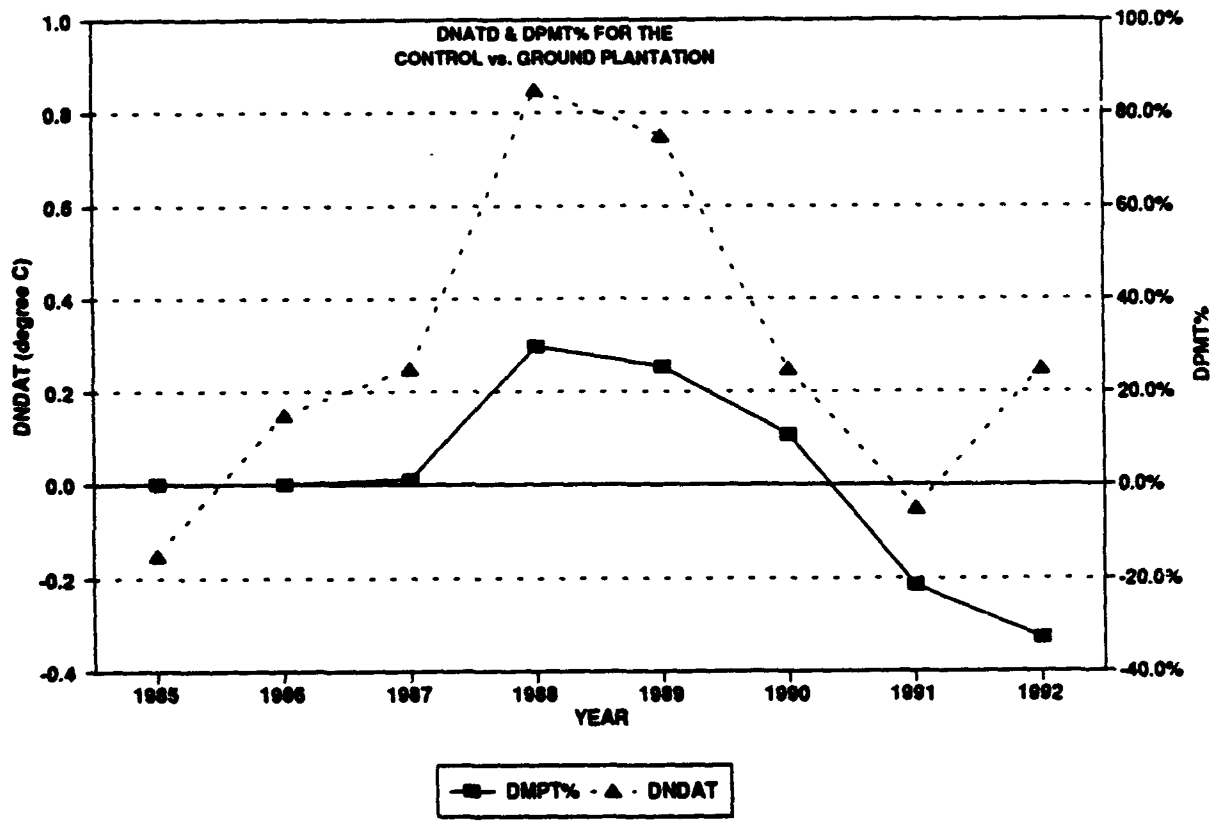


Figure 1.7



the control and ground plantations in 1990-1992 is related to the reduced differences in the percentage of trees in the specific height interval. In 1990 the control plantation had only 10% more of the marked red pine trees within the 1.25 to 2.75 m height interval than the ground plantation and consequently the DNATD was reduced to 0.2 °C. During 1991 and 1992 the ground had a greater portion of the red pine (15-32%) within the specified height interval than the control and thus the differences in air temperature between sites were less or similar to NDAT established from the 1985-1986 average temperatures. A similar relationship was found when comparing data from the control and antenna sites. These results support the conclusion that the red pine canopy has altered the air temperature at the 2m sensor height and that the differing growth rates at the sites have contributed to the annual variation in air temperature between the control and test plantations. The effects of the canopy on air temperature has been reduced in the plantation as the canopies over topped the air temperature sensors.

Summary: As in previous years analyses, air temperature at the control site was found to be significantly higher than at the test sites. The consistently higher temperatures at both stand types at the control indicates that differences in air temperatures among sites are to a great extent related to differences in regional climate or local topography among sites. This is most evident in the hardwood stands where differences in air temperature between the control and antenna sites have remained between 0.6 and 0.9°C over the eight year period. However, differences between air temperatures in the control and test plantations have varied with differences increasing from 1986 to 1989 and then decreasing there after. These changes in air temperature are related to the influence of the planted red pine on air temperature at the 2m sensor height and the differences in the height growth of the red pine among sites.

At this time there has been no direct evidence to conclude that the ELF antenna operation has altered the air temperature at the test sites. This is clearly evident when comparing the hardwood stands where air temperature differences have remained stable. However, in the plantations the annual variation at a given site and between control and test sites has been altered by the increasing height of the plantation red pine and the differences in red pine height growth among sites. Although there is evidence that height growth has been increased by antenna operation (Element 2), it is likely that the increase in height growth at the test sites was not of a significant magnitude to alter changes in temperature related to the inherent differences in tree productivity between the control and test sites.

Soil Temperature

Soil temperature like air temperature has a direct influence on plant physiological processes such as cell division and elongation. However soil temperature also indirectly influences plant growth by affecting permeability of roots and thus water uptake (Kramer 1983), biological decomposition and availability of nutrients (Brady 1974). Climatic conditions or stand characteristics such as insolation, air temperature, and precipitation as well as soil characteristics are the main factors controlling soil temperatures. Thus possible changes in vegetation or soil properties (organic matter content etc.) due to ELF antenna operation could have a major effect on soil temperature. These effects would appear to be more dramatic in the hardwood stands where microclimate is influenced to greater degree by vegetation than it is in the younger plantation stands.

Soil Temperature (depth of 5 cm)

Site Comparisons: Differences in mean soil temperatures (5cm) at the control and test plantations during the growing season have been less or equal to 0.5°C during each year of the study except 1989. The mean daily soil temperature (5 cm) during the growing season at the control was consistently warmer than or equal to the soil temperature at the ground plantation during each year of the study. However, during a number of years, soil temperatures (5cm) were cooler at the control than at the antenna plantation (Table 1.4). Unlike the plantations, soil temperatures in the control hardwoods were consistently warmer than in the antenna hardwoods each year of the study. The consistently warmer soil temperatures in the control hardwoods and the stability in the differences in soil temperatures between the two sites in the hardwoods, reflects 1)the higher air temperatures at the control compared to the antenna site and 2) relative stable canopy cover of this stand type during the study period. No significant differences in soil temperatures (5cm) were found between the control and ground sites ($p=0.336$) or the control and antenna sites ($p=0.189$) indicating that observed differences in soil temperature among sites is not greater than the spatial variation in soil temperature (5 cm) within sites.

Annual Comparisons: Annual variation in mean growing season soil temperatures (5 cm) during 1985-1992 were 2.4 °C for the control vs. ground comparisons and 2.3 °C for the control vs. antenna comparison. These ranges are 75 to 100% greater than were reported last year due to the low soil temperatures observed in 1992. Soil temperatures in the plantations were at least 0.9 to 1.6 °C cooler than in any prior year. The reduced soil temperature in the plantations during 1992 reflect not only the reduced air temperatures which occurred last year but also the decreased insolation associated with the increased leaf area and litter layer of the aggrading plantations. Annual differences in soil

Table 1.4 Comparison of mean soil temperature (°C) at a depth of 5 cm during the 1985-92 growing seasons (April-Oct.).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.5	12.9	12.5	0.0	-0.4
1986	13.3	13.5	13.5	0.2	0.0
1987	13.4	13.7	13.6	0.2	-0.1
1988	13.2	13.5	13.7	0.5	0.2
1989	12.3	12.6	13.2	0.9	0.6
1990	12.2	12.7	12.6	0.4	-0.1
1991	12.5	12.6	12.6	0.1	0.0
1992	11.4	11.0	11.0	0.4	0.0
Ave.	12.6	12.8	12.8	0.2	0.0

Hardwoods

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985		10.1	10.8		0.7
1986		11.2	11.7		0.5
1987		11.8	12.3		0.5
1988		11.2	11.6		0.4
1989		10.6	11.1		0.7
1990		10.7	11.1		0.4
1991		10.9	11.6		0.5
1992		9.8	10.7		0.9
Ave.		10.8	11.4		0.6

1985-92 MEAN DAILY SOIL TEMPERATURE (5cm) C°

Site Comparison

Control	Ground
12.8 a	12.6 a
Control	**Antenna**
12.1 a	12.6 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.5 b	11.6 d
1986	13.4 a	12.5 b
1987	13.6 a	12.9 a
1988	13.5 a	12.5 b
1989	12.7 b	11.9 c
1990	12.4 b	11.8 cd
1991	12.6 b	11.9 c
1992	11.2 c	10.6 e

[1]Sites or years with the same letters for a specific site combination not significantly different at p=0.05

temperature (5 cm) were significant (p=<.001) for both comparisons. Multiple range tests showed soil temperatures (5cm) during 1986-1988 to be greater than the remaining five study years. Soil temperatures during 1992 were significantly lower than in all prior years (Table 1.4).

Site by Year Comparisons: Site by year interactions were not significant for the control vs. antenna comparison (p=0.574) but this interaction was significant for the control vs. ground comparison (p=0.022). Soil temperatures (5 cm) were significantly higher in 1989 at the control than at the ground comparison but differences among sites for the other years were not significant (p=0.05). Differences between the control and ground site appeared to be the greatest during the years when differences in air temperature between these two sites were the greatest, indicating a link between air temperature at the plantations and differences in soil temperature. As noted previously, the soil temperature (5 cm) at the control hardwoods have been consistently warmer than at the antenna hardwoods during each year of the study, while soil temperatures (5 cm) at the control and antenna plantations have not differed. As a result site by stand type interactions were significant (p=.045) for the first time during the study. However site by stand type by year interactions were not significant (p=.794) .

Soil Temperature (depth 10 cm)

Site Comparisons: Average soil temperatures (10 cm) at the control site were within 0.7 ^{o}C and 1.5 ^{o}C of the antenna average soil temperatures (10 cm) at the test site plantations and hardwoods respectively during the entire study period (Table 1.5). As in previous years soil temperature (10 cm) was not significantly different between the control and ground (p=.626) or the control and antenna sites (p=.101).

Annual Comparisons: ANOVA tests indicated significant differences (p<.001) in soil temperature (10 cm) for all site comparisons. Rankings of annual soil temperature at a depth of 10cm were similar to rankings of annual soil temperature at a depth of 5cm. For both site comparisons 1986-1988 temperatures were significantly greater than 1985 or 1989-1992 temperatures and 1992 soil temperatures were the coldest during the entire study period (Table 1.5).

Site by Year Comparisons: Site by year interactions were not significant for either the control vs. ground (p=0.193) or the control vs. antenna (p=0.140) comparisons. Site by stand type interactions were not significant (p=.073) but site by stand type by year interactions were significant (p=.007). Figure 1.8 shows soil temperature (10cm) in the plantation and hardwoods of the control and antenna sites as well as the

Table 1.5 Comparison of soil temperature (10 cm) during the 1985-92 growing seasons (April-Oct.).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.2	12.6	12.4	0.2	-0.2
1986	13.0	13.4	13.3	0.3	-0.1
1987	13.2	13.5	13.6	0.4	0.1
1988	13.3	13.2	13.2	-0.1	0.0
1989	12.0	12.5	12.7	0.7	0.2
1990	11.7	12.4	11.9	0.2	-0.5
1991	12.3	12.4	12.0	0.2	0.0
1992	10.9	11.1	10.7	-0.2	-0.4
Ave.	12.3	12.6	12.5	0.2	-0.1

Hardwoods

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985		10.1	10.7		0.6
1986		10.9	11.4		0.5
1987		11.7	11.5		-0.2
1988		11.0	11.3		0.3
1989		10.3	10.9		0.6
1990		10.4	10.9		0.5
1991		10.7	11.6		0.9
1992		9.2	10.7		1.5
Ave.		10.5	11.1		0.6

1985-92 MEAN DAILY SOIL TEMPERATURE (10CM) C^O^

Site Comparison

Control	Ground
12.5 a	12.3 a

Control	Antenna
11.8 a	11.6 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.3 b	11.4 c
1986	13.1 a	12.3 b
1987	13.4 a	12.6 a
1988	13.3 a	12.2 b
1989	12.3 b	11.6 c
1990	11.8 c	11.4 c
1991	12.1 bc	11.7 c
1992	10.8 d	10.4 d

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

Figure 1.8

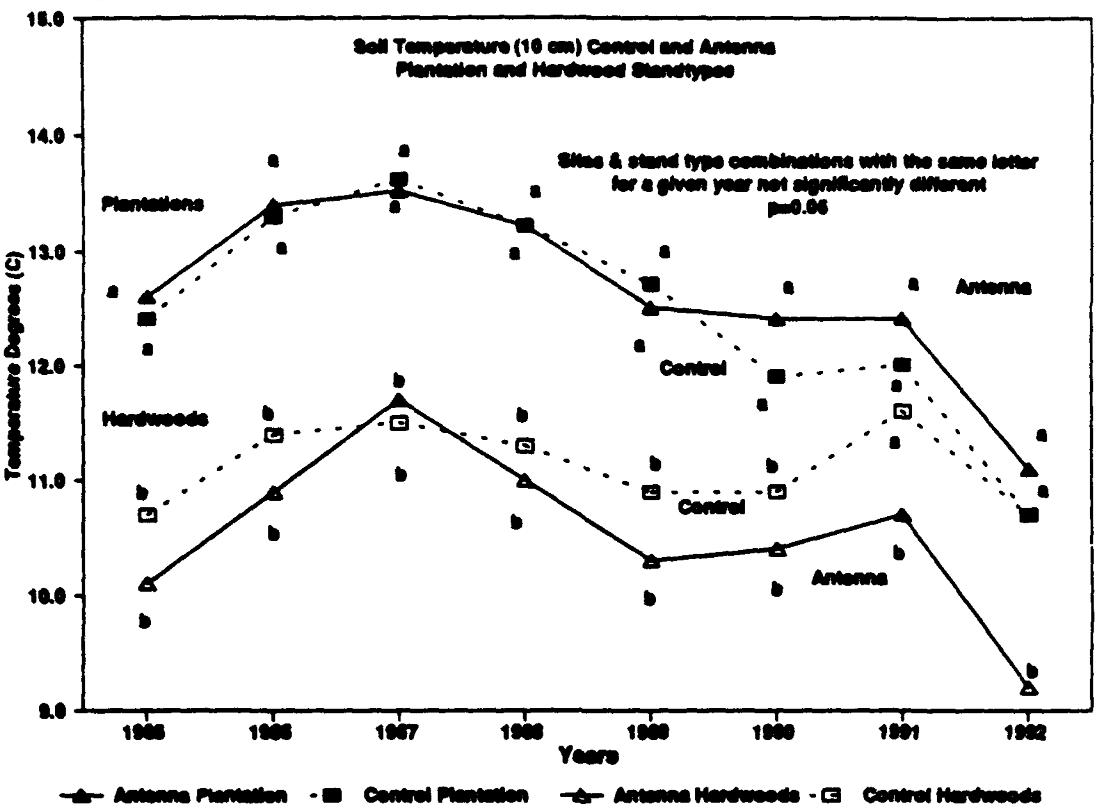
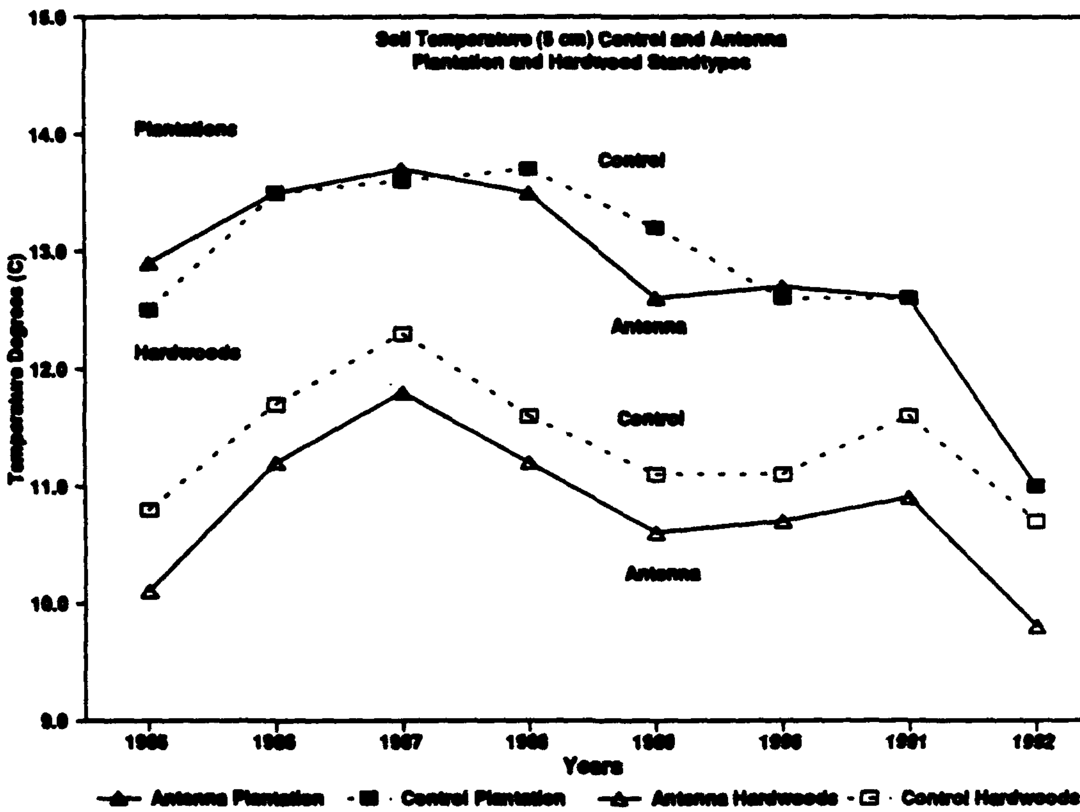


Figure 1.9



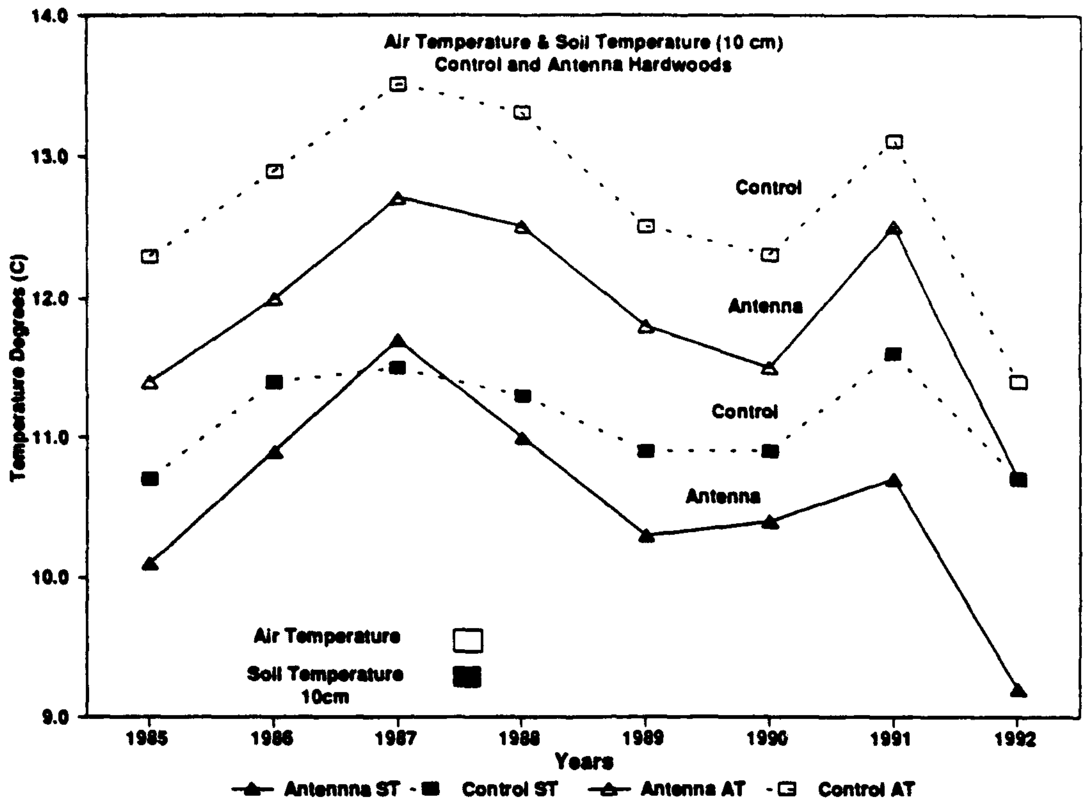
results from the multiple range test. During 1985-1990 differences in soil temperature (10cm) between sites for a given stand type and year were not significant ($p=.05$, Figure 1.8). However beginning 1991 soil temperature in the control hardwoods was significantly higher than in the antenna hardwoods. Also during 1991 and 1992 soil temperatures at this depth were not significantly greater ($p=.05$) in the plantations than in the control hardwoods.

Similar changes in soil temperatures at a depth of 5cm were also evident (Figure 1.9) although site by stand type by year interactions were not significant. The most obvious similarity between the temperatures at the two depths was the decrease in soil temperature in the plantations compared to the hardwoods in 1991 and 1992. This decrease is a result of the increased amount of leaf area, the development of a relatively uniform forest floor, and the accompanying decreased insolation in the aggrading plantations. Differences between the soil temperatures at the control and antenna hardwoods at this depth also increased in 1991 and 1992. However, this increase was of a smaller magnitude than the increases observed at a depth of 10cm.

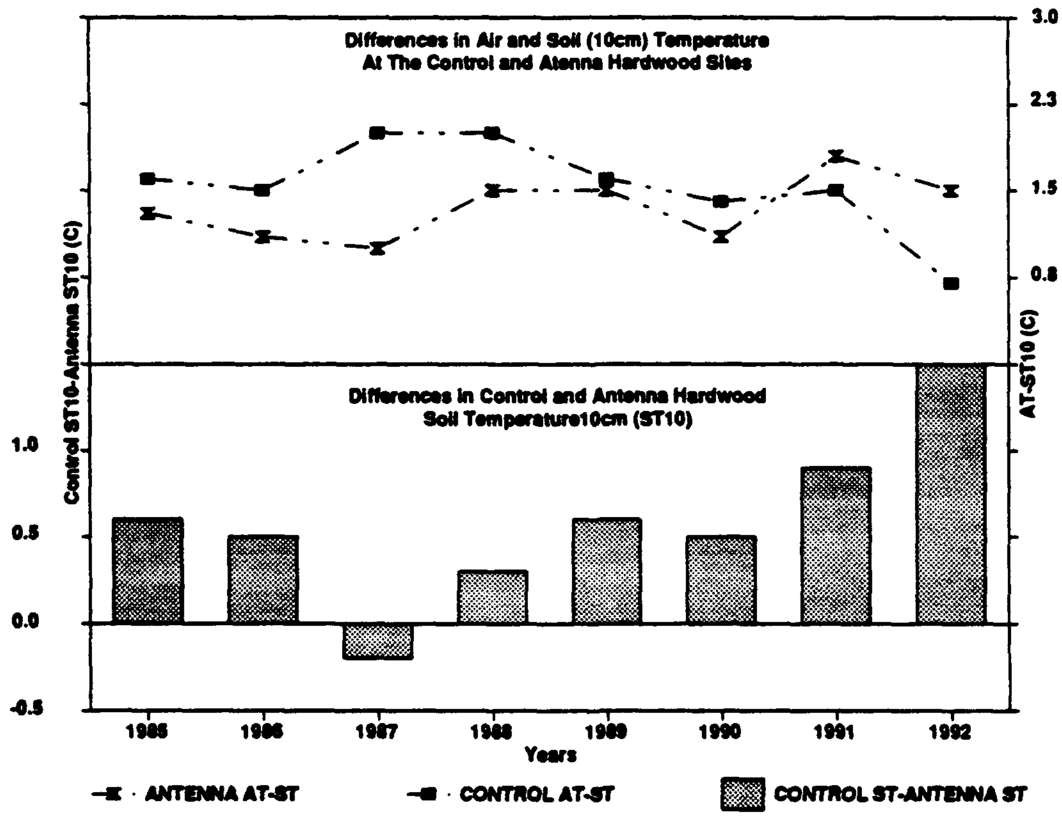
To a great extent the annual variation in soil temperature (10 cm) in the hardwoods is caused by the annual variation in air temperature (Figure 1.10). Prior to 1990, increased or decreased air temperatures at the hardwoods resulted in similar increases or decreases in soil temperatures with soil temperatures consistently being lower than the air temperatures. In 1990 air temperature decreases resulted in little change in soil temperatures. This lack of reduction in soil temperature was caused by a decrease in leaf area, as indicated by a 25% reduction in foliar litter weight during 1990 (Mroz et al. 1992). The reduction in foliage resulted in an increase in insolation and thus a higher soil temperature than expected given the air temperature during the growing season. During 1991 air temperature increased in the control hardwoods (Figure 1.10) and again so did soil temperature (10cm). Although increases in average growing season air temperature at the antenna site from 1990 to 1991 were similar to those found at the control site, increases in soil temperatu e (10cm) at the antenna were 0.4 ^{o}C less than the increases at the control hardwoods. In 1992 air temperature during the growing season decreased by 0.8^{o}C and 0.9^{o}C from 1991 levels at the antenna and control hardwoods respectively. However soil temperatures decreased from 1991 levels by 1.5 ^{o}C at the antenna and 0.9^{o}C at the control site.

Differences in the relationship between air temperature and soil temperature (10cm) for each of the hardwood stands are presented in Figure 1.11. Below normal differences in air temperature and soil temperature at the control site (1992) and above normal differences at the antenna site (1991-1992) correspond to the increased differences in soil temperature (10cm) between the two sites (Figure 1.11). The change in the air temperature-soil temperature relationship at the control is more readily explained than the change at the antenna site.

Figure 1.10



Figue 1.11



In 1991 31 trees died or failed to leaf out at the control as compared to two trees at the antenna site. In 1992 another six trees were killed and six heavily damaged by a severe windstorm (Mroz et al. 1993). This mortality appears to have reduced the amount of foliage in the canopy of the control site. In 1992 less foliar litter was collected at the control site in comparison to the antenna site than in any year of the study (Element 5). This reduction in foliage and thus leaf area would increase insolation within the stand thereby increasing soil temperatures relative to air temperature. Although the reduction in leaf biomass is evident from the litter collections, PAR (30cm) was not found to increase at the one sensor location in the control hardwood stand during 1991 or 1992 (refer to this element). The localized mortality and the limited number of PAR sensors has no doubt contributed to the lack of measured change in PAR with reduction in leaf area at this site.

Although the increased tree mortality and corresponding reduction in canopy foliage can explain the alteration in the relationships of air and soil temperature at the control, amounts of foliar litter collected at the antenna site during 1991 and 1992, although above the 1984-1992 average, were within the range collected prior to 1991. Thus reductions in soil temperature at this site do not appear to be related to foliar production. Soil moisture content at depths of 5 and 10cm were also well within the ranges observed prior to 1991.

It is possible that specific leaf area at the antenna site could have increased there by decreasing insolation without altering foliage production or litter weights at this site. Comparisons of PAR between the sites do not appear to indicate a change in leaf area. However, from this one sensor it is impossible to determine if this alteration of leaf morphology has occurred or whether it is responsible for the changes in soil temperature without more specific measurements of leaf area.

Summary: ANOVA tests showed significant (p=0.022) soil temperature (5cm) site by year interactions for the control vs. ground comparisons. Significant site by stand type by year interactions (p=0.007) were also evident for the control vs. antenna comparisons of soil temperature (10cm). Comparison of soil temperatures (5cm) at the control and ground plantations did not indicate any ELF effect. The significant site by stand type by year interactions for the control and antenna sites were a result of increases in soil temperature at the control hardwoods and decreases in the antenna hardwoods. The increased temperatures at the control appear to be related to natural mortality of trees from drought and wind storms. We were not able to find any specific environmental or biological reason which explains the alteration in soil temperature at the antenna site. Alteration in leaf morphology (specific leaf area) could explain the changes in temperature at the antenna. However,

links between the changes in temperature and this characteristic is only speculation at this time.

Currently there is no evidence to suggest that ELF fields have directly or indirectly altered the soil temperature in either of the test sites. However, the decreased soil temperature (10cm) at the antenna stand in 1991-1992 is still unexplained. The final year of field measurements should be able to determine if the trend of decreasing soil temperature at the antenna hardwood site continues, is stabilizing, or is reversed.

Soil Moisture

The amount and availability of water is a key factor in determining forest site productivity. The importance of water to plant growth should not be underestimated since almost all plant processes are influenced by the supply of water (Kramer 1983). Water in the soil is the primary media for transportation of nutrients within plants and is a reagent in photosynthesis. Apical and radial growth of trees have been shown to be highly correlated to soil water supplies (Zahner 1968).

Soil moisture is measured in the field and expressed as a percent of the dry soil weight at a given depth. Although moisture content gives a valuable measurement of the amount of water contained in the soil, it does not reflect to what degree plants can utilize this water. The tension at which water is held in the soil or soil water potential determines the availability of water to plants. Given a specific moisture content, the availability of water can vary depending on soil characteristics. Thus soil water potential may give a more sensitive estimate of moisture relationships among the sites and years with respect to vegetation growth and productivity. Soil water potential values were estimated from equations relating soil moisture content at each plot to soil water potential (Appendix C 1987 Herbaceous Plant Cover and Tree Studies Annual Report). These equations were then applied to daily average soil moisture content at each depth at each plot.

Soil Moisture Status(depth 5 cm)

Site Comparisons: Soil moisture content (5cm) at the control plantation was greater than at the antenna plantation for all years of the study but was only greater than at the ground site during 1986, 1988, 1989, 1990, and 1992 (Table 1.7). Soil moisture content at the control hardwoods was greater than at the antenna hardwoods for all years except 1992. ANOVA tests indicated significant higher soil moisture content (5cm) at the control than at the antenna site ($p=0.004$) but not the ground ($p=.110$). Average soil moisture content (5 cm) during 1986-1992 was 1.1% and 3.3% greater at the control plantation than at the ground and antenna

Table 1.6 Comparison of soil moisture content (%) and soil water potential(-Mpa) at a depth of 5 cm during the 1986-92 growing seasons (April-Oct.).

	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa
Plantation										
1986	13.2	.024	9.2	.022	16.0	.013	2.8	-.011	6.8	-.009
1987	13.6	.022	11.3	.013	13.5	.018	-0.1	-.004	2.2	.005
1988	11.8	.029	11.3	.016	12.9	.024	1.1	-.005	1.6	.008
1989	13.0	.018	10.9	.014	14.2	.020	1.2	.002	3.4	.006
1990	16.6	.010	13.7	.009	18.9	.008	2.3	-.002	5.2	-.001
1991	15.2	.011	13.6	.011	15.0	.012	-0.2	.001	1.4	.001
1992	14.5	.014	12.3	.010	15.5	.012	1.0	.002	3.2	.004
Ave.	14.0	.017	11.8	.013	15.1	.014	1.1	-.003	3.3	.001
Hardwoods										
1986			10.4	.024	14.1	.024			3.7	.000
1987			10.8	.023	10.9	.031			0.1	.008
1988			9.5	.026	10.6	.046			1.1	.020
1989			9.5	.023	11.2	.046			1.7	.023
1990			12.6	.010	16.2	.013			3.6	.003
1991			11.6	.014	14.3	.019			2.7	.006
1992			13.5	.010	13.4	.015			-0.1	.005
Ave.			11.1	.017	13.0	.025			1.9	.008

Site Comparison

	Control	Ground
Moisture Content	15.1 a[1]	14.0 a
Soil Water Pot.	.014 a[2]	.017 a
	Control	**Antenna**
Moisture Content	14.0 a	11.4 b
Soil Water Pot.	.019 b	.015 a

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-Mpa	%	-Mpa
1986	14.6 bc	.018 b	12.4 c	.020 c
1987	13.6 c	.020 bc	11.6 d	.020 c
1988	12.3 d	.027 b	11.1 d	.026 d
1989	13.6 c	.018 b	11.4 d	.023 cd
1990	17.8 a	.012 a	15.4 a	.010 a
1991	15.1 b	.012 a	13.5 b	.014 b
1992	15.0 b	.013 a	13.7 b	.011 a

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05
[2]ANOVA and multiple range tests of soil water potential performed on transformed (inverse natural log) data

Table 1.7. Water holding capacity of the mineral soil to a depth of 15cm at each site and stand type

	g water/m^2 soil	
	Plantation	Hardwood
Ground	240.9	
Antenna	125.9	188.3
Control	239.2	257.5

plantations respectively (Table 1.6). Differences between the two hardwood stands averaged 1.9%. The differences in moisture content of the control and antenna sites is related to the higher water holding capacity at the control compared to the antenna site (Table 1.7). Water holding capacity of the soils in the control plantation and hardwoods are respectively 90% and 37% greater than the water holding capacity of the soils in the antenna plantation and hardwoods. Differences in water holding capacity of the soils in the control and ground plantations are minimal.

Soil moisture contents are generally higher in the plantation than the hardwoods due to the lower amounts of leaf area and thus evapotranspiration. Differences in soil moisture content (5cm) of the two stand types were greater at the control than at the antenna site but site by stand type interactions were not significant ($p=.059$).

Differences in soil water potential between the sites were not found to be significant ($p=0.799$) for the control vs. ground comparison but were significant for the control vs. antenna comparison ($p=0.024$). Although soil moisture content was greater at the control site than at the antenna site, soil water potential was lower (more negative) at the control compared to the antenna site indicating a higher availability but not a higher amount of water at the antenna compared to the control.

Annual Comparisons: Differences in soil moisture content (5cm) and soil water potential (5 cm) were significant ($p \leq .004$) among years for both the control vs. ground and control vs. antenna comparisons. Soil moisture content (5 cm) and soil water potential (5 cm) were significantly higher ($p \leq .05$) in 1990 and 1991 than in any other previous year of the study. The higher moisture contents and lower water potentials in these years can be attributed to relatively high

Table 1.8 Average soil moisture content 5cm for differing soil water potentials at control and antenna hardwoods.

	Antenna		Control	
	Soil Wat.Pot. -MPA	**Moist. Content %**	**Soil Wat. Pot. -MPA**	**Moist. Content %**
Field Capacity	0.01	13.3	0.01	17.6
	0.03	7.6	0.03	9.5
Permanent Wilt. Point	1.5	2.9	1.5	3.1

levels of precipitation, a very uniform distribution of precipitation, and low levels of evapotranspiration due to relatively cool air temperatures during the growing season (see precipitation and air temperature sections).

Site by Year Comparisons: Soil moisture content (5cm) site by year interactions were significant for the control vs. antenna comparison (p<.001) but not the control vs. ground comparison (p=.117). The site by stand type by year interaction was also significant (p=.001) for the control vs. antenna analysis. Soil moisture content (5cm) was not significantly greater at the control plantation than at the ground plantation during any year of the study (Figure 1.12). However, multiple range tests showed significant differences between the control and antenna plantation during 1986-1990 and 1992. (Figure 1.13).

Differences in soil moisture content (5cm) between the control and antenna hardwoods were significant during 1986, 1990, and 1991 These differences increased from 1988 to 1991 and appear to reflect an overall increase in soil moisture status at these sites rather than a change in community or stand dynamics. During periods of adequate precipitation and low evapotranspiration, differences in soil moisture content at the sites reflect differences in the field capacity of the soils at the sites. Since moisture contents of the soils at field capacity are quite different (Table 1.8), moisture content at field capacities are an upper bound at which the two sites would differ during periods of little or no moisture stress. Thus during 1990 and 1991 when moisture contents at both sites were at their greatest levels, differences in soil moisture content between sites were the greatest.

As a result of the higher detection limits associated with soil water potential (5cm) and the varying relationships

Figure 1.12

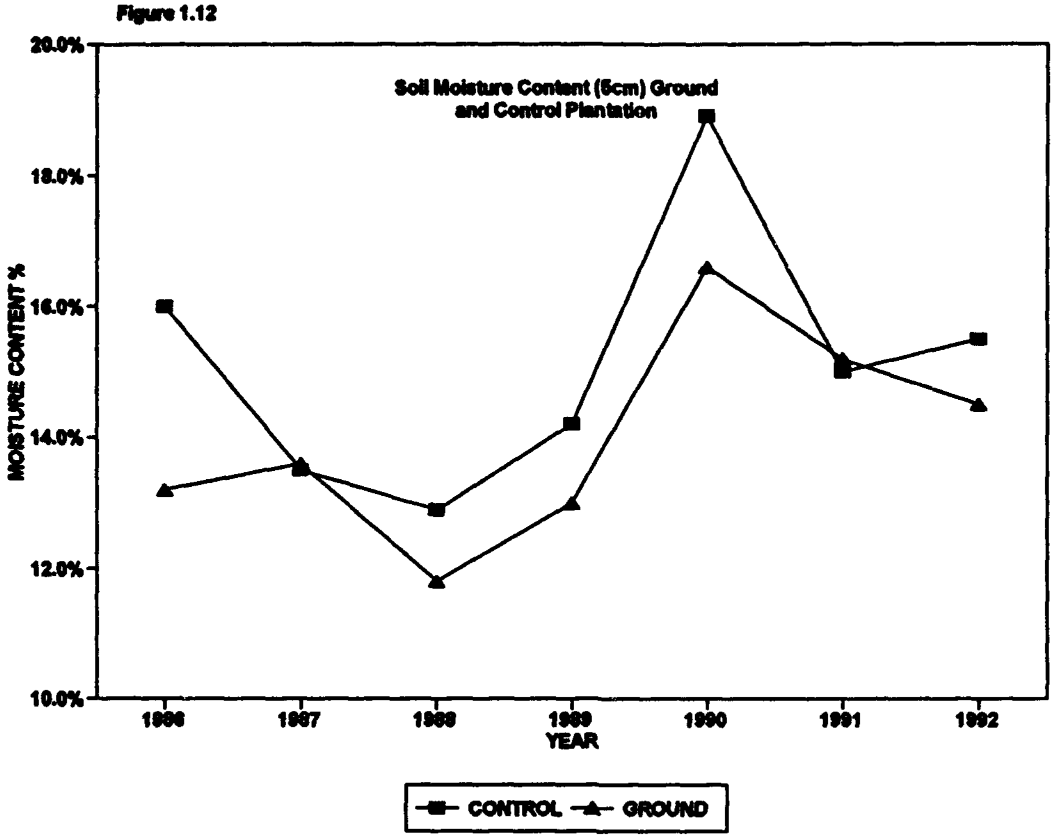
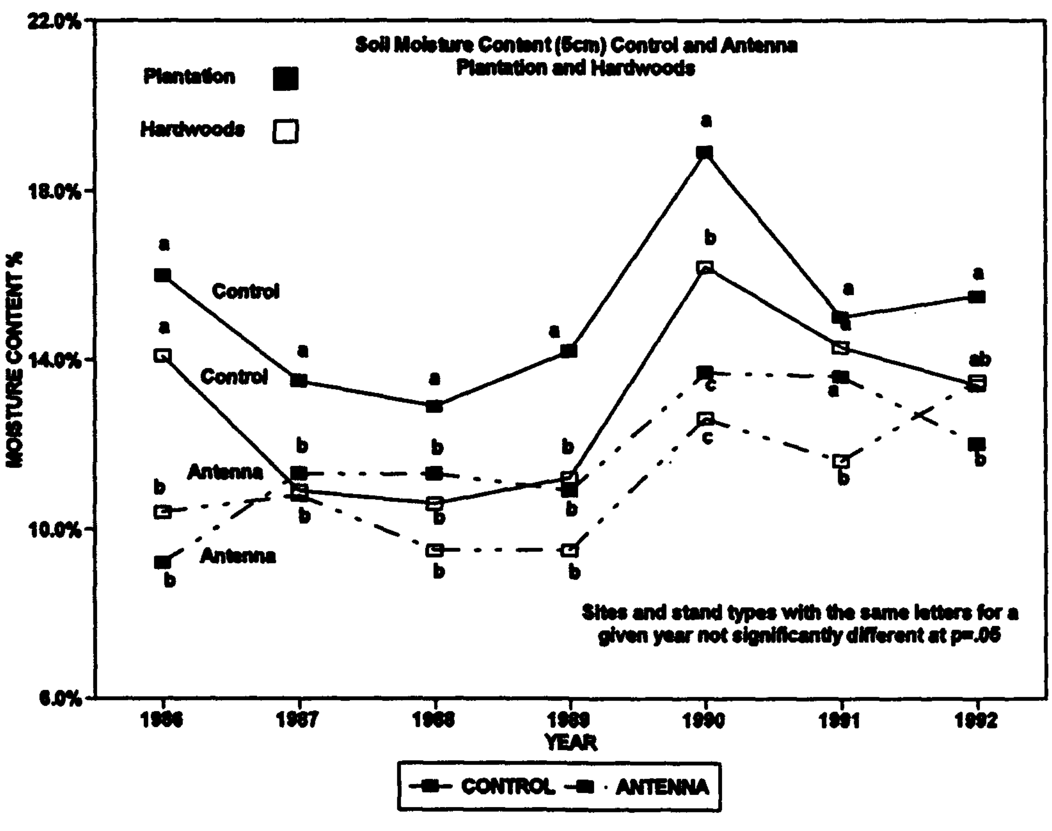


Figure 1.13



between soil moisture content and soil water potential among sites, site by year interactions were only significant for the control and antenna comparison (p=0.002). Neither the site by year interaction for the control vs. ground comparison (p=0.759) nor the site by stand type by year interaction for the control vs. antenna comparison (p=0.828) were significant. Differences in soil water potential at the sites were least during years of high moisture status because soils were at or near field capacity for much of the growing season. During more stressful years differences among sites were greater (Table 1.6).

Soil Moisture Status (depth 10 cm)

Site Comparisons: Comparisons of soil moisture content and soil water potential (10 cm) among sites were similar to comparison of soil moisture content and water potential at depths of 5 cm. Soil moisture content (10cm) at the control was not significantly higher than the ground site (p=0.113) but was significantly higher than the antenna site (p=0.009). However differences in soil water potential were not significant for either control vs. ground (p=0.842) nor the control vs. antenna (p=0.228) comparisons. Differences in soil moisture content (10 cm) between the control and antenna sites were greater than between the control and ground sites (Table 1.9).

Analyses in prior years has indicated significant site by stand type interactions for the control vs. antenna comparison. However this year's analysis showed no significant site by stand type interactions (p=0.074). Differences in the soil moisture at the two stand types at the control and antenna sites has been related to the greater water holding capacity of the antenna hardwood soils compared to the antenna plantation soils. If the current change in the ANOVA results reflect actually changes in moisture contents in the stand types, it is likely that the aggrading plantation may be altering the water holding capacity of the plantations.

Annual Comparisons: Moisture content and soil water potential at depths of 10cm were significantly higher ($p \leq .05$) during 1990 than in any other year of the study for the control vs. antenna and the control vs. ground comparisons (Table 1.9). Soil water potential (10cm) showed similar trends with 1990-1992 having higher values (less negative) than in previous years. Both soil moisture content and water potential (10cm) were generally at their lowest levels in 1988 and 1989. Like soil moisture content (5cm), annual fluctuations in soil moisture content (10cm) generally follow climatic trends in precipitation and air temperature.

Table 1.9 Comparison of soil moisture content (%) and soil water potential(-Mpa) at a depth of 10 cm during the 1986-92 growing seasons (April-Oct.).

Plantation

	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa
1986	15.2	.018	9.2	.018	14.6	.017	-0.6	-.001	5.4	-.001
1987	14.2	.016	9.8	.014	15.1	.014	0.9	-.002	5.3	.000
1988	12.9	.021	10.3	.018	14.4	.019	1.5	-.003	4.1	.001
1989	14.0	.016	10.7	.013	14.4	.020	1.4	.004	3.7	.007
1990	13.4	.018	12.1	.009	18.4	.009	5.0	-.009	6.3	.000
1991	13.8	.014	10.6	.014	14.9	.013	1.1	-.001	4.3	-.001
1992	14.1	.013	11.2	.013	14.2	.014	0.1	.001	3.0	.001
Ave.	13.9	.016	10.5	.014	15.1	.015	1.2	-.001	4.6	.001
Hardwoods										
1986			10.0	.023	12.6	.025			2.6	.002
1987			11.2	.022	12.7	.021			1.5	-.001
1988			10.5	.019	12.8	.021			2.3	.002
1989			9.8	.022	11.1	.031			1.3	.009
1990			12.5	.010	15.5	.012			3.0	.002
1991			11.4	.012	13.4	.018			2.0	.006
1992			11.4	.013	12.9	.017			1.5	.003
Ave.			11.0	.016	13.0	.020			2.0	.004

Site Comparison

	Control	Ground
Moisture Content	15.1 a[1]	13.9 a
Soil Water Pot.	.015 a[2]	.016 a
	Control	**Antenna**
Moisture Content	14.1 a	10.8 b
Soil Water Pot.	.017 a	.015 a

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-Mpa	%	-Mpa
1986	14.9 b	.017 b	11.6 c	.020 c
1987	14.7 b	.015 b	12.2 bc	.017 c
1988	13.6 b	.020 b	12.0 bc	.019 c
1989	14.2 b	.023 b	11.5 c	.018 c
1990	15.9 a	.012 a	14.6 a	.010 a
1991	14.4 b	.014 a	12.6 b	.014 b
1992	14.1 b	.014 a	12.5 b	.014 b

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

[2]ANOVA and multiple range tests of soil water potential performed on transformed (inverse natural log) data

Site by Year Comparisons: ANOVA tests of soil moisture content (10cm) showed significant site by year interactions for the control vs. ground comparison (p=0.001) and also the control vs. antenna comparison (p=0.015). The significant interaction for the control and test sites appears to be related to the moisture contents at the sites during 1990 (Figure 1.14, Figure 1.15). Differences in moisture content between the control and test sites during this year were greater than in all years prior or after 1990. Differences in soil moisture between the ground and control were extremely large in 1990 due to a reduction in soil moisture at this depth at the ground site (Table 1.9, Figure 1.14). As shown in Table 1.6, average moisture content at a depth of 5cm at all sites was higher in 1990 than in 1989. Thus the decreased soil moisture contents at a depth of 10cm in 1990 at the ground site appear to be an anomaly which is related to the inherent precision of the soil moisture sensors rather than an actual change in moisture content.

Site by stand type by year interactions were not significant for either soil moisture content (p=0.540) or soil water potential (p=0.806) at a depth of 10cm. These results indicate that the relationships of these parameters between the two stand types have remained stable over the duration of the study. The lack of any significant annual variation in this relationship supports the conclusion that any present or past differences in the moisture content of the two stand types at the control and antenna sites is related to the differences in the soil physical characteristics rather than biotic changes.

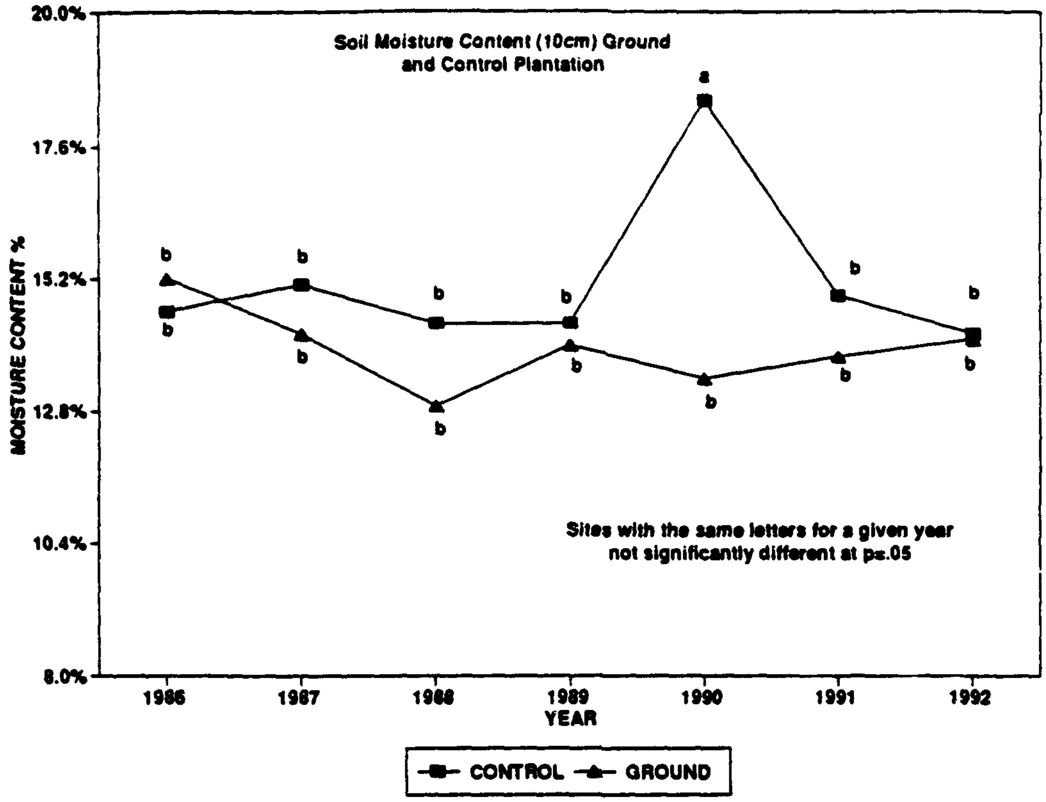
Summary: At this time there is no evidence to conclude that ELF fields or ELF antenna operation has altered the soil moisture content or soil water potential of the test sites. This conclusion is based on the following results and observations:

1) Although site by year interactions of soil moisture content at a depth of 10cm for both comparisons or at a depth of 5cm for the control vs. antenna comparisons were significant ($p \leq .05$), no trends were evident which were consistent with ELF antenna operation.

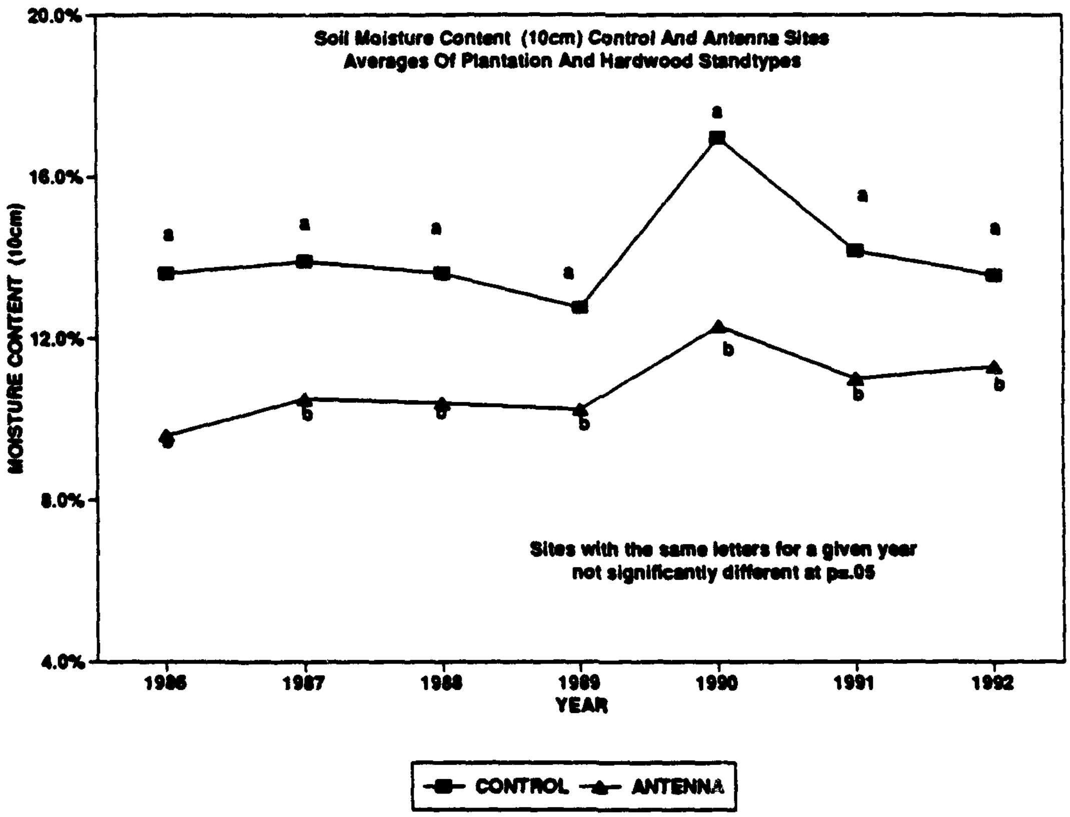
2) Increased differences in moisture content (5cm) between the control and antenna sites appears to be related to increases in soil moisture status rather than ELF antenna operation. Relationships of both soil moisture content (10cm) and soil water potential (10cm) among sites and/or stand types were stable over the duration of the study.

3) Changes in moisture status during the study period were primarily related to annual variation in

Figure 1.14



Figue 1.15



precipitation and air temperature rather than changes in vegetation structure or dynamics.

4) The lack of significant site by stand type by year interactions indicate that any differences in the relationships between stand types at the two sites have remained stable during the study and are related to soil physical characteristics rather than any biological processes.

Precipitation

The amount of precipitation and the distribution of precipitation over time are two primary factors controlling availability of water for plant growth. Thus precipitation is an important factor in the climatic monitoring program.

Site Comparisons: Differences in the total amount and distribution of precipitation has not dramatically differed among the three sites during the 1985-1992 study period (Figure 1.16). During this period the ground and antenna sites respectively received 3.39 cm and 3.54 cm more precipitation during the growing season than did the control site. The majority of this difference occurs during July and August (Figure 1.17). During these two months the ground and antenna site on the average have received 4.00 cm more precipitation than the control.

Although the test sites have received approximately 10% more precipitation than the control, differences in the weekly precipitation amounts were not significant for either the control vs. ground comparison (p=0.533) or the control vs. antenna comparison (p=0.542).

Annual Comparisons: Annual variation in the average weekly amount of precipitation is much greater than the variation in precipitation among sites (Table 1.10). Almost 1 cm/week more precipitation fell during 1991 and 1985 than in 1986. Precipitation levels during the growing season of 1992 were respectively 0.25, 0.20, and 0.06 cm less than the average precipitation levels from 1985-1992 at the ground, antenna, and control sites respectively. ANOVA tests showed no significant differences in the average annual weekly precipitation amounts for the control vs. antenna comparison (p=0.088) or the control vs. ground comparisons (p=0.140).

Site by Year Comparisons: Site by year interactions were neither significant for the control vs. ground comparison (p=.981) nor the control vs. antenna comparison (p=.988). Within the range of detection limits for these analyses (Table 1.15, 1.16), it does not appear that the annual variation in precipitation among sites has differed during the study period.

Figure 1.16 RUNNING TOTAL PRECIPITATION 1985-1992 GROWING SEASON

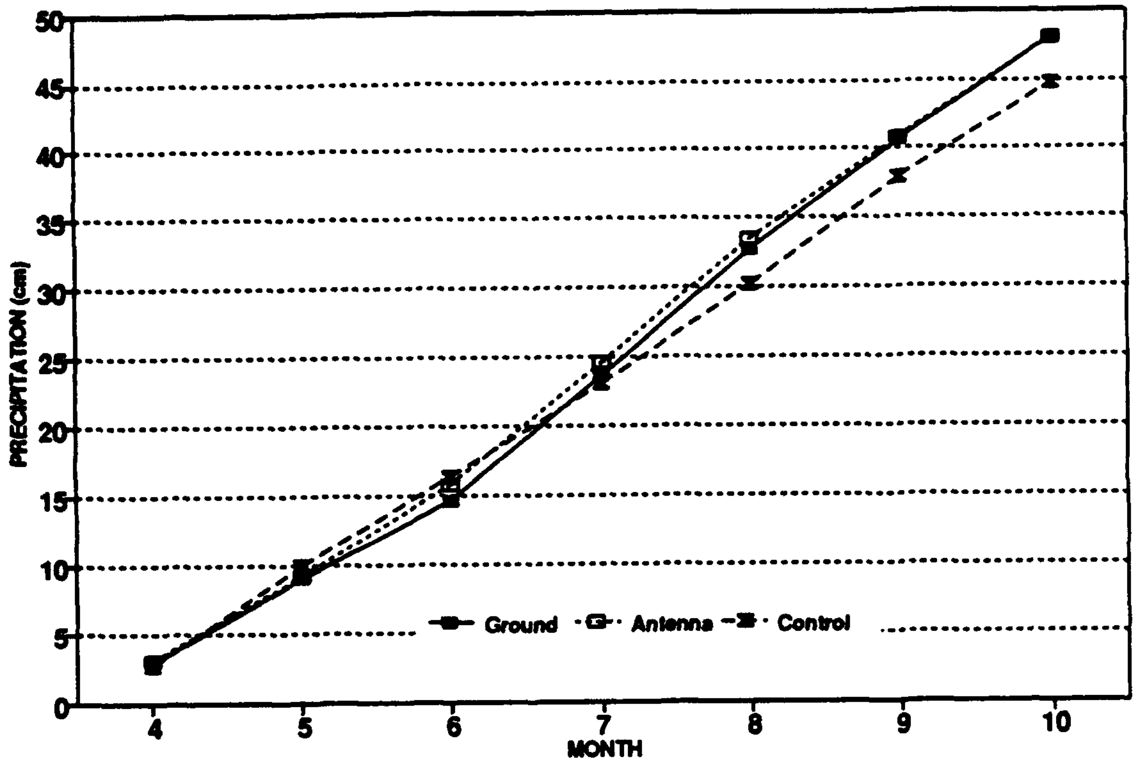


Figure 1.17 AVERAGE MONTHLY PRECIPITATION 1985-1992

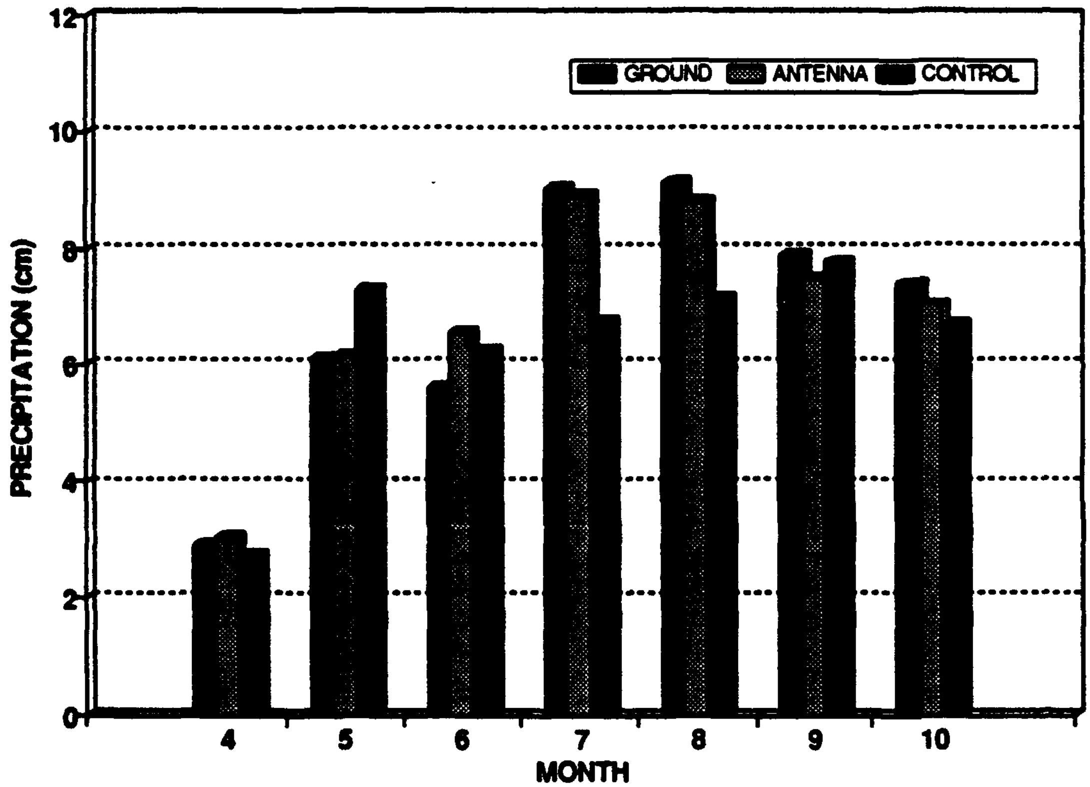


Table 1.10 Comparison average weekly precipitation amounts (cm) during the 1985-92 growing seasons (April-Oct.).

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	2.41	2.46	1.97	-0.44	-0.49
1986	1.25	1.18	1.26	0.01	0.08
1987	1.78	1.87	1.78	0.00	-0.09
1988	1.80	1.77	1.49	-0.31	-0.28
1989	1.48	1.40	0.98	-0.50	-0.42
1990	1.60	1.72	1.80	0.20	0.09
1991	2.10	2.09	2.07	-0.03	-0.02
1992	1.48	1.46	1.56	0.08	0.10
Ave.	1.73	1.74	1.61	-0.12	-0.15

Site Comparison

Control	Ground
1.61 a[1]	1.73 a
Control	**Antenna**
1.61 a	1.74 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	2.22 a	2.19 a
1986	1.25 a	1.22 a
1987	1.82 a	1.78 a
1988	1.63 a	1.65 a
1989	1.23 a	1.19 a
1990	1.70 a	1.76 a
1991	2.09 a	2.08 a
1992	1.52 a	1.51 a

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

Summary: ANOVA tests have not indicated any significant differences in weekly precipitation among sites or years during the entire study period as a whole or during any single year of the study. However, the sensitivity of these tests are limited due to their high detection limits. The location of the precipitation sensors above the canopy of the plantation would eliminate any possible ELF field effects on this climatic parameter.

Global Solar Radiation

Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus solar radiation is monitored at the study sites.

Comparisons of global solar radiation did not include July of 1987 or April of 1988. Data from July of 1987 was not available due to the lightning strike at the ground site and the sensor calibration was performed during April of 1988. Thus it was felt that a more suitable comparison of yearly information could be made if April and July were excluded from the analyses.

Annual Comparisons: Comparisons of global solar radiation are only performed for May, June, August, September, and October measurements due to sensor failure in July of 1987 and sensor calibration in April of 1988. Measurements of global solar radiation in August of 1988 were low because 16 days of measurements were missing due to a computer failure (Figure 1.17). Average global solar radiation during 1990 was 392.3 Langleys/day the highest recorded average value to date (Table 1.11). Differences in average daily global solar radiation among years were not significant ($p=0.473$). Figure 1.18 shows that variation of global radiation within years are much greater than the variation among years.

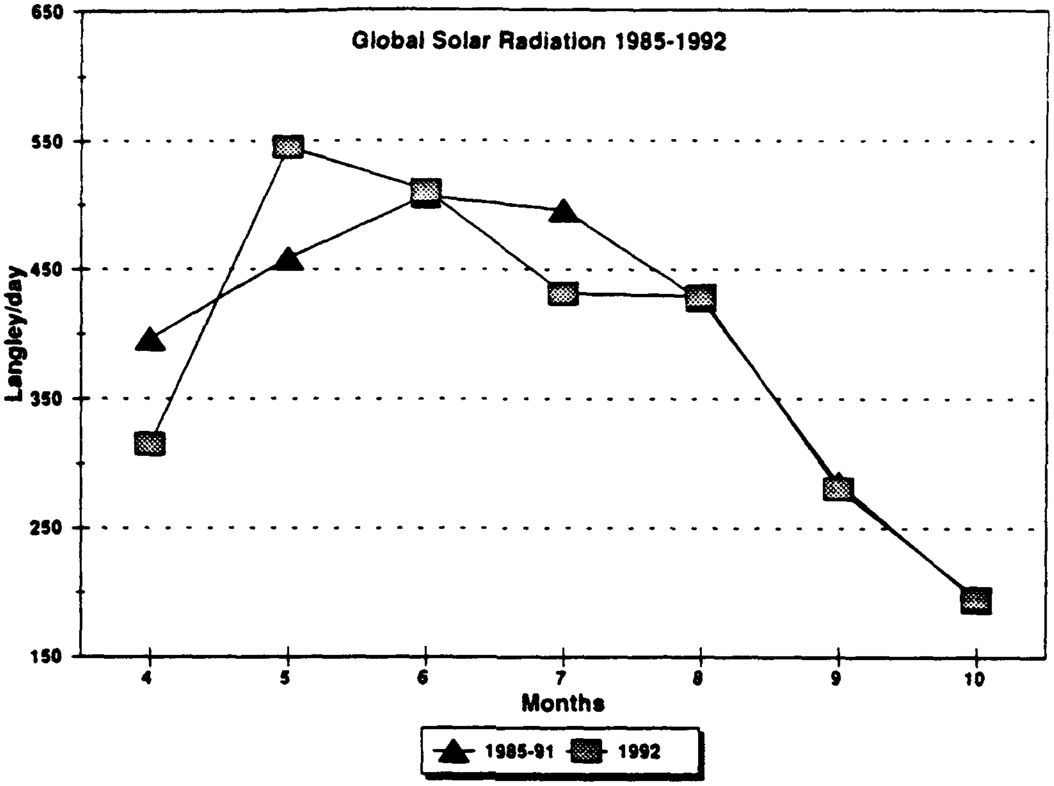
Table 1.11 Average global solar radiation during the 1985-1992 adjusted growing seasons.

Global Solar Radiation[1] (Langleys/Day)

1985	**1986**	**1987**	**1988**
385.1 a[2]	360.9 a	364.0 a	331.0 a
1989	**1990**	**1991**	**1992**
383.2 a	363.5 a	373.9 a	392.3 a

[1]Averages and analysis using May-June, August-October. July and April was excluded from the analysis due to missing information from July 1987 and April 1988.
[2]Years with the same letter not significantly different at $p=0.05$

Figure 1.18


Global Solar Radiation 1985-1992
650
550
450
350
250
150
Langley/day
4
5
6
7
8
9
10
Months
1985-91
1992

Summary: Average daily global solar radiation has not been found to significantly differ in any of the analysis to date. Detection levels (Table 1.15) for this variable are relatively high and do not afford an extremely sensitive statistical comparison of the annual variation of solar radiation at this site. Since the sensor is located above the canopy of the red pine plantation at all times, any statistically significant relationships between global radiation and ELF antenna operation would be coincidental. Given the current results of the ANOVA tests it does not appear that such a relationship exists and/or is detectable.

Relative Humidity

Atmospheric humidity is an influential factor determining rates of plant transpiration and respiration. Humidity is related to vapor pressure gradients which influence the amount of transpiration and evaporation from a given land area. In an attempt to fully monitor the climate at the study sites, relative humidity is measured by the ambient monitoring systems.

As a result of sensor repairs and system failures 1991 was the sixth year that relative humidity was monitored during the entire growing season. Calibration endpoints of the sensor at the ground site in 1990 drifted repeatedly making measurements collected at this site unusable. Thus annual comparisons and site comparisons are limited to 1987-1989 and 1991 for the control vs. ground analysis. Initiation of relative humidity monitoring begins each year after snow melt. Generally there are only 14 to 21 days in April when relative humidity is monitored. In order to eliminate bias from comparisons of years or sites, April measurements were not included in the analyses.

Site Comparisons: Average relative humidity during the study period was higher at the test sites than at the control site (Table 1.12). Differences were significant ($p \leq 0.001$) for the control vs. antenna (1987-1992) and the control vs. ground ($p = .002$) comparisons (1987-1989, 1991-1992). Average relative humidity was 10.6% greater at the antenna than control site during 1987-1992 while relative humidity at the ground was 6.7% higher than at the control site during 1987-1989, 1991-1992.

Annual Comparisons: Decreases in relative humidity from 1987 to 1989 appear to be related to decreases in precipitation. The increase in relative humidity in 1990 and in 1991 at the sites also appears to be related to the increase in precipitation above 1989 levels during this year. The ranking of average annual relative humidity during the growing season is as follows 1990=1991=1987>1992=1988>1989 for the control vs. antenna comparisons and

1987=1991>1992=1988>1989 for the control vs. ground (Table 1.12).

Site by Year Comparisons: Differences in relative humidity between the control and both test sites decreased in 1991 and 1992 from 1989 or 1990 levels (Figures 1.19a and 1.19b). Site by year interactions were significant for the control vs. ground ($p \leq .001$) and the control vs. antenna ($p = .005$) interactions. Multiple range tests showed significant differences between control and test site relative humidity for all years except 1991 and 1992. Decreases in the differences in relative humidity may be relat i to the increased height of the trees in the plantations in much the

Table 1.12 Comparison of relative humidity during May-Oct of 1987-1992 (May-Oct.).

Relative Humidity %

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1987	81.0	84.1	70.0	-11.0	-14.1
1988	78.7	80.0	62.5	-16.2	-17.5
1989	65.9	73.1	58.3	-7.6	-14.8
1990		87.3	70.3		-17.0
1992=					
1991	74.1	80.3	76.9	3.0	-3.4
1992	72.8	75.0	70.9	-1.9	-4.1
Mean					
(87-92)		79.7	68.1		-11.8
(87-89,91,92)	74.5		67.7	-6.8	

Relative Humidity %

Control	Ground
67.7 b	74.4 a
Control	**Antenna**
68.1 b	79.7 a

	1987	1988	1989	1990	1991	1992
Control vs. Ground	75.5 a	71.3 b	62.1 c		75.1 a	71.9 b
Control vs. Antenna	77.1 a	71.2 b	65.7 c	78.8 a	78.6 a	73.0 b

1/Years with the same letter not significantly different at $p=0.05$

Figure 1.19a

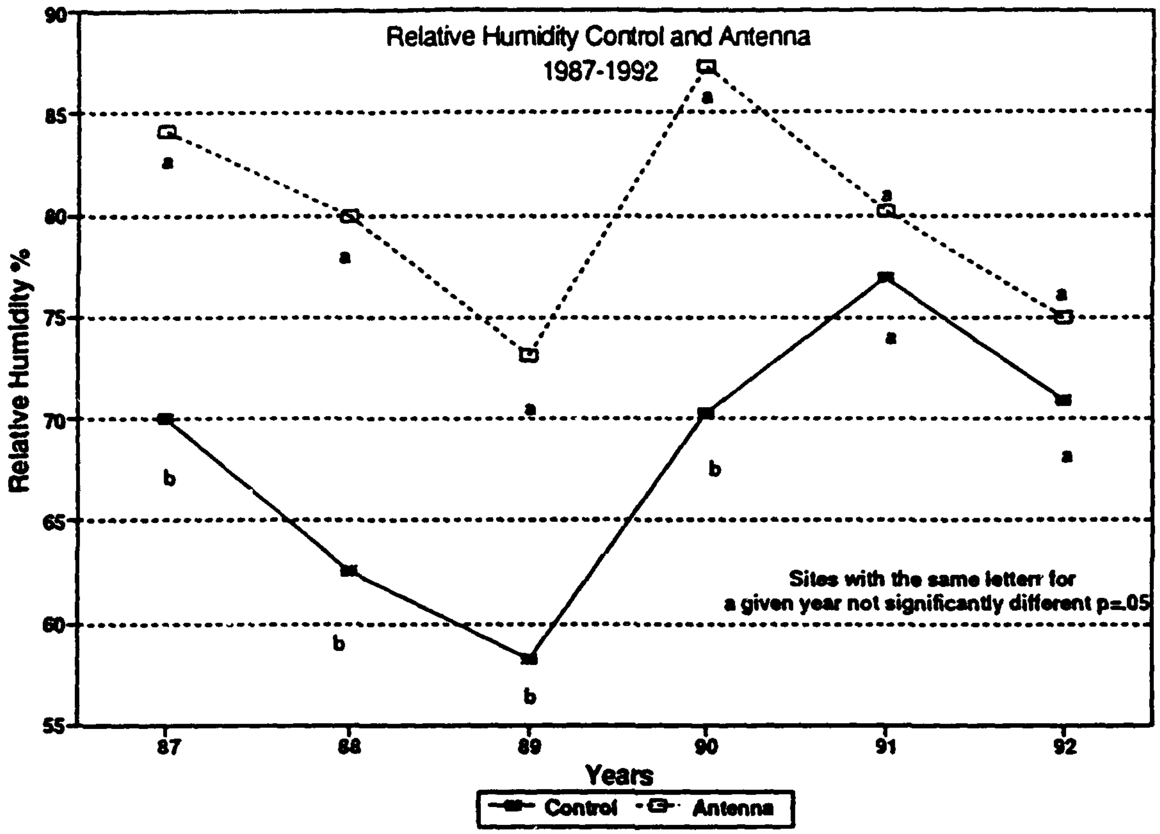
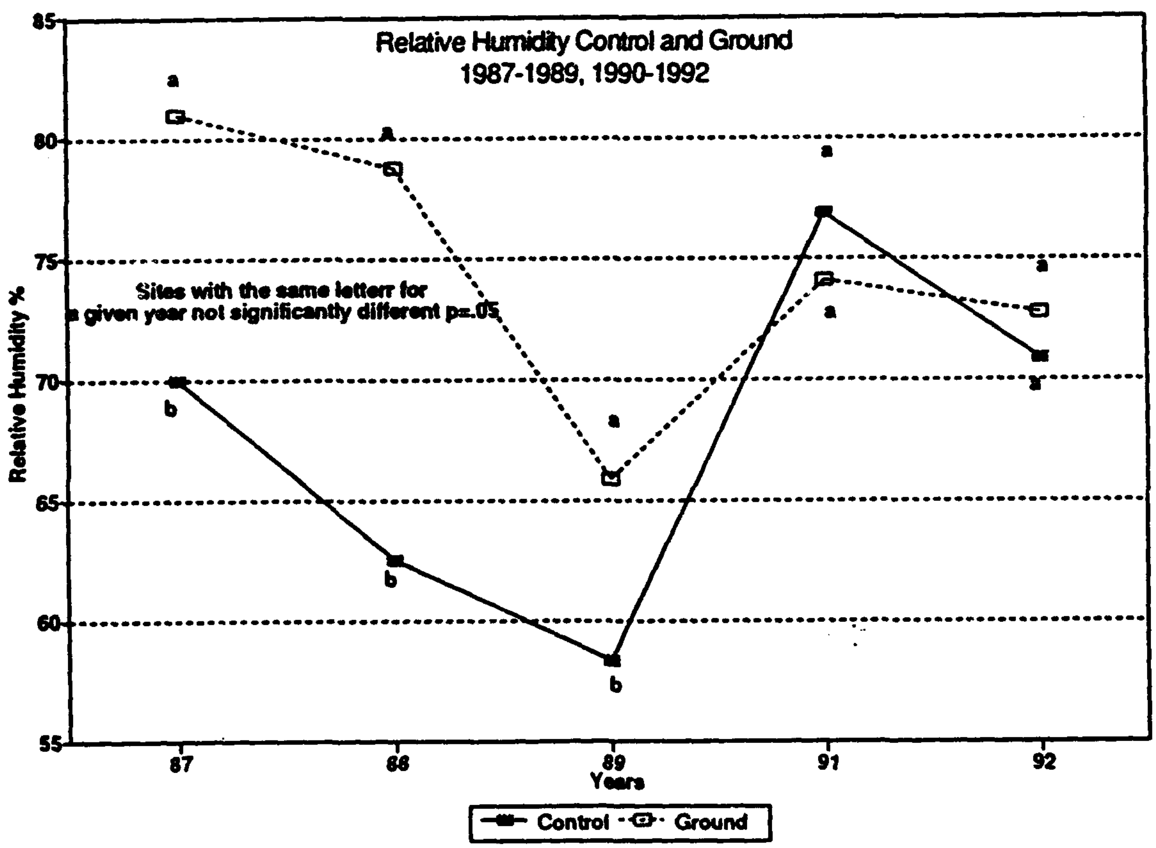


Figure 1.19b



same manner that air temperature has been altered. The changes in the relationship of relative humidity among sites was more and dramatic and occurred over a shorter period of time than was observed for air temperature. This was probably due to the limited number of relative humidity sensors at each site. Since only one sensor is located in each plantation and the red pine at the sites can grow as much as 0.7 meters a year, changes in climatic conditions which are effected by the canopy could be striking. Differences in relative humidity may also be related to inherent precision limits (4-5%) which these sensors can be calibrated. Monitoring of relative humidity in 1993 should verify whether the changes in relative humidity is related to these factors.

Summary: Site by year interactions were significant ($p \leq .05$) for the control vs. ground and control vs. antenna comparisons. Although trends in relative humidity at the test sites during 1987-1990 do not appear to be related to the ELF antenna operation, 1991 was the first year that differences between control and test site relative humidities were not significant. Future monitoring of relative humidity should be able to determine whether relative humidity has been altered at the test sites.

Photosynthetically Active Radiation (PAR)

Photosynthetically active radiation is measured underneath the canopy in the hardwood stands at the control an antenna sites. This climatic variable should be sensitive to possible ELF induced changes in the canopy of the hardwood stand. Reduction of foliage biomass or changes in the timing of leaf expansion would alter the amount of radiation reaching the forest floor over the duration of the growing season. This type of change would affect the growth of forest floor vegetation and the microclimate in the hardwood stands.

Sensor and system failures have limited the amount of months of data which can be used for this analysis. Currently measurements from May through July of 1986-1992 are used for ELF effect testing. Measurements during this time span should give a good indication of any changes in leaf area or timing of leaf expansion between the control and test sites.

Site and Annual Comparisons: Comparisons of sites and years are limited to the months of May through July of 1986-1992 due to the downtime of the platforms. PAR is dramatically reduced during the end of May and beginning of June when leaf expansion of the hardwood stands occur. Thus the time period used in the analysis gives both an indication of the changes in the timing of leaf expansion as well as the total amount of light interception by the canopy over the six year period. In 1990 litter weights were 25% below normal. Increased PAR during this period reflects the presumably lower amounts of leaf area during this year.

Average PAR was 1.30 Einstein's/day higher at the antenna site than at the control site during 1986-1992 (Table 1.13). However, differences is PAR between sites were not significant (p=0.529) for the current study period. Annual average PAR varied from a low of 4.42 to a high of 6.55 Einsteins/day but annual differences were not significant (p=0.521). Site by year interactions were significant (p=0.051) for the first time during the study. At the p=0.05 level average PAR for individual site by year combinations could not be separated by the multiple range test. At p=0.10 the test indicated that PAR was significantly higher at the antenna hardwoods than the control hardwoods only in 1989 and 1992. Both of these years occurred during full power antenna operation. However, differences were not significant during the other two years of full power operation (1990 and 1991) and were the least during the study. Since differences in PAR during full power operation were the lowest as well as the greatest observed from 1986-1992, there appears to be no direct influence of ELF on the amount of PAR at 30cm at the antenna site.

Summary: Since PAR above the canopy should be similar at the two sites, the higher levels of PAR at the antenna reflect the lower leaf area at the sensor location at this site. A number of factors such as timing of leaf expansion, tree mortality, and natural variation in leaf area can effect PAR at a given site. As the result of these interacting factors, temporal variability and thus detection limits for PAR are quite high. Thus it is not surprising that site and year

Table 1.13. Comparison of photosynthetically active radiation during 1986 -1992 (May-July).

Average Daily PAR (Einsteins/Day)

	1986	1987	1988	1989	1990	1991	1992	86-92
Control	4.77a[1]	5.06a	4.53a	3.27b	6.42a	5.24a	4.32b	4.79
Antenna	6.33a	5.83a	6.10a	5.56a	6.69a	5.44a	6.71a	6.09
Control-Antenna	-1.56	-0.77	-1.57	-2.29	-0.25	-0.22	-2.39	-1.30
Average	5.55	5.45	5.31	4.42	6.55	5.34	5.51	

[1] Sites for a given year with the same letter not significantly different at p=0.10

differences were not significant for a large part of the study. However, differences in PAR between sites for 1989 and 1992 were significant (p=0.10). Since differences in PAR between the sites were at their highest as well as lowest levels during the four years of full power operation, these results do not indicate any trends which are related to the ELF antenna operation.

Initially these sensors were located in the stand to monitor available PAR to the ground vegetation. Amount of PAR was considered as a covariate for analyses in Element 3 (Phenophase Description and Documentation). Since measurements for this Element was discontinued after 1992, measurements of PAR were discontinued in November of 1992.

Air Temperature (30 cm above ground)

Air temperature is being monitored 30 cm above the ground to give a more accurate measurements of climatic conditions at the understory air interface. These sensors were not operational in 1987 and thus analyses and summaries were only performed on the 1985-1986 and 1988-1992 measurements. Due to the height of this sensor, it is not operational in April until the snow pack has melted from each site. Consequently initial temperature measurements from these sensors begin at different times each year. Analyses and summaries only include the months from May to October in order to ensure the same time period for each year of analysis.

Site Comparisons: Average air temperature (30 cm) was 1.0 ^{o}C warmer at the control than at the antenna hardwood stand for the six years of measurements (Table 1.14). Differences in temperature (1.0^{o}C) between sites at 30 cm above the ground were similar in magnitude to site differences in average air temperature at 2 m above the ground and were significant (p=0.001).

Annual Comparisons: Annual trends in air temperature (30) cm were similar to those found for air temperature 2 meters aboveground in the hardwoods at the two sites. The highest temperatures observed (Table 1.14) at 30cm aboveground were in 1988 and the lowest in 1985 and 1990. Average annual temperatures were significantly different among years (p=0.028) but site by year interactions were not significant (p=0.923) for this years analysis. Mean annual temperatures were significantly (p=0.05)lower in 1992 than in 1988. No differences were significant for all other year combinations (Table 1.14).

Summary: The detection limits for this variable, like many other climatic variables which are only measured with one sensor at each site, are high (Table 1.16). Given the similarity in temperatures at aboveground heights of 2m and 30cm in the hardwood stands, it would appear that comparisons of air temperature at 2m would give a better indication of the effects of ELF antenna operation than would the 30cm temperature sensors. Regardless of the air temperature

Table 1.14 Comparison of air temperature 30 cm above the ground at the control and antenna hardwood stands during 1985, 1986, 1988, 1989, 1990, 1991, 1992 (May-October)

Average Daily Air Temperature 30 cm (^{o}C)

	1985	**1986**	**1988**	**1989**	**1990**	**1991**	**1992**	**$\bar{x}$**
Control	13.3	13.6	14.8	13.9	13.2	14.1	12.9	13.8 a[1]
Antenna	12.6	12.8	13.6	12.9	11.9	13.3	11.5	12.8 b
Control-Antenna	0.8	0.8	1.2	1.0	1.3	0.8	1.4	1.0
$\bar{x}$	12.9ab	13.2ab	14.2a	13.4ab	12.6ab	13.7ab	12.2b	13.3

[1] Sites and years with the same letter not significantly different at $p=0.05$

variable considered, there is no indication that ELF antenna operation has modified the air temperatures of this stand type. Like PAR this sensor was installed primarily to give ambient measurements at the level of the height of the ground vegetation. This information was used as a possible covariate for Element 3 (Phenophase Description and Documentation). Since measurements for Element 3 have been concluded, the measurements of PAR were discontinued in November of 1992.

Detection Limits

Detection limits (DTL) calculated for the temperature variables (air, soil (5cm), and soil (10cm)) are generally lower than the DTL calculated for any of the other variables (Table 1.15, 1.16) due to greater precision of these sensors, lower spatial variability of these climatic variables, and the number of sensors operated at each site. The air temperature and soil temperature DTL are near the precision limits of the equipment and it is not expected that any improvement (decrease) of the DTL for these variables will be made in future analyses. Since the DTL are low for the temperature variables, it is also expected that these measurements will give the best indication of the effects of ELF radiation on the microclimate of the test sites. The higher DTL associated

Table 1.15 Detection limits (DTL) and detection limits as a percent of overall mean (DTL%) for control vs. ground site comparisons (1985-1992).

Variable	Site		Year		Site by Year	
	DTL[1]	DTL%	DTL	DTL%	DTL	DTL%
Air Temperature 2m (°C)	0.4	3.1	0.3	2.5	0.4	3.5
Soil Temp. 5cm (°C)	0.5	3.8	0.3	2.6	0.5	3.7
Soil Temp. 10cm (°C)	0.7	5.3	0.3	2.7	0.5	3.8
Soil Moist. 5cm (°C)	1.4	9.7	1.0	7.4	1.5	10.4
Soil Wat. Pot. 5cm (°C)	0.71	41.3	0.30	19.7	0.53	28.0
Soil Moist. 10cm (°C)	1.5	10.8	0.9	6.4	1.2	9.0
Soil Wat. Pot. 10cm (°C)	0.84	50.2	0.31	18.7	0.41	26.3
Sol. Rad. (L d^{-1})			59.8	56.0		
Rel. Humidity (%)	2.9	4.0	3.2	4.5	4.5	6.3
Weekly Prec. (cm)	0.46	27.7	0.77	46.0	0.54	32.6

1 DTL calculated at p=0.05

Table 1.16 Detection limits (DTL) and detection limits as a percent of overall mean (DTL%) for control vs. antenna site comparisons (1985-1992).

Variable	Site		Year		Site by Year		Site by Stand Type		Site by Stand Type by Year	
	DTL[1]	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%
Air Temp. (°C)	0.2	1.5	0.2	1.5	0.3	2.1	0.4	4.0	0.3	2.4
Soil Temp. 5cm (°C)	0.5	4.2	0.2	1.8	0.3	2.6	0.4	3.4	0.7	5.9
Soil Temp. 10cm (°C)	0.2	2.1	0.2	1.9	0.3	2.6	0.6	5.4	0.5	4.3
Soil Moist. 5cm (%)	1.2	9.9	0.7	6.1	1.1	8.6	1.5	12.2	1.3	10.6
Soil Wat. Pot. 5cm (-Mpa)	0.20	14.8	0.20	12.0	0.26	16.9	0.49	31.4	0.40	24.3
Soil Moist. 10cm (%)	1.8	15.5	0.6	5.1	0.8	7.2	2.1	17.9	1.4	12.1
Soil Wat. Pot. 10cm (-Mpa)	0.30	17.1	0.15	8.8	0.20	12.5	0.40	23.4	0.40	22.7
PAR 30cm (E/day)	3.80	71.1	2.4	37.6	2.8	53.3				
Relative. Humidity.	2.9	4.0	3.6	4.9	5.1	6.9				
Weekly Prec. (cm)	0.47	32.3	0.75	52.2	1.06	73.8				
Air Temp.30cm °C	0.50	3.8	1.1	8.7	1.6	12.3				

[1] DTL calculated at p=0.05

with moisture content and soil water potential measurements are in part a result of the lower precision of the soil moisture sensors as well as the high spatial variation of soil moisture within the sites.

Soil moisture content DTL were lower than soil water potential DTL for all depths (Table 1.15,1.16). DTL for site and year factors were below 11% of the mean for soil moisture content but not soil water potential in both comparisons. DTL for site by stand type, and site by stand type by year interactions were also less than 18% for soil moisture content but not soil water potential.

DTL expressed as a percent of the overall study means for solar radiation and precipitation were often in excess of 30%. These high values are a result of only utilizing one sensor at a site. For these climatic measurements spatial variation is limited and one sensor is adequate for the accurate measurements of these variables. However, the lack of additional sensors reduce the sensitivity of the statistical tests employed in hypothesis testing.

DTL were also generally lower for the control vs. antenna comparisons than the control vs. ground comparisons (Table 1.15,1.16). The increased sensitivity of the control vs. antenna comparisons is a result of having two stand types (six plots) included in the analyses rather than just one stand type (three plots). The increased number of plots and thus observations for a given variable reduces the standard errors used in the calculation of the DTL associated with site, year, and site by year factors.

Summary

A large number of climatic factors were found to vary significantly among sites and/or years (Table 1.17-1.18). Air temperature (2m), air temperature (30cm), soil moisture content at 5 cm and 10 cm depths, soil water potential at 5 cm, and relative humidity are climatic variables which have been found to differ among the control and tests sites. Air and soil temperature, soil moisture , soil water potential, precipitation, and relative humidity change annually at the sites. Any of these climatic variables which differ among sites and/or years are good candidates for modeling efforts or covariate analysis in the other elements of the project. However, before these climate variables are included in any final analyses, it must be demonstrated that they are not correlated to or affected by the ELF antenna operation.

We expect that any change in a climatic variable as a result of ELF antenna operation would be caused by a change in the ecology at the test sites. To detect and quantify any changes in the climate at the test sites, comparisons of the climatic relationships between the control and test sites are made over the duration of the project. Changes in the relationships of the climate between the control and test sites would indicate possible ELF field effects on these factors at the test sites.

Table 1.17 Significant differences for control vs. ground site comparisons (1985-1992)

	FACTOR		
Variable	Site	Year	Site by Year
Air Temp. (2m)	*	*	*
Soil Temp. (5 cm)	-	*	*
Soil Temp. (10 cm)	-	*	-
Soil Moist. (5 cm)	-	*	-
Soil Wat. Pot. (5 cm)	-	*	-
Soil Moist. (10 cm)	-	*	*
Soil Wat. Pot. (10 cm)	-	*	-
Relative. Humidity.	*	*	*
Precipitation.	-	-	-

[1] Factors denoted by * $p \leq .05$.

Factors denoted by - $p > .05$

These changes are expressed in our statistical design through significant site by year or site by stand type by year interactions. As of 1992 air temperature (2m), soil temperature (5cm), soil moisture content (5cm), soil water potential (5cm), soil moisture content (10cm), and relative humidity were shown to have significant site by year interactions for the control vs. ground comparisons and/or the control vs. antenna comparison. During 1985-1992 site by stand type by year interactions for both soil temperature 10cm and soil moisture content 5cm were significant (Table 1.18).

The significant site by year air temperature (2 m) interations have been shown to be related to differences in the red pine productivity at the control and test sites. The changes in air temperature among sites during the study are related to the greater productivity (height growth) at the control site compared to the test sites. Red pine at the control site reached the level of the air temperature sensors much earlier during the study than the trees at the tests sites. This resulted in a greater difference in air temperatures at the control compared to the test sites during 1987-1989 than years prior to 1987 or after 1989. Results from Element 2 suggest that a stimulation rather than an inhibition of red pine height growth occurs with EMF exposure. Since height growth is greater at the control than the test sites, the significant interactions indicated by the analysis do not reflect an alteration of air temperture as a result of the effects of ELF electromagnetic fields on height growth. Given the results from Element 2, any effects from ELF electromagnetic fields on air temperature should have reduced rather than increased the differences in air tempertures among the control and test sites.

Table 1.18 Significant differences for the control vs. antenna comparisons (1985-1992)

	FACTORS				
Variable	Site	Year	Site by Year	Site by Stand Type	Site by Stand Type by Year
Air Temp. (2m)	*	*	-	-	-
Soil Temp.(5 cm)	-	*	-	*	-
Soil Temp.(10 cm)	-	*	-	-	*
Soil Moist.(5 cm)	*	*	*	-	*
Soil Wat. Pot.(5 cm)	*	*	*	-	-
Soil Moist.(10 cm)	*	*	*	-	-
Soil Wat. Pot.(10 cm)	-	*	-	-	-
PAR	-	-	*		
Air Temp.(30 cm)	*	*	-		
Rel. Hum.	*	*	*		
Precipitation	-	-	-		

[1] Factors denoted by * p<=0.05

Factors denoted by - p>0.05

To some degree the significant site by stand type by year interactions for soil temperature is also correlated with the red pine productivity and its effects on insolation at the control and antenna plantations. However, soil temperature at 10cm in the control hardwoods site appears to have increased relative to the soil temperature observed in the antenna hardwoods and control air temperature during 1991-1992. Furthermore soil temperature has decreased relative to air temperature within the antenna hardwoods. Although changes in soil temperature at the control may be related to mortality of trees in 1991-1992, decreases in soil temperature at the antenna hardwoods currently can not be explained by the climatic or productivity variables measured during the study. Although there is no indication that soil temperature at the antenna has been altered by the ELF EMF, it would be inappropriate to conclude there hasn't been an ELF effect on soil temperature until it is determined whether the observed trend in soil temperatures at the antenna hardwood stand continues during the final year of the study. As of the 1992 the significant interactions for soil moisture (5cm & 10cm), soil water potential (5cm), soil temperature (5cm), and relative humidity have not appeared to be related to ELF antenna operation or changes in vegetation productivity among the sites.

Another approach used to quantify the relationships between ELF antenna operation and ambient measurements was to determine the correlation coefficients between 76 Hz field strengths and climatic variables. Significant correlations between these two factors could suggest that either ELF antenna operation has affected a given ambient variable or that a coincidental relationship exists between a specific climatic factor and antenna operation. Table 1.19 presents the results from this approach for the plantations and hardwoods separately. Ambient measurements used for the correlations were plot or site averages or totals for each year during 1985-1992. The mean maximum magnetic field strengths (76Hz) for each plot and year are presented in Table 1, Appendix A.

Global solar radiation, relative humidity, PAR, and vegetation temperature were not significantly correlated with magnetic fields (Table 1.19). Air and soil temperatures as well as soil moisture content (10cm) were significantly ($p \leq 0.05$) correlated with maximum mean magnetic ELF fields estimated for the plots in both the plantation and hardwoods during the study. However, these correlations may be misleading. For example air temperature appears to be strongly correlated with magnetic fields in the hardwoods (Table 1.19), but when air temperature is plotted with magnetic field strengths from both the control and antenna sites (Figure 1.20), it is apparent that the correlations to a large degree are related to the differences in air temperatures at the two sites rather than any trend in field strengths during the study. Air temperature was lowest in 1985 prior to antenna operation and again in 1990 and 1992 when field strengths were at their maximum (Figures 1.20).

The poor relationship among field strengths and climatic variables is more clearly evident when correlation coefficients were determined for each site separately (Table 1.20). Air temperature and soil moisture content (10cm) variables which appeared to be strongly correlated with field strengths in the

Table 1.19. Correlation coefficients and significance levels associated with annual ambient variables and plot averages of maximum magnetic (M) 76Hz field strengths (1985-1992).

	Plantation	Hardwoods
Air Temp. 2m	-.417 **	-.482**
Soil Temp. 5cm	-.430 **	-.477 **
Soil Moist. 5cm	-.097	-.172
Soil Temp. 10cm	-.384 **	-.557**
Soil Moist. 10cm	-.329 **	-.326**
Average Weekly Precipitation	-.041	
Global Solar Radiation	.211	
Relative Humidity	.299	
.Solar Radiation	.195	
Par		.326
Air Temperature 30cm		-.569

1 ‡ $.05<p\leq.10$
* $.05\geq p>.01$
** $.01\geq p$

hardwood stands (Table 1.19) were not significantly correlated ($p\leq0.05$) with magnetic flux densities when the control and antenna sites are considered individually. Only soil temperature 10cm in the antenna hardwoods and air temperature and soil temperature 5cm in the control hardwoods were significantly correlated with magnetic fields.

In the plantations a number of variables were strongly correlated with the magnetic fields (Table 1.20). Again with the exception of the control site air temperature was only weakly correlated to magnetic fluxes in the test site plantations (Table 1.20). Soil temperature 5cm and 10cm were significantly ($p\leq0.05$) correlated with field strengths at all three sites. Soil temperatures 5cm and 10cm showed decreasing trends with increasing field strengths (ex. Figure 1.21). Soil moisture content 5 & 10cm in the antenna plantation was positively and significantly correlated with field strengths (Table 1.20). Soil

Figure 1.20

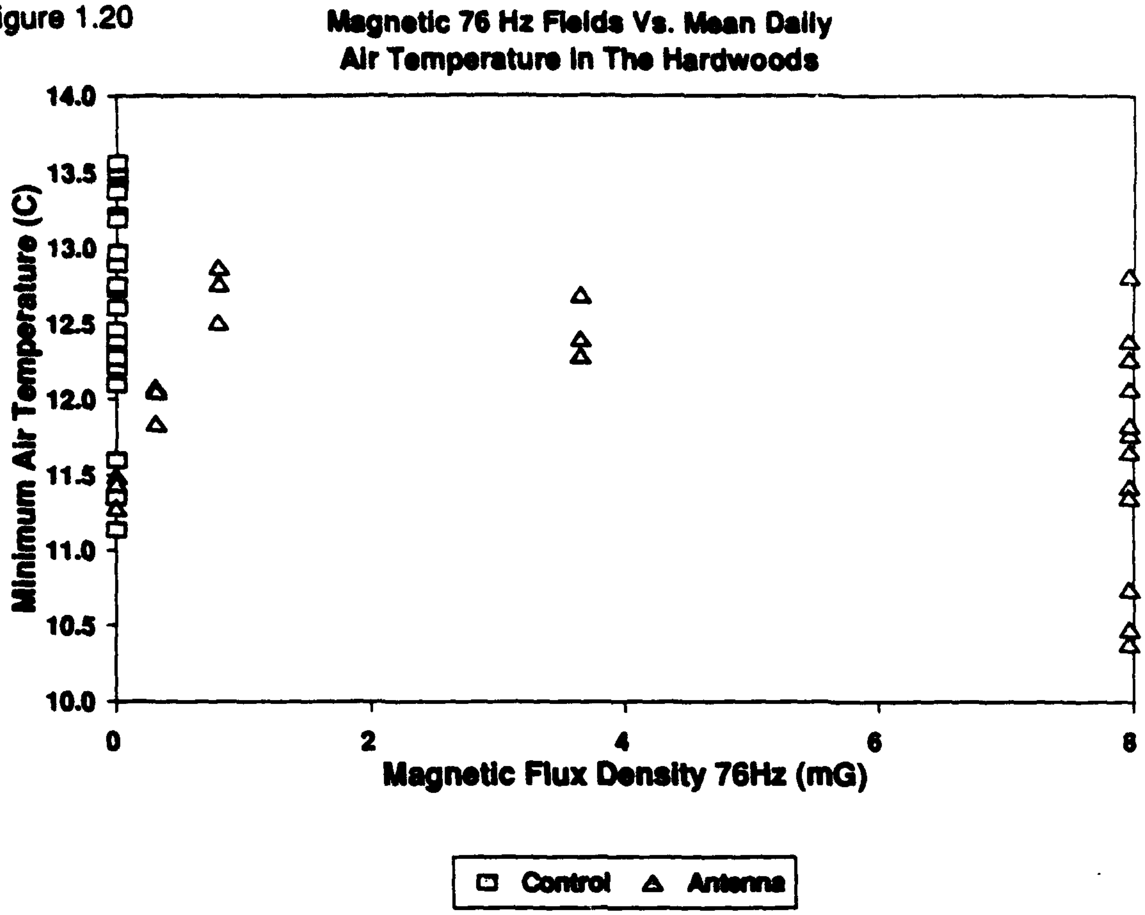

Magnetic 76 Hz Fields Vs. Mean Daily
Air Temperature In The Hardwoods
Minimum Air Temperature (C)
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
0
2
4
6
8
Magnetic Flux Density 76Hz (mG)
Control
Antenna

Table 1.20. Correlation coefficients and significance levels associated with annual ambient variables and plot averages of maximum magnetic (M) 76Hz field strengths (1985-1992).

	Ground	Antenna	Control
	M	M	M
PLANTATION			
Air Temp. 2m	-.370‡[1]	-.245	-.638**
Soil Temp. 5cm	-.677**	-.585**	-.803**
Soil Moist. 5cm	.397‡	.673**	.095
Soil Temp. 10cm	-.621**	-.633**	-.764**
Soil Moist. 10cm	-.308	.795**	-.217
HARDWOODS			
Air Temp. 2m		-.299	-.506*
Soil Temp. 5cm		-.368‡	-.444*
Soil Moist. 5cm		.392‡	.422‡
Soil Temp. 10cm		-.483*	-.258
Soil Moist. 10cm		.280	.116

[1] ‡ $.05<p\leq.10$
* $.01<p\leq.05$
** $.01\geq p$

moistures generally increased from 1986-1992 with the increased field strengths (Figure 1.22).

Since soil temperatures were significantly correlated with magnetic fluxes at the test and control plantations it is doubtful that a mechanistic relationship exists between the fields and soil temperatures. Most likely the decrease in soil temperature with magnetic fluxes reflects the influence of the aggrading plantation on the soil temperature during the study at all three sites. However, decreasing soil temperatures with increasing magnetic field levels were also evident within the hardwoods (ex. Figure 1.22) but correlations were much weaker and more inconsistent between sites. The decreasing soil temperatures in the antenna hardwoods associated with the increasing magnetic fields coupled with the unexplained changes in soil temperatures within this site as indicated by the ANOVA could suggest a ELF effect. Comparisons in the differences between the mean annual soil temperatures in the control hardwoods and soil temperatures at each plot in the antenna hardwoods were significantly correlated (p=.471, p=0.010) to mean maximum plot magnetic fluxes estimated for the antenna hardwoods. Differences of soil temperature 10cm at the hardwoods generally increased with increasing magnetic field exposure after 1986 (Figure 1.23). Results from these comparisons indicated that temperature in the hardwoods at the antenna decreased and decreased to a greater degree than in the hardwoods at the control with the increased field exposures. It is not known to

Figure 1.21

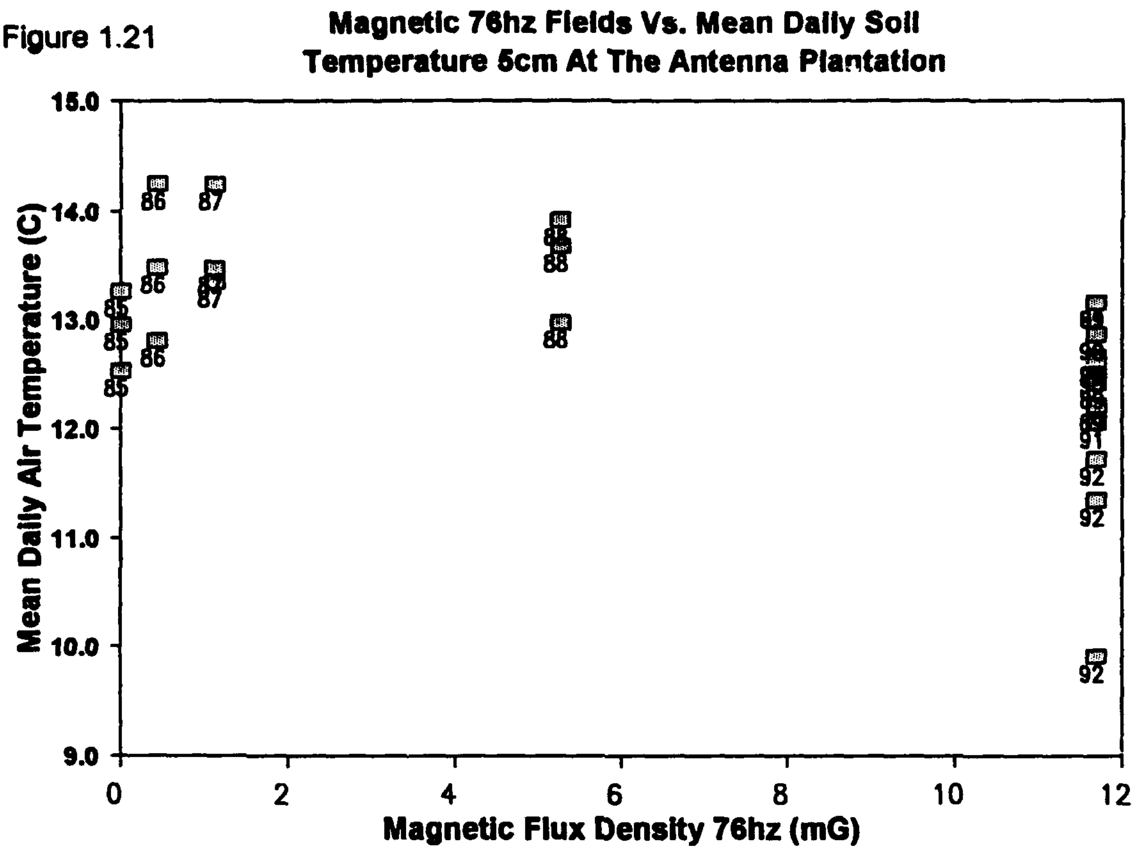


Figure 1.22

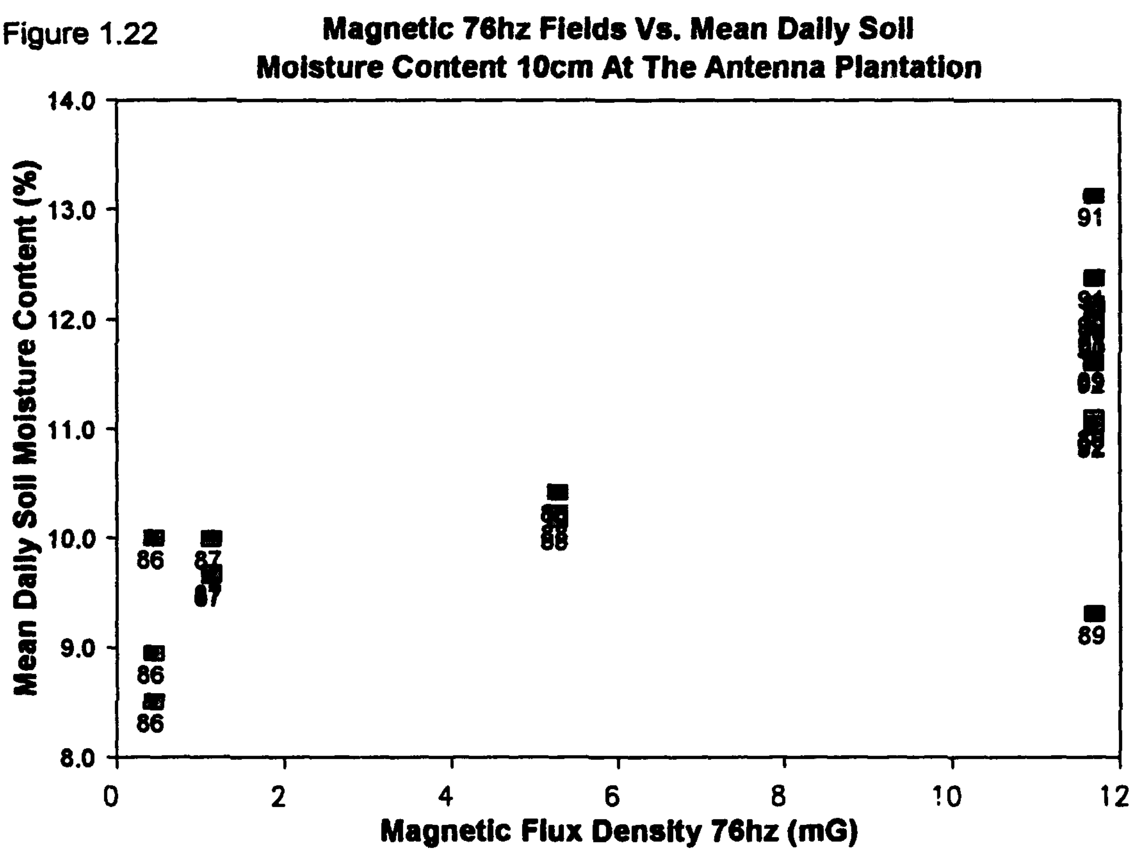
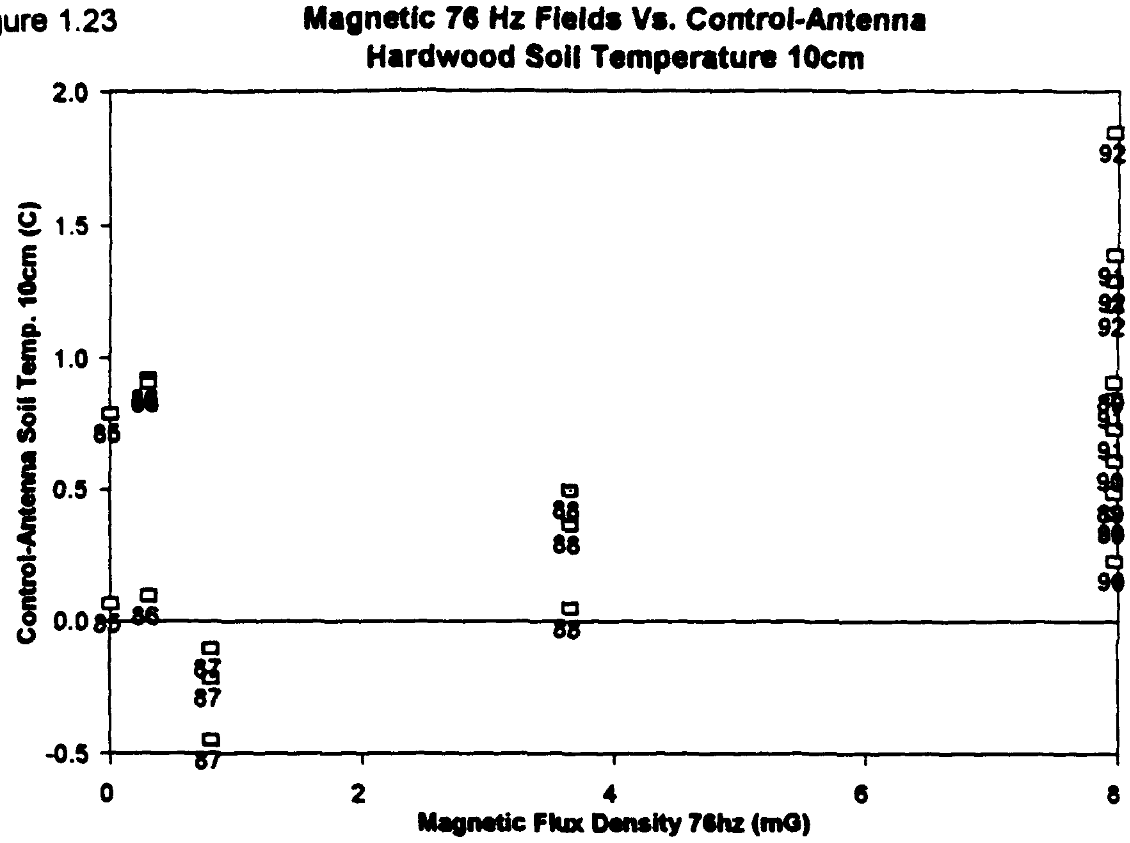


Figure 1.23



Magnetic 76 Hz Fields Vs. Control-Antenna
Hardwood Soil Temperature 10cm
Control-Antenna Soil Temp. 10cm (C)
Magnetic Flux Density 76hz (mG)
2.0
1.5
1.0
0.5
0.0
-0.5
0
2
4
6
8

what degree the paper birch or the storm related mortality of the trees in the control hardwoods during 1991-1992 has increased the soil temperature at this site and thus strengthen the correlations between the differences in temperatures and magnetic fields. However, the strong correlations of the magnetic fields with soil temperature in the antenna hardwoods and the differences between temperatures at the control and antenna hardwoods coupled with significant site by stand type by year interactions for soil temperature 10cm is the strongest indication of an ELF effect on microclimate to date.

Soil moisture content 5cm and 10cm were both strongly correlated with field strengths in the antenna plantation but only weakly correlated if at all in the other two plantations (Table 1.20). If the increased biomass and leaf area of the red pine were responsible for the significant correlations between the EM fields and soil moisture content, we would expect that correlation coefficients would be significant for all sites and that soil moisture content during the study would decrease with the increased leaf area and corresponding evapotranspiration. However, soil moisture content increased at the antenna plantation and depending on the depth of measurement increased or decreased at the control and test plantations from 1986-1992. Furthermore, soil moisture contents were not significantly correlated with magnetic field at the control and ground plantations. Site by year and site by stand type ;by year interactions were found to be significant ($p \leq 0.05$) for soil moisture content at a depth of 5cm but not at 10cm. The results of the ANOVA tests along with the correlation coefficients (Table 1.20) are consistent with a potential alteration of soil moisture content by ELF antenna operation in the plantation. However, it does not seem likely that soil moisture content would be altered at only the antenna plantation and not the ground plantation or antenna hardwoods. Of the three sites, the antenna site does have the lowest water holding capacity. It is possible that the aggrading plantation has altered the moisture holding capacity of the soil and thus has increased the moisture content during the study. Although changes in moisture holding capacity would be more evident at this site compared to the other sites, due to the greater initial water holding capacities at the control and ground sites, differences in soil moisture content between the plantations at antenna and other two sites have not increased appreciably during the study period.

To date soil temperature within the hardwood stands show the indication of being altered by the ELF antenna operation. However, to a certain extent the perceived changes in temperature between the control and antenna hardwoods may be related to increased insolation as a result of tree mortality at the control site. Other climate variables may have coincidental relationships with the increased field strengths but do not appear to have been altered by ELF EMF at the test sites. The final year of climate measurements will help to quantify these potential coincidental relationships and evaluate the possibilities of any mechanistic relationships.

Soil Macronutrient Monitoring

Background

Soils are sampled using a push probe inserted to a depth of 15 cm in the mineral soil. Five composite samples made up of 4 randomly selected probes are collected from each plot. These samples are dried at 60°C, sieved and mixed, and analyzed for Kjeldahl N, total P, and exchangeable Ca, Mg, and K. Unused portions of samples are stored.

Soil nutrient samples were collected monthly during the growing season from 1985 through 1990. Project reports and reviews beginning in 1987 noted the wide variability among soil nutrient values. In 1990, after careful review, the 1985 data were judged inaccurate. Our 1991 report documented that variability on the sites, as with many other temperate forest ecosystems, was also high (Mroz, 1992). Briefly, variability of Ca and Mg was greatest while variability of N was the least. Site detection limits ranged from 12.2% to 66.3% while detection limits for year factors were lower with a range of 6.0% to 17.8%. The increased detection limits associated with the site compared to the year factor is directly attributed to the large spatial variability associated with soil elemental concentrations. The low detection limits associated with the annual measurements of soil nutrients were still judged to be well within the accuracy needed for use as a covariate or modeling variable associated with temporal changes in other study elements.

Although the variability in soil nutrient values reduced the value of soil nutrients as an ELF response variable, nutrient information continued to be an important component of ANCOVA and modeling efforts in a number of elements. Given the importance of soil nutrient information to the project as a whole, it was proposed in 1991 to revise sampling procedures. Since June and July nutrient values had contributed the most to other study elements, soil sampling was revised to only sample in these months for the last two years of study (1991 and 1992). In addition, archived samples from June and July of previous years were composited and reanalyzed with consistent, one point in time laboratory techniques to construct a soil nutrient dataset consisting of composite values for these two months for each year.

Analytical Progress

The reanalyses of June-July composite soil samples for nutrient concentration were completed in 1992 for both the plantations and hardwood stands. Nutrient concentrations were combined with sample depth, soil bulk density and coarse fragment content to calculate soil nutrient content (Tables 1.21 & 1.22).

Analysis of variance showed significant differences in nutrient content among sites and years (Table 1.23). Every nutrient showed year differences on both the plantations and hardwood stands while site differences in nutrients were evident only in the hardwood stands. Soil nutrients are generally highest on the control site and lowest on the antenna site across the years. Correlations with ambient variables prior to full power operation showed soil nutrients on the plantations to be most related ($p<.05$) with maximum air temperature during the growing season and soil moisture at the 10cm depth in June and July. In the hardwood stands, nutrients were most related ($p<.05$)to soil moisture and temperature at the 10cm depth.

These factors were used in ANCOVA, respectively, to attempt to explain site differences in nutrient content for the plantations and hardwood stands (Table 1.24). Covariate analysis explained site differences for all nutrients in both stand types but did less to explain year differences. Significant ($p<.05$) year differences in soil nutrient content remained for P, K, Ca and Mg in the plantations and for Mg and K in the hardwood stands. Significant site by year interactions remained for Ca in the plantations and K and P in the hardwood stands. Multiple range tests showed hardwood site K differences occurred in 1987, 1989 and 1991 (Figure 1.24) while there were more widespread differences for Ca (Figure 1.25) and P (Figure 1.26).

Soil monitoring efforts contimued in 1993 and a summary will appear in the final report.

Table 1.21. Average June-July soil nutrient content by year for antenna and control hardwood plots.

	Year							
	85	86	87	88	89	90	91	92
	Kg/Ha							
Antenna								
N	1280	1119	1187	929	989	1024	1034	1044
P	476	603	654	586	547	684	600	700
K	49	47	43	42	41	45	26	46
Ca	342	330	216	252	238	172	189	213
Mg	35	37	33	25	43	34	30	36
Control								
N	1593	934	1193	1047	1093	961	1038	973
P	701	804	815	774	774	783	813	751
K	79	49	54	49	59	52	45	59
Ca	621	404	384	406	570	319	291	290
Mg	61	41	53	41	67	58	41	53

Table 1.22. Average June - July soil nutrient contents by year, ground antenna and control plantations

	Year							
	85	86	87	88	89	90	91	92
	Kg/Ha							
Ground								
N	1981	1092	1241	1114	1018	1206	1248	1325
P	510	569	529	450	463	603	505	551
K	78	55	57	64	65	73	43	73
Ca	835	455	460	477	430	505	456	560
Mg	74	41	46	39	65	72	46	70
Antenna								
N	1659	1033	1056	1003	1017	1026	1057	1095
P	466	671	612	681	555	738	632	732
K	68	55	48	52	54	58	35	65
Ca	530	456	371	351	390	330	305	375
Mg	55	42	33	27	52	49	36	48
Control								
N	1714	1104		1175	1120	1230	1153	1232
P	784	725	829	816	765	855	762	756
K	79	62	68	61	50	67	45	80
Ca	823	554	752	583	760	529	378	668
Mg	61	46	56	42	73	65	40	67

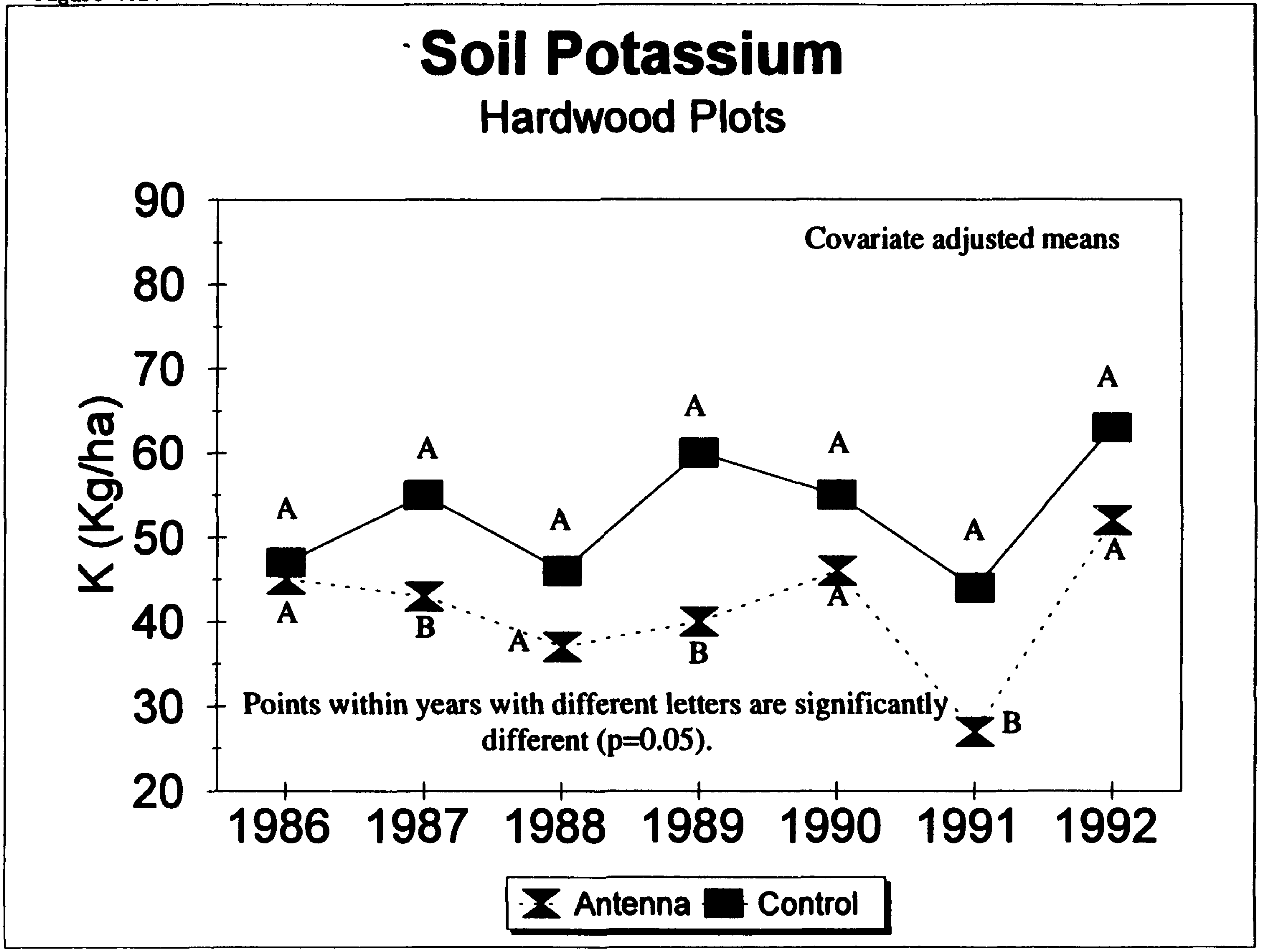
Table 1.23. Significance levels from the analysis of variance of soil nutrient content 1986-1992.

Plantations	N	P	K	Ca	Mg
Site	.005	.191	.049	.001	.025
Year	.474	.036	.000	.000	.000
Year x Site	.895	.144	.144	.001	.038
Hardwoods					
Site	.828	.046	.044	.082	.041
Year	.050	.067	.000	.005	.001
Year x Site	.201	.015	.018	.117	.249

Table 1.24 Significance levels from the analysis of covariance of soil nutrient content, 1986-1992.

Plantations	N	P	K	Ca	Mg
Site	.669	.201	.529	.909	.322
Year	.183	.005	.000	.001	.000
Year x Site	.846	.097	.394	.001	.082
Hardwoods					
Site	.118	.557	.320	.419	.199
Year	.113	.424	.000	.057	.002
Year x Site	.138	.030	.044	.129	.160

Figure 1.24



Soil Potassium
Hardwood Plots
Covariate adjusted means
K (Kg/ha)
90
80
70
60
50
40
30
20
1986
1987
1988
1989
1990
1991
1992
Points within years with different letters are significantly different (p=0.05).
Antenna
Control

Figure 1.25

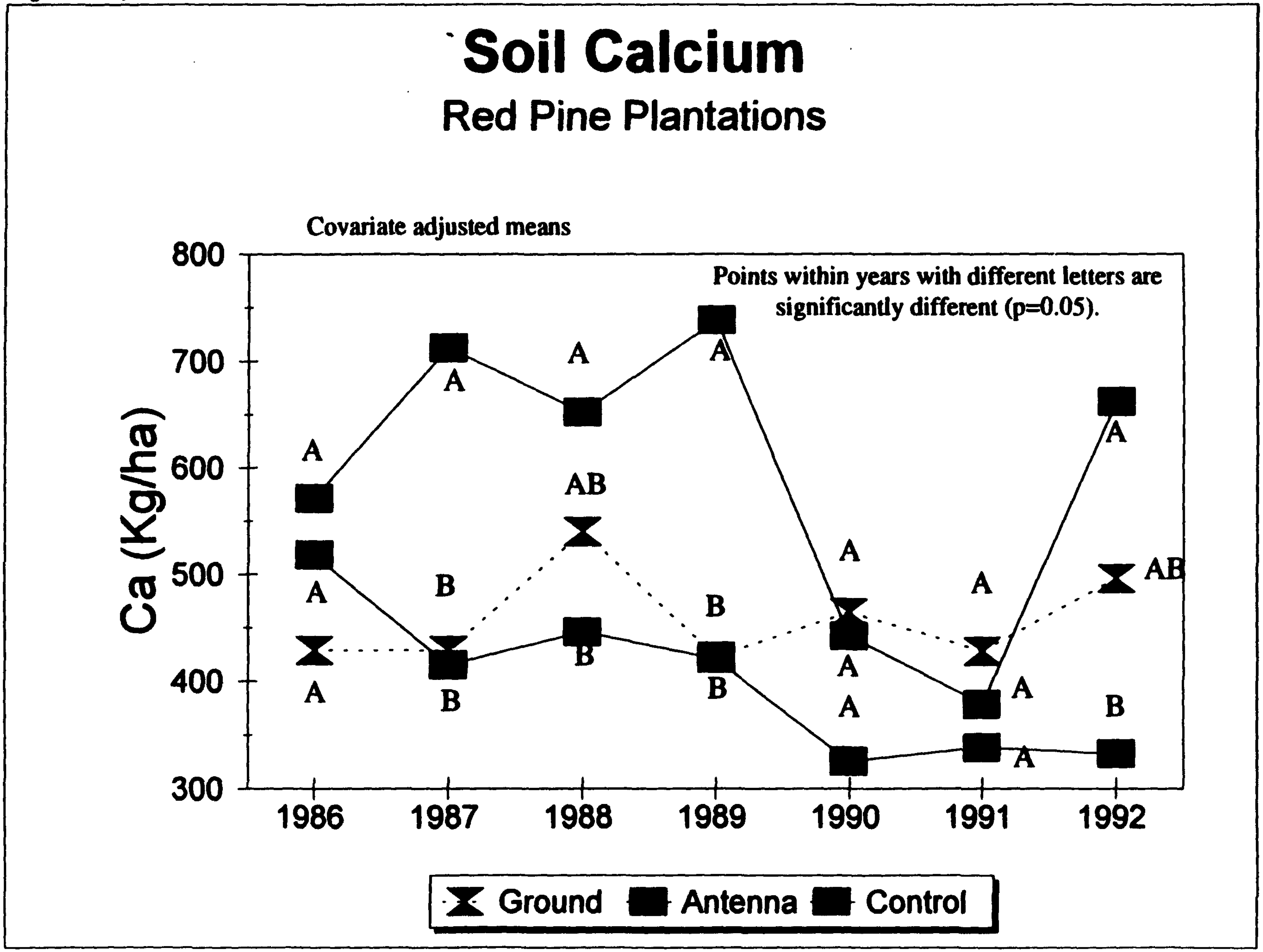
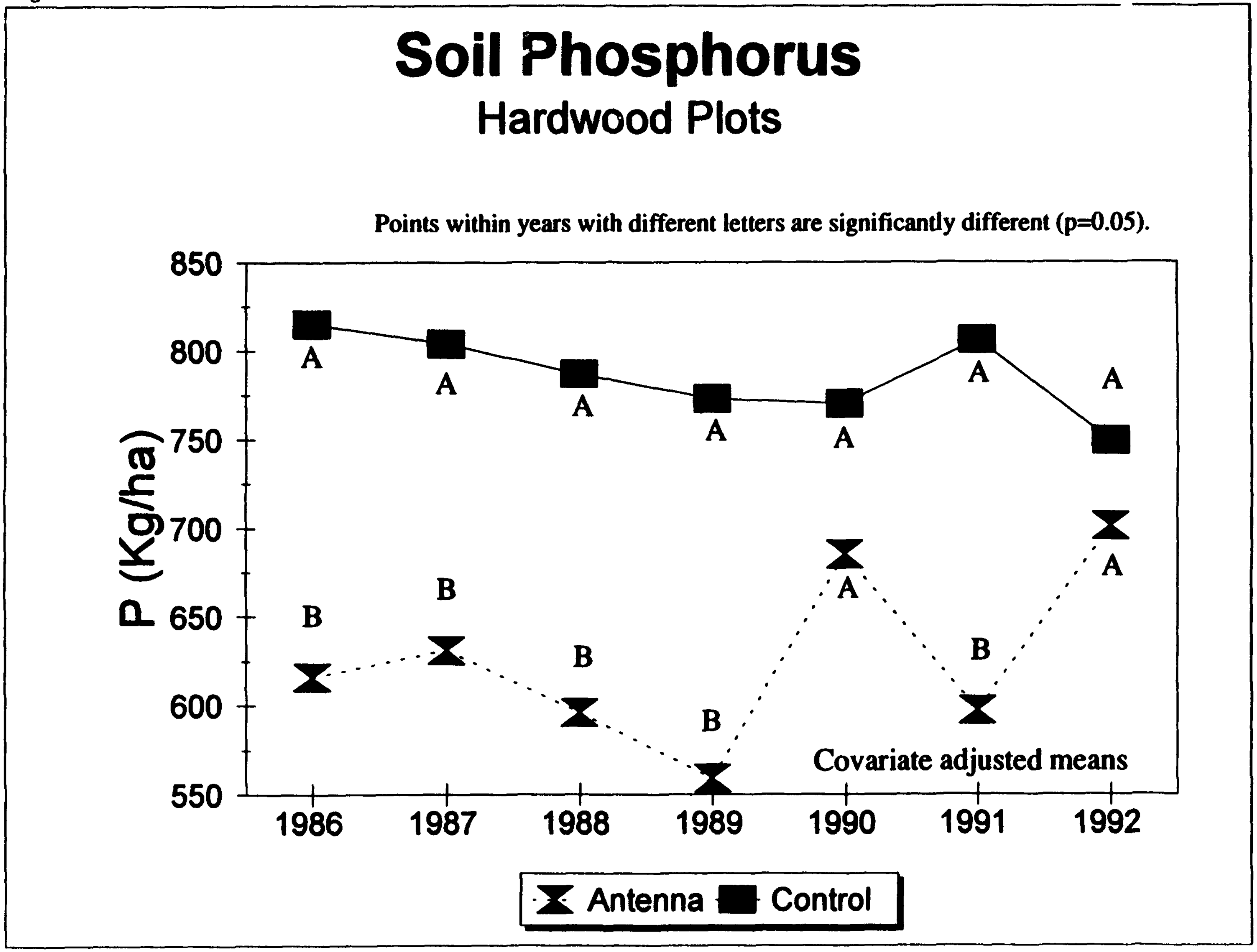

Soil Calcium
Red Pine Plantations
Covariate adjusted means
Points within years with different letters are significantly different (p=0.05).
Ca (Kg/ha)
800
700
600
500
400
300
1986
1987
1988
1989
1990
1991
1992
Ground
Antenna
Control

Figure 1.26


Soil Phosphorus
Hardwood Plots
Points within years with different letters are significantly different (p=0.05).
P (Kg/ha)
850
800
750
700
650
600
550
1986
1987
1988
1989
1990
1991
1992
A
B
Covariate adjusted means
Antenna
Control

Nitrogen Mineralization

Tree productivity analysis completed during the past years have indicat-d that soil nutrients are valuable covariates in explaining site and year differences. Of these nutrients, nitrogen (N) is the one required by trees in the greatest quantity (Auchmoody and Filip 1973; Stone 1973; Keeney 1980). Trees assimilate N almost entirely in the inorganic state as either NH_4^+ or NO_3^- (Miller and Donahue 1990). However, the bulk of the nitrogenous materials found in soils or added to them as plant litter is organic, and consequently, the rate at which organic N is converted to NH_4^+ and further oxidized to NO_3^- is critically important. In response to reviewer comments we initiated a study in 1990 which investigates the effects of N availability on tree growth. The study uses an in situ buried bag technique described below to estimate N mineralization rates. When used with other growth regulating covariates, mineralization rate should help to refine our understanding and modeling of tree growth on the ELF sites. Naturally, mineralization rates will also have to tested to show independence of ELF effects.

This study has focused on gathering field data and analyzing for site, stand and temporal effects. Once completed, the data will be included in growth modeling efforts to develop a model which predicts mineralizable N from our past measures of total N and climate related variables.

Background

The conversion of organically bound N to inorganic N (mineralization) describes two distinct processes: ammonification, in which NH_4^+ is formed from organic compounds; and nitrification, the oxidation of NH_4^+ to NO_3^- (Carlyte 1986). Forest floor and surface mineral soils are two important sites for N mineralization, since most substrates and microorganisms that mediate N mineralization have been found in these two horizons. The objective of this study is to estimate rates of ammonification and nitrification in both red pine plantations and hardwood stands at the antenna and control sites. The overall hypothesis for this study is :

Ho: There are no differences in the rates of N mineralization (ammonification and nitrification) rates in both forest floor and mineral soil (0-10 cm) between antenna and control sites.

Sampling and Data Collection

This study was conducted at only the antenna and control sites. Nitrogen mineralization (ammonification and nitrification) were measured in each hardwood and plantation plot at both sites. An in situ buried bag technique was used to determine net ammonification and nitrification in forest floor and mineral soils (0-10 cm).

Soil Incubation

Soil sampling points were randomly selected within plots at each site. Samples were taken of both forest floor and mineral soils by using a soil corer 5 cm in diameter and 15 cm in depth. The thickness of the forest floor at each sampling point was measured before sample collection. Based on the thickness of the forest floor, a soil core was collected to obtain a mineral soil sample of 10 cm depth. Core samples were removed from the hole and placed undisturbed into a polyethylene bag (0.001 mm thick), tied, returned to the same hole, covered with the litter, and then incubated for four weeks. A separate forest floor sample was collected (about 100 g) near the core sampling point to determine moisture content. A second core sample of both forest floor and mineral soil was collected next to each soil incubation core to determine initial soil NH_4^+-N and NO_3^--N levels, and bulk density.

Laboratory Procedures

All samples were sent to the laboratory within 24 hours of collection and stored at 2°C. The forest floor in each core sample was separated from mineral soil as described by Federer (1982). Five grams of forest floor were extracted with 2 M KCL (Bremner 1965) and the extracts analyzed for NH_4^+-N and NO_3^--N using an automated spectrophotometer (Technicon 1978). Forest floor samples taken to determine moisture content were dried at 105°C for 48 hours. Mineral core samples were homogenized and 5 grams extracted with 2 M KCL and analyzed for NH_4^+-N and NO_3^--N. The initial and incubation soil samples for a given sampling point and collection period were composited. Soil moisture content, organic carbon, and total N were measured on the composited samples.

Soil incubation started in April 1990 and ended October 1991. Forest floor and surface mineral soil (0-10 cm) samples were incubated at four week intervals during the growing season (from May to October). Bulk density was used to convert ammonification and nitrification concentrations to a weight per unit area basis (kg/ha).

Data Analysis

Data from 1990 and 1991 growing seasons (May-Oct) were used for statistical analyses. A split-plot in time and space ANOVA was used to determine differences in rates of net ammonification and nitrification between the sites, years, stand types, and among months (Table 1.25). Factors which were found to differ significantly by the ANOVA tests were separated with Student-Newman-Keuls (SNK) multiple range procedure. Detection limits

Table 1.25. Analysis of variance for the rates of ammonification and nitrification.

Source of variance	df	Sum of Squares	Mean Squares	F - Ratio
Site	1	SS_S	MS_S	$MS_S/MS_{P(S)}$
Plot(site)	4	$SS_{P(S)}$	$MS_{P(S)}$	
ST	1	SS_T	MS_T	$MS_T/MS_{TP(S)}$
ST * Site	1	SS_{TS}	MS_{TS}	$MS_{TS}/MS_{TP(S)}$
ST * Plot(site)	4	$SS_{TP(S)}$	$MS_{TP(S)}$	
MO	5	SS_M	MS_M	$MS_M/MS_{MP(S)}$
MO * Site	5	SS_{MS}	MS_{MS}	$MS_{MS}/MS_{MP(S)}$
MO * Plot(site)	20	$SS_{MP(S)}$	$MS_{MP(S)}$	
YR	1	SS_Y	MS_Y	$MS_Y/MS_{YP(S)}$
YR * Site	1	SS_{YS}	MS_{YS}	$MS_{YS}/MS_{YP(S)}$
YR * Plot(site)	4	$SS_{YP(S)}$	$MS_{YP(S)}$	
YR * MO	5	SS_{YM}	MS_{YM}	$MS_{YM}/MS_{YMP(S)}$
YR * MO * Site	5	SS_{YMS}	MS_{YMS}	$MS_{YMS}/MS_{YMP(S)}$
YR * MO * Plot(site)	20	$SS_{YMP(S)}$	$MS_{YMP(S)}$	
YR * MO * ST * Site	10	SS_{YMTS}	MS_{YMTS}	$MS_{YMTS}/MS_{YMTP(S)}$
YR * MO * ST * Plot(site)	22	$SS_{YMTP(S)}$	$MS_{YMTP(S)}$	

Note: YR = Year, MO = Month, ST = Stand Type, Plot(site) = Plot within Site.

for ammonification and nitrification were calculated using the Student-Newman-Keuls (SNK) multiple range test. Person's correlation coefficient was used to determine linear relationships among ammonification, nitrification and major soil properties (moisture, temperature, organic carbon, organic matter, bulk density, and pH). All tests were performed with a p=0.05 probability level.

Progress

Ammonification in Forest Floor

Site comparisons: Average ammonification rates during 1990 and 1991 were lower at the antenna than those at the control site (Table 1.26). ANOVA tests showed that the rates of ammonification were significantly greater at the control than at the antenna site (p=0.033). The statistical analysis also indicated that the ammonification rates were higher in hardwood

Table 1.26. Average ammonification and nitrification (kg N/ha) in the forest floor during the 1990-1991 growing seasons (May-Oct)

	Ammonification			
	Plantation		Hardwood	
	Antenna	**Control**	**Antenna**	**Control**
1990	1.60	4.18	5.89	9.01
1991	2.48	5.10	7.66	8.90

	Nitrification			
	Plantation		Hardwood	
	Antenna	**Control**	**Antenna**	**Control**
1990	2.42	2.35	1.91	2.55
1991	1.52	1.49	1.59	1.87

than in plantation ($p=0.025$). However, the site and stand type interaction was not found to be significant ($p=.787$) (Table 1.27).

Although annual ammonification rates were lower in 1991 than in 1990, ANOVA test did not show a significant difference between years ($p=0.139$). However, monthly rates of ammonification differed significantly ($p<0.001$) during the two year study period. The monthly mean ammonification rates show a clear seasonal trend (Figure 1.27). The low rates of ammonification in October are most likely related to the large flux of fresh leaves from leaf fall. The corresponding increase in organic carbon and C:N ratios would cause large amounts of NH_4^+-N and NO_3^--N to be immobilized by microorganisms.

Figure 1.27 Average ammonification in forest floor

(May 1990 - Oct 1991)

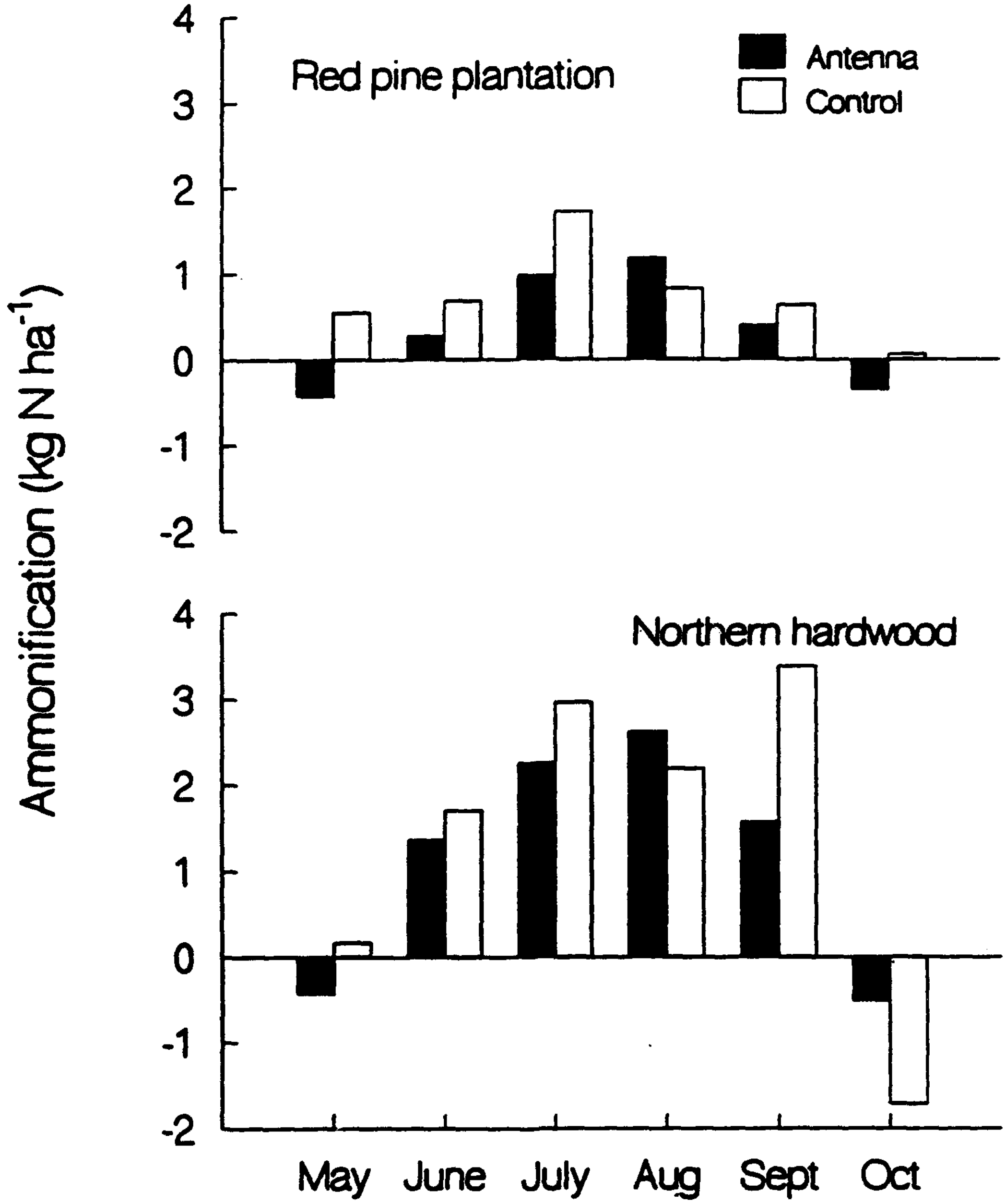


Table 1.27 Significant levels from the analysis of variance for ammonification and nitrification in forest floor and detection limits of site, stand type, and site by stand type interaction

Factors	**Ammonification**	**Nitrification**
Site	0.033	0.331
Stand type	0.025	0.962
Stand type * Site	0.788	0.342
Year	0.139	0.044
Month	0.000	0.000
Year * Month	0.014	0.002
Year * Site	0.541	0.598
Year * Stand type	0.852	0.460
Year * Stand type * Site	0.464	0.381
	Detection Limits	
Site	0.322	0.101
stand type	0.544	0.101
Site * stand type	0.554	0.104
Site * stand type * year	0.402	0.084
	% Mean	
Site	36.2	32.3
Stand type	61.1	32.5
Site * stand type	62.2	33.4
Site * Stand type * year	45.1	27.0

Forest floor ammonification site by year ($p=0.598$) and site by year by stand type ($p=0.381$) interactions were not significant. However, year by month, stand type by month, site by stand type by year by month interactions were significant (Table 1.27). These results indicate that changes of ammonification rates in forest floor were mainly controlled by the climatic and soil factor seasonal variations, while ELF antenna operation do not appear to have a detectable effect on this process.

Rates of ammonification in forest floor for both stand types and both sites were significantly correlated with the average monthly temperatures at 5 cm depths ($r=0.54$, $p<0.001$) and initial NO_3^--N in forest floor ($r=-0.32$, $p=0.003$). Initial NH_4^+-N and moisture in forest floor were not significantly correlated with the ammonification rates (Table 1.30).

Nitrification in Forest Floor

Site comparisons: Annual nitrification rates were similar between antenna and control sites (Table 1.26) and no significant differences were detected by the ANOVA test (p=0.331). Stand type and site by stand type interactions were also not significant (Table 1.27). These results show that the rates of nitrification in forest floor were similar at the two sites and stand types.

ANOVA tests showed significant differences in nitrification rates between years (Table 1.26). The nitrification rates at antenna and control sites were higher in 1990 than in 1991 for the both the plantation and hardwoods. Like the ammonification rates in forest floor, the nitrification rates also displayed a clear seasonal trend during the two year study period **(Figure 1.28)**.

The seasonal trends in nitrification rates in the forest floor at the antenna and control sites were similar during the study period. Forest floor nitrification rate site by year, stand type by year, and site by stand type by year interactions were not significant (Table 1.27). Although the stand type by month interaction was significant (p=0.015), the site by month, stand type by site by month interactions were not significant (Table 1.27).

Nitrification processes are particularly sensitive to changes in environmental factors (Paul and Clark 1989). In our study, nitrification rates in the forest floor were significantly correlated with the average monthly soil temperatures at a 5 cm depth ($r=0.52$, $p<0.001$), initial NO_3^--N forest floor contents ($r=0.28$, $p=0.009$), and forest floor moisture content (-0.27, $p=0.011$). However, initial NH_4^+-N was not correlated with the nitrification rates (Table 1.30).

Ammonification in Mineral Soil (0-10 cm)

Annual ammonification rates in mineral soil (0-10 cm) were not significantly different (p=0.417) between antenna and control sites (Table 1.28). ANOVA tests showed that the ammonification rates were significantly lower ($p<0.001$) in the plantations than in the hardwood stands. Site by stand type interactions were not found to be significant (p=0.272) for this process and thus ammonification was lower in the plantations

Figure 1.28 Average nitrification in forest floor
(May 1990 - Oct 1991)

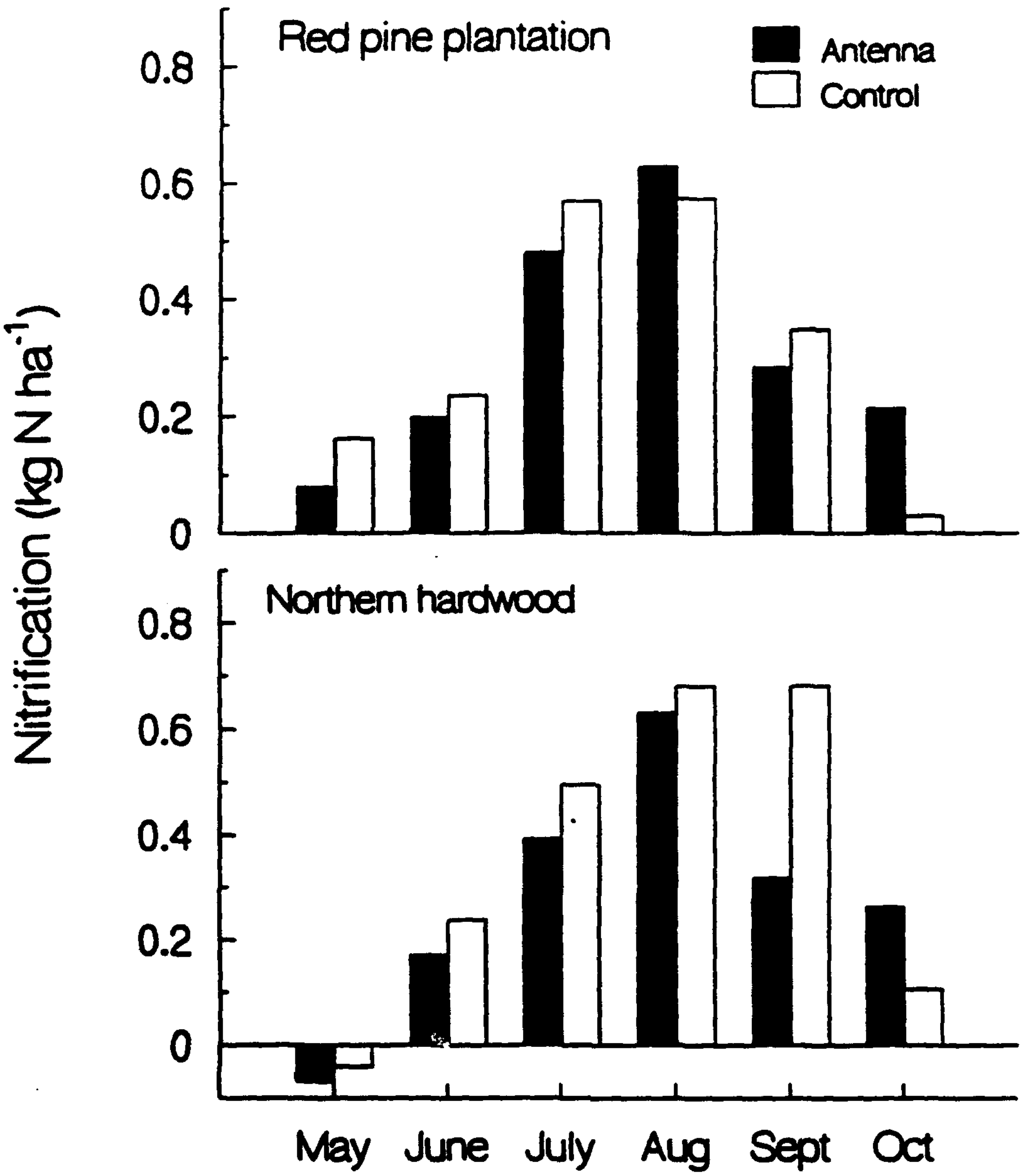


Table 1.28 Comparison average ammonification and nitrification (kg N/ha) in mineral soil (0-10 cm) during 1990-1991 growing seasons (May-Oct)

	Ammonification			
	Plantation		Hardwood	
	Antenna	**Control**	**Antenna**	**Control**
1990	31.70	28.92	55.49	63.32
1991	32.16	32.33	55.90	53.01

	Nitrification			
	Plantation		Hardwood	
	Antenna	**Control**	**Antenna**	**Control**
1990	10.05	9.92	12.20	12.31
1991	8.68	9.05	10.76	10.94

than the hardwoods at both sites (Table 1.29).

Rates of mineral soil ammonification did not differ significantly between 1990 and 1991 (p=0.381). However, a clear seasonal variation in ammonification rates was evident in both stand types at the two sites (Figure 1.29). Soil ammonification rates for the both plantation and hardwood stands at the two sites remained stable during the two study years. ANOVA tests for the antenna vs. control comparison showed no significant site by year interactions for soil ammonification rates (p=0.272). Site by year, stand type by year and site by stand type by year interaction were also not significant (Table 1.29).

Figure 1.29 Average ammonification in mineral soils (0-10 cm)

(May 1990 - Oct 1991)

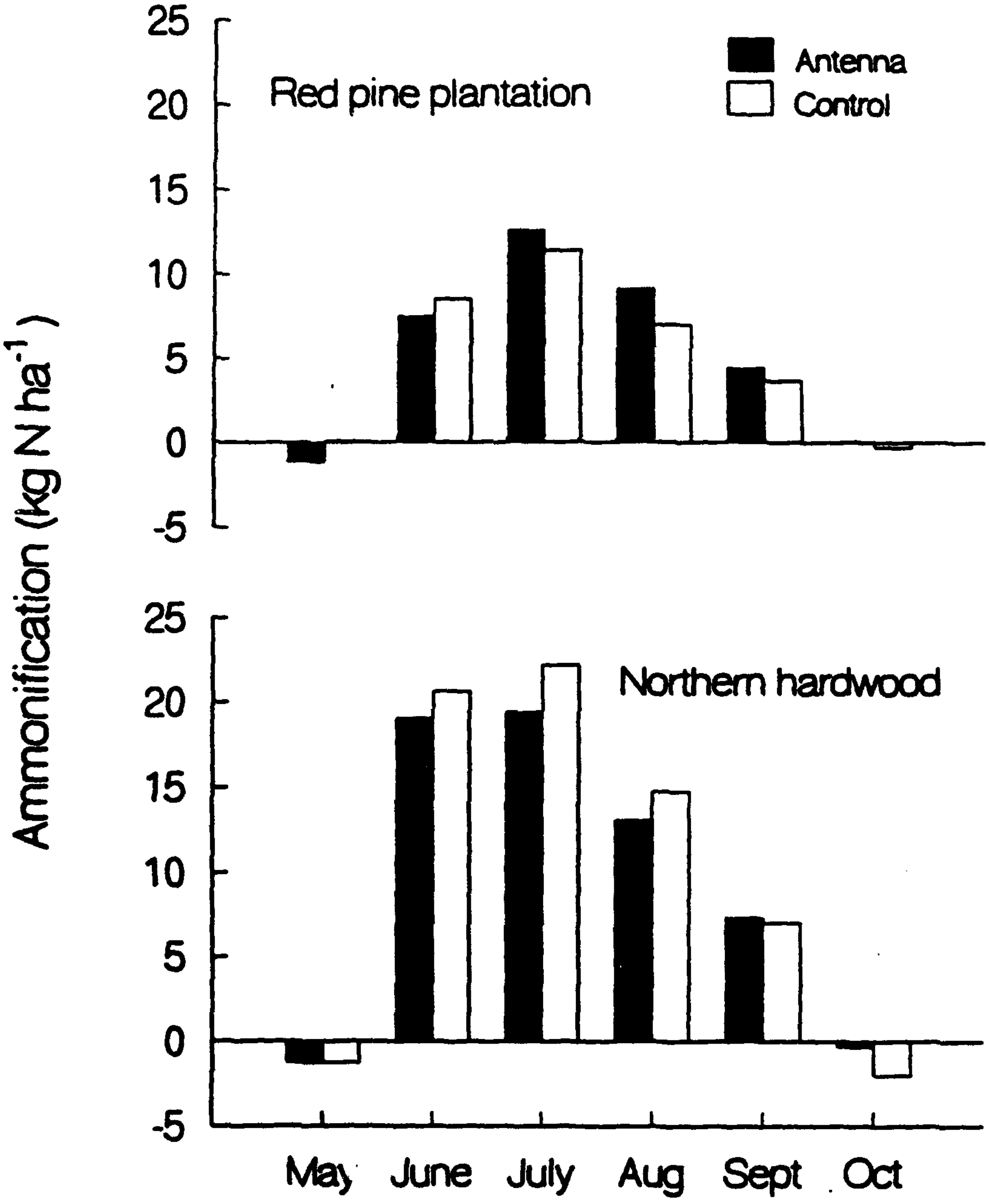


Table 1.29. Significant levels from the analysis of variance for ammonification and nitrification in mineral soils (0-10 cm) and detection limits of site, stand type, and site by stand type interaction

Factors	Ammonification	Nitrification
Site	0.417	0.902
Stand type	0.000	0.027
Stand type * Site	0.272	0.951
Month	0.000	0.000
Year	0.381	0.146
Year * Month	0.000	0.001
Year * Site	0.323	0.916
Year * Stand type	0.433	0.649
Year * Stand type * Site	0.166	0.814
	Detection Limits	
Site	0.543	0.149
Stand type	0.883	0.260
Site * stand type	0.924	0.273
Site * Stand type * year	1.086	0.301
	% Mean	
Site	7.09	8.35
Stand type	11.53	14.59
Site * stand type	12.06	15.31
Site * stand type * year	14.18	16.88

Rates of soil ammonification for both plantation and hardwood stands at antenna and control sites were highly correlated with C:N ratios ($r=-0.77$, $p<0.001$), Soil moisture content, organic carbon, average soil temperature at 10 cm depth and total N were also significantly correlated with the ammonification rates, but not soil pH (Table 1.30).

<u>Nitrification in Mineral Soils (0-10 cm)</u>

ANOVA tests did not show significant differences in soil nitrification rates between antenna and control sites (Table 1.29). However, nitrification rates at the hardwoods were approximately twice as great as in the plantations (Table 1.28) and differences between stand types were significant ($p=0.027$).

The differences in stand types were similar at the two sites and thus the site by stand type interaction was not significant ($p=0.951$). Annual differences in soil nitrification rates were not significant ($p=0.146$) but differences among monthly rates were significant ($p<0.001$). Mineral soil nitrification rates like ammonification rates, were relatively constant between the two study years but showed clear seasonal trends at both sites and both stand types.

ANOVA tests for the antenna vs. control site comparison showed no significant site by year interactions for soil nitrification rates ($p=0.916$). Stand type by year and site by stand type by year interactions were also not significant (Table 1.29). Rates of soil nitrification for both stand types at antenna and control sites were highly correlated with C:N ratios ($r=-0.51$. $p<0.001$) and total N ($r=-0.45$, $p< 0.001$). Soil organic carbon, organic matter, soil bulk density, average soil temperature at 10 cm depth and soil moisture were also significantly correlated with the nitrification rates, but not soil pH (Table 1.30).

When rates of ammonification and nitrification were combined from both sites to express amounts of total N mineralized over both growing seasons. Amounts were 43.3 kg N/ha/yr in plantations and 73.4 kg N/ha/yr in the hardwoods. This compares well with other N mineralization values reported in the Great Lakes region (Table 1.31).

Summary

These results indicate that ammonification and nitrification in mineral soil (0-10 cm) and nitrification in forest floor do not differ significantly between sites. Although rates of these processes differed between stand types, these differences were similar at each site. Assuming that the rates of nitrification in the forest floor and of both nitrification and ammonification in mineral soil did not differ prior to ELF antenna operation, there does not appear to be any evidence that ELF fields have affected these processes. Ammonification in the forest floor was found to differ significantly between sites with rates being higher at the control site than at the antenna site. At this time there is no evidence to indicate that rates of

Table 1.30. Correlation coefficients of forest floor (FAMM) and mineral soil (SAMM) ammonification and forest floor (FNITR) and mineral soil (SNITR) nitrification with major soil factors (n=288; '*' $p<0.05$; '**' $p<0.001$)

Factor	**FAM**	**FNITR**	**SAMM**	**SNITR**
IFNH4-N	-0.17	0.01		
IFNO3-N	0.32**	0.28**		
Forest floor moisture%	-0.004	-0.27		
T5	0.54**	0.52**		
T10			0.24*	0.35**
Soil pH			-0.06	0.01
Soil moisture %			0.50**	0.30**
Bulk density			-0.37**	-0.34**
Soil organic carbon %			-0.47**	-0.42**
Soil organic matter %			-0.20	-0.21*
Soil Total N (kg/ha)			-0.30**	-0.45**
Soil C:N ratio			-0.74**	-0.51**
ISNH4-N			-0.001	0.04
ISNO3-N			0.04	-0.06

Note: IFNH4-N = Initial NH_4^+-N (kg/ha) in forest floor
IFNO3-N = initial NO_3^--N (kg/ha) in forest floor
ISNH4-N = Initial NH_4^--N (kg/ha) in mineral soil
ISNO3-N = Initial NO_3^--N (kg/ha) in mineral soil

Table 1.31. N mineralization as determined under field conditions in the Great Lakes region

Study site	**N Mineralization**	**Sample depth**	**Study period**	**Reference**
Wisconsin:				
Red pine	32	0-10 cm	one year	Nadelhoffer et al. (1982)
Sugar maple	62	0-10 cm		
Ontario, Canada:				
Sugar maple-beech	74-114	0-8 cm	two years	Hill and Shackleton (1989)
pine	20-29	0-8 cm		
Lower Michigan:				
Sugar maple-red oak	101	0-3.8 cm	one year	Zak and Pregitzer (1990)
Massachusetts:				
White pine	21.7	0-15 cm	Apr-Oct	Boone (1992)
Sugar maple	107.9	0-15 cm		
Western upper Michigan:				
Maple	102	0-10 cm	May-Oct.	Mldenoff (1987)
Hemlock	89	0-10 cm		

ammonification in the forest floor differed between the sites prior to ELF antenna operation. Thus we cannot conclude that antenna operation has not alter this process at the antenna site.

Current work is focusing on determining what factors (mineral soil nutrient content, climatic variables, litter fluxes etc.) control the rate of these processes at the study sites. Using a model developed from this information and our measurement of these factors prior to antenna operation, we will evaluate whether rates of these process were similar at the two sites prior to antenna operation. This process will give a better indication whether nitrification and ammonification rates have been altered by ELF antenna operation.

Element 2. Tree Productivity

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to treatment, accurate tree measurements are essential. The most widely accepted tree growth measurements are diameter at breast height outside bark (dbh) and height. Of these two growth variables, height is the more difficult to measure on mature trees. The installation of permanent dendrometer bands on the stem of a tree allows measurement of minute changes (0.008 cm) in diameter over a short time interval (Husch *et al*. 1982). Two additional advantages of using dbh as a measure of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1986) and the strong correlation between dbh and total tree biomass (Spurr 1952, Crow 1978). Consequently, measurement of diameter increment is the primary response variable for assessing the effects of ELF fields on hardwood stand growth. Tree height was used for initial stand characterization.

While dbh and height measurements can provide information on present stand production and a means to predict future productivity, the capacity of the stand to continue producing is also dependent on stand structure (the distribution of trees by diameter classes). Stand structure changes from year to year due to natural growth, reproduction, and mortality. Any environmental disturbance could produce an effect on these factors. Therefore, to achieve a complete picture of possible ELF field effects on tree and stand production, dbh, height, ingrowth, and mortality are being measured in order to distinguish natural changes from those caused by stand disturbances.

In addition to tree productivity in hardwood stands, studies involving planted red pine are being conducted on the ground, antenna, and control sites. These studies were initiated in response to a need for a larger number of conifers in the ectomycorrhizal studies as well as to address the Michigan DNR concerns about forest regeneration. Since young trees often exhibit rapid growth rates compared to older trees, possible ELF field effects may be more easily detected on young rather than on older trees. In the red pine, both diameter and height increment are response variables for assessing any possible effects due to ELF fields. Again, as in the case of trees in the hardwood stands, diameter, height, and mortality are being measured.

Hardwoods

Diameter increment is the primary response variable for assessing the effects of ELF fields on the hardwood stands located at the antenna and control sites. Permanently installed dendrometer bands allow continual measurement of incremental growth on each tree in the stand. This information provides a view of both the total growth in an entire growing season and the rate or distribution of diameter growth over the growing season.

Hardwood stands on both study sites are classified in the *Acer-Quercus-Vaccinium* habitat type (Coffman *et al.* 1983). Those overstory species common to both sites and included in the analyses are northern red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*Populus tremuloides*), and red maple (*Acer rubrum*). A summary of stand information for both sites at the beginning of the 1992 growing season can be found in Table 2.1; the change in average dbh on the study sites for each year since 1984 is given in Table 2.2.

The overall null hypothesis for the analyses is:

> H_0: There is no difference in the magnitude or the pattern of seasonal diameter increment before or after the ELF antenna became operational.

This hypothesis is addressed by testing differences between the control and the antenna sites and testing between post-operational years and previous years. The system operated at low levels throughout the growing seasons of 1986 (6 amps), 1987 (15 amps), and 1988 (75 amps) and at full power since 1989 (150 amps). The east-west antenna was de-energized for repairs early in the 1991 growing season (May 8 through July 12) and during the winter of 1991-92 (December 23 through March 28) (Appendix A). Whenever possible, differences between sites and between 1989-92 and previous years are examined. Tests concerning the rate or the distribution of diameter growth are made using the diameter growth model discussed later in this section. Tests in previous years (Mroz *et al.* 1988) have shown that there are no significant differences in the parameters of the growth models between years or among sites. Comparisons of post-operational years with previous years are in part made by examining differences between observed and predicted individual tree diameter growth over years and sites. Differences in the magnitude or amount of seasonal diameter growth are examined through the analysis of covariance. The analysis of covariance table used in this study is found in Table 2.3. The analyses reported here are performed using data collected through 1992. The 1993 data will be added to the analyses following the completion of data collection and laboratory analysis of the soil nutrient concentrations, a critical covariate and predictor variable in the diameter growth models.

Sampling and Data Collection

To monitor diameter growth on both sites, permanent dendrometer bands were installed in 1984 on all trees greater than or equal to 10 cm dbh. Due to vandalism, 175 new bands were installed on the control site in 1985. On the antenna site the number of study trees was reduced from 209 to 197 in 1985 due to a few band failures and a small vandalism incident unrelated to that on the control site. The death of one bigtooth aspen on the control site reduced that sample to 274 trees in 1985. At the

Table 2.1. Summary of hardwood stand information for the antenna and control sites at the beginning of the 1992 growing season.

Species	Average DBH (cm)[b]	Basal Area Per Hectare (m^2/ha)	Number Bands in 86	Number Bands in 92[b]	Died in 1992	Number of Stems Per Hectare	Site Index	Age (yrs)
Antenna Site								
Northern Red Oak	25.04	8.69	44	49	0	156	68	53
Paper Birch	21.20	0.96	8	8	0	25	66	61
Aspen[a]	27.29	2.94	15	15	0	48	68	56
Red Maple	15.73	9.54	129	146	0	464	56	48
Control Site								
Northern Red Oak	22.22	22.70	174	171	1	542	72	58
Paper Birch	18.74	1.32	38	14	0	45	60	60
Aspen	24.79	5.34	43	34	4	108	65	61
Red Maple	12.11	0.78	15	21	1	67	58	51

a/ The two aspen species are combined.

b/ Includes trees which grew larger than 10.0 cm dbh since 1985 but not trees which died since 1985.

Table 2.2 Average dbh (cm) by species and site at the beginning of each year of the study[a/].

Species	1984	1985[b/]	1986	1987	1988	1989	1990	1991	1992	1993
Antenna Site										
Northern Red Oak	22.18	22.45	22.69	23.09	23.36	23.76	23.99	24.05	24.54	24.52
Paper Birch	20.02	20.22	20.42	20.56	20.70	20.83	20.93	21.03	21.13	21.20
Aspen[c/]	24.59	25.01	25.37	25.67	25.93	26.20	26.49	26.71	27.02	27.29
Red Maple	14.87	15.09	15.23	15.33	15.44	15.89	15.98	15.71	15.54	15.92
Control Site										
Northern Red Oak	20.45	20.62	20.82	20.94	21.12	21.58	21.76	21.68	22.03	22.25
Paper Birch	16.12	16.23	16.30	16.36	16.41	17.21	17.24	16.79	18.02	18.74
Aspen	22.21	22.55	22.82	23.03	23.18	23.47	23.61	23.77	24.37	24.79
Red Maple	11.37	11.64	11.85	12.01	12.17	12.28	12.40	12.51	12.62	12.73

a/ Only trees banded prior to 1987 are represented here.

b/ Values given for the beginning of the growing season were calculated by adding all previous years growth to diameter taken in 1984.

c/ The two aspen species are combined.

Table 2.3. Analysis of covariance table used for examining annual diameter growth by species.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Covariates (Group A)	# Group A Covariates	SSC	MSC	MSC/MSE(S)
Site	1	SSS	MSS	MSS/MSE(S)
Error (S)	# Trees - 2 - # Covariates	SSE(S)	MSE(S)	
Years	# Years - 1	SSY	MSY	MSY/MSE(SY)
Site X Years	(1) (# Years - 1)	SSSY	MSSY	MSSY/MSE(SY)
Covariates (Group B)	# Group B Covariates	SSCY	MSCY	MSCY/MSE(SY)
Error (SY)	(# Trees - 2 - # Covariates) (# Years - 1)	SSE(SY)	MSE(SY)	

Group A Covariates differ by site but not by year, such as soil characteristics. Group B Covariates, such as annual rainfall, change from year to year.

start of the 1987 growing season, the trees which had band failures in 1985 on the antenna site, as well as all trees which had become larger than 10 cm dbh since 1984, were banded on both sites (Table 2.1). In 1988, there were three trees on the control site (two paper birch and one bigtooth aspen) which died. This mortality in 1988 occurred on trees that had not grown appreciably since 1984, indicating that they were not very vigorous, and they probably succumbed to climatic stress during the 1988 growing season. In 1989, additional trees which had grown to exceed 10 cm dbh were banded giving a total of 220 trees on the antenna site and 281 trees on the control site at the start of the 1991 growing season. In 1991, there were two red maples that died on the study plots at the antenna site. On the study plots at the control site, 23 paper birch did not leaf out in the spring of 1991. Upon inspection, it became obvious that there had been an outbreak of bronze birch borer (*Agrilus anxius* Gory.). This outbreak occurred across northern Michigan and southern Canada (R. Heyd, Personnal Communication) and appears to have been related to climatic conditions in the preceeding years (Mroz *et al.* 1991, Jones *et al.* 1993). There were four additional northern red oaks and four quaking aspen on the control site which died in 1991, probably due to climatic stress.

In August, 1992, there was a severe windstorm at the control site with damage to a number of banded trees on the study plots. Most of the damage was caused by the blowdown of a large northern red oak in the buffer zone which landed inside plot three. Three bigtooth aspen, one red maple, and one northern red oak on the study plot were broken off and killed by this falling tree. Six additional trees suffered minor damage and six more received heavier damage, but were not killed. These trees are being monitored in 1993 and, if growth appears to be abnormally low, they will be removed from the analyses. One additional tree in plot one was broken off by the wind, but no surrounding trees were damaged.

Bands were read to the nearest 0.01 inches of circumference (0.008 cm of diameter) at both study sites beginning on April 14 in an attempt to insure monitoring of growth initiation. Weekly measurements will continue into October until over 50 percent of leaf fall takes place.

Progress

Growth Analysis

Magnitude and rate of diameter increment were examined for each species. Analysis of tree diameter is approached in two ways. The analysis of covariance is used to determine if there is any change in the magnitude of average yearly diameter growth which may be due to ELF fields. Secondly, regression models developed in past years (Mroz *et al.* 1988, Appendix C) are used to further quantify the relationships between tree, site, and climatic variables and tree diameter growth. These models are used to test for changes in both seasonal growth pattern within a year and relationships affecting total annual growth due to ELF fields. Examination of the differences between the observed and predicted individual tree diameter growth is conducted to determine if there have been changes in the effects of tree, site, or climatic variables on individual tree diameter growth and to examine the effects of the level of ELF field exposure on diameter growth. The modeling analyses use information for all trees, including those banded since 1985. The analysis of covariance only utilizes growth information on trees which have been banded for the entire study period.

Analysis of Total Seasonal Diameter Growth

At present, nine complete years (1984 through 1992) of diameter increment data have been collected from trees on the study sites. In 1984, first incremental growth was not collected until early June due to a relocation of the control site. Because of this, total diameter increment in 1984 was not derived from dendrometer band data, but from spring and fall diameter tape measurements of individual trees. Also, due to installation and calibration of the ambient monitoring equipment, the climatic variables were not completely available for 1984. For these reasons, the 1984 diameter growth measurements are not included in the analysis of covariance. The tree growth data from 1993 will be added to the analyses following the completion of data collection and laboratory analyses of soil nutrient data which are important covariates. Table 2.4 presents the total annual diameter growth by species for each of the nine growing seasons, even though data from 1984 are not included in the analyses.

Results of an intensive variable screening procedure to select covariates to include in the analysis of covariance for each species have been reported previously (Mroz *et al.* 1988, Reed *et al.* 1992b). There have been no attempts to redefine the set of covariates for each species this year. Since antenna activity has increased, attempts to redefine covariates using information from later years could be confounded with possible ELF effects on diameter growth. The covariates used are total air temperature degree days through May for red maple and through September for the other three species, July soil potassium concentration for all four species, soil water retention capacity from 5 to 10 cm for red maple, and soil water retention capacity from 10 to 30 cm for paper birch.

An initial analysis of variance, without covariates, was performed for individual tree annual diameter growth for each species (Table 2.5). In all four species, there were significant ($p<0.05$) differences in individual tree diameter growth rates among the study years. There were also differences ($p<0.05$) between the study sites for all species. For aspen, there was a significant site X year interaction. As indicated in previous years, a logarithmic transformation was applied to the northern red oak and red maple data prior to the analyses. An analysis of covariance using the covariates listed previously indicated that

Table 2.4. Average seasonal diameter growth (cm) for tree species on each site (1984-1992 growing seasons).[a/]

	Sample Size	1984	1985	1986	1987	1988	1989	1990	1991	1992
		cm								
Northern Red Oak										
Antenna Site	44	0.2778	0.2389	0.1991	0.2710	0.2354	0.2256	0.2258	0.2876	0.2018
Control Site	167	0.1707	0.2030	0.1508	0.1823	0.1595	0.1773	0.1561	0.1860	0.1459
Paper Birch										
Antenna Site	8	0.2000	0.2038	0.1500	0.1304	0.1132	0.0990	0.1081	0.0990	0.0850
Control Site	14	0.1050	0.0765	0.0652	0.0406	0.0419	0.0345	0.0187	0.0280	0.0429
Aspen										
Antenna Site	15	0.4133	0.3653	0.2993	0.2355	0.2576	0.2877	0.2205	0.3288	0.2833
Control Site	34	0.3386	0.2643	0.2164	0.1529	0.1713	0.1415	0.1204	0.1615	0.1865
Red Maple										
Antenna Site	127	0.2163	0.1374	0.1017	0.1130	0.0830	0.0899	0.0952	0.0778	0.0628
Control Site	15	0.2667	0.2040	0.1533	0.1768	0.0690	0.1152	0.1272	0.0986	0.1040

a/ Only trees banded prior to 1987 are represented here.

Table 2.5. Significance levels[a/] for the analysis of variance and covariance of individual tree diameter growth.

Species	Source of Variation		
	Site	Year	Site X Year Interaction
Analysis of Variance (No Covariates)			
Northern Red Oak	0.0426	0.0000	0.8640
Paper Birch	0.0371	0.0000	0.4409
Aspen	0.0020	0.0000	0.0038
Red Maple	0.0153	0.0000	0.0839
Analysis of Covariance			
Northern Red Oak[b/]	0.5933	0.0000	0.6272
Paper Birch	0.0682	0.0000	0.6252
Aspen	0.6678	0.0000	0.0019
Red Maple	0.8744	0.0000	0.0698

a/ A significance level less than 0.05 indicates a significant difference at p=0.05.

b/ For northern red oak and red maple, a logarithmic transformation was performed on individual tree diameter growth prior to analysis.

there were no detectable differences (p=0.05) in individual tree diameter growth rates between sites for any of the four species. There were differences among years for all four species and there was a significant site X year interaction for aspen, indicating that the relationship between individual tree diameter growth rates on the two sites changed over time for this species.

To further investigate the yearly differences in total annual diameter growth for each species, SNK multiple comparison procedures (Zar 1980) were performed for each species. These tests compared the average yearly diameter growth to determine which years had similar levels of growth. The adjusted total annual diameter growth from the analysis of covariance was ranked by year from least to most as indicated below for each species with years that had similar growth denoted by the same letter.

Northern Red Oak:

1985[a] 1989[b] 1990[bc] 1991[bc] 1987[bc] 1992[cd] 1988[d] 1986[e]

For northern red oak, there were differences among years as noted previously. Years of full power antenna operation (1989, 1990, 1992) grouped among the years of testing. The one pre-operational year (1985) had significantly lower adjusted mean annual diameter growth than did the other years. There is no clear evidence of an ELF effect on northern red oak annual diameter growth.

Paper Birch:

1992[a] 1989[a] 1990[a] 1991[a] 1987[b] 1988[b] 1986[b] 1985[c]

For paper birch, the differences among years were ordered chronologically, with the last four years (1989-92) having the lowest growth and being similar to each other. The pre-operational year (1985) had the greatest growth while the transitional years (1986-88) grouped at an intermediate level. As noted by Jones *et al.* (1993), the paper birch mortality in 1991 appears to be due to climatic condition in the preceeding years which is consistent with these findings from the analysis of covariance. The surviving paper birch on the study sites have not yet recovered from the stressful conditions in preceeding years.

Aspen (Control Site):

1990[a] 1989[a] 1992[a] 1988[b] 1987[b] 1991[b] 1985[c] 1986[c]

Aspen (Antenna Site):

1990[a] 1992[a] 1987[b] 1988[b] 1989[b] 1986[bc] 1985[c] 1991[d]

Interpretation of the results for aspen is complicated by the site X year interaction in the analysis of covariance. The years were grouped differently at the antenna site than at the control site. For instance, 1991 was the year with the greatest adjusted mean diameter growth at the antenna site; however, at the control site adjusted mean diameter growth in 1991 was lower than 1985 and 1986. For the antenna site, there is no clear grouping of operational years, but 1986-1989, the years of testing and the first year of full-power operation, are all grouped similarly at the antenna site. These relationships between growth on the two sites in different years are being examined further in the diameter growth model analyses discussed below.

Red Maple:

1988^{a} 1991^{b} 1985^{b} 1987^{c} 1986^{c} 1990^{d} 1989^{e} 1992^{e}

For red maple, there were no differences between sites in the analysis of covariance. There were year differences with 1989 and 1992 having the greatest adjusted mean diameter growth followed by 1990. These are the three years of full-power antenna operation. On the other hand, the pre-operational year (1985) was not different from 1988 or 1991. These relationships are being investigated further in the diameter growth model analyses discussed below.

One of the critical assumptions of the analysis of covariance is that the covariates are independent of the treatments, in this case the EM field exposure levels. Violation of this assumption means that the effects of the fields could be confounded with the covariates and the results given above should be investigated further prior to concluding with certainty that there is or is not an ELF effect on individual tree diameter growth. The diameter growth model analyses discussed below address these data in more detail using a method which explicitly tests whether or not the EM field exposures are affecting diameter growth.

Diameter Growth Model

Many of the relationships between diameter growth and tree, site, and climatic variables can be expected to be nonlinear (Spurr and Barnes 1980, Kimmins 1987). These nonlinear relationships may include breakpoints or threshhold levels, or other functional relationships which cannot be linearized or easily accounted for in the analysis of covariance described above. In order to supplement the analysis of covariance, diameter growth models for each of the four species were developed (Mroz *et al.* 1988, Reed *et al.* 1992a, Appendix C) to further account for the variability in growth between sites and among years. The growth model also provides an annual residual (observed minus predicted growth) for each tree which can be examined to see if the diameter growth following antenna activation is diverging from patterns seen in previous years; no similar quantity is available for individual trees from the analysis of covariance. Since the seasonal pattern of diameter growth as well as total annual growth could be subject to ELF field effects, the weekly cumulative diameter growth (cm) was selected as the response variable.

Differences in diameter growth since 1985 include differences in the timing of growth between sites, differences in the timing of growth among species, and differences in the timing of growth among years (Mroz *et al.* 1986). Since the stand conditions did not change drastically from 1985 through the 1990 growing seasons, these observed differences are largely due to differences between species, climatic differences between years, and physical differences between sites. These differences have largely been accounted for in the diameter growth models (Mroz *et al.* 1988, Reed *et al.* 1992a, Appendix C).

Cumulative diameter growth is broken into the component parts of total annual growth and the proportion of total growth completed by the date of observation. This simplifies the testing for significant effects of ELF fields on tree diameter growth. Cumulative diameter growth to time t is therefore represented by:

$$CG_t = \text{(Total Annual Growth)(Proportion of Growth to Time } t\text{)}$$

This formulation allows the testing of ELF field effects on both the level of total annual growth (TAG) and the pattern of seasonal growth. In the model, total annual growth is further broken into the component parts of potential growth, the effect of intertree competition, and the effect of site physical, chemical, and climatic properties:

$$TAG = \text{(Potential Growth)(Intertree Competition)(Site Physical, Chemical, and Climatic Properties)}$$

The degree of intertree competition is dependent on the distances and sizes of neighboring trees. Since the original stand maps extended only to the plot boundaries, the competitors of trees near the boundaries could not be determined. For this reason, only trees in the center 15 m could be utilized for the growth model analyses from 1985 through 1989. In 1989, an additional 10 m buffer zone was mapped around each plot to allow the utilization of more trees in the analyses. These border trees were initially measured in the fall of 1989; the additional trees are used in the analyses for the 1990 and subsequent growing seasons.

The possible effects of ELF fields on total diameter growth are investigated by examining the individual tree residuals (observed growth minus the diameter growth predicted by the model) each year. If there is an effect from ELF fields on diameter growth, the residuals should increase or decrease, indicating a divergence from past patterns of growth. Any apparent increase or decrease in residuals can be further investigated by examining the relationships between the residuals and ELF field exposure variables for each site and year. Possible changes in seasonal diameter growth pattern can be examined by looking at the expected pattern of growth from the model and deviations from that pattern in the measurements.

Total Annual Diameter Growth

Differences between the predicted total annual diameter growth and the observed value were obtained by site and year for each species. If there is a change in the way a tree is responding to site or climatic conditions then the model will not perform as well. In other words, the differences between the observed and predicted diameter growth will increase if an additional factor is introduced which impacts tree growth. Average residual and studentized 95 percent confidence intervals for the average residual are given by site and year for northern red oak in Table 2.6, for paper birch in Table 2.7, for aspen in Table 2.8, and for red maple in Table 2.9. It should be emphasized that the average residuals are not the predicted average diameter growth values but they are the average differences between the diameter growth predicted for each tree and the measured diameter growth.

The differences in the numbers of observations indicated in Tables 2.6-2.9 are due to the inclusion of the mapped trees in the 10 m buffer zone in the calculation of the competition indices for additional measured trees on the study plots. In Table 2.6, for example, there were 49 observations at the antenna site in 1990. This includes the 23 trees measured in the previous years plus 26 additional trees the mapping of the buffer zone allowed to be included in 1990. This means that more than half of the observations used to calculate the average residual were new in 1990 and were not included in the analyses in previous years. This impacts the calculation of the studentized 95 percent confidence interval. Again from Table 2.6 at the antenna site, the studentized 95 percent confidence interval was calculated by taking the average residual $\pm t_{22,.05}*0.0229$ which equals the average residual $\pm$ 0.0474. In 1990, due to the increased degrees of freedom in the t value and the reduction in the standard error of the residuals due to the increased numbers of trees, the studentized 95 percent confidence interval was given by the average residual $\pm$ 0.0366, a reduction of 23 percent in the width of the interval. This increased the sensitivity of the evaluations of changes from the growth trends predicted by the model.

The information in Tables 2.6-2.9 deals with plot-level average residuals and their variance, explicit examination of the relationships with EM field exposure levels is given below. For northern red oak, 1992 is the first year since the study began when there was a difference in the average residual (as indicated by non-overlapping 95% studentized confidence intervals for the residuals) between the control and the antenna sites. Otherwise, during the pre-treatment year (1985), the testing years (1986-1988), full operational years (1989 and 1990), and 1991 when a portion of the antenna was de-energized for repairs, there were no differences in the average residuals between sites, indicating

Table 2.6. **Performance of the combined northern red oak diameter growth model by site and year.**

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	20	0.0204	0.0251	-0.0321, 0.0776
	1987	22	0.0797	0.0323	0.0125, 0.1469
	1988	23	0.0250	0.0202	-0.0169, 0.0669
	1989	23	0.0085	0.0229	-0.0389, 0.0559
	1990	49	0.0403	0.0183	0.0037, 0.0769
	1991	49	0.0872	0.0206	0.0460, 0.1284
	1992	49	0.0021	0.0167	-0.0313, 0.0355
Control	1986	61	-0.0069	0.0103	-0.0275, 0.0137
	1987	62	0.0135	0.0112	-0.0089, 0.0359
	1988	62	-0.0178	0.0113	-0.0414, 0.0048
	1989	62	-0.0144	0.0084	-0.0309, 0.0021
	1990	177	0.0154	0.0062	0.0032, 0.0276
	1991	172	0.0343	0.0073	0.0200, 0.0486
	1992	171	-0.0492	0.0068	-0.0625, -0.0359

Table 2.7. Performance of the combined paper birch diameter growth model by site and year.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	3	0.0191	0.0241	-0.0846, 0.1228
	1987	3	-0.0053	0.0153	-0.0711, 0.0605
	1988	3	-0.0048	0.0207	-0.0939, 0.0843
	1989	3	-0.0345	0.0062	-0.0612, -0.0078
	1990	8	-0.0786	0.0630	-0.2239, 0.0667
	1991	8	-0.0852	0.0579	-0.2187, 0.0483
	1992	8	-0.1080	0.0582	-0.2422, 0.0262
Control	1986	10	0.0047	0.0162	-0.0319, 0.0413
	1987	10	0.0007	0.0086	-0.0188, 0.0202
	1988	10	0.0270	0.0208	-0.0200, 0.0740
	1989	9	-0.0162	0.0059	-0.0295, -0.0029
	1990	39	-0.0382	0.0095	-0.0574, -0.0190
	1991	14	-0.0343	0.0179	-0.0705, 0.0019
	1992	14	-0.0612	0.0202	-0.1021, -0.0203

Table 2.8. Performance of the combined aspen diameter growth model by site and year.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	11	0.0282	0.0193	-0.0143, 0.0707
	1987	11	0.0599	0.0227	0.0099, 0.1099
	1988	10	0.1175	0.0175	0.0779, 0.1571
	1989	10	0.0107	0.0225	-0.0402, 0.0616
	1990	15	0.0105	0.0305	-0.0549, 0.0759
	1991	15	0.1850	0.0324	0.1155, 0.2545
	1992	15	-0.0254	0.0270	-0.0833, 0.0325
Control	1986	30	0.0533	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	-0.0240, 0.0304
	1988	28	0.0033	0.0184	-0.0345, 0.0411
	1989	28	-0.1094	0.0156	-0.1414, -0.0774
	1990	42	-0.0141	0.0120	-0.0384, 0.0102
	1991	37	0.0682	0.0122	0.0435, 0.0929
	1992	33	-0.0925	0.0170	-0.1272, -0.0578

Table 2.9. Performance of the combined red maple diameter growth model by site and year.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	70	-0.0019	0.0059	-0.0136, 0.0098
	1987	80	0.0002	0.0064	-0.0125, 0.0129
	1988	84	-0.0771	0.0053	-0.0876, -0.0666
	1989	84	0.0696	0.0049	0.0599, 0.0792
	1990	148	0.0392	0.0048	0.0298, 0.0486
	1991	146	-0.0342	0.0082	-0.0503, -0.0181
	1992	146	0.0396	0.0040	0.0318, 0.0474
Control	1986	10	0.0307	0.0143	-0.0016, 0.0630
	1987	10	0.0095	0.0129	-0.0197, 0.0387
	1988	10	-0.0852	0.0243	-0.1402, -0.0302
	1989	12	0.0599	0.0138	0.0286, 0.0912
	1990	22	0.0576	0.0123	0.0320, 0.0832
	1991	22	-0.0447	0.0175	-0.0811, -0.0083
	1992	21	0.0676	0.0092	0.0484, 0.0868

that there is very little evidence of an ELF effect on northern red oak diameter growth. This is born out below in subsequent analyses.

Paper birch growth has been severely reduced by c`imatic conditions in recent years (Jones *et al.* 1993) and the trees have apparently not yet recovered from these poor growing seasons. The control site has been more severely affected, but there are no differences in the average diameter growth model residuals between the two sites in any year (1985-1992). This indicates that there is no detectable impact of ELF fields on paper birch diameter growth which is consistent with results detailed below.

Aspen annual diameter growth residuals were increasing at the antenna site through 1988, while residuals at the control site were consistent and not different from zero (Mroz *et al.* 1989). In 1989 and 1990, when the antenna was operating at full power (150 amp), the residuals at the antenna site were not different from zero. In 1991, when EM field exposure levels at the antenna site were roughly in between those of 1987 and 1988, the aspen average annual diameter growth residuals were much greater than expected given existing climatic conditions. In 1992, when the antenna returned to full power operation, the residuals at the antenna site were again not different from zero. These results are consistent with a stimulation of aspen diameter growth by ELF fields at the ranges of exposures on the antenna site in 1987, 1988, and 1991. Further analyses investigating this possibility are discussed below.

As discussed in previous years, both the antenna and control site red maple residuals have generally been greater than or less than expected growth in different years. This is consistent with some environmental factor or factors which are not accounted for by the growth model affecting red maple diameter growth. This possibility is explicitly addressed in the analyses discussed below.

As in past years (Mroz *et al.* 1992), further evaluation of the effects of ELF fields on individual tree total annual diameter growth was conducted by examining the level of exposure to the magnetic flux generated by the antenna for all banded trees using the interpolation equations given in Appendix A. In the past, the primary method for assessing the relationships between magnetic flux exposure and diameter growth was correlation analysis. A more rigorous modeling approach was taken this year as described below. Prior to conducting these analyses, it was necessary to determine if there was serial correlation among the residuals for different years from individual trees. If there is a relationship between the residuals from different years, one would expect residuals from two successive years to be more highly correlated than those that are two, three, or more years apart. A positive correlation between residuals of different years would indicate that a tree which had greater than expected growth in one year would tend to have greater than expected growth in following years. A similar relationship would hold for trees which had less than expected growth. A negative correlation between residuals of different years would indicate that a tree which had greater than expected growth in one year would tend to have less than expected growth the following year. Similarly, a tree which had less than expected growth in one year would tend to have more than expected growth the following year.

The correlations between diameter growth model residuals in different years were calculated and averaged by species and site (Table 2.10). A one-year lag in the table indicates correlations between successive years (1986 and 1987, 1987 and 1988, and so on). A two-year lag indicates correlations between residuals two years apart (1986 and 1988, 1987 and 1989, and so on), a three-year lag indicates correlations between residuals three years apart (1986 and 1989, 1987 and 1990, and so on), up through a six-year lag (1986 and 1992). The lack of a significant correlation implies that the assumption of a time independence can be made during subsequent analyses and there is no need to consider a time-dependent structure to the residuals. There has been some variability in these comparisons from year to year (Mroz *et al.* 1992). Following the 1992 growing season, the only significant correlation in Table 2.10 is a one-year lag for red maple at the antenna site. This correlation increased to -0.27 in 1992 after being -0.22 following the 1991 growing season. Since these comparisons are tested at the p=0.05 level of significance, approximately two significant correlations (of the total of 48) would be expected in Table 2.10 due to chance alone. We will continue to monitor these relationships after the addition of the 1993 data but, for now, due to the inconsistent results in different years, the fact that only one relationship is statistically significant (which could be due to chance, especially since it was not significant last year), and the overall low levels of correlations (including the one which was significant), the subsequent analyses were performed under the assumption that there was no time dependent structure to the data. If results from 1993 indicate that it is necessary to do so, we will modify the 1993 analyses to account for a time dependent structure to the red maple residuals at the antenna site.

As discussed above, aspen at the antenna site showed greater than expected growth in 1987 and 1988 during antenna testing, and no change from expected growth in 1989, 1990, and 1992 when the antenna was operating at full power. In 1991, aspen again had greater than expected growth at the antenna site; this was the time period when the section of the antenna nearest the site was under repair and exposures were at levels between those of 1987 and 1988 at the antenna site. At least three studies have shown similar responses of the aboveground portions of plants as shown in Figure 2.1 (Wiewiorka and Sarosiek 1987, Krizaj and Valencic 1989, and Wiewiorka 1990). In all cases, there was a lower threshhold of response, a stimulation of growth, and a gradually decreasing effect at higher exposure levels.

In Table 2.11 and Figure 2.2, all observations from the antenna site were placed in one of seven classes based on average magnetic flux exposure level during a given growing season: less than 0.5 mG, 0.5-1.5 mG, 1.5-2.5 mG, 2.5-3.5 mG, 3.5-5.5 mG, 5.5-8.5 mG, and greater than 8.5 mG. Due to the extreme spatial

Table 2.10. Correlations between diameter growth model residuals in successive years by species and site.

		Time Lag					
Site	**Species**	**1 Year**	**2 Years**	**3 Years**	**4 Years**	**5 Years**	**6 Years**
Antenna							
	Northern Red Oak	-0.100	-0.205	0.038	0.061	-0.220	0.048
	Paper Birch	0.150	-0.027	0.022	-0.350	-0.180	-0.115
	Aspen	-0.416	-0.039	0.211	-0.190	-0.077	0.011
	Red Maple	-0.268 *	-0.173	0.177	-0.189	0.003	-0.049
Control							
	Northern Red Oak	-0.018	-0.089	-0.135	-0.071	-0.197	0.009
	Paper Birch	-0.130	-0.153	-0.081	-0.143	0.118	-0.112
	Aspen	-0.064	-0.240	0.075	-0.115	-0.107	-0.049
	Red Maple	-0.228	-0.217	0.229	-0.201	-0.090	0.002

A * signifies a correlation which is different from zero (p=0.05).

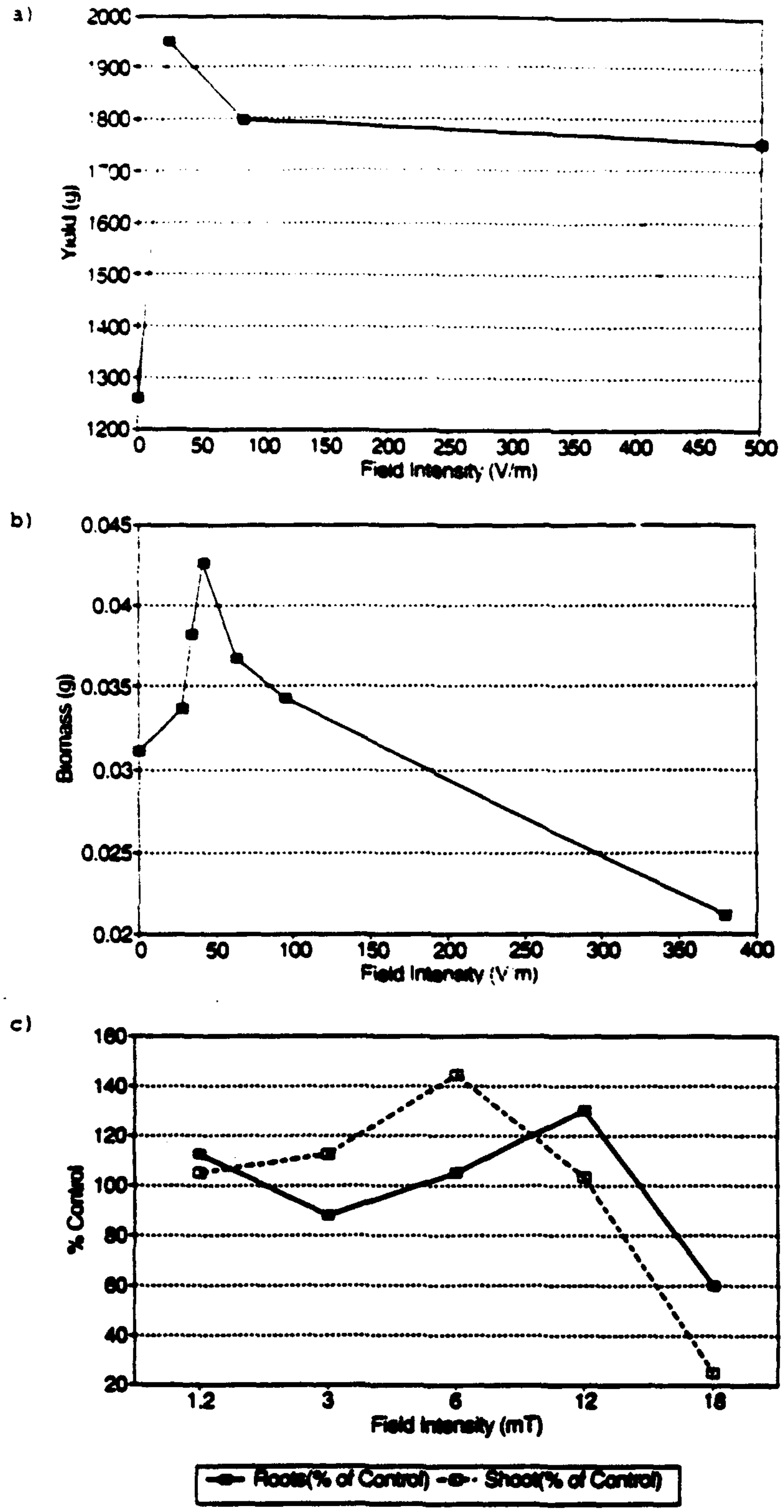


Figure 2.1. The effect of EM fields on a) tomato yield (Wiewiorka 1990), b) liverwort biomass (Wiewiorka and Sarosiek 1987), and *Lepidium sativum* (Krizaj and Valencic 1989).

Table 2.11. Number of observations and average diameter growth model residual for each species by magnetic flux exposure class.

Exposure Level	Average Diameter Growth Model Residual (cm)							
	Northern Red Oak		Paper Birch		Aspen		Red Maple	
mG	n	cm	n	cm	n	cm	n	cm
<0.5	19	-.01±.02	3	-.00±.02	11	.02±.02	70	-.02±.01
0.5-1.5	23	.07±.03	6	-.01±.01	11	.06±.02	80	-.00±.01
1.5-2.5	40	.07±.02	6	-.13±.06	9	.20±.03	101	-.05±.01
2.5-3.5	22	.08±.03	4	.03±.04	9	.15±.05	87	-.04±.01
3.5-5.5	10	.06±.03	0	-	7	.12±.02	41	-.08±.01
5.5-8.5	120	.01±.01	19	-.13±.04	27	.01±.02	306	.05±.01
>8.5	27	.07±.02	6	.01±.04	18	.01±.03	133	.06±.01

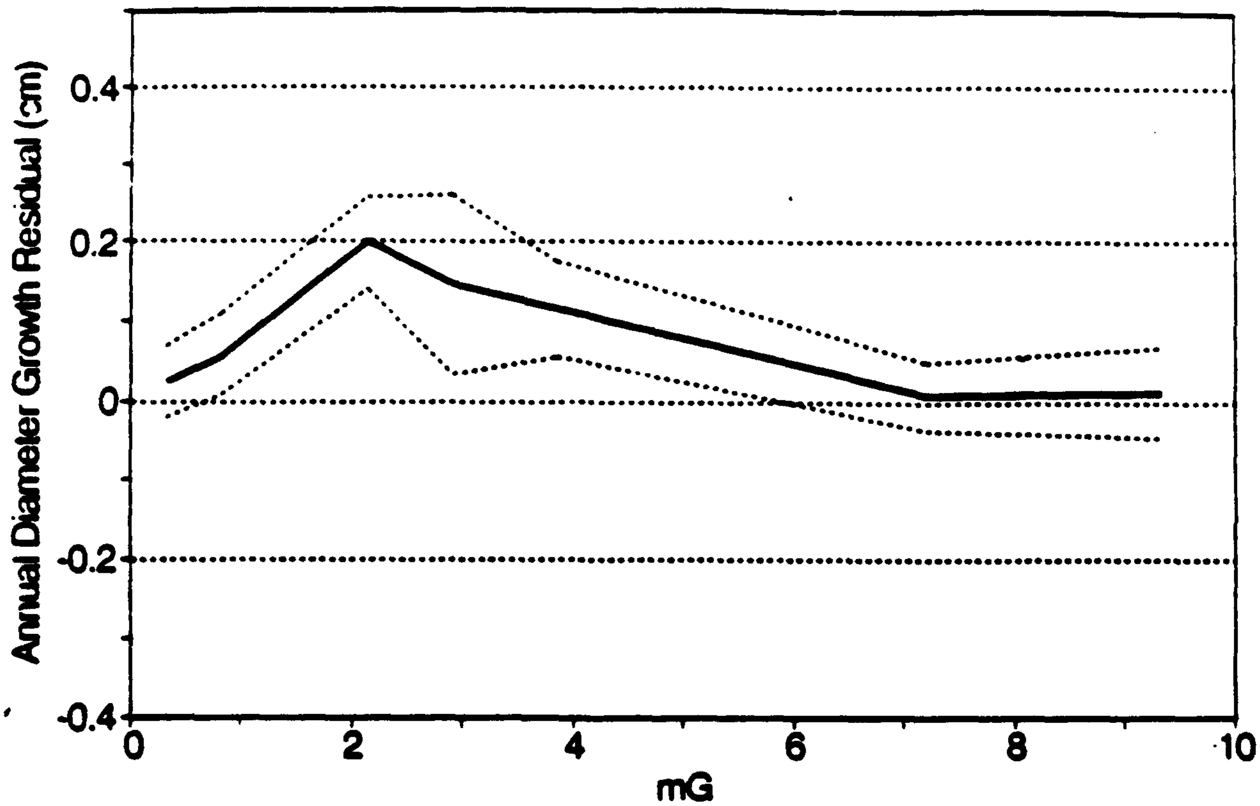


Figure 2.2. The effect of EM fields on aspen diameter growth residuals (and 95% confidence limits) from the antenna site (1986-1992).

variability of electric fields generated by the antenna (probably due to their partial dependency on soil moisture and texture, presence or absence of roots, etc.), magnetic flux is used in these analyses to represent the entire spectrum of EM fields generated by the antenna. For northern red oak and paper birch, there is no pattern in the residuals that is related to magnetic flux exposure levels. There is greater ($p<0.05$) than expected growth at exposure levels for 1.5-5.5 mG for aspen as compared to growth at low (< 0.5 mG) and high (> 8.5 mG) magnetic flux exposure levels. These growth differences were also greater than those from the control stands for the same time periods. For red maple, there is greater growth at higher exposure levels than at lower levels, but this analysis does not yet factor out the corresponding growth for the same time periods at the control site.

The approach used to quantify the relationships between the diameter growth model residuals and magnetic flux exposure is a modification of change point analyses (Esterby and El-Shaarawi 1981) based on suggestions of El-Shaarawi.[1/] The following equation was fitted for each species:

$$R_{Aik} = a_0 + b_1 R_{Ck} \qquad mG_{ik}<t_1,\ mG_{ik}>t_2$$

$$R_{Aik} = a_0 + b_1 R_{Ck} + c_0 + c_1\, mG_{ik} + c_2/mG_{ik} \qquad t_1 \le mG_{ik} \le t_2$$

where R_{Aik} is the residual from the i^{th} tree in the k^{th} year at the antenna site, R_{Ck} is the average residual from the same species at the control site for the k^{th} year, mG_{ik} is the interpolated magnetic flux exposure level for the i^{th} tree in the k^{th} year, and t_1 and t_2 are lower and upper threshholds of effect, respectively. To insure that these equations are equal at the threshholds, t_1 and t_2 were constrained during the estimation process as follows:

$$t_1 = [-c_0 + (c_0^2 - 4\, c_1\, c_2)^{1/2}] \,/\, 2\, c_1$$

$$t_2 = [-c_0 - (c_0^2 - 4\, c_1\, c_2)^{1/2}] \,/\, 2\, c_1$$

For a given species, if no differences in growth exist between the antenna and control sites, the a_0 and b_1 should equal zero. A nonzero value of a_0 indicates an inherent difference in productivity for the given species between the antenna and control sites which is not accounted for by the diameter growth model. A nonzero value of b_1 indicates that there is some environmental factor not identified in the diameter growth model which is affecting both sites. In this case, b_1 should be approximately equal to one if the effect is equal at both sites. If there is no response to the ELF fields, then c_0, c_1, and c_2

1/ El-Shaarawi, A.H. 1993. Statistical approach for assessing the impact of ELF operation on the ecosystem. Unpublished document distributed at the 1993 ELF Environmental Monitoring Program Technical Symposium, Sault Ste. Marie, MI.

should all equal zero. Nonzero values of these parameters indicate an effect of the ELF fields on tree growth.

The equations were estimated using the SAS procedure NLIN (SAS 1985). This procedure uses a recursive estimation process which allows the estimation of t_1 and t_2 simultaneously with the other parameters. Estimates for the parameters in the equations are given in Table 2.12. For paper birch, c_0, c_1, and c_2 are not different from zero, indicating no effect of ELF exposures on diameter growth. For northern red oak, c_0 and c_1 are not different from zero, but c_2 was asymptotically different from zero. A conservative conclusion is that northern red oak diameter growth is not affected by the magnetic flux exposure levels on the study plots.

For aspen and red maple, c_0, c_1, and c_2 are all different from zero, indicating that ELF fields have a significant effect on tree diameter growth after accounting for temperature, soil moisture, soil nutritional status, intertree competition, and growth potential by the diameter growth model. These results are consistent with the results from past years for aspen (Mroz *et al.* 1992). In past years, the red maple results have been confounded by the fact that there is apparently some environmental factor which similarly affects the trees on both the antenna and control sites, but which is not accounted for in the diameter growth model (Mroz *et al.* 1992). The magnetic flux equations incorporate the control site residuals and adjust for this effect; as can be seen in Table 2.12, b_1 is significantly *greater than zero* and slightly larger than one for red maple which would be expected if some factor was affecting both sites but was not accounted for in the diameter growth model.

The peak response was at 2.4 mG for aspen and 3.2 mG for red maple. The lower threshhold is around 1 mG for both species and the upper threshhold is between 6 and 7 mG. The magnitude of the peak response is 0.14 cm for aspen and 0.08 cm for red maple. These are increases of 48% and 74%, respectively, over the average diameter growth of trees on the study sites since 1984. For comparison, this is within the range of responses to nutrient fertilization experiments for aspen (Van Cleve 1973). There is still a considerable amount of variability in the responses of individual trees to ELF fields (Figures 2.3-2.4) although the cause of this is not clear.

Although the units used to measure exposure differ in various experiments and different plant species seem to respond to different exposure levels, but the response patterns in Figures 2.3 and 2.4 are clearly similar to those in controlled experiments using other species (Figure 2.1). When both field studies and controlled experiments indicate similar response, there is strong evidence of the responsiveness of plants to electromagnetic fields and the consistency of this response in different studies. Taken together, this provides strong evidence (Moesteller and Tukey 1977) of a cause and effect relationship between electromagnetic fields and plant growth stimulation.

The cellular mechanisms involved in mediating this response are unknown. A recent review article (Grundler *et al.* 1992) identifies three possible mechanisms of nonionizing

Table 2.12. Estimated coefficients and their asymptotic standard errors for ELF exposure equations for each species.

Species	a_0	b_1	c_0	c_1	c_2	t_1 a/	t_2 a/
Northern Red Oak	-0.115* b/ (0.195)	1.058 (0.051)	0.162* (0.180)	2 E-9* (0.002)	-0.009 (0.001)	-	-
Paper Birch	-0.059 (0.008)	1.131 (0.063)	3.549* (2.343)	-0.635* (0.471)	-4.590* (2.901)	-	-
Aspen	0.021 (0.010)	0.178* (0.134)	0.382 (0.102)	-0.050 (0.017)	-0.290 (0.103)	0.85	6.79
Red Maple	-0.032 (0.006)	1.331 (0.114)	0.469 (0.101)	-0.060 (0.014)	-0.635 (0.141)	1.73	6.08

a/ The asymptotic standard errors are undefined for t_1 and t_2 due to the constraints in the estimation process. The threshholds were not calculated if c_0, c_1, or c_2 were not asymptotically different from zero (p=0.05).

b/ An * indicates that the estimated coefficient is not asymptotically different from zero (p=0.05).

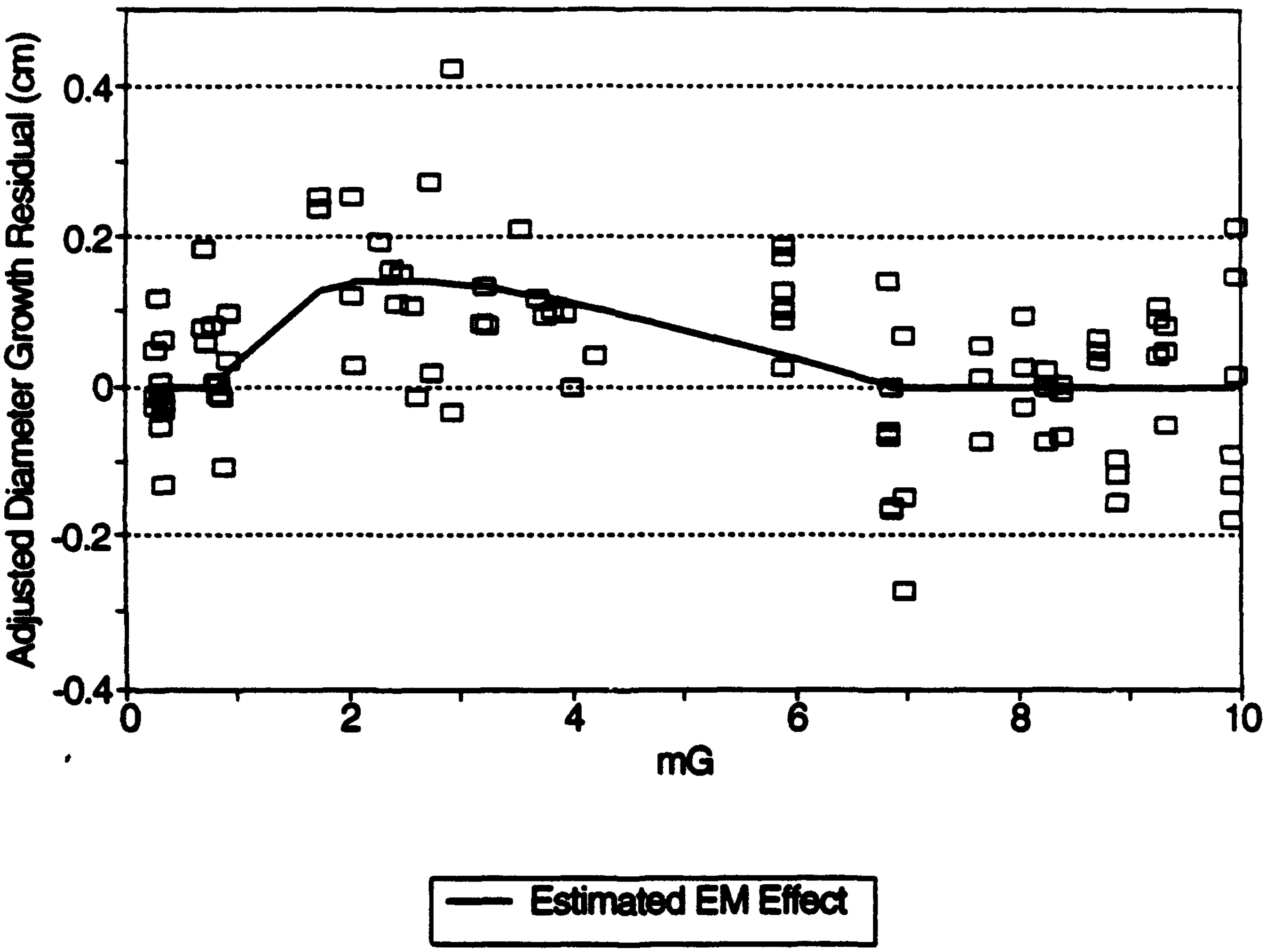


Figure 2.3. Observed aspen annual diameter growth residuals from the antenna site and estimated effect of EM fields on aspen diameter growth.

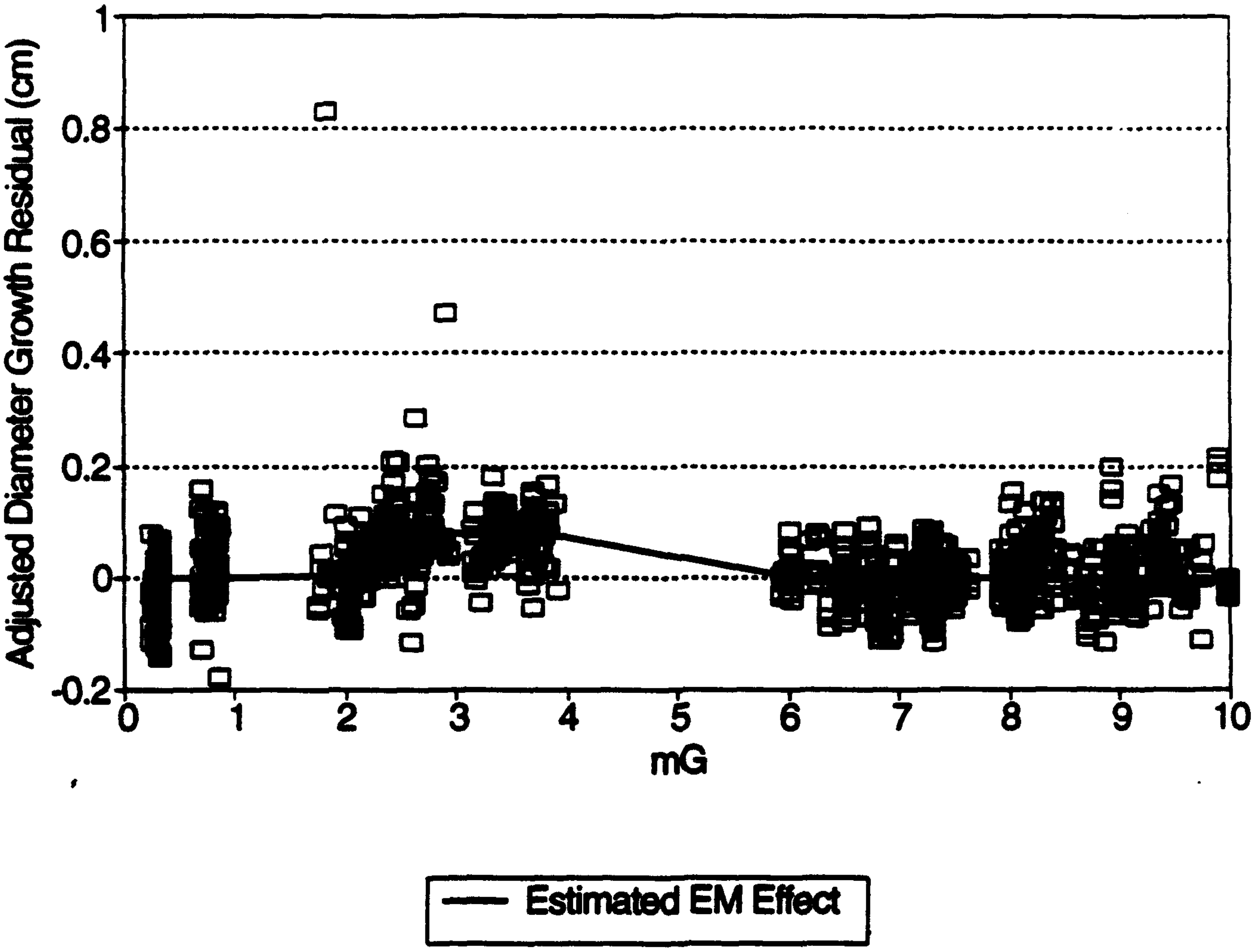


Figure 2.4. Observed red maple annual diameter growth residuals from the antenna site and estimated effect of EM fields on red maple annual diameter growth.

electromagnetic field effects on cellular systems: 1) spin-mediated electromagnetic effects in chemistry, 2) influences of weak external fields on periodic processes in a nonlinear dynamical method, and 3) biological signal transduction and amplification. There is some experimental evidence in support of all three mechanisms.

Seasonal Growth Pattern

Possible ELF field effects on seasonal diameter growth pattern are examined using the Kolmogorov-Smirnov procedure to compare the distribution of seasonal diameter growth predicted by the diameter growth model (Mroz *et al.* 1988, Reed *et al.* 1992a, Appendix C) to the observed distribution of seasonal growth from each plot each year. If an environmental factor which is not accounted for in the growth model is significantly impacting seasonal diameter growth, the observed growth pattern will differ from that predicted by the model.

There were no significant differences between the observed and predicted seasonal diameter growth pattern for northern red oak on either site in 1986, 1987, 1988, 1990 (Mroz *et al.* 1991), or 1992. In 1989 there was a significant ($p<0.05$) difference between the observed and predicted seasonal diameter growth patterns on one plot at each site. In 1991, there were no differences at the antenna site and a difference on one plot at the control site. Given these results, there is no evidence of a significant effect of ELF fields on the seasonal pattern of northern red oak diameter growth.

In past years there had been some differences between the observed and predicted seasonal diameter growth patterns of paper birch at both sites though there had been more differences at the control site than the antenna site (Mroz *et al.* 1991). In both 1991 and 1992, there were no differences ($p=0.05$) between the observed and predicted seasonal diameter growth patterns for paper birch at either site. The differences noted in the past may have been related to the apparent climatic stress on these trees and the subsequent mortality in the paper birch at the control site (Jones *et al.* 1993). There is no evidence of a significant ELF effect on paper birch seasonal diameter growth pattern.

There was a significant difference ($p<0.05$) between the observed and predicted seasonal diameter growth patterns of aspen at the control site in 1986 and 1989. At the antenna site, there was one plot, which contained only one aspen individual, which had differences between the observed and predicted seasonal diameter growth patterns in 1988, 1989, and 1990 (Mroz *et al.* 1991). In 1991 and 1992, there were no differences between the observed and predicted seasonal diameter growth pattern at either site. Since the two plots at the antenna site containing most of the aspen individuals did not show any significant differences in any year, there is no real evidence of a change in the seasonal diameter growth pattern of aspen which could be attributed to ELF fields from antenna operation.

There were significant differences ($p<0.05$) between the observed and predicted seasonal diameter growth patterns for red maple on only a single plot at the control site in 1988, on a single plot at the antenna site in 1986, and on a different plot at the antenna site in 1989 (Mroz *et al.* 1989). There were no significant differences between the observed and predicted seasonal diameter growth pattern for red maple on any plot at either site in 1989, 1990, 1991, or 1992. There is, therefore, no evidence of an effect of ELF fields on the seasonal diameter growth pattern of red maple.

Summary

1. With additional data and investigation of other analytical alternatives, it has become apparent that the analyses of covariance, which do not explicitly test for ELF effects on tree diameter growth, must be supplemented by further analyses which are discussed below. The analyses of covariance do not indicate any differences between the antenna and control sites for any species, though there is a significant site X year interaction for aspen. These results are complicated by the associations between the covariates and the ELF fields which could mask differences in total annual diameter growth between the two sites.

2. To provide a more robust analysis, the diameter growth model was developed and used to overcome many of the possible limitations of the analysis of covariance. Possible ELF field effects are examined by determining if the differences between observed and predicted diameter growth values are related to ELF exposure levels. For aspen and red maple, the results provide strong evidence of a stimulation of diameter growth at magnetic flux levels of approximately 1 to 7 mG. These results are consistent with the stimulation of aboveground production in several other plant species in controlled experiments. There is no evidence of an ELF effect on total annual diameter growth for either paper birch or northern red oak.

3. There are no differences between the observed and predicted seasonal diameter growth patterns for any of the four species which are related to ELF exposure levels.

Red Pine

Seedling Growth

Since young trees experience rapid growth rates, any effects of ELF electromagnetic fields on growth may be more easily detected on younger trees rather than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) Michigan DNR concerns over effects on forest regeneration, 2) the lack of sufficient natural conifer regeneration on the study sites for mycorrhizae studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Thus, planting of red pine at the antenna and ground sites allows the study trees to be closer to the electromagnetic source than mature tree plots which require a buffer strip of trees along the right-of-way.

Total height (cm) and basal diameter (cm) increment on the red pine seedlings are the response variables for assessing possible ELF electromagnetic field effects. Measurements made weekly (on seedling height only), every two weeks (on seedling diameter only), and seasonally (seedling height and diameter) allow examination of both the total growth in a growing season as well as the distribution of growth within the season. This study is conducted on the ground, antenna, and control sites. A summary of the average diameters and heights of trees still remaining in the analysis at the end of each growing season at each study site are found in Table 2.13. Trees which die or suffer leader damage (by ice, insects, disease, etc.) are removed from the growth analyses.

The evaluation of red pine seedling growth is divided into two areas: 1) the determination of annual growth, vigor, and survival, and 2) the evaluation of seedling growth patterns as a function of time. The overall null hypotheses tested in this phase of the study are:

> H_o: There is no difference in the level of seasonal diameter growth of planted red pine seedlings before and after the ELF antenna becomes operational.

and

> H_o: There is no difference in the level or the pattern of seasonal height growth of planted red pine seedlings before and after the ELF antenna becomes operational.

As discussed earlier in the hardwood stand analyses, evaluation of possible ELF electromagnetic fields effects on height growth is approached in two forms: the level or amount of height growth in a growing season is examined using an analysis of covariance while the pattern of height growth within a growing season is described through a nonlinear height growth model. As mentioned earlier, the

Table 2.13. Average diameter (cm) and height (cm) for each site at the end of each year of this study.[a/]

	Sample Size	Basal Diameter (cm)	Total Height (cm)
Ground			
1984	300	0.450	7.18
1985	170	0.743	22.73
1986	130	1.315	38.65
1987	124	1.935	63.46
1988	117	2.567	95.54
1989	115	3.610	141.68
1990	112	4.786	181.79
1991	106	6.241	228.08
1992	104	7.583	284.05
Antenna			
1984	300	0.441	16.80
1985	188	0.701	23.92
1986	158	1.283	41.10
1987	153	2.180	68.80
1988	137	2.862	103.43
1989	132	3.967	148.04
1990	125	5.435	192.73
1991	124	7.022	246.48
1992	121	8.302	299.50
Control			
1984	300	0.459	18.96
1985	217	0.792	28.33
1986	203	1.370	50.86
1987	191	2.131	82.70
1988	184	2.726	117.71
1989	172	3.741	160.80
1990	168	5.107	206.28
1991	155	6.505	266.50
1992	148	7.745	328.68

a/ These data include only trees which have not died or been damaged either in height or diameter during the study years.

ELF system has operated at low levels throughout the 1986 (6 amps), 1987 (15 amps) and 1988 (75 amps) growing seasons. Since 1989 the system has operated at full power (150 amps). However, as mentioned earlier, the east-west antenna was de-energized for repairs early in the 1991 growing season (May 8-July 12) as well as from December 23 to March 28. Each of these analyses examines possible site differences as well as any existing differences between pre-operational years (1985-1988) and post-operational years (1989-1993). The analysis of covariance table used is the same as that found in the hardwood studies (Table 2.3). Development of a nonlinear height growth model from previous year's data (Mroz *et al.* 1988 and Jones *et al.* 1991, Appendix C) provides weekly residuals from the model for individual seedling height growth. By examining the residuals, comparisons may then be made between different levels of antenna operation across time as well as any changes due to site or climatic variables. Their effects on the amount and timing of seasonal height growth can then be evaluated. The amount of diameter growth in a growing season is analyzed solely through an analysis of covariance.

Sampling and Data Collection

Areas at the antenna, ground, and control sites were whole-tree harvested in June of 1984. These areas were immediately planted with 3-0 stock red pine seedlings at a 1 m by 1 m spacing. This density provided adequate numbers of seedlings for destructive sampling throughout the study period, allowed for natural mortality, and will leave a fully stocked stand when the study is completed. Following planting, 300 seedlings at each site were randomly selected and permanently marked for survival and growth studies. Additional details concerning the establishment of the red pine plantations can be found in past reports (Mroz *et al.* 1985, 1986).

Natural mortality following the first full growing season (1985) was 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control site. This mortality was somewhat high due to the late planting date which resulted in planting shock as well as desiccation of seedlings during handling and planting. In addition, Mroz *et al.* (1988) observed that 61 percent of the apparently healthy seedlings that did not form terminal buds following planting died, which further indicates the inability of some seedlings to adapt to the planting site. Precipitation during 1985 was adequate for seedling establishment and competition around each seedling was minimal. It is unlikely that these environmental factors had a significant effect in causing this mortality. The mortality that occurred in 1985 was not evident in subsequent years (Table 2.13).

Natural vegetative recovery following whole-tree harvesting in 1984 increased in 1986. This vegetation competed with the red pine seedlings for physical resources such as moisture, nutrients, and light. Vegetation control was necessary in 1986 to prevent the competing vegetation from affecting the unrestricted growth of the seedlings. In early June of 1986, competing vegetation was mechanically removed from each plantation plot using gas powered weed-eaters equipped with brush blades. This method was successful in releasing overtopped seedlings and essentially eliminating competition in 1986. Since then we have found sufficient carryover effect to suggest that it was not necessary to repeat weed control again, although woody stump sprouts and aspen suckers were mechanically removed in 1989.

For red pine growth analyses, each of the live permanently marked seedlings on each site was measured at the end of the 1984 through 1993 growing seasons and the following information recorded:

basal diameter (cm)
total height (cm)
terminal bud length (mm)
microsite
physical damage
presence of multiple leaders
number of neighboring seedlings

Information on microsite, physical damage, multiple leadered seedlings, and the number of neighboring seedlings was collected for use in explaining results of the growth analyses. Those individuals suffering physical damage severe enought to reduce growth as well as multileadered individuals were identified and removed form the permanent data set. Microsite described the physical environment in the immediate vicinity of the seedling such as rocky soil surface or proximity to a stump or skid trail. In 1988 this measurement also included whether the seedling was located in a frost pocket or not. This was based on a visual determination of the surrounding topography. Any physical damage to a seedling such as frost or animal damage was also recorded. Some seedlings possess two or more leaders, none of which expressed dominance over the others, and this situation was noted as well. In addition, beginning in 1987, the number of seedlings surviving in neighboring planting spacings was also recorded to aid in describing any future competition for light and moisture between neighboring seedlings. In 1989, the position and the elevation of each seedling was mapped on a coordinate system; this is used in estimating exposure ELF fields. In order to account for evident competition between seedlings for available resources, additional measurements were made on neighboring seedlings in 1990 - 1993. These measurements included the distance of each neighbor to the seedling, the neighbor's diameter, height, previous year's growth, and crown width.

To further describe the growth of the red pine seedlings, a subsample of 100 seedlings per site was selected from the permanently marked seedlings for weekly height growth measurements. These weekly measurements were obtained in 1985 through 1993. Measurements began in mid-April while shoots are still dormant and continued until mid-July when shoot elongation was completed. Measurements were made from the meristematic tip or the tip of the new terminal bud to the center of the whorl of lateral branches.

Progress

Growth Analysis

The two response variables in this segment of the study are height and diameter increment of red pine seedlings. Differences in total seasonal height or diameter increment from site to site or from year to year are analyzed through the analysis of covariance where tree, soil physical and chemical properties, and climatological data are used as covariates. The pattern of height growth in terms of the elongation of the leading shoot during the growing season is depicted through a growth model. This analysis supplements the analysis of covariance to further account for the variability between sites and over time. The model has been developed to describe the pattern of weekly height increment only and will be used to provide a weekly residual for each tree. The residual is examined to determine if current year shoot elongation changes from patterns observed in earlier growing seasons.

Total Annual Height and Diameter Growth

Covariate selection

Separate analyses of covariance examine differences in seasonal height and diameter increment among the three sites as well as from year to year. At this point there are nine years of growth measurements (1985 through 1993). The 1993 growth and climate data are not yet completely edited and summarized for inclusion in the analyses. All growth analyses discussed include data from 1985 through 1992 only. The average seasonal growth for each of these response variables on each site at the end of each growing season are found in Table 2.14. Covariates for analyses on both height and diameter growth were selected based on an intensive variable screening procedure discussed in previous work (Mroz *et al.* 1988). No modification of covariates has been

Table 2.14. Average seasonal diameter growth (cm) and height growth (cm) for each site from 1985 to 1992. [a/]

	1985	1986	1987	1988	1989	1990	1991	1992
Diameter Growth (cm)								
Ground	0.27	0.53	0.60	0.54	0.95	1.07	1.42	1.33
Antenna	0.23	0.55	0.86	0.65	1.09	1.41	1.59	1.30
Control	0.32	0.57	0.76	0.61	1.02	1.33	1.48	1.21
Height Growth (cm)								
Ground	5.08	14.28	23.75	28.70	41.99	36.64	46.00	52.59
Antenna	6.61	16.06	26.96	33.53	46.03	41.28	54.29	51.58
Control	8.34	22.34	31.87	35.02	42.73	43.89	62.34	43.81

a/ These data include only trees which have not died or been damaged either in height or diameter during the study years.

done;covariate determination was completed using information collected prior to antenna operation.

Annual height growth

Past analyses (Mroz *et al.* 1988) indicated that use of the previous year's site physical and chemical and climatic data explained more site and yearly variation than the current year's data when analyzing annual height growth. For this reason, height growth occurring from 1986 to 1992 coupled with 1985 to 1991 soil physical and chemical properties and climatic data are included in this particular analysis. The use of the previous year's soil physical and chemical properties and climatic data provides results that are consistent with the fact that red pine is a species of deterministic growth. Height growth in any year is strongly related to the size of the terminal bud which was formed under the previous year's site physical, chemical and climatic conditions (Kozlowski *et al.* 1973). The covariates identified from previous work (Mroz et al. 1988) were implemented again in the analyses of covariance. These covariates included average maximum air temperature for the month of June, total Kjeldahl nitrogen in the upper 15 cm of mineral soil during July, and water holding capacity from 10 to 30 cm in the soil.

Prior to the analysis of covariance, an analysis of variance (no covariates included) was performed and highly significant differences in height growth were found among the three sites and among the three study years ($p<0.001$). There was also a significant interaction between the study sites and years ($p<0.001$) (see Table 2.15). With the addition of the three above-mentioned covariates, existing yearly differences in annual height growth still exist ($p<.05$) in the analysis of covariance. A significant site-year interaction also remained, indicating that the relationship between individual tree height growth rates on the three sites changed over time.

In order to identify where the significant differences in average annual height growth exist among the study sites and among the study years a SNK multiple comparison test (Zar 1980) was performed on the adjusted mean height growth values (Table 2.16). The test showed:

1) the ground and antenna sites were not ($p=0.05$) from each other each year, but that the control site was different ($p=0.05$) from the two test sites each year except 1989, 1991, and 1992

2) average height growth for each site is significantly different ($p=0.05$) each year

The significant time factor is not surprising when considering the young age of the seedlings. Early growth is

Table 2.15. Significance levels from the analysis of height growth (cm) and diameter growth (cm) with and without the use of covariates.

Factor	No Covariates	Covariates
Height Growth (cm)		
Site	0.0392[a/]	0.3110
Year	0.0000	0.0000
Site X Year	0.0000	0.0000
Diameter Growth (cm)		
Site	0.0001	0.0082
Year	0.0000	0.0000
Site X Year	0.0000	0.0000

a/ A significance level smaller than 0.05 indicates a significant effect (p=0.05).

Table 2.16. Significant relationships in the analyses of covariance on both sites and among years for mean seasonal height growth (cm) which have been adjusted by the covariates and arranged in order of magnitude from lowest to highest.[a/]

Pre-Operational (1986-1988)

A86^{a} G86^{a} G87^{ab} G88^{ab} A87^{b} C86^{b} A88^{bc} C87^{c} C88^{c}

Post-Operational (1989-1992)

G90^{cd} G89^{cde} A90^{cde} C89^{de} C90^{e} C92^{ef} G91^{ef} A89^{ef} C91^{f} A91^{f} A92^{f} G92^{f}

a/ Different letters indicate significant differences (p=0.05) in adjusted height growth. The letter G signifies the ground site, A signifies the antenna site, and C signifies the control site.

generally sigmoidal in shape until the seedlings are older and growth slows down and becomes more linear. An assumption in the analysis of covariance is that the covariates are independent of the levels of ELF magnetic flux density (mG); in this case, each covariate selected should not be correlated with the EM field exposure levels to avoid confounding any possible effects of the fields on tree growth. Because in previous years correlations between covariates and EM field exposures have been found (*Mroz et al.* 1992) and confounds the analysis of covariance further, an alternate analysis which is discussed in the height growth model analyses below addresses height growth in more detail using a method which explicitly tests whether or not the EM field exposures are affecting height growth on red pine. Thus, at this point in time, the covariate analysis indicates significant differences ($p=0.05$) among the three sites and among all growing seasons. However, from this particular analysis, there is not a clear picture of what may be causing these differences.

Annual diameter growth

In the diameter growth analyses, the current season's site physical, chemical and climatic data explained more site and yearly variation than information from the previous season. This is consistent with the physiological nature of the seedlings. Thus, in the diameter growth analyses, average annual growth from 1985 through 1992 were used in the analyses.

As found last year, the existence of multicollinearity reduced the number of covariates in this analysis by one; only three variables now are used in the analysis. Minimum air temperature in May no longer adds to the analysis and was removed. The three remaining variables explaining the greatest amount of variation were: air temperature degree days through August (on a 4.4^{o} basis), total Kjeldahl nitrogen in July, and available water at 10cm in the month of August. The selection of climatic variables is consistent with the fact that cambial growth begins a little later than shoot elongation (which begins in mid-April) and is only two-thirds completed when shoot growth ceases (end of July). The need to include variables to account for soil nutrient differences and possible moisture stresses is also consistent with other covariate selections.

Initial analysis of variance (without the use of covariates) found highly significant differences among sites and among study years ($p<0.0001$). There also was a significant interaction between study sites and years ($p<0.0001$) indicating that the trends in growth on the sites were not constant from year to year (Table 2.15).

With the addition of the covariates, neither site differences (p=.0082) nor yearly differences (p<0.001) were completely explained and a site-year interaction (p<.001) still remained (Table 2.15). Because of the existing differences, SNK multiple comparison tests (Zar 1980) were employed to examine the adjusted diameter growths from the covariate analysis on each site during each study year. Table 2.17 depicts the differences (p=0.05) among the sites and among the study years.

Each of the three test sites are significantly different (p=0.05) from one or both other sites before and after the antenna became operational. At the same time, the diameter growth at each site was generally different (p=0.05) each year both before and after the antenna became operational. However, except for the 1987 growing season, the diameter growth patterns were consistent from year to year among the three sites; diameter growth either increased or decreased in a given growing season at all three sites (Figure 2.5). There are existing significant correlations between covariates and EM field exposures (*Mroz et al.* 1992) which helps to present a confounded picture. Zhang's work (1992) found site differences in red pine biomass were due to differences in site characteristics; therefore, the existing differences in average annual diameter growth from the covariate analysis may be the result of site characteristics not accounted for by the covariates rather than the EM fields.

Seasonal Pattern of Height Growth

Height growth models based on incremental seasonal growth of the leading shoot were developed (Jones *et al.* 1991, Appendix C). Possible ELF field effects were examined through the residuals from the growth model (observed height growth minus predicted height growth) and compared by site and year to determine if they remain the same, increase, or decrease. They also evaluate changes that might occur in the pattern or timing of seedling height growth among the three study sites or from year to year (Jones *et al.* 1991 and Mroz *et al.* 1988). The model is comprised of two components. Previous work by Perala (1985) found that climatic conditions were more useful predictors and could explain much of the variation in the timing and the amount of shoot elongation among sites. In this study air temperature degree days (on a 4.4° C basis) is the ambient variable comprising the first component. To further explain the variation in the system, a negative exponential component modifies the expected growth based on soil water tension (Zahner 1963). The height growth model provides an weekly residual for each seedling at each site each year where the residual is equal to observed individual tree height growth minus predicted individual tree height growth.

Table 2.17. Significant relationships in the analyses of covariance on both sites and among years for mean seasonal diameter growth (cm) which have been adjusted by the covariates and aranged in order of magnitude from lowest to highest.[a/]

Pre-Operational (1985-1988)

G86[a] G85[a] A85[ab] C87[ab] G87[ab] C85[bc] C86[cd] A86[d] G88[d]

C88[e] A87[ef] A88[f]

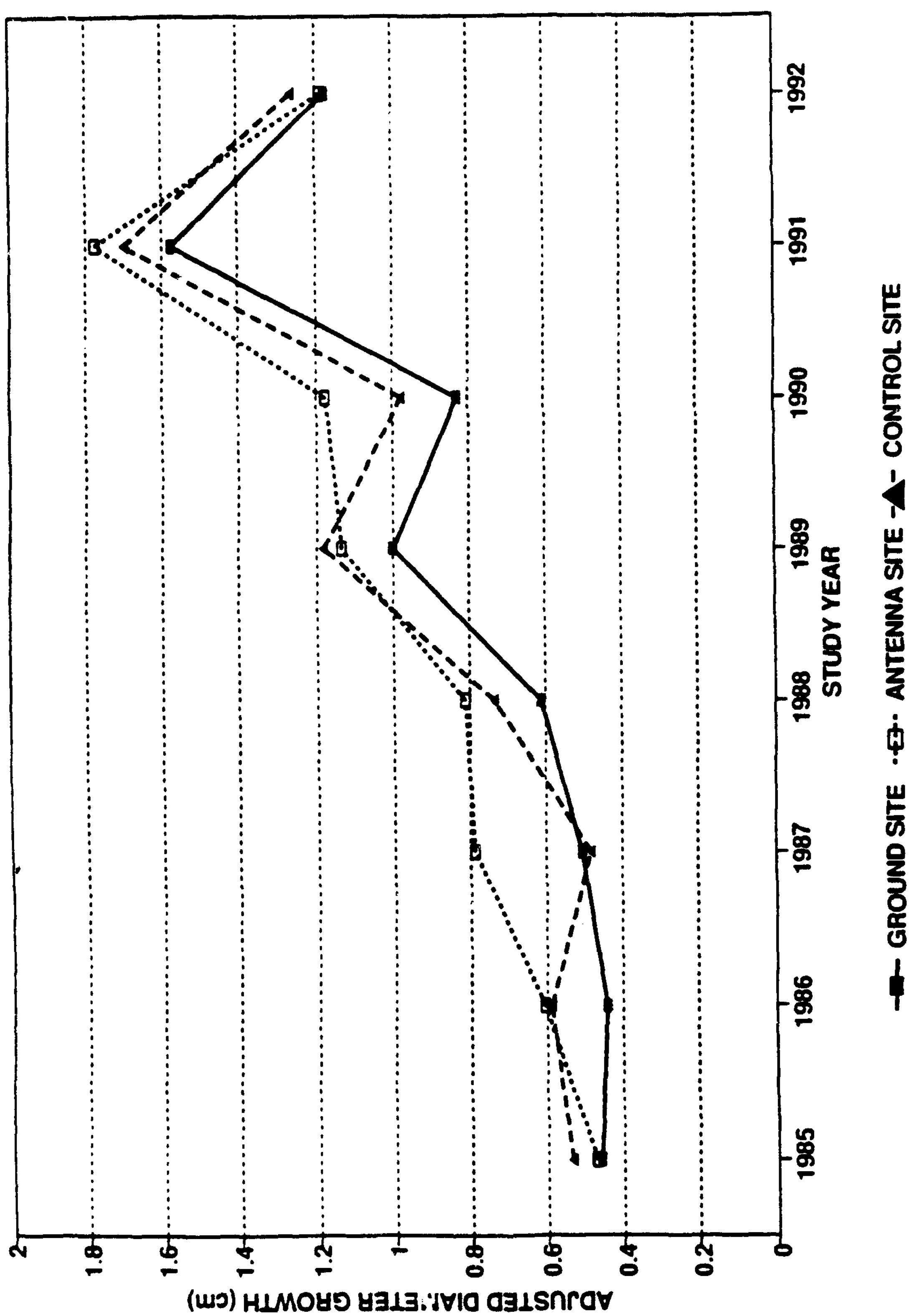
Post-Operational (1989-1992)

G90[f] C90[g] G89[g] A89[h] G92[h] A90[h] C89[h] A92[h] C92[i]

G91[j] C91[k] A91[l]

a/ Different letters indicate significant differences (p=0.05) in adjusted diameter growth. The letter G signifies the ground site, A signifies the antenna site, and C signifies the control site.

Figure 2.5 Adjusted height growth (cm) for the three study sites from 1986 to 1992.



If there is any change attributable to EM fields in the height growth from previous years, the residual will either increase or decrease. Although the cumulative curves may mask any possible absolute differences, the advantage in standardizing is that established proportions of growth may be examined.

As discussed earlier with the hardwood diameter growth residual analysis, the independence of the red pine height growth residuals with respect to time was tested before any further analysis. The correlations between seedling height growth residuals were calculated and averaged by site. A one year lag compared the correlations between successive years (1986 and 1987, 1987 and 1988, 1988 and 1989, 1989 and 1990, 1990 and 1991, and 1991 and 1992). Similarly, a two year lag compares correlations which are two years apart, a three year lag compares correlations which are three years apart, a four year lag compares correlations which are four years apart, and a five year lag compares correlations which are five years apart. Significant correlations (p=0.05) were found for the first time (Table 2.18). There was a significant correlation between residuals in a one-year time lag at all three sites and between residuals in a two-year time lag at the ground and antenna sites. Because no correlations for any of the time lags at any of the three sites were significantly different from zero (p=0.05) for any time lags in previous years and because all of the significant correlations were generally low (the significant correlations have p-values between 0.01 and 0.005), subsequent analyses were performed under the assumption that there was no time dependent structure to the data. If results from 1993 indicate that it is necessary to do so, the 1993 analyses will be modified to account for a time dependent structure to the red pine height growth residuals.

Examination of the residuals from 1986 through 1992 found no significant differences (p=0.05) between the observed proportions and the predicted proportion of seasonal height growth (Table 2.19 and Figure 2.6). The 95% studentized confidence intervals from all sites overlapped zero as well as overlapping each other. However, the inconsistent pattern in residual values from year to year indicates that there may be some environmental factor or factors which are not accounted for by the growth model. Therefore, additional analyses using these residuals was incorporated in the same manner with which the hardwood residuals from the diameter growth model were addressed.

The average residuals generally showed predicted height growth was greater than that which was observed each growing season. As discussed previously in the hardwood section, all red pine observations from the ground and antenna sites were placed in one of seven classes based on average magnetic flux density exposure level during a given growing season. The classes ranged from < 0.5 mG up to > 8.5 mG (see Table 2.20 and Figure 2.7). From Table 2.20 and Figure 2.7, it is apparent that the same trend which was found for

Table 2.18. Residual analysis from the height growth model for the ground, antenna, and control sites (1986-1992).

Year	Average Weekly Residual (cm)	Studentized 95% Confidence Interval (cm)
Ground Site		
1986	-0.0568	(-0.2019, 0.0833)
1987	-0.0762	(-0.2998, 0.1474)
1988	-0.0400	(-0.3216, 0.2417)
1989	-0.1098	(-0.3430, 0.1234)
1990	-0.1466	(-0.6388, 0.3456)
1991	-0.1020	(-0.5006, 0.2966)
1992	0.0111	(-0.6101, 0.6322)
Antenna		
1986	-0.1093	(-0.2258, 0.0072)
1987	-0.0708	(-0.2608, 0.1192)
1988	0.0427	(-0.2564, 0.3418)
1989	-0.1533	(-0.3847, 0.0781)
1990	-0.1577	(-0.7057, 0.3899)
1991	-0.1074	(-0.5054, 0.2906)
1992	0.0247	(-0.6107, 0.6601)
Control		
1986	-0.0687	(-0.2600, 0.1226)
1987	-0.0562	(-0.2723, 0.1597)
1988	-0.0600	(-0.3238, 0.2038)
1989	-0.1091	(-0.3555, 0.1373)
1990	-0.1348	(-0.7494, 0.4797)
1991	-0.0967	(-0.5892, 0.3958)
1992	0.0385	(-0.7915, 0.8685)

Table 2.19. Autocorrelations for one through six year lags at the ground, antenna, and control sites (1985-1992).

	Ground	Antenna	Control
One-Year Lag	0.3655 *	-0.2813 *	0.3528 *
Two-Year Lag	-0.2601 *	-0.2924 *	-0.1695
Three-Year Lag	-0.1408	-0.2419	-0.2003
Four-Year Lag	-0.0748	0.0853	-0.1238
Five-Year Lag	-0.0731	0.0026	-0.0526
Six-Year Lag	0.0728	0.0077	0.0365

A * indicates that the correlation coefficient is significantly different from zero (p=0.05).

Figure 2.6. Red pine height growth residuals for the three study sites from 1986 to 1992.

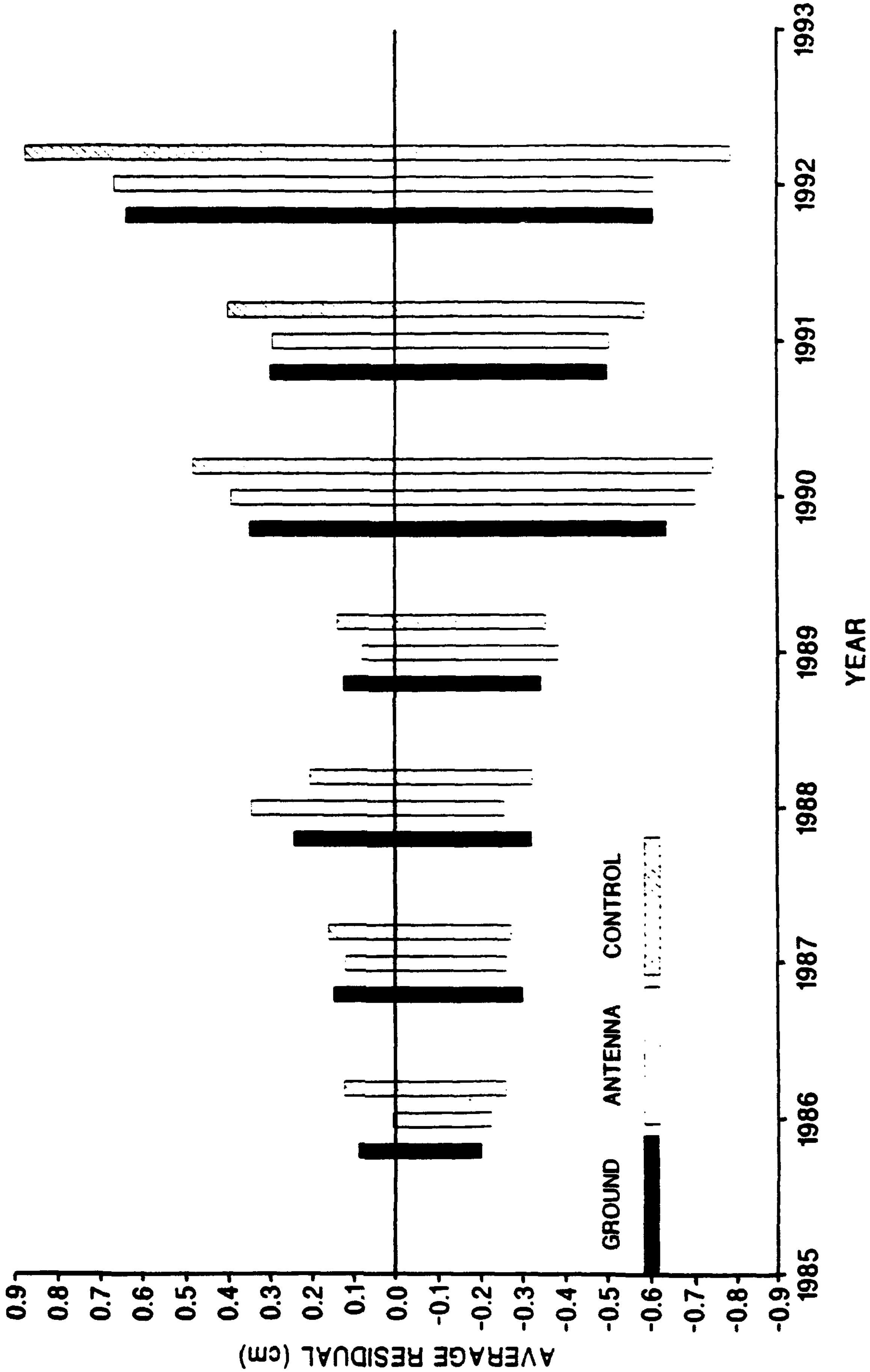
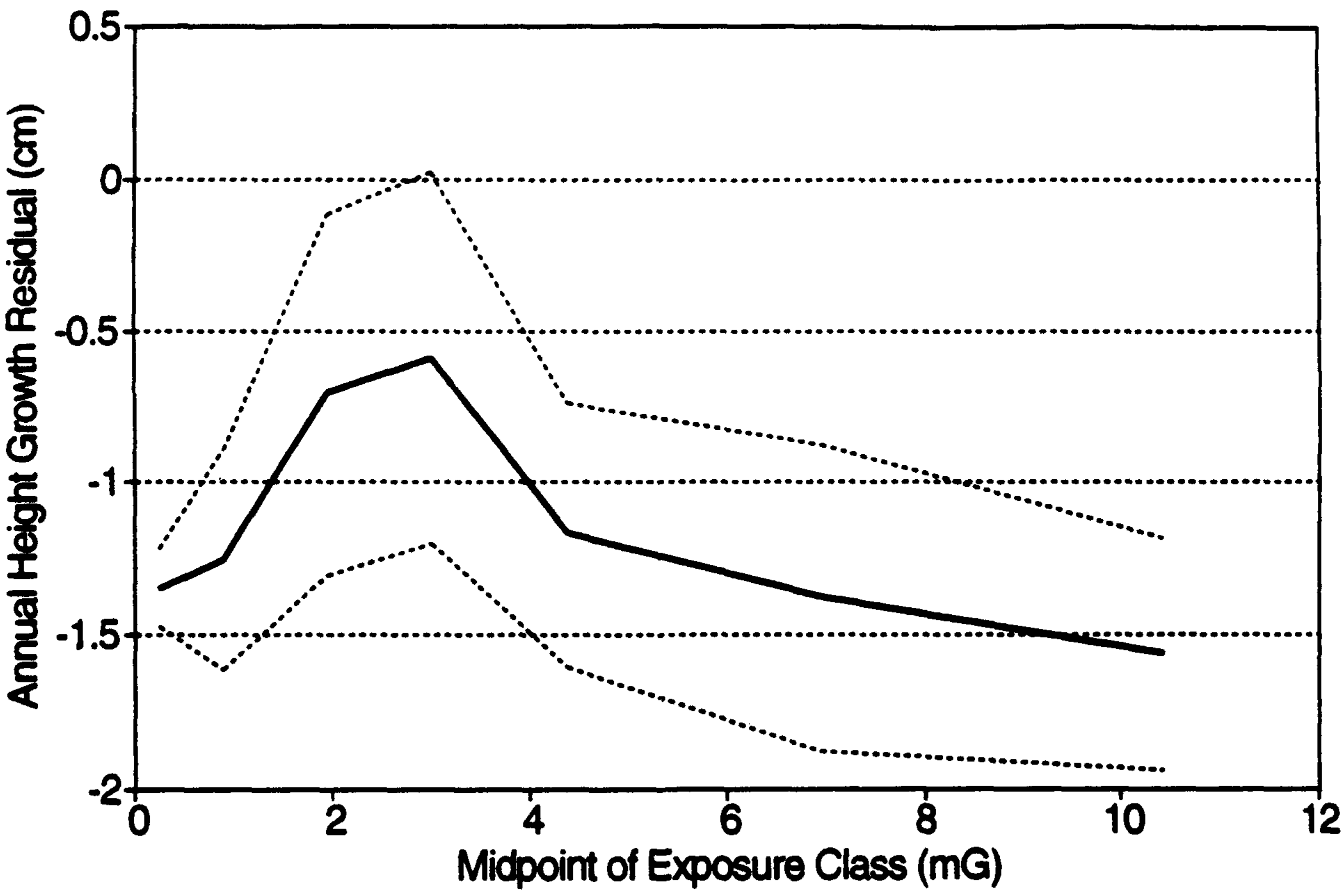


Table 2.20. Number of observations and deviation from expected growth for each species by magnetic flux exposure class.

Exposure Level	Deviation from Expected Growth [a]			
	Ground		Antenna	
	n	cm	n	cm
<0.5	91	-1.06±.09	117	-1.35±.08
0.5-1.5	66	-1.09±.12	75	-1.26±.22
1.5-2.5	44	-1.38±.20	55	-0.71±.36
2.5-3.5	40	-1.38±.24	44	-0.59±.36
3.5-5.5	53	-1.30±.21	68	-1.17±.26
5.5-8.5	30	-1.24±.39	36	-1.39±.30
>8.5	63	-1.32±.31	44	-1.57±.22

a/ Average observed minus predicted height growth.

Figure 2.7. Red pine height growth versus EM fields at the antenna site for 1986 to 1992.



the residuals for aspen diameter growth is also true for the residuals for red pine height growth. The larger residuals at exposure levels of 1.5 to 3.5 mG indicate a greater than expected growth $(0.05<p<0.10)$ as compared to the growth at low (< 0.5 mG) and high (> 8.5 mG) magnetic flux density exposure levels. This trend with residuals from the red pine height growth analysis was not apparent at the control site.

To quantify these relationships between residuals and magnetic flux exposure, the modified change point analyses (Esterby and El-Shaarawi 1981) described in the hardwood section were employed. Estimates of the parameters from this analysis are given in Table 2.21. For red pine, c_0, c_1, and c_2 were all significantly different from zero $(p=0.05)$ at both the antenna and ground sites. This indicates that there is an effect of electromagnetic fields on tree growth after accounting for site and climatic factors used in the height growth model. The peak response was at 2.2 mG; the lower threshhold was approximately 1 mG and the upper threshhold was approximately 6-7 mG. These results are consistent with those found in the hardwood section as well as several plant species in controlled experiments, though at differenct exposure levels (Krizaj and Valencic 1989, Wiewiorka 1990, Wiewiorka and Sarosiek 1987).

The Kolmogorov-Smirnov procedure was employed to examine if EM fields affected the seasonal height growth pattern. Differences in the distribution of observed cumulative growth percentage and that predicted by the growth model were calculated for each plot at each site for the 1986 throught the 1992 growing seasons. If an enviromental factor which is not accounted for in the growth model significantly impacts seasonal height growth, then the observed growth pattern will differ from the predicted and the difference between the two will be significantly different from zero. Figures 2.8, 2.9, and 2.10 illustrate the observed and predicted cumulative growth percentages at each site for the 1992 growing season. There were no significant differences $(p=0.05)$ between the observed and predicted distributions of growth on any plot at any site during this year; this result has held true for all study years to date (1986 through 1992). This suggests that ELF fields have had no significant impact on the pattern or distribution of seasonal height growth through the 1992 growing season.

Summary

1. The analyses of covariance indicate that diameter and height growth differences do exist among sites and years. The analyses is confounded because of the violation

Table 2.21. Estimated coefficients and their asymptotic standard erro… …r the antenna and ground sites.

Species	a_0	b_1	c_0	c_1	c_2	t_1 a/	t_2 a/
Antenna Site							
	-0.144*	1.107	1.959	-0.262	-1.208	0.68	6.80
	(0.145)	(0.085)	(0.337)	(0.070)	(0.450)		
Ground Site							
	-0.247	0.882	9.669	-1.144	-17.865	2.73	5.72
	(0.079)	(0.049)	(4.113)	(0.503)	(8.057)		

a/ The asymptotic standard errors are undefined for t_1 and t_2 due to the constraints in the estimation process. The threshholds were not calculated if c_0, c_1, or c_2 were not asymptotically different from zero ($a = 0.05$).

b/ An * indicates that the estimated coefficient is not asymptotically different from zero ($p=0.05$).

Figure 2.8. The observed versus predicted height growth for red pine at the ground site in 1992.

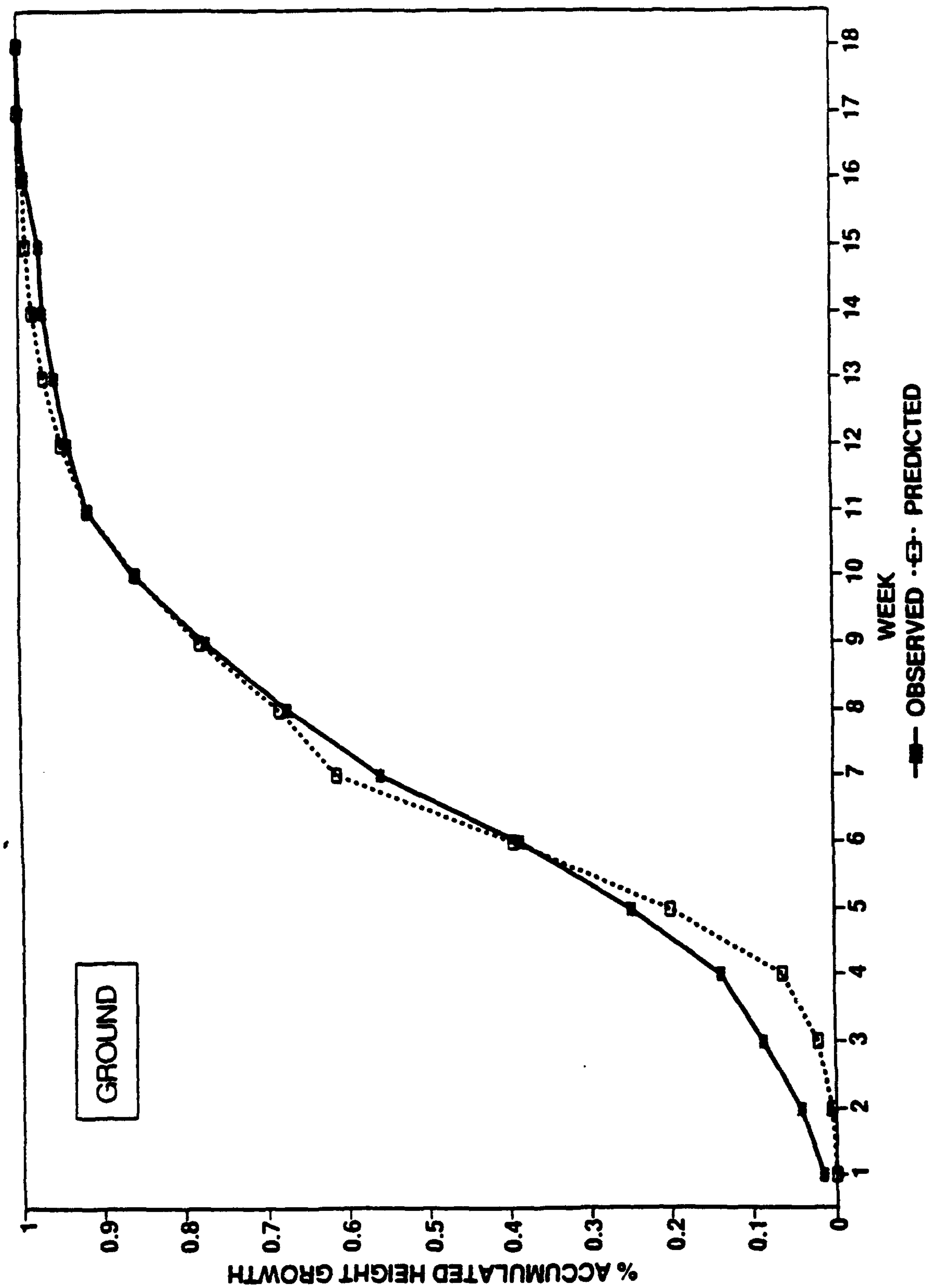


Figure 2.9. The observed versus predicted height growth for red pine at the antenna site in 1992.

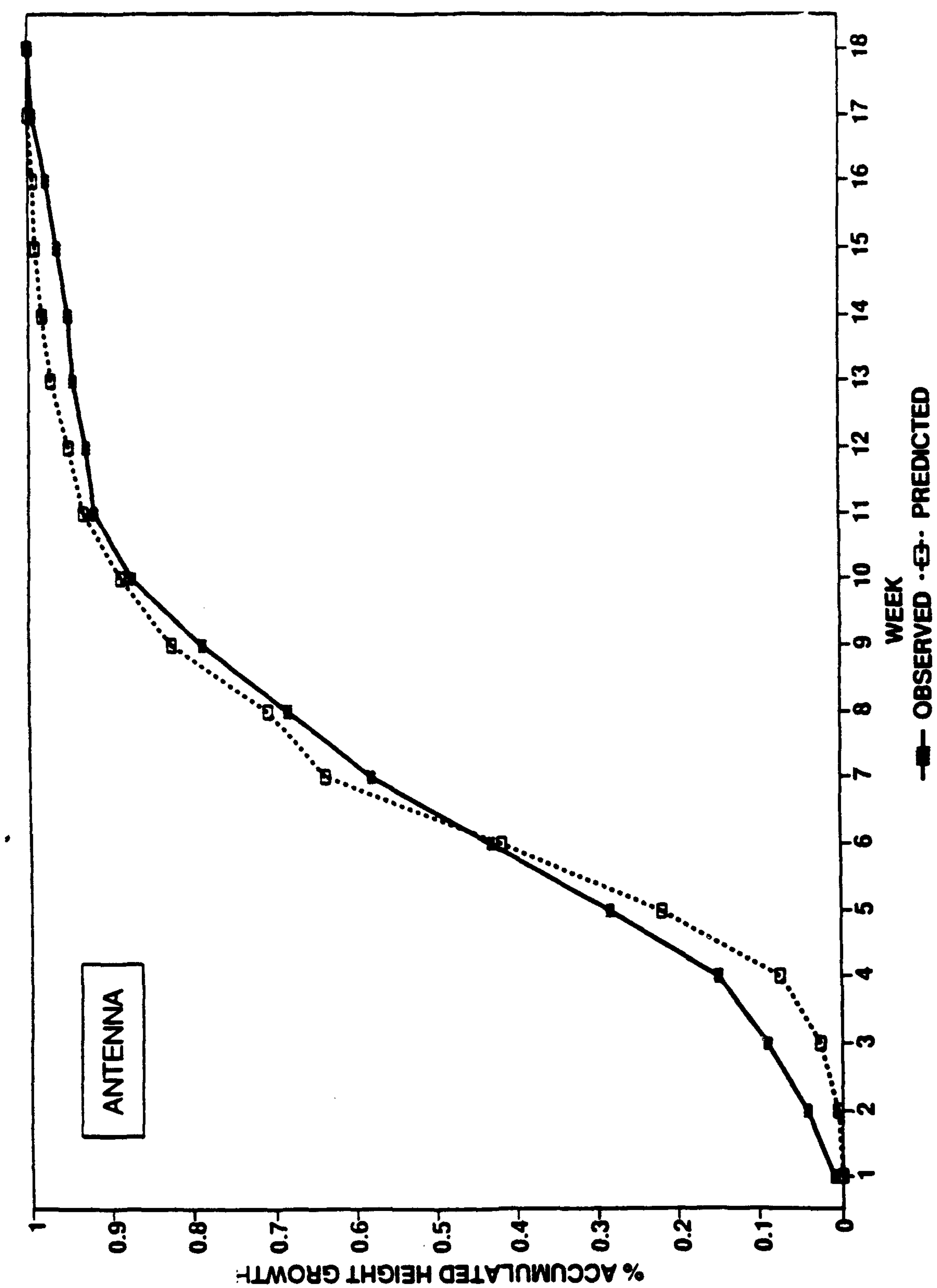
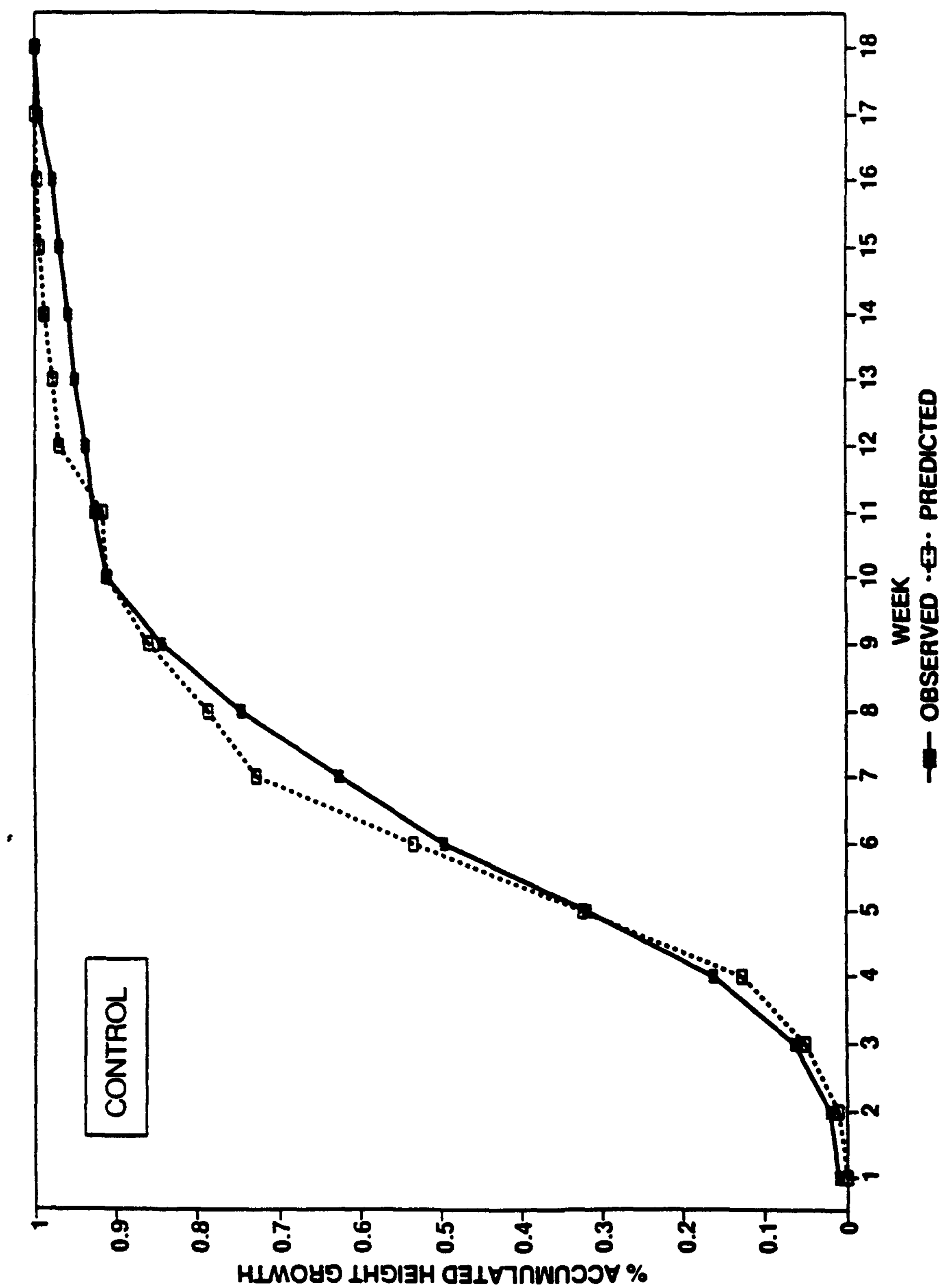


Figure 2.10. The observed versus predicted height growth for red pine at the control site in 1992.



of some assumptions and thus the differences can not be directly attributed to EM field exposures.

2. The individual height growth model was developed to supplement the analysis of covariance. Effects due to ELF fields were examined by determing if a relationship existed between the growth model residuals and the EM field exposures. The results showed a stimulation of height growth at magnetic flux levels of 1 mG to 7 mg.

3. Results from the Kolmogorov-Smirnov test indicate that there is no difference between the observed and predicted seasonal height growth patterns due to ELF EM fields through the 1992 growing season.

Red Pine Foliage

The macronutrients (N,P,K,Ca, and Mg) are important constituents of plant tissues, catalysts in biochemical reactions in plants, osmotic regulators in plant cells, and regulators of plant cell wall permeability (Kramer and Kozlowski 1979). Thus an adequate supply of macronutrients is needed by plants to remain healthy and complete a normal life cycle (Binkley 1986, Kramer and Kozlowski 1979). Healthy individuals of a given specie which receive adequate supplies of nutrients will generally exhibit (at a given developmental stage and time of the year) relatively consistent macronutrient concentrations and ratios in a specific type of tissue (Ingestad 1979). This consistent relationship among the nutrients primarily reflects the biochemical requirements which are determined by the genetic composition of the individual plant specie. However, the amounts of biochemical constituents and thus macronutrients change when the plants are stressed by either natural or anthropogenic sources. Often these changes in the biochemistry of the plant are evident long before external signs of the stress are manifested (Margolis and Brand 1990). Given the importance of the macronutrients to plant health and the sensitivity of nutrient concentrations in plant tissue to plant stress, macronutrient concentrations in plant tissue would appear to be a valuable indicator of plant responses to ELF electromagnetic radiation.

Foliar nutrient analysis is the most widely used type of tree tissue analysis because foliage contains the highest concentrations of nutrients in the tree and is the active area of photosynthesis (Mead 1984, Pritchett and Fisher 1987). Thus sampling of red pine foliage and subsequent macronutrient analysis is performed annually to determine 1) whether ELF fields can affect the nutrition of the red pine seedlings and 2) whether red pine foliar nutrient status is a useful tool for explaining site differences in red pine growth rates. The following hypothesis is used to meet the goals stated in the first objective. Objective 2 will be addressed later after hypotheses related to the growth rates of the red pine and objective 1 has been answered.

> H_O: There is no difference in the foliar nutrient concentrations of red pine seedlings before and after the ELF antenna becomes activated.

Sampling and Data Collection

Sampling and Chemical Analysis

Red pine foliage was collected from 50 seedlings per site at the time of planting, from 45 seedlings per site in October of 1984 and from 15 seedlings per site thereafter in October of each year. Seedlings selected are the same seedlings selected for destructive sampling in the leaf water potential and mycorrhizal studies. Measurements associated with the other two studies (basal diameter, height, current height growth, etc.) are also available for data analysis in this portion of the study. At each collection period all one year old fascicles are removed from the tree. Approximately 100 to 200 fascicles are then randomly selected for foliar analysis. The fascicles are then dried at 60° C, ground, and analyzed for concentrations of N, P, K, Ca and Mg.

A semi-micro Kjeldahl method is used for the determination of total N and P. After digestion concentrations are measured colorimetrically with a TRAACS 800. Ca, Mg, and K are determined by a Atomic Absorption Spectrophotometer after ashing and dissolution by hydrochloric acid. As a laboratory quality control measure for Ca, K, and Mg, National Bureau of Standards (NBS) red pine foliage is analyzed with the red pine samples collected from the three sites.

During 1993 foliar concentrations from the NBS samples were used to determine if foliar concentrations reported are within the quality control objectives (within +/- 10%) for this portion of the study. If foliar concentrations determined by the laboratory for a given group of samples were outside these limits (as determined from NBS certified values for Ca, K, and Mg), concentrations for the specific nutrient and group of samples were adjusted using results from the NBS standard. To date the only adjustments required were for K in 1987 and 1988 givent these criteria.

Data Analysis

Comparisons of foliar nutrient concentrations among sites and years follow the split-plot and time experimental design. Specific differences for a given nutrient are determined through the split-plot analysis of variance or covariance (Table 2.22) and SNK multiple range tests. The determinate growth patterns of red pine dictates that site and tree conditions at the time of bud set and foliage expansion can influence foliar nutrient concentrations. Thus nutrient concentrations of one year old fascicles can reflect conditions and nutrient regimes during bud set and leaf expansion as well as the amount and extent of translocation of nutrients from and to the foliage during the year of sampling (Van Den Driessche 1984). For one year old needles, time of leaf expansion and bud set are respectively one and two years prior to the year of foliage sampling. Thus covariates considered for inclusion in the analysis were factors measured two and one years prior to sampling as well as the year during sampling. The range of factors considered as potential covariates for this portion of the study were listed in previous reports (Mroz et al. 1993)

Evaluation and selection of covariates was performed using four years of data (1986-1989). Bud set and leaf expansion of the one year old foliage collected during this period was prior to 150 amp antenna operation. Thus, foliar concentrations during these four years were considered to be unaffected by the antenna operation. Acclimation of the foliar concentrations to site conditions were judged to be incomplete in 1985 and not included

Table 2.22 Anova table used for analysis of each individual macronutrient concentration

Source of Variation	D.F.	M.S.	F-Test
Covariate	# Group A Cov.[1]	MSC_a	MSC_a/MSE P(S)
Site	2	MSS	MSS/MSE P(S)
Error P(S)	3(2)-# Cov	MSE P(S)	
Covariate	# Group B Cov.	MSC_b	MSC_b/MSE YxP(S)
Years	# Years-1	MSY	MSY/MSE YxP(S)
Site x Years	(2)(Years-1)	MSSY	MSY/MSE YxP(S)
Error YxP(S)	(Years-1)3(2)- #Cov	MSSYxP(S)	

[1] Group A covariates differ by site but not by year
Group B covariates may differ among sites and years

with the 1986-1989 developmental data (Mroz et al. 1991).

Variables which were not significantly correlated ($p \leq .05$) with the foliar concentrations were eliminated from covariate consideration. The remaining variables were further evaluated using the ANCOVA model. Covariates, which were significant in the model at the p=.10 level for a given foliar concentration, were combined to determine if performance of the covariates were enhanced when used together. Finally covariates or covariate combinations which were significant (p=.10) were compared. Covariates or combination of covariates which had the highest p-value from this group were then selected for use in the final analyses. Individual covariates or groups of covariates were included in the analyses if they increased the sensitivity of the analysis or reduced the variation associated with the independent factors in the analysis, while maintaining the statistical assumptions inherent to analysis of covariate procedures. Results from this work was initially reported in the 1992 report (Mroz et al. 1993). Due to adjustments in foliar concentrations of K for the 1987 and 1988 samples as well as an error with the coding of tree measurements for the samples collected in 1987, this work was repeated again this year. This was done to incorporate the correct tree measurements for 1987 and the corrected foliar K concentrations for 1987-1988 into the covariate determination from the 1986-1989 data set.

After covariate selection, analysis of variance and covariance were performed using seven years of information (1986-1992) to determine differences in foliar concentration among sites and years. The coefficients of the selected covariates for the ANCOVA tests were not constrained to preantenna operational values and were refitted using the additional three years of data. Multiple range tests (SNK) were used to determine differences among sites, years, or site by year groups after significant ANOVA or ANCOVA tests.

To further investigate the potential effects of ELF fields on red pine nutrition, differences between the mean foliar concentration at the control and the foliar concentration of each sample tree at the test sites for a given nutrient and year were compared to the magnetic field exposure estimated for the location of the sample tree for that year. Only trees sampled in 1990-1992 were used for this part of the study because prior to 1990 tree locations were not recorded and/or the antenna was operated at differing levels of power during the year of foliage development and sampling. Since only the years 1990-1992 were used in this comparison, variation in ELF exposure represents the variation in field strengths within plots and not variation with preoperational and operational time intervals. Relationships between magnetic fields and differences in foliar nutrient concentrations between the control and sample trees at the test sites were quantified using Pearson Product Moment Correlation Coefficients.

Progress

Adjustments to foliar concentrations as indicated by NBS samples were included in the reported values of K for 1987 and 1988. Foliar concentrations of K for all sites for 1987 were increased by 0.06%. Foliar concentrations of K were decreased between 0.05 and 0.06% for a subset of the samples collected in 1988.

Nutrient concentrations and standard deviation for each site and year from 1986-1992 are presented in Table 2.23. In general, most nutrient concentrations have been found to be above or near levels reported for adequate growth of red pine. Critical foliar concentration levels have been reported for Mg (0.05%), and Ca (0.12%), while concentrations of N above 1.0% and P above 0.16% have been found to be adequate for growth in plantations (Stone and Leaf, 1967; Hoyle and Mader, 1964; Alban, 1974). Only K concentrations have consistently remained low during the study. K concentrations of .30-.51% have been reported for low to deficient levels for red pine in plantations (Hieberg and Leaf,1961; Madgwick, 1964). Concentrations of N in 1989 were below 1% for the first time during the study. In 1990-1992 nutrient concentrations increased above 1.0%. Nutrient concentrations are ranked in the order: N > K > Ca > P > Mg for all years sampled.

Standard deviations of individual nutrient concentrations are generally within 10 to 20% of the mean for all sites and years (Table 2.23). Standard deviations during 1984 after planting and 1985 were generally higher than the other years due to the initial acclimation of red pines to the site. The small

Table 2.23. Mean and standard deviation of foliage nutrient concentrations for red pine seedlings at ELF study sites (1986-1992)

Site	N%	P%	K%	Ca%	Mg%
1986					
Ground	1.42(.16)	0.13(.01)	0.47(.06)	0.19(.03)	0.08(.01)
Antenna	1.59(.12)	0.14(.02)	0.51(.04)	0.18(.03)	0.08(.01)
Control	1.34(.20)	0.13(.01)	0.49(.06)	0.23(.03)	0.09(.01)
1987					
Ground	1.06(.12)	0.11(.01)	0.40(.07)	0.21(.02)	0.09(.01)
Antenna	1.10(.16)	0.12(.02)	0.39(.04)	0.24(.07)	0.09(.01)
Control	1.04(.15)	0.12(.01)	0.42(.06)	0.23(.03)	0.09(.01)
1988					
Ground	1.16(.14)	0.14(.02)	0.52(.06)	0.25(.05)	0.11(.01)
Antenna	1.27(.15)	0.15(.02)	0.51(.07)	0.22(.04)	0.10(.01)
Control	1.17(.09)	0.13(.01)	0.48(.04)	0.25(.05)	0.09(.01)
1989					
Ground	0.99(.13)	0.14(.03)	0.33(.06)	0.25(.04)	0.11(.01)
Antenna	1.10(.20)	0.13(.01)	0.33(.03)	0.27(.04)	0.10(.01)
Control	0.98(.12)	0.16(.04)	0.33(.03)	0.27(.04)	0.10(.01)
1990					
Ground	1.06(.10)	0.13(.02)	0.38(.03)	0.31(.06)	0.10(.01)
Antenna	1.11(.07)	0.14(.01)	0.38(.04)	0.29(.05)	0.10(.02)
Control	1.20(.07)	0.15(.03)	0.38(.05)	0.31(.06)	0.10(.01)
1991					
Ground	1.09(.08)	0.14(.03)	0.39(.04)	0.28(.05)	0.09(.01)
Antenna	1.07(.07)	0.17(.05)	0.37(.04)	0.27(.04)	0.09(.01)
Control	1.12(.10)	0.13(.03)	0.40(.05)	0.30(.04)	0.10(.01)
1992					
Ground	1.07(.06)	0.13(.04)	0.38(.06)	0.28(.04)	0.09(.01)
Antenna	1.02(.10)	0.17(.08)	0.33(.06)	0.26(.04)	0.09(.01)
Control	1.03(.06)	0.14(.04)	0.36(.04)	0.26(0.5)	0.08(.01)

variation during 1986-1992 reflects the relatively uniform conditions within a site and the lack of genetic variation in red pine.

Covariate Selection: Covariates selected from the analyses are presented in Table 2.24 along with the p-value and detection limits for the ANOVA and ANCOVA tests using the covariate developmental data. Addition of covariates generally reduced detection limits associated with the factors rather than explaining any potential differences associated with a given

Table 2.24. Results of red pine foliage nutrient analyses of variance (p value) and computed detection limits (%) with and without covariates for covariate developmental data (1986-1989).

	N	P	K	Ca	Mg
	P Value				
Without Covariates					
Site	.042	.060	.946	.139	.016
Year	.000	.000	.000	.000	.000
Year x Site	.249	.451	.276	.410	.008
	%				
Without Covariates					
Site	7.0	4.4	6.3	7.7	2.8
Year	5.0	5.6	5.7	10.4	4.8
Year x Site	8.6	9.8	9.9	18.0	8.4
	P Value				
	N[1]	P[2]	K[3]	Ca[4]	Mg[5]
With Covariates					
Site	.019	.163	.187	.382	.016
Year	.000	.076	.000	.093	.000
Year x Site	.298	.041	.083	.084	.003
	%				
With Covariates					
Site	4.4	4.1	3.4	9.4	2.7
Year	5.1	4.5	4.3	8.4	4.3
Year x Site	8.9	7.8	7.4	14.6	7.5

[1]Covariate=Basal diameter normal probability density -0.50

[2]Covariate=Mean soil water potential 5cm (September)& soil temperature 10cm (June) current year

[3]Covariate=Basal diameter normal probability density-0.50, soil water potential 10cm July previous year, & soil temperature 5cm (May) current year. (Only 1987-1989 data was used in this analysis due to the lack of soil moisture data in 1985)

[4]Covariate=Soil moisture 10cm (June) & soil temperature 10cm (May) current year

[5]Covariate=Sum of current year degree days (April 15-Aug.31) and previous year degree days (June 15-September 31).

factor. However, covariates did explain differences among years for P and Ca. Detection limits associated with year and site by year interactions for N were increased rather than decreased with the addition of covariates (Table 2.24). Covariates observed for each individual tree, such as basal diameter normal probability densities, were significant covariates for N and K concentrations. Soil moisture and soil temperature were significant covariates for P, K, and Ca while growing season degree days was a significant covariate for Mg concentrations (Table 2.24). Decreases in detection limits for the various factors were between 0.1 and 3.4% after inclusion of the covariates. Increases in N detection limits were .1 to .3% respectively for site and site by year interactions.

Application of these covariates to the 1986-92 data set also decreased the detection limits for practically all factors and nutrient concentrations. Only detection limits associated with year and site by year interactions for N and site factors for Mg were increased (Table 2.25). Although detection limits were generally reduced, covariates frequently did not explain a significant proportion of the variation in the nutrient concentrations when applied to the entire data set. Only the covariates used with the Ca and Mg analyses were significant for at least one of the error terms in the ANCOVA. Although the combination of the covariates for a given nutrient did not explain a significant portion of the variation of these nutrients, a number of individual covariates in a group did have coefficients which were significantly greater or less than 0.

One of the assumptions inherent with the ANCOVA tests is that the relationships between the covariates in the ANCOVA and foliar nutrient concentrations are homogeneous with regard to ELF antenna fields. A change in relationship between the covariate and foliar concentrations with regard to ELF fields is indicated by a significant difference in the coefficients derived from the test sites after full power operation compared to coefficients derived from the test sites prior to full power antenna operation and the control site. Analyses used to test these assumptions indicated that coefficients associated with the N, K, and Ca ANCOVA's did not significantly differ ($p=0.05$) between these two groups of data. Although all covariates were selected using data prior to full power ELF antenna operation, coefficients associated with sum of current year degree days (April 15-Aug.31) and previous year degree days (June 15-September 31) for the Mg analysis and soil temperature (10cm) in June of current year for the P analysis differed significantly (respectively $p=0.022$ and $p=0.006$) between the full power operational time periods at the test sites compared to the control and the preoperational periods at the test sites. If coefficients for these covariates continue to differ significantly with the inclusion of the 1993 foliar nutrient concentrations in the final analysis, the covariates will be removed in order to maintain the assumptions of ANCOVA.

Site & Year Comparisons: ANOVA tests indicated significant ($p\leq0.05$) differences among years for all nutrients and among sites for Mg (Table 2.26). The antenna site had significantly

Table 2.25. Results of red pine foliage nutrient analyses of variance (p value) and computed detection limits (%) with and without covariates (1986-1992).

	N	P	K[1]	Ca	Mg
	P Value				
Without Covariates					
Site	.103	.082	.473	.180	.020
Year	.000	.003	.000	.000	.000
Year x Site	.001	.092	.253	.410	.022
	%				
Without Covariates					
Site	5.4	10.7	5.8	6.7	3.2
Year	4.7	10.0	5.5	9.0	5.4
Year x Site	8.2	17.3	9.5	15.7	9.3

	N	P	K	Ca	Mg
	P Value				
With Covariates					
Site	.218	.041	.046	.031	.030
Year	.000	.294	.000	.000	.000
Year x Site	.001	.055	.243	.186	.009
	%				
With Covariates					
Site	4.9	8.9	3.6	2.2	3.4
Year	4.8	9.5	5.4	8.4	5.2
Year x Site	8.3	16.4	9.3	14.5	8.9

[1]Only 1987-1992 data was used in this analysis due to the lack of soil moisture data as a covariate in 1985

lower concentrations of Mg (0.091%) compared to the control (0.094%) or the ground site (0.096%). Concentrations of Ca and Mg generally increased .during 1986-1990 at all sites (Figure 2.18 Figure 2.20). These consistent changes during this time period reflected the changes of foliar nutrient concentrations with increasing plant maturity (Walworth and Sumner 1987,Lambert

1984, Miller 1981). During 1990-1992 concentrations of these elements have appeared to stabilize and, to some degree, decrease.

Site by year interactions were only significant ($p \leq 0.05$) for nitrogen ($p=0.001$) and magnesium ($p=0.002$) (Table 2.25). Figure 2.12 shows that the significant interactions for N are primarily related to the significantly higher concentrations at the antenna site than the other two sites in 1986. Differences in foliar concentrations of N among sites were not significant for any other year (Figure 2.11). Multiple range tests were not able establish any significant differences among sites for foliar concentrations of Mg in any single given year (Figure 2.19). However, significant site by year interactions appear to be related to higher levels of Mg at the control site than the other two sites in 1986. In the years following 1986 foliar concentrations of Mg at the control are lower or similar to concentrations in the test sites.

For some nutrients the relationships in foliar concentrations appear to have changed between the control and an individual test site in the years following full power ELF operation. For example prior to 1990 foliar concentrations of N were greater at the antenna than at the control site but during 1990-1992 concentrations were lower at the antenna then at the control (but not significantly). However, during these two periods differences in foliar concentrations between the control and the ground have shown no consistent trend. Foliar concentrations of P at the antenna site have increased with respect to concentrations at the control during 1991-1992 but again there is no evidence of a similar change in foliar P at the ground site. Thus there does not appear to be any consistent changes foliar nutrient concentrations at the test sites in relation to the control .which would indicate an ELF effect (Figures 2.11, 2.13, 2.15, 2.17, and 2.19).

Increased sensitivity of the analysis with the inclusion of the selected covariates indicated significant differences among sites for P, K, and Ca in addition to Mg (Table 2.25). Covariate adjusted Mg foliar concentrations were significantly higher for the ground site (0.10%) than either the control (0.09%) or the antenna (0.09%) site while adjusted foliar concentrations were significantly ($p=0.05$) greater at the antenna site (0.26%) compared to the control and antenna (0.25%) for the seven year period. Multiple range tests ($p=0.05$) were not able to separate adjusted site means for K or P. Site by year interactions were significant for P ($p=0.055$), N ($p=0.001$), and Mg ($p=0.009$).

Regardless of whether the covariate adjusted or unadjusted means are compared (Figures 2.11-Figure 2.20) there appears to be no evidence that ELF antenna operation has affected the nutrient concentrations of the red pine foliage. Differences in foliar concentrations of K and Ca among sites were not found to be significant ($p \leq 0.05$) for any year during the seven year study period irrespective whether unadjusted or adjusted mean in concentrations were considered (Figures 2.15-2.18). Differences in foliar concentrations of N among sites were only significant during 1986 two years prior to full antenna operation (Figures

FIGURE 2.11 UNADJUSTED RED PINE FOLIAR NITROGEN CONCENTRATIONS 1986 - 1992

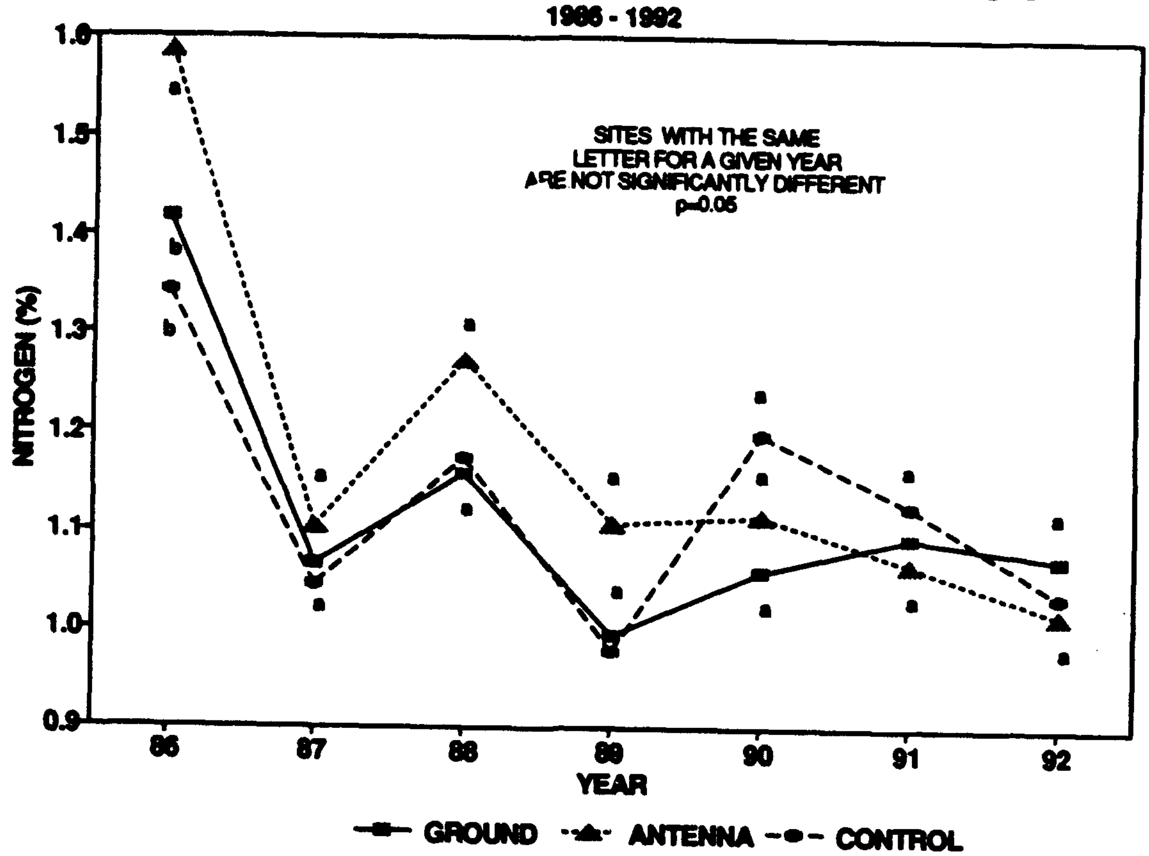


FIGURE 2.12 ADJUSTED RED PINE FOLIAR NITROGEN CONCENTRATIONS 1986 - 1992

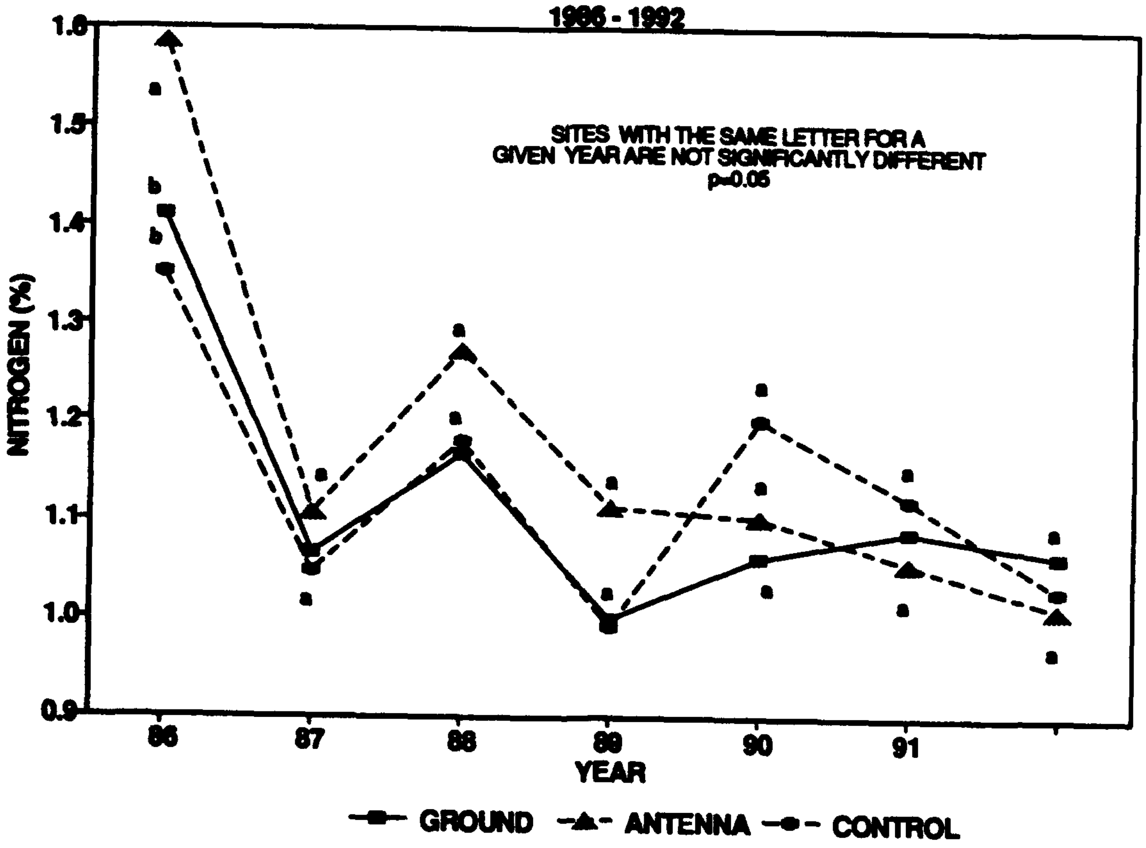


FIGURE 2.13 UNADJUSTED RED PINE FOLIAR PHOSPHORUS CONCENTRATIONS 1986 - 1992

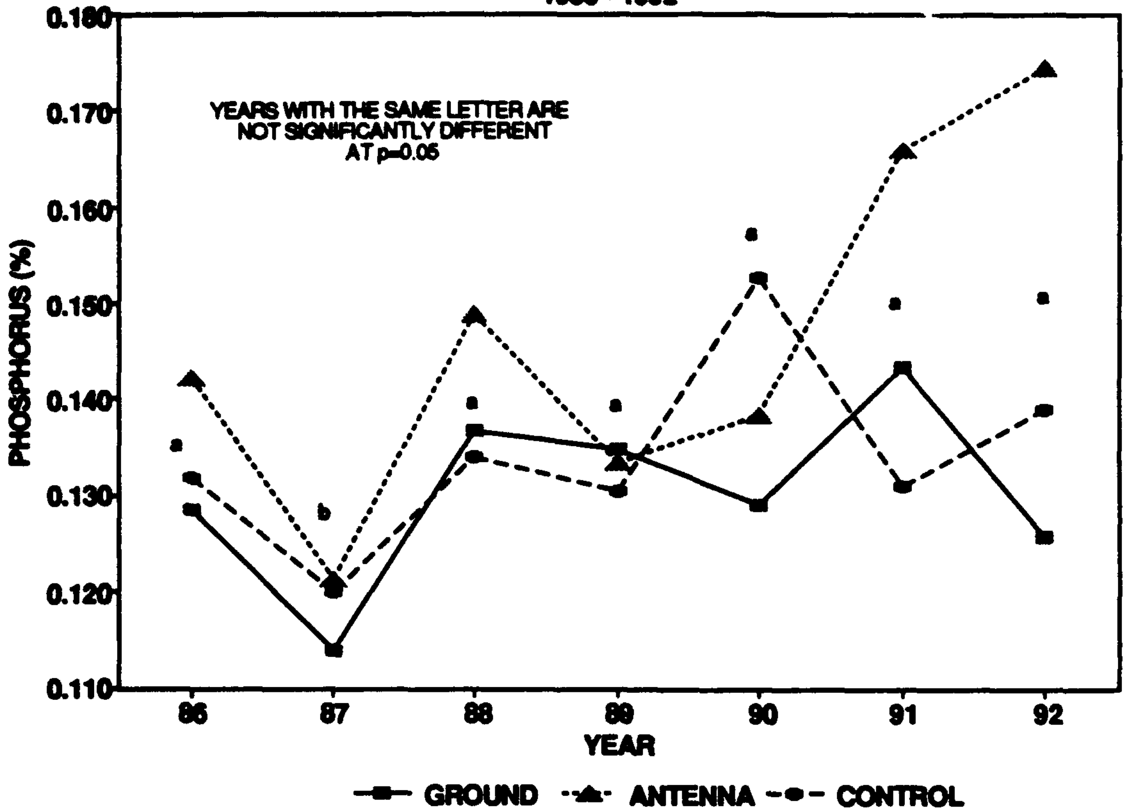


FIGURE 2.14 ADJUSTED RED PINE FOLIAR PHOSPHORUS CONCENTRATIONS 1986 - 1992

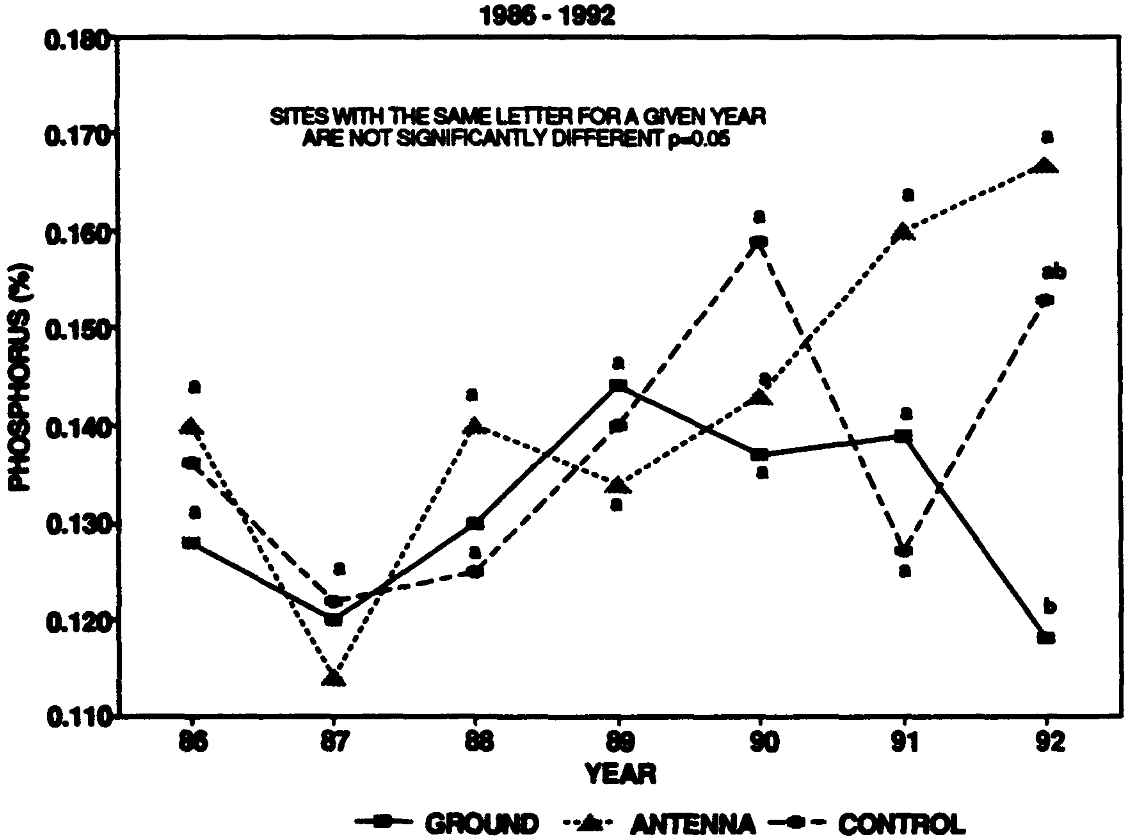


FIGURE 2.15 UNADJUSTED RED PINE FOLIAR POTASSIUM CONCENTRATIONS 1986 - 1992

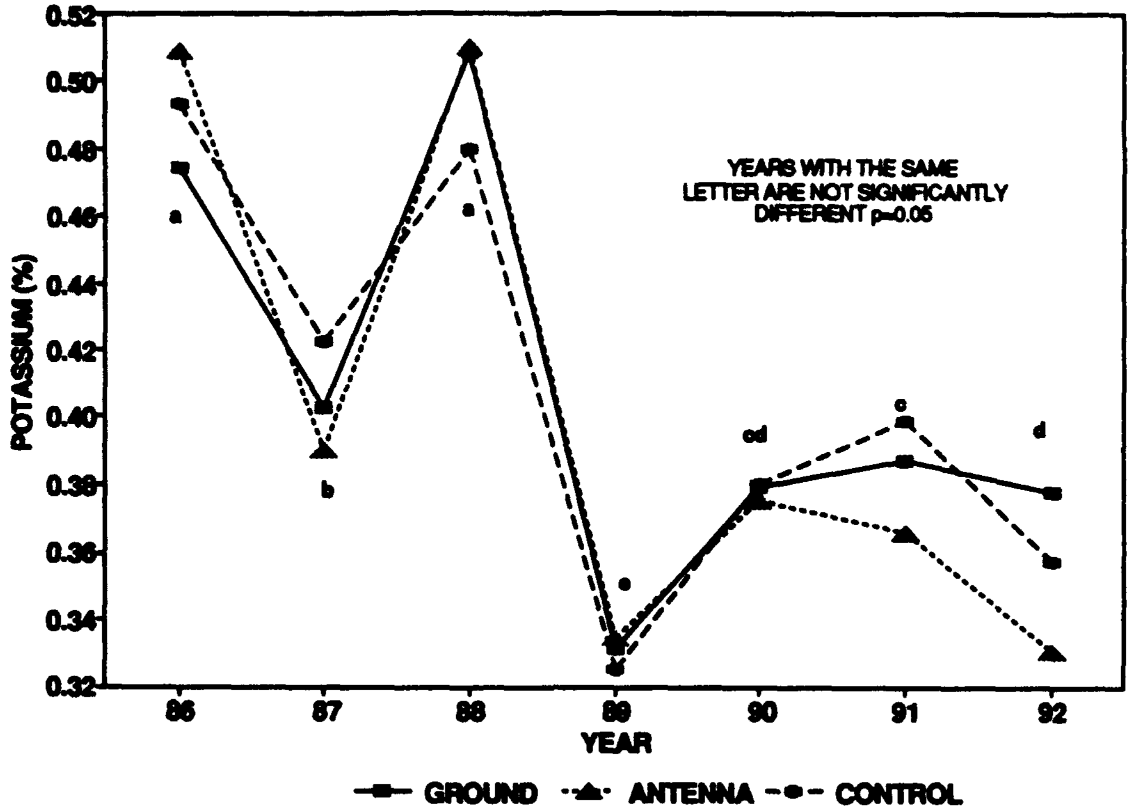


FIGURE 2.16 ADJUSTED RED PINE FOLIAR POTASSIUM CONCENTRATIONS 1987 - 1992

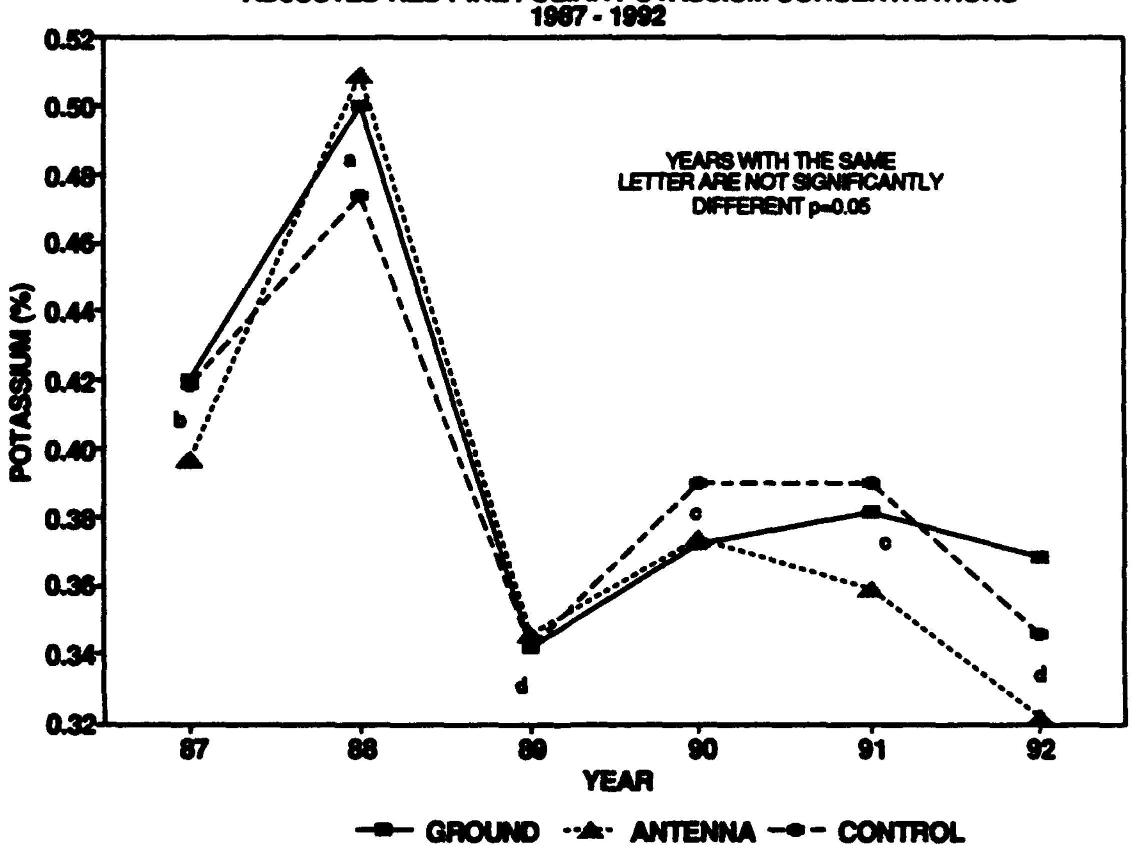


FIGURE 2.17 UNADJUSTED RED PINE FOLIAR CALCIUM CONCENTRATIONS 1986 - 1992

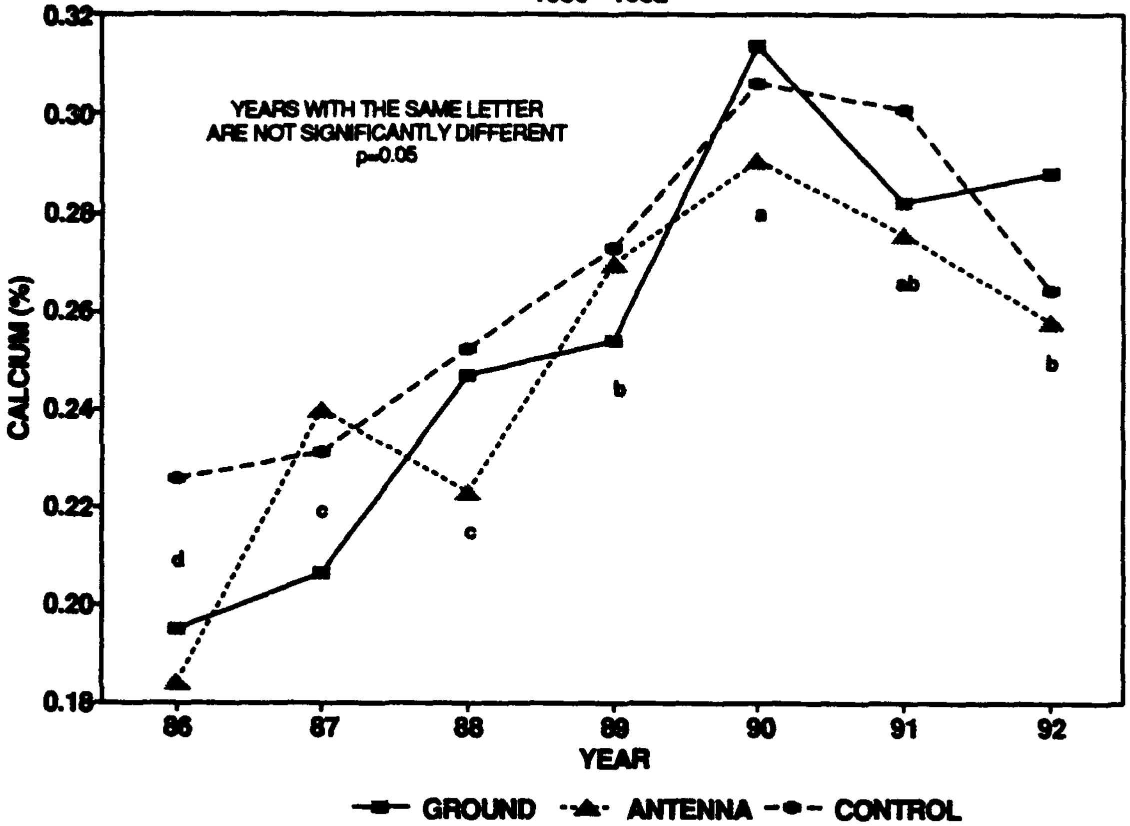


fIGURE 2.18 ADJUSTED RED PINE FOLIAR CALCIUM CONCENTRATIONS 1986 - 1992

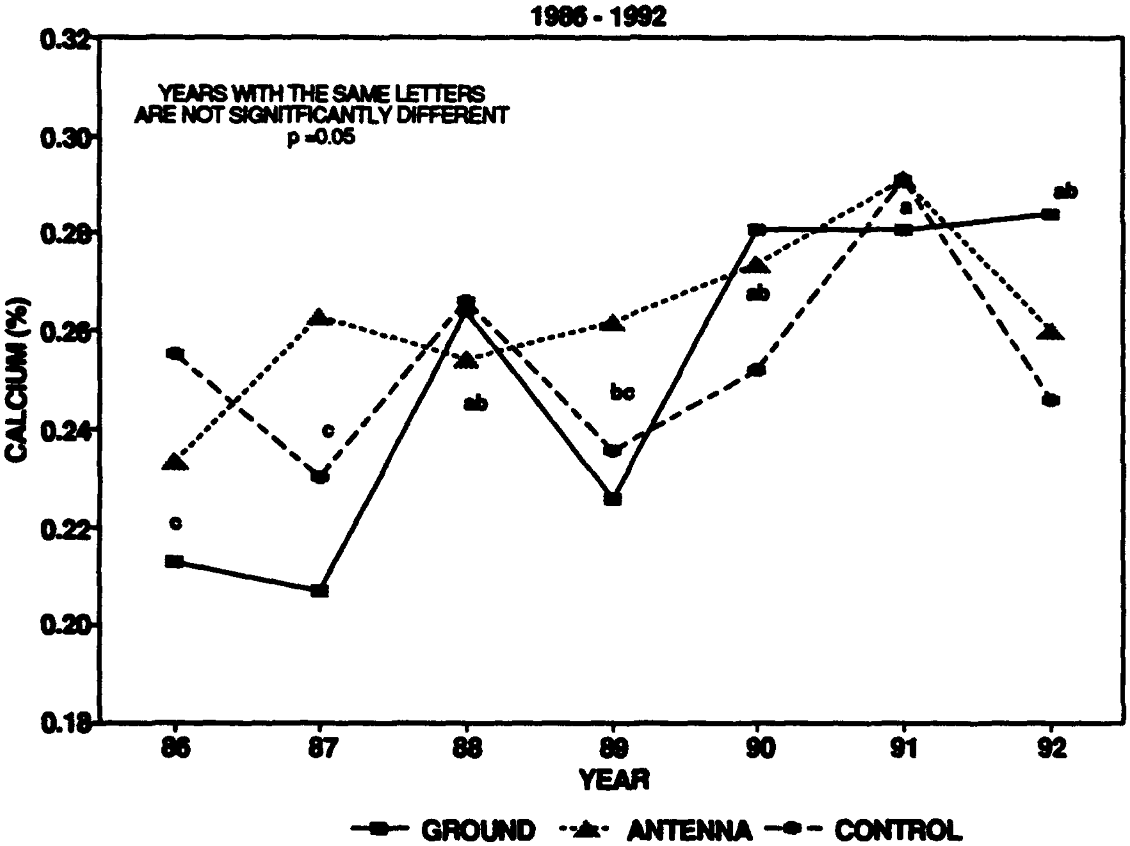


FIGURE 2.19 UNADJUSTED RED PINE FOLIAR MAGNESIUM CONCENTRATIONS 1986 - 1992

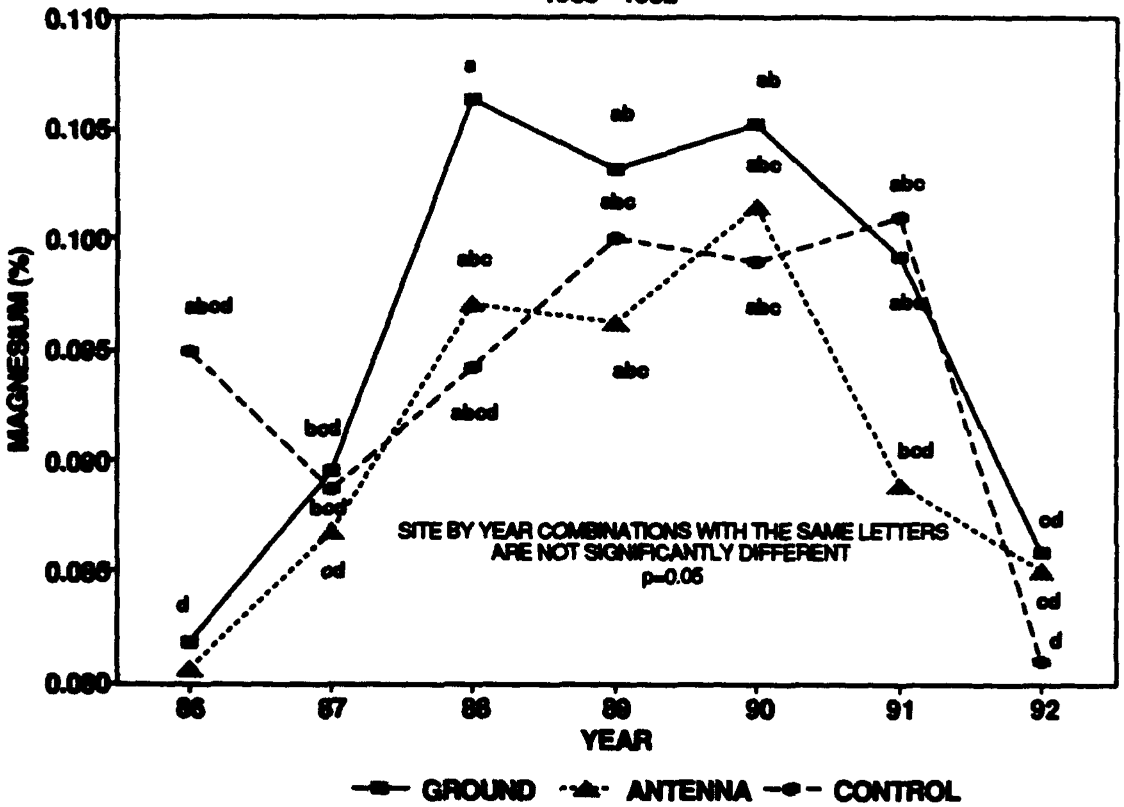
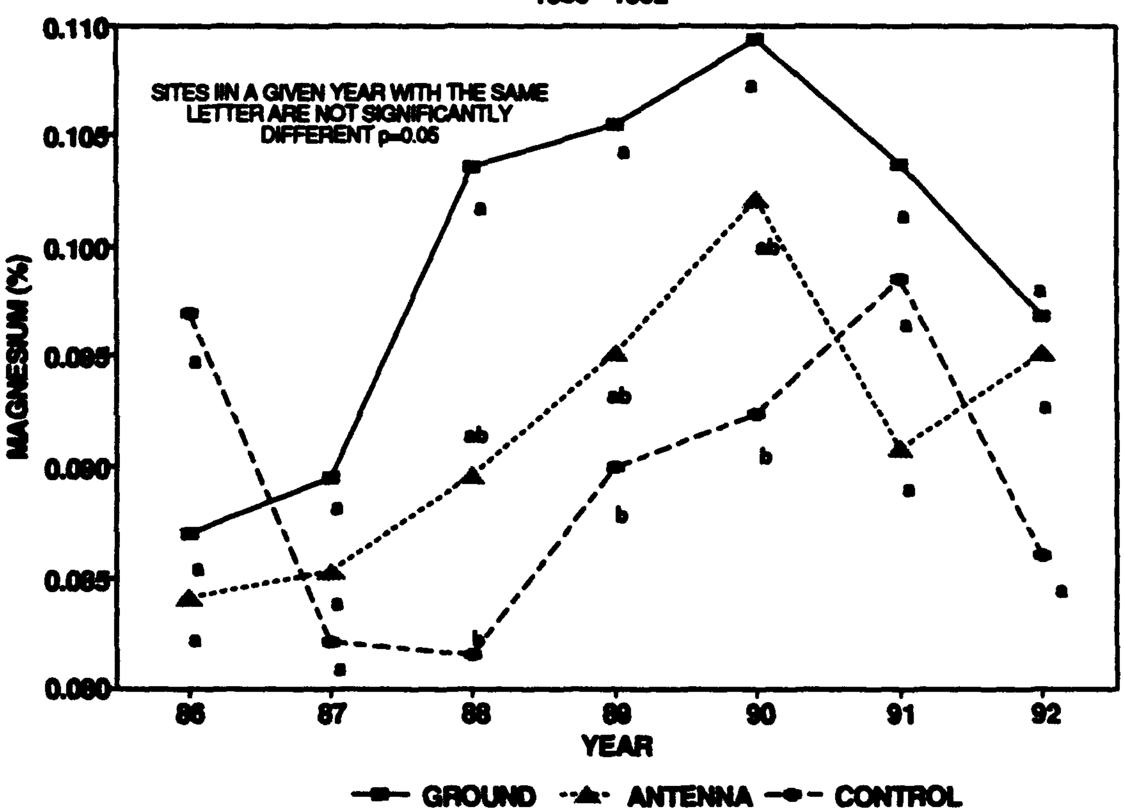


FIGURE 2.20 ADJUSTED RED PINE FOLIAR MAGNESIUM CONCENTRATIONS 1986 - 1992



2.11-2.12). Although differences in foliar concentrations of P and Mg exist after full antenna operation, differences between the control and tests sites are not consistent and do not indicate an ELF effect on foliar concentrations (Figures 2.13-2.14, Figures 2.19-2.20).

Although ANOVA and ANCOVA tests did not indicate a change in foliar nutrient concentrations at the test site with full power antenna operation, magnetic flux densities (76Hz) estimated for the location of each sample tree were significantly correlated ($p \leq 0.05$) with differences between annual mean foliar concentrations at the control (1990-1992) and individual sample tree concentrations for Ca at the ground, Mg and K at the antenna, and N when both test sites were considered together (Table 2.26). It is not clear whether these significant correlations actually indicate a change in foliar nutrient concentrations because different foliar nutrient concentrations at the two sites were significantly correlated with magnetic flux densities. Mean magnetic flux densities estimated for the sample trees (1990-1992) at the ground were slightly higher (9.95 mG) than at the antenna site (8.36 mG). The ranges in magnetic flux density for the trees at the ground (2.12-15.95 mG) were also slightly greater than at the antenna site (5.79-14.36 mG). Given the similar range in magnetic flux density at the two sites, we would expect that if the increased magnetic fields altered red pine nutritional balances, similar changes in foliar nutrient concentrations would be evident at both test sites. If the 76Hz magnetic fields altered foliar nutrient concentrations, magnetic flux densities should be consistently correlated with differences in foliar concentrations no matter what site was considered. This was not evident (Table 2.26) using the last three years of data.

Comparison of magnetic field strengths and the differences in foliar nutrient concentrations (Figures 2.21-2.25) did not indicate any nonlinear relationships as have been found with the height growth of the red pine. However, height growth was found to be altered at field strengths of 0.68-6.80 mG with the effects maximized at 2.2 mG (refer to red pine heigth grwoth). Only 29% of the trees sampled from the ground and antenna site for foliar nutrient concentrations during 1990-1992 had field exposures within this range and only 5% of the trees sampled at the ground were exposed to magnetic field strengths of 2.2 mG or less. Thus it is uncertain to what degree these trees would indicate a change in foliar concentrations consistent with the exposure levels which stimulate the height growth of the red pine. Further work will include quantification of possible nonlinear relationships between the magnetic fields and the differences in foliar nutrient concentrations at control and test sites.

It is possible that comparisons of foliar chemistry with other EMF parameters may indicate a more consistent relationship. Longitudinal EM fields are more variable within and between the test sites than magnetic fields. If foliar chemistry is altered by exposure to these fields rather than magnetic fields, inconsistent relationships between magnetic fields and foliar chemistry at the two test sites could be expected.

Table 2.26. Correlation coefficients and significance levels associated with magnetic flux densities and differences in foliar nutrient concentrations (control-test) during 1990-1992 for ground, antenna, and ground & antenna sites.

	Ground	Antenna	Ground & Antenna
N	-0.168 (p=.277)	0.113 (p=.459)	-0.241 (p=.005)
P	-0.057 (p=.715)	-0.002 (p=989)	0.027 (p=.759)
K	-0.190 (p=.223)	0.302 (p=.049)	-0.074 (p=.404)
Ca	0.386 (p=.011)	0.154 (p=.325)	0.070 (p=.435)
Mg	0.215 (p=.166)	0.300 (p=.051)	0.110 (p=.2[illegible]6)

Future work will concentrate on comparing foliar chemistry to longitudinal fields as well as magnetic fields.

Summary

- At this time there has been no indication that the ELF antenna operation has altered the nutrient status of the red pine. No significant and consistent changes in foliar concentrations were evident at the test sites after antenna operation. Furthermore, correlation's between the magnetic flux densities and differences in foliar nutrient concentrations were not consistent when test sites were compared separately. Future work will focus on the inclusion of foliar concentrations sampled in 1993 to the analyses, quantifying possible nonlinear EMF foliar concentration relationships, as well as inclusion of longitudinal EM fields to correlation analyses performed this year.

Leaf Water Potential

The leaf water potential study ended in 1992. A summary of this work appeared in the 1992 Annual Report for this project. A summary of the work will appear in the final report.

FIGURE 2.21

CONTROL-TEST SITE N CONCENTRATIONS VS MAGNETIC FLUX DENSITY

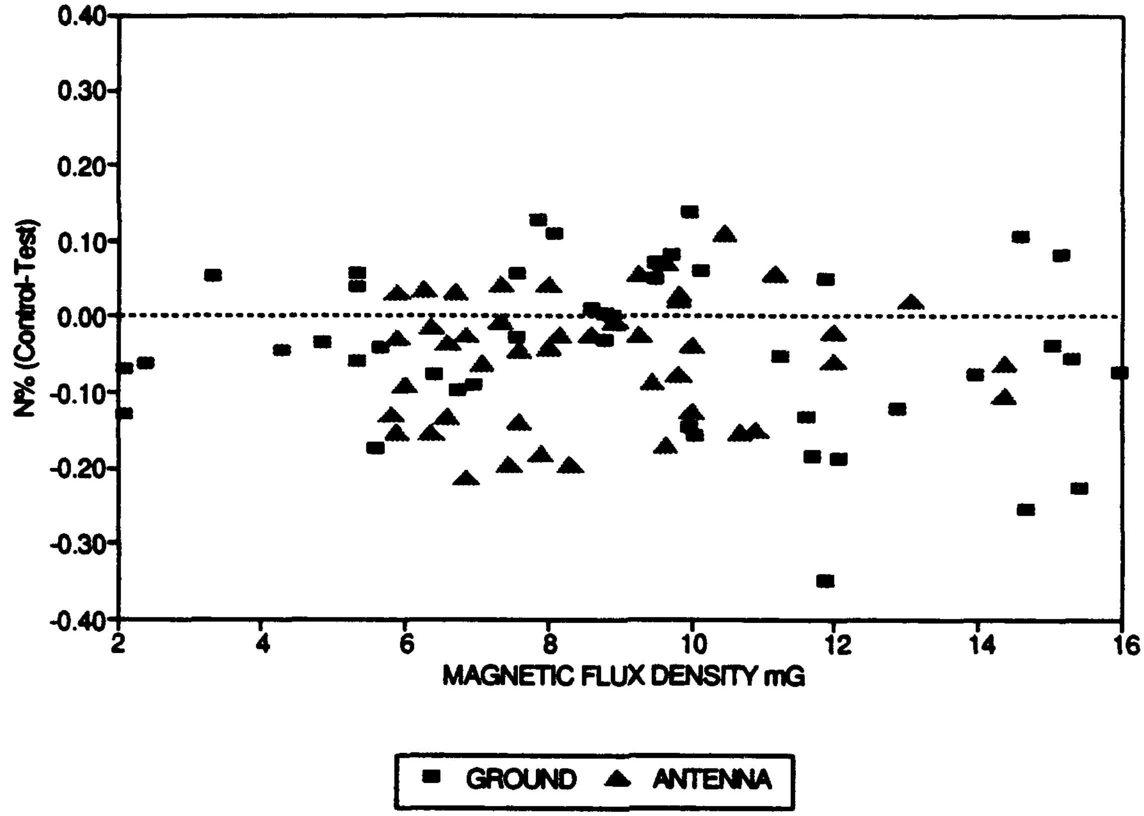


FIGURE 2.22

CONTROL-TEST SITE P CONCENTRATIONS VS MAGNETIC FLUX DENSITY

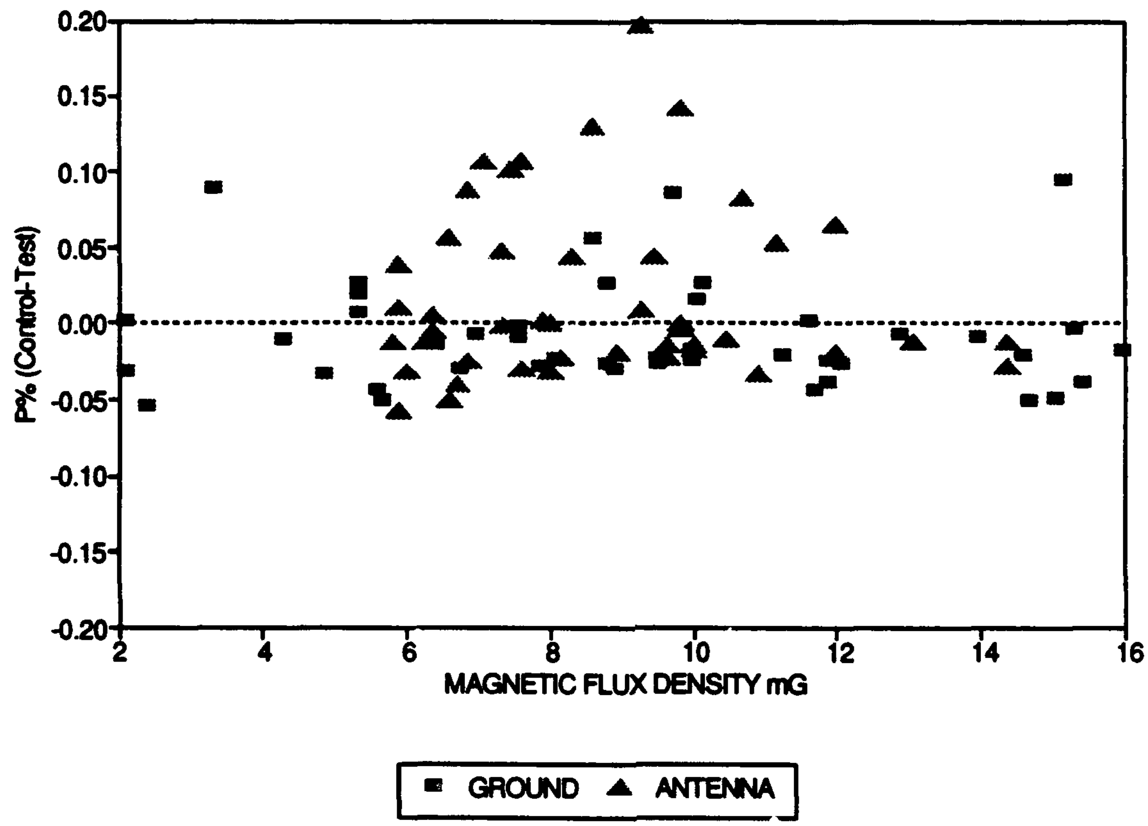


FIGURE 2.23

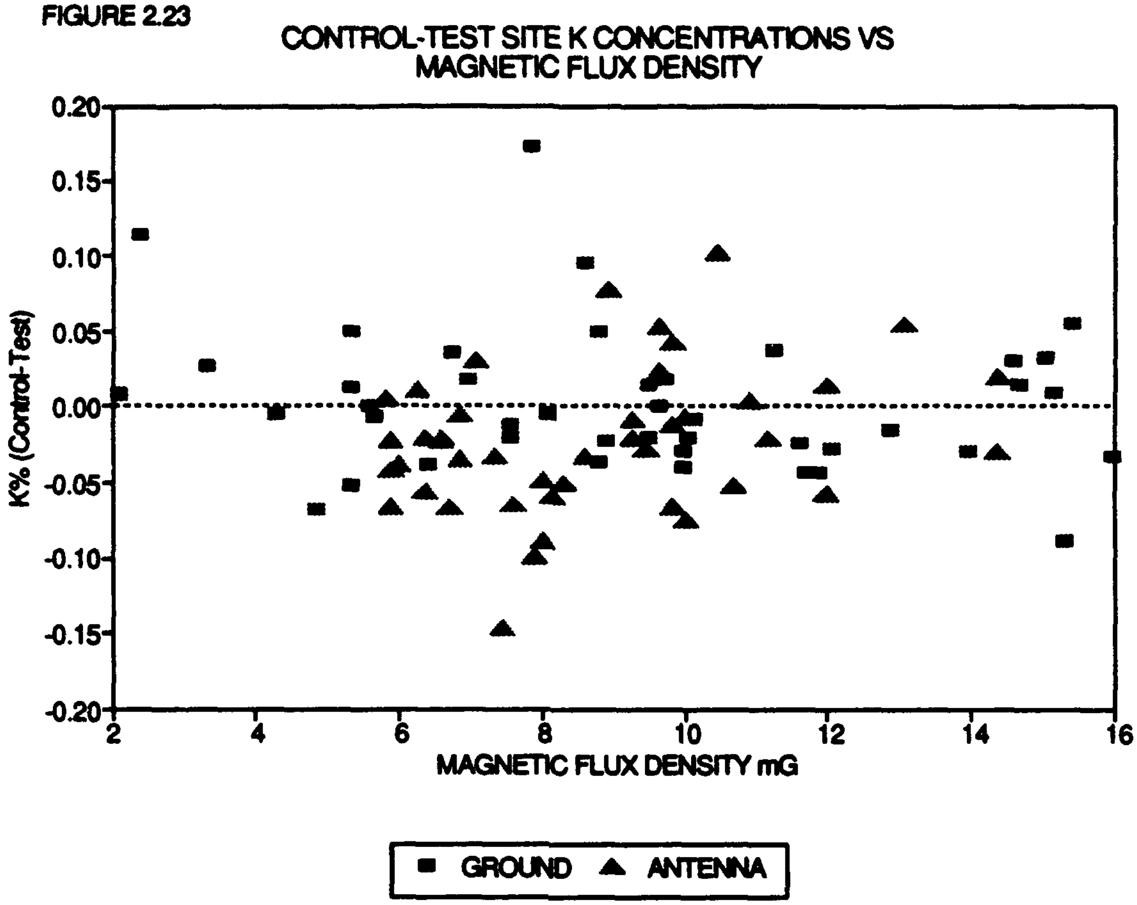


FIGURE 2.24

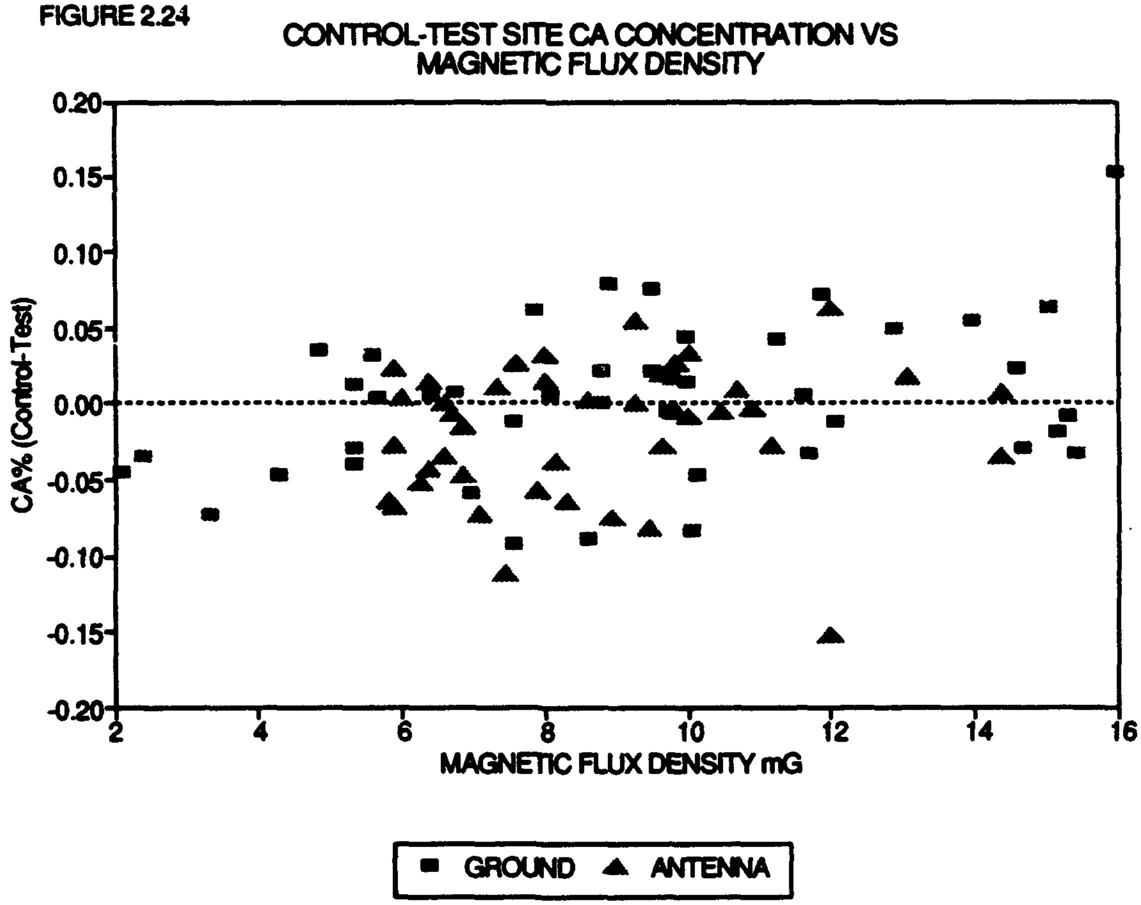
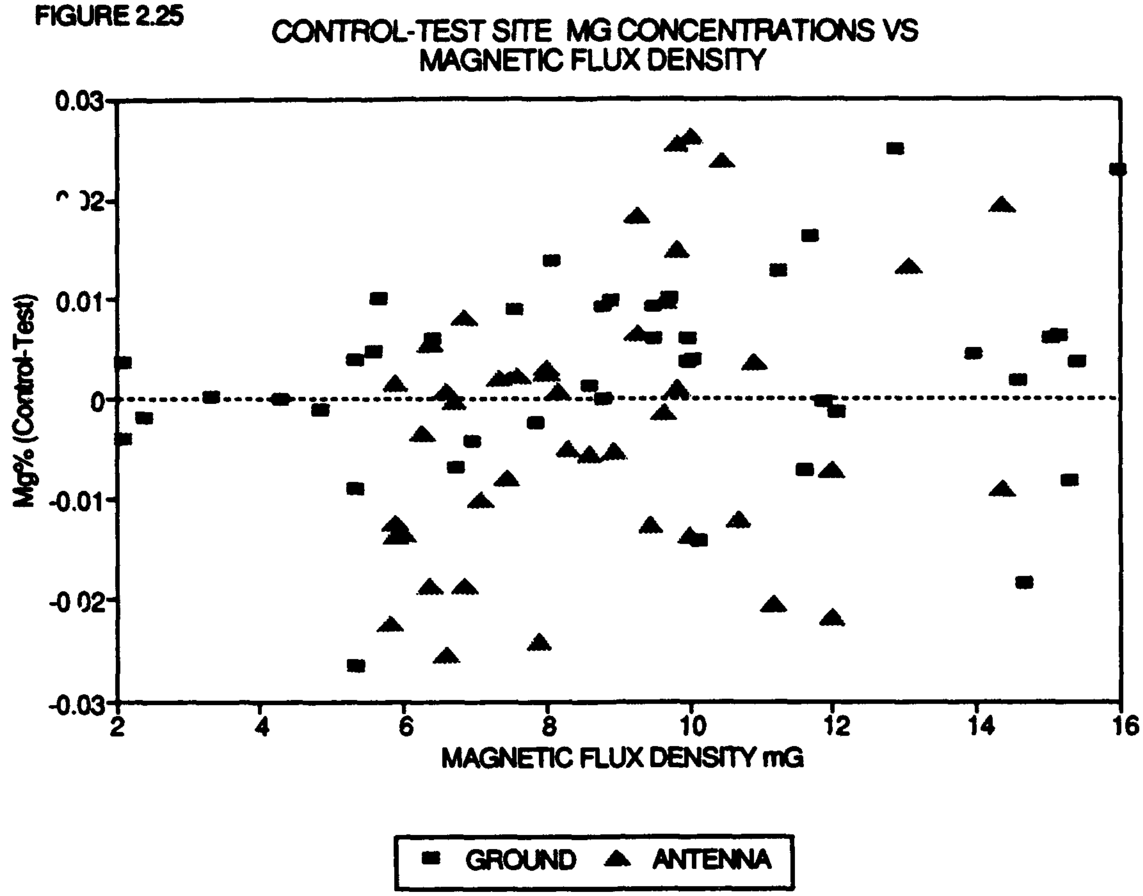


FIGURE 2.25


CONTROL-TEST SITE MG CONCENTRATIONS VS
MAGNETIC FLUX DENSITY
Mg% (Control-Test)
0.03
0.01
0
-0.01
-0.03
2
4
6
8
10
12
14
16
MAGNETIC FLUX DENSITY mG
GROUND
ANTENNA

ELEMENT 3: PHENOPHASE DESCRIPTION AND DOCUMENTATION

Phenological events, or the timing of certain morphological processes, are important phytometers of plants under stress. Events, such as stem elongation, bud break, leaf expansion, flowering, fruiting and leaf senescence have been used in the past to monitor and assess a plant's response to factors such as climate and soils. Morphological characteristics, such as leaf area, stem length, number of buds, number of leaves, number of flowers, and number of fruit have also been used to monitor a plant's response to these factors. By combining both phenological and morphological information, researchers have obtained a better understanding of the potential changes plants will exhibit in response to perturbations.

Starflower, *Trientalis borealis* Raf., is an important herbaceous species in many northern ecosystems. It is especially important in hardwood ecosystems of the North Central region of the United States. Phenophases of starflower have been well documented in northern Wisconsin by Anderson and Loucks (1973) and in Canada by Helenurm and Barrett (1987). Because of this prior information on phenophases and morphological characteristics of starflower and because we consider starflower to be a sensitive species to stand disturbances, it has been chosen as an indicator of ecosystem responses to extremely low frequency (ELF) fields. It is a major herbaceous species on both the control site and the ELF antenna site.

To assess the effects of ELF fields on *Trientalis borealis*, the objectives of this element are to: 1) describe and document specific changes in phenological events and in the morphological characteristics of *Trientalis borealis* prior to and during operational use of the ELF antenna and 2) use these data to test hypotheses of possible changes in physiological and phenological processes due to ELF fields.

> The main scientific hypothesis to be tested each year is there is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* between the antenna and the control sites within a year.
>
> The hypothesis to be tested over all years is there is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* before and after the ELF antenna becomes operational.

Morphological characteristics (number of buds, number of flowers, number of fruit, and leaf senescence) will also be analyzed within the context of these hypotheses. Ambient characteristics, described in Element 1, within each year will be used as covariates to explain significant differences in phenological characteristics of leaf expansion, leaf size (area, length, and width), and stem length between sites, and among years and site by year interactions.

Sampling and Data Collection

During the 1992 field season, data were collected at the antenna and control sites from May 7 until August 7. Each site was sampled twice a week from May 7 until June 18 to delineate flowering periods and leaf expansion with greater precision. After full leaf expansion and flower development, each site was sampled once a week until August 6. Parameters measured per plant for each observation period included stem length, length and width of the largest leaf, number of leaves, number of buds, number of flowers, number of fruit, number of yellow leaves (leaves senescing), and number of brown leaves. To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained for each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 m^2 subplots. Individual plants within each subplot were then numbered and tagged until a normal distribution of mean stem length was attained. Stem length was used as the response variable for this determination because it is a prime indicator of a herbaceous plant's potential sexual productivity. A normal distribution of stem length ensures an adequate representation of the population for analysis of variance techniques. The number of meter square subplots, required to obtain a minimum sample size of 200 plants, varied between the antenna and control site and among weeks sampled. To reduce bias in choosing the 200th individual, all individual plants were tagged and measured in the subplot where the 200th plant occurred, hence sample size was unequal across sampling days. This sampling method was maintained for each individual plant until tagged individuals began to die or were eaten. Thereafter, observations were taken only on the remaining tagged individuals. Maximum leaf area was estimated for each plant by 1) taking the largest leaves on 15 randomly sampled plants off the herbaceous reserves at each observation period in 1986-1992, 2) measuring leaf length, leaf width and leaf area on these 15 samples, and 3) developing regression equations for leaf area (dependent variable) using leaf length and width as independent variables.

Progress

Phenological characteristics

In 1992, due to snow and cool weather conditions in May, the initiation of stem and leaf expansion in addition to bud formation was not monitored before May 7; bud formation had already begun on both sites (Figure 3.1H). Flowering on the control site also began 5 days earlier (May 16) than flowering on the antenna site (May 21) (Figure 3.2H). As with flowering, fruiting occurred 4 days earlier (May 26) on the control site than on the antenna site (May 30) (Figures 3.3O and 3.3P). Leaf senescence (yellowing leaves) began 7 days earlier on the control site (June 4) compared with the antenna site (June 11) (Figures 3.400 and 3.4P) while the occurrence of dead leaves (brown leaves) earlier on the antenna site (May 30) than on the control site (June 11) (Figures 3.5O and 3.5P). Similar relationships occurred in the 1991, 1990, 1989, 1988, 1987, 1986, and 1985 growing seasons. Statistically, site x year interactions were not significant ($p > 0.05$) for initiation julian dates of flowering, fruiting, senescing leaves, and browning leaves indicating that ELF fields present after the 1989 growing season had no effect on the timing of these starflower's phenological events. Significant site by year interactions ($p < 0.01$) were determined for julian dates of initial leafout and budbreak. These differences were, however, due to fluctuations in the beginning sampling date for each year. Site differences in julian dates for these variables were not detected after the ELF antenna became operational.

During the 1985-1989 growing seasons, flowering and fruiting on both sites began when the previous event (e.g., bud break and flowering, respectively) was at its maximum (Figures 3.6A-3.6J). However in 1990 and 1992 (after the antenna became fully operational - September, 1989), flowering and fruiting on the antenna site seemed to be different from previous years and from the control site (Figures 3.6K, 3.6L, 3.6O, and 3.6P). The initiation of flowers and fruits began before the peak (maximum) number of plants with buds and number of plants with flowers. Reasons for the changes observed in 1990 and 1992 are unclear. In 1991, timing of flowering and fruiting on the antenna site was similar to patterns in 1989, 1988, 1987, 1986, and 1985. Optimum climatic conditions in 1991 (higher temperatures and precipitation amounts - Element 1) may be the reasons for similar patterns in 1991.

Over all years, the number of plants with buds, flowering, and fruiting were significantly lower on the antenna site in 1986, 1987, and 1988 than on the control site (Figures 4A and 4B). Reasons for this are unknown. No significant differences between the antenna site and control site ($p < 0.05$) in the number of plants flowering and fruiting were observed after 1988. The number of plants with buds were significantly higher on the control site in 1989 and 1990; however these differences were not evident after 1 These analyses indicate no significant effects on p logical processes due to ELF fields.

Figure 3.1: Relative frequency for number of plants with one or more buds by sampling date on the control and the antenna sites for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), 1990 (F), 1991 (G), 1992 (H).

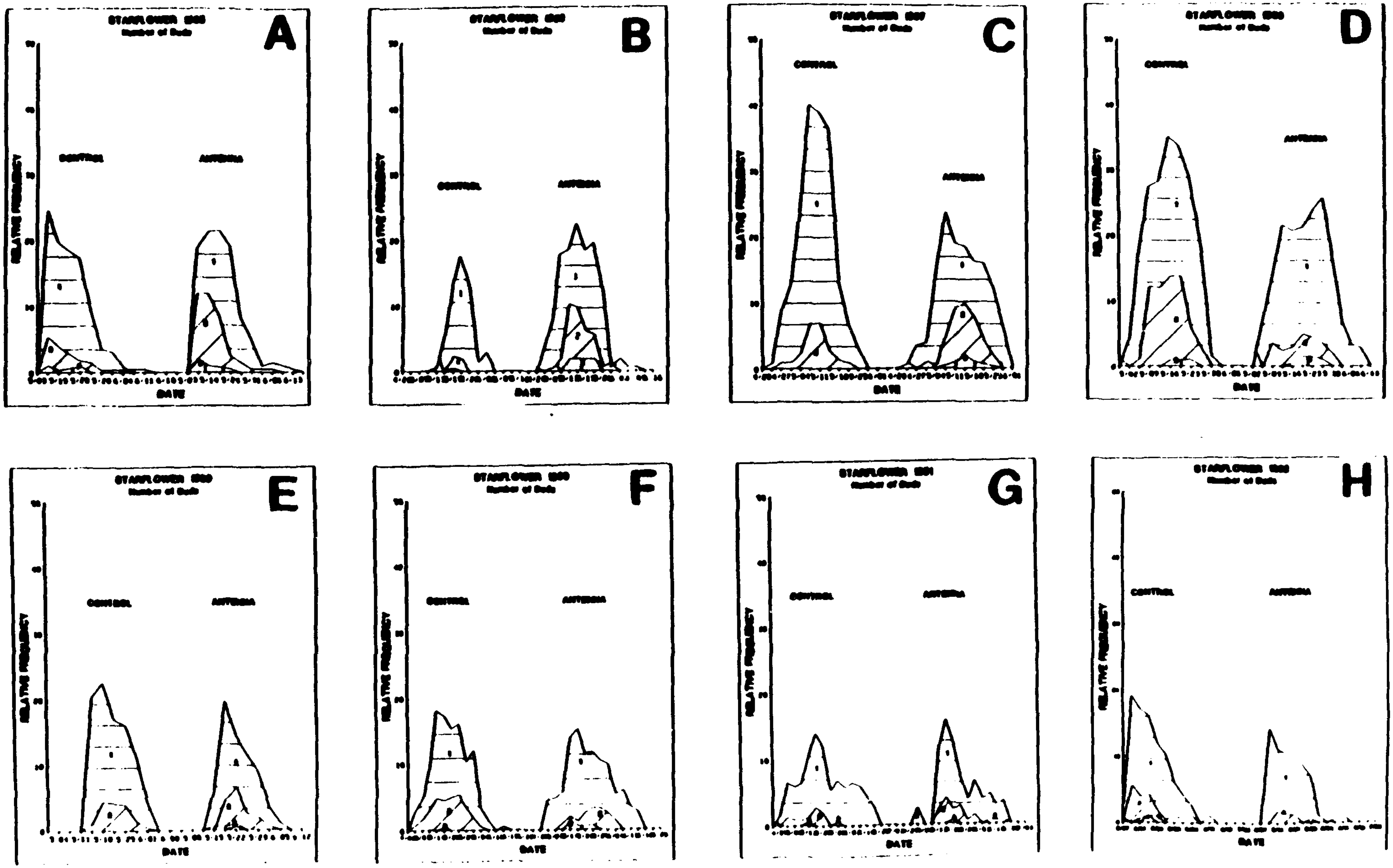


Figure 3.2: Relative frequency for number of plants with one or more flowers by sampling date on the antenna site and the control site for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), 1990 (F), 1991 (G), 1992 (H).

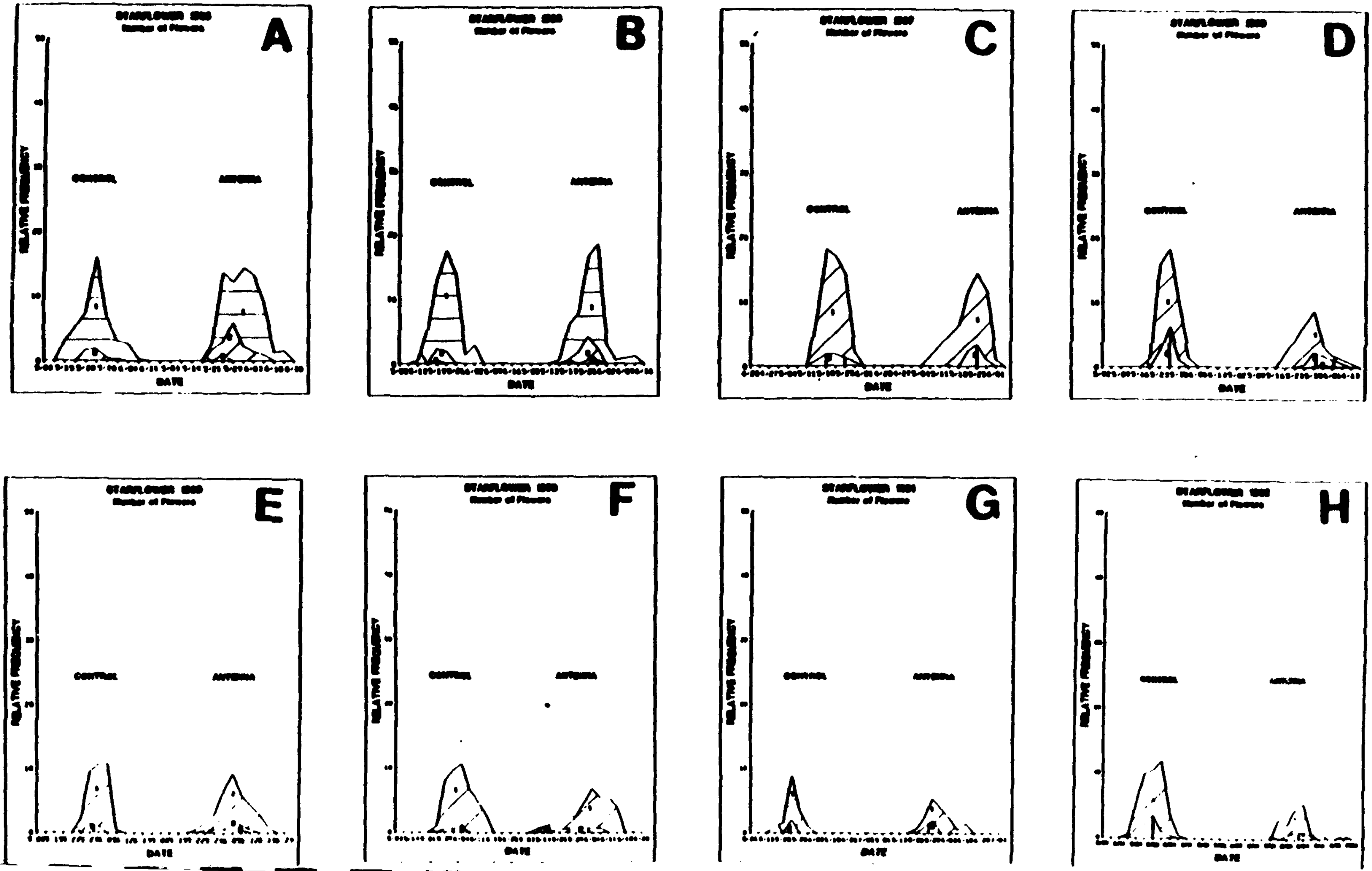
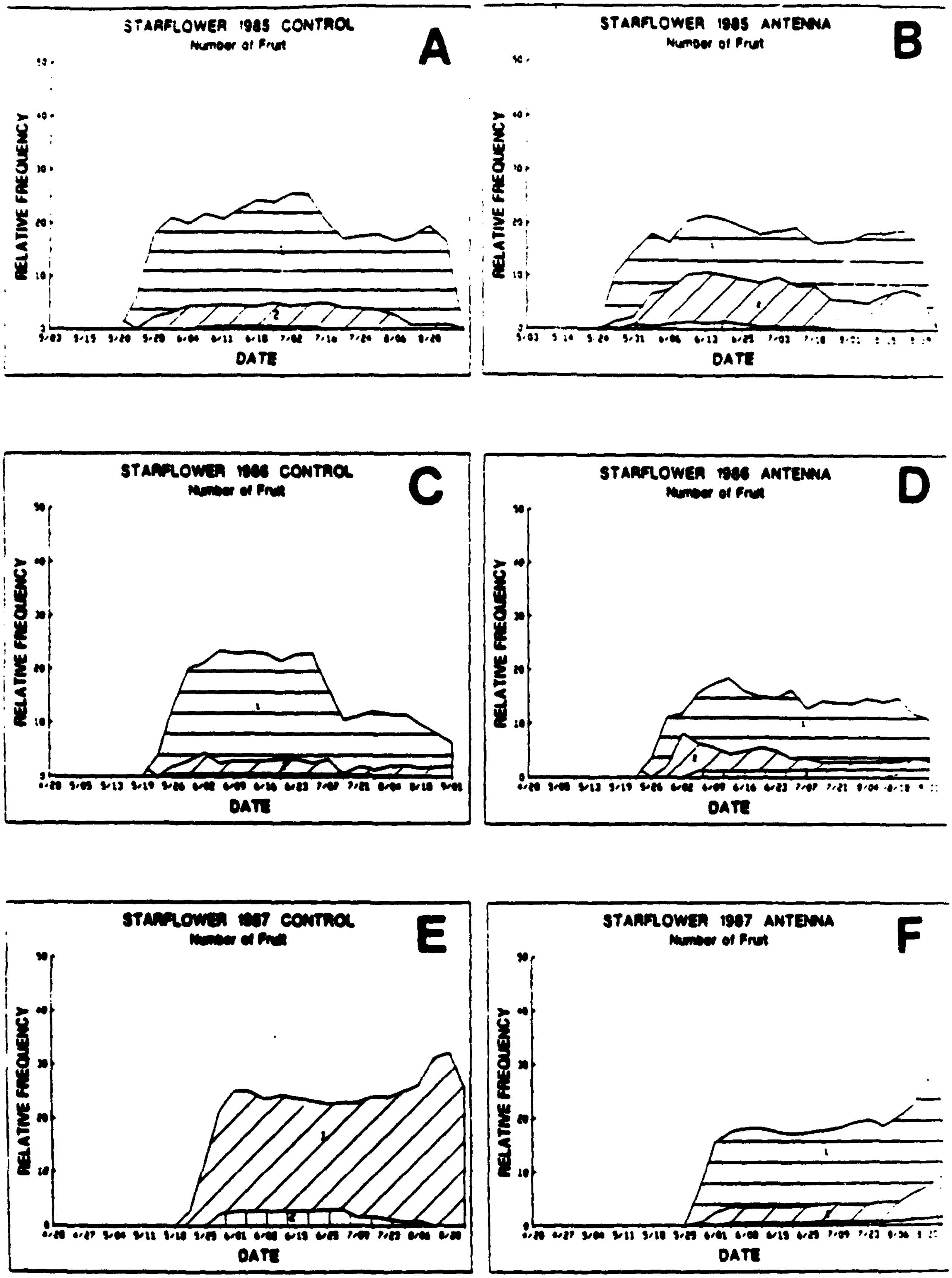
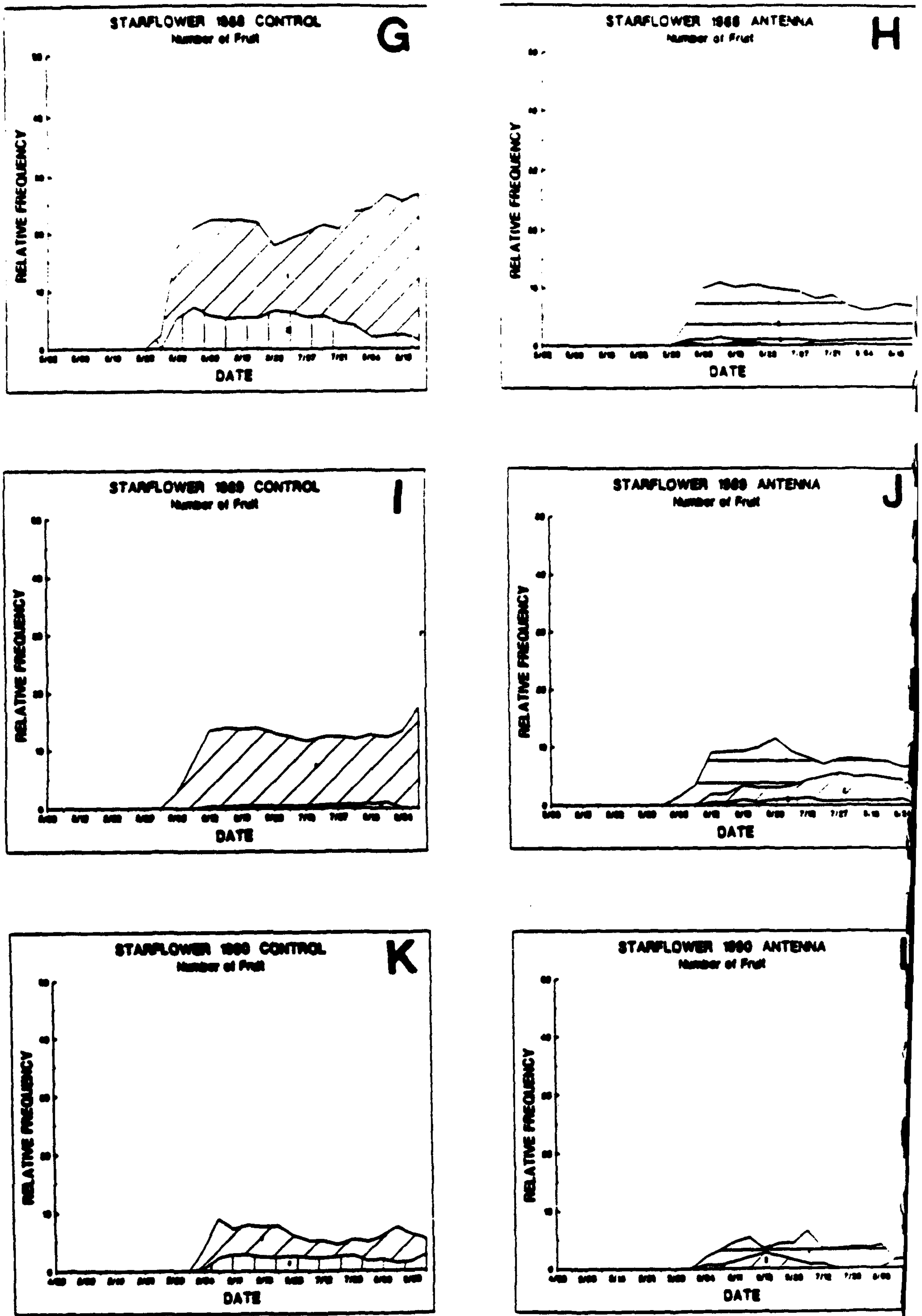
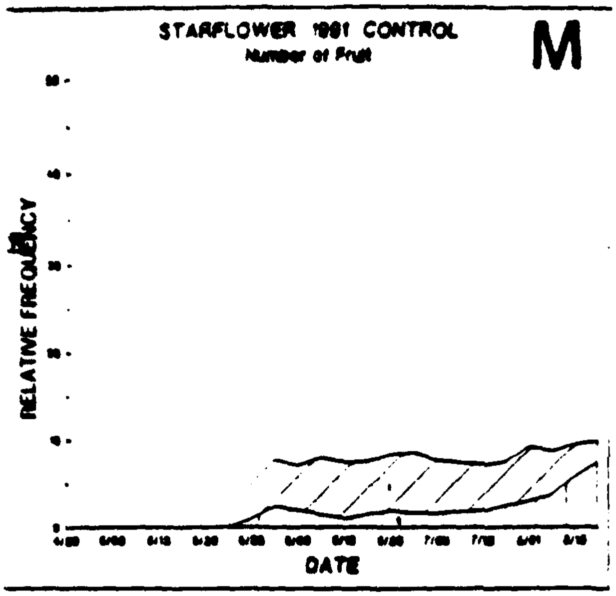


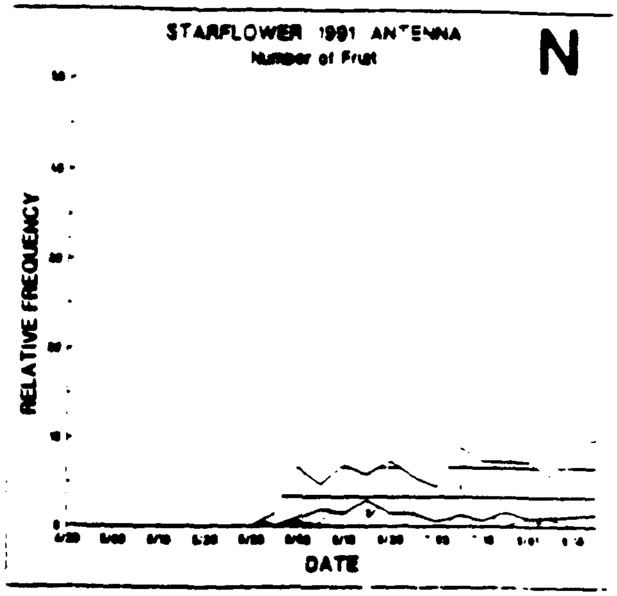
Figure 3.3: Relative frequency for number of plants with one or more fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N), and 1992 (P).

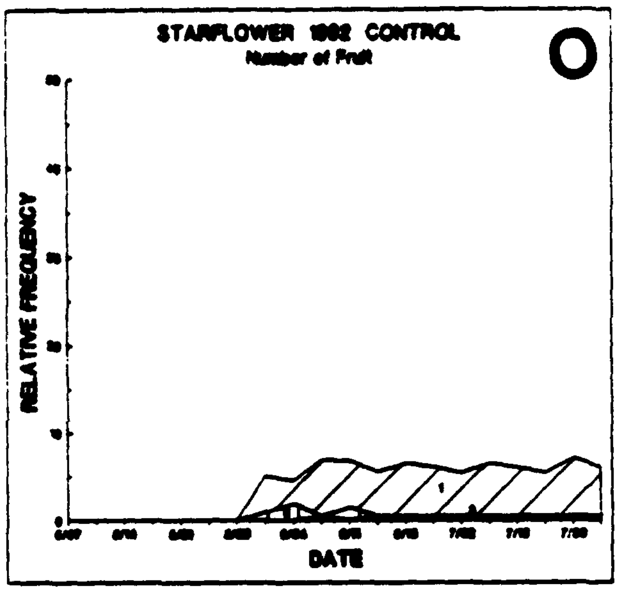




STARFLOWER 1988 CONTROL
Number of Fruit
G
RELATIVE FREQUENCY
DATE
STARFLOWER 1988 ANTENNA
Number of Fruit
H
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 CONTROL
Number of Fruit
I
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 ANTENNA
Number of Fruit
J
RELATIVE FREQUENCY
DATE
STARFLOWER 1990 CONTROL
Number of Fruit
K
RELATIVE FREQUENCY
DATE
STARFLOWER 1990 ANTENNA
Number of Fruit
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 CONTROL
Number of Fruit
M
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 ANTENNA
Number of Fruit
N
RELATIVE FREQUENCY
DATE


STARFLOWER 1992 CONTROL
Number of Fruit
O
RELATIVE FREQUENCY
DATE

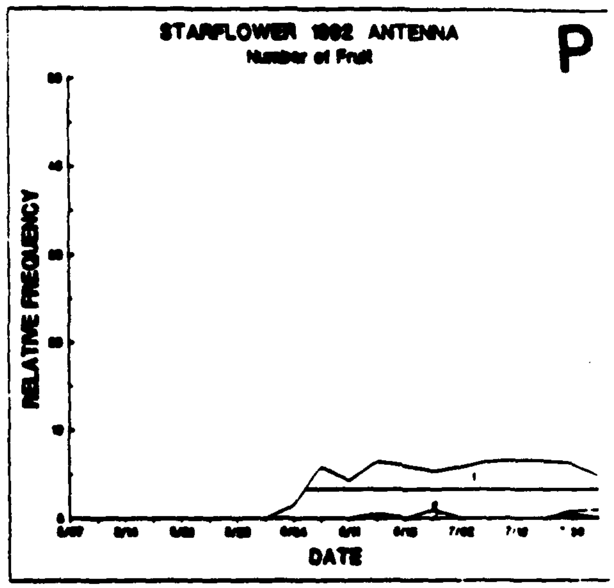
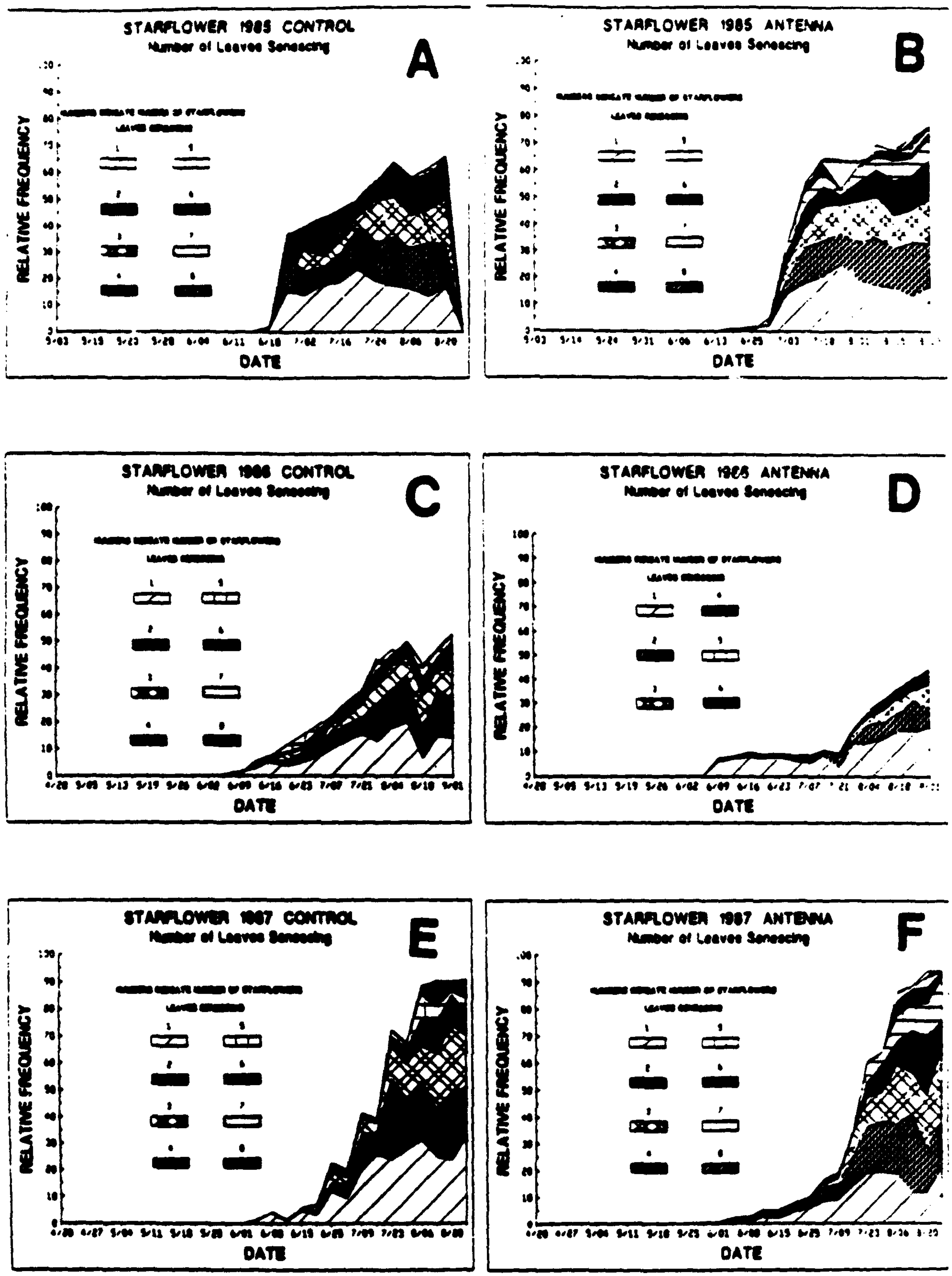
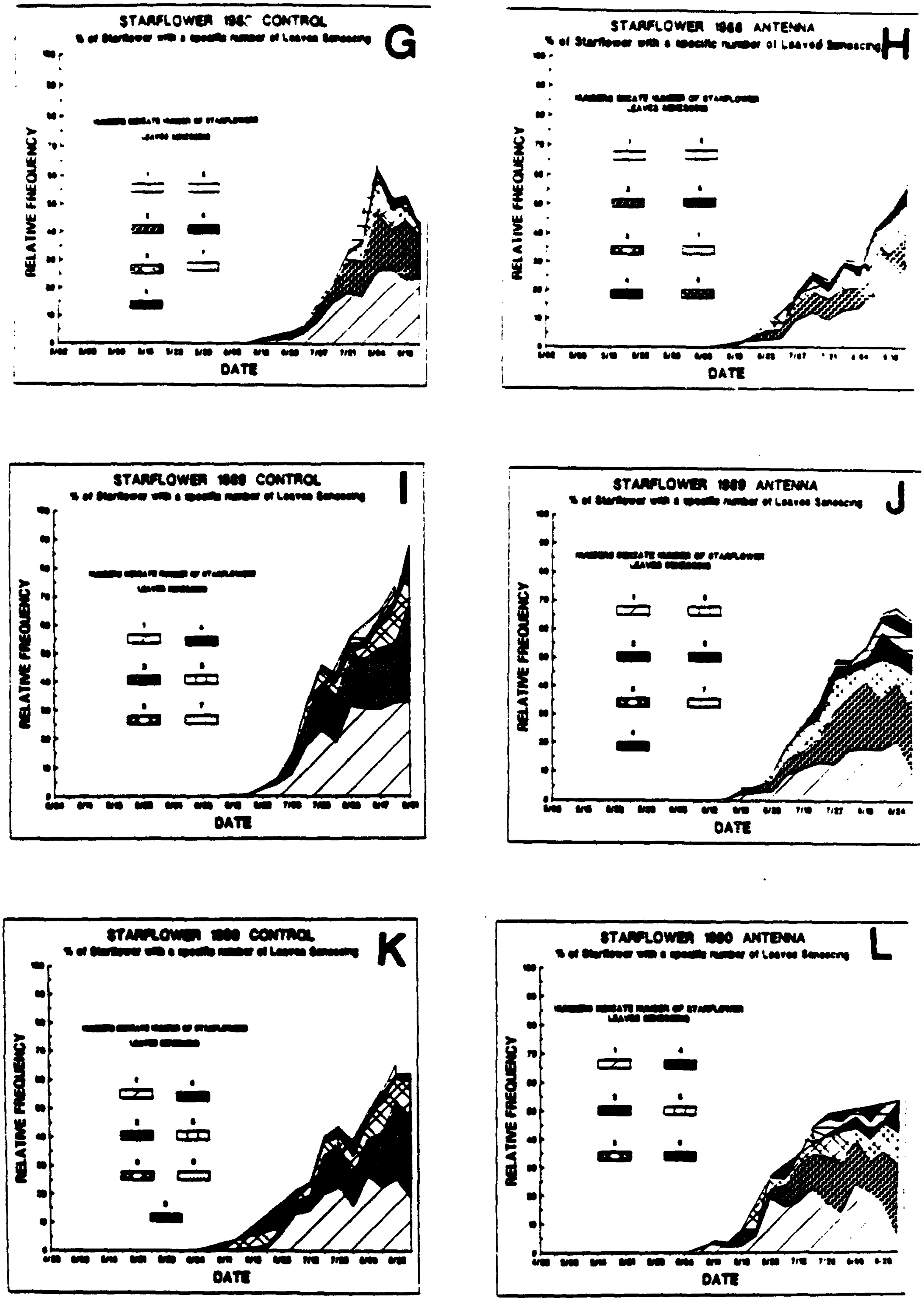

STARFLOWER 1992 ANTENNA
Number of Fruit
P
RELATIVE FREQUENCY
DATE

Figure 3.4: Relative frequency for number of plants with one or more leaves senescing by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N), and 1992 (P).




STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Leaves Senescing
H
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Leaves Senescing
I
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Leaves Senescing
J
RELATIVE FREQUENCY
DATE
STARFLOWER 1990 CONTROL
% of Starflower with a specific number of Leaves Senescing
K
RELATIVE FREQUENCY
DATE
STARFLOWER 1990 ANTENNA
% of Starflower with a specific number of Leaves Senescing
L
RELATIVE FREQUENCY
DATE
G
RELATIVE FREQUENCY
DATE

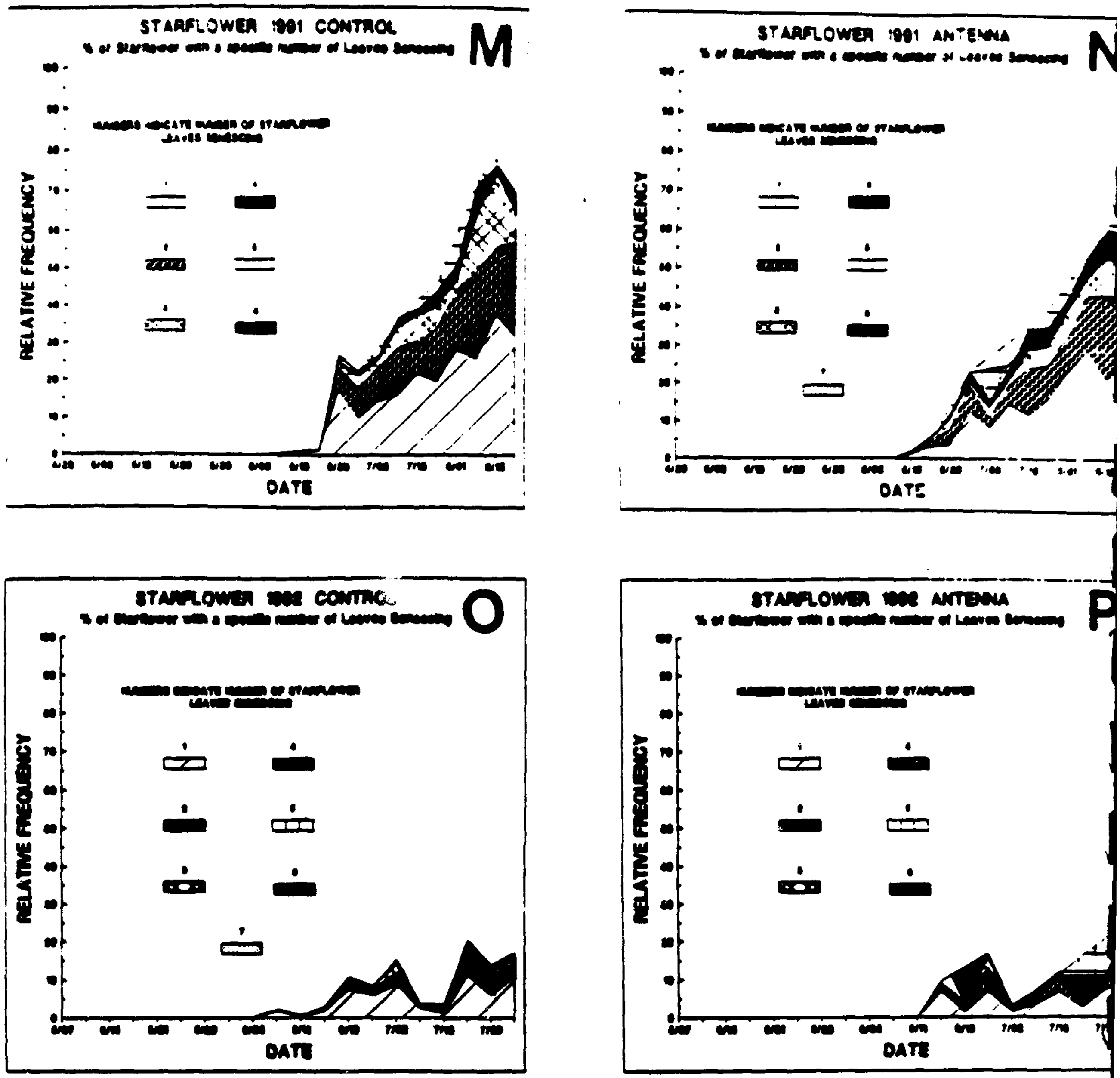
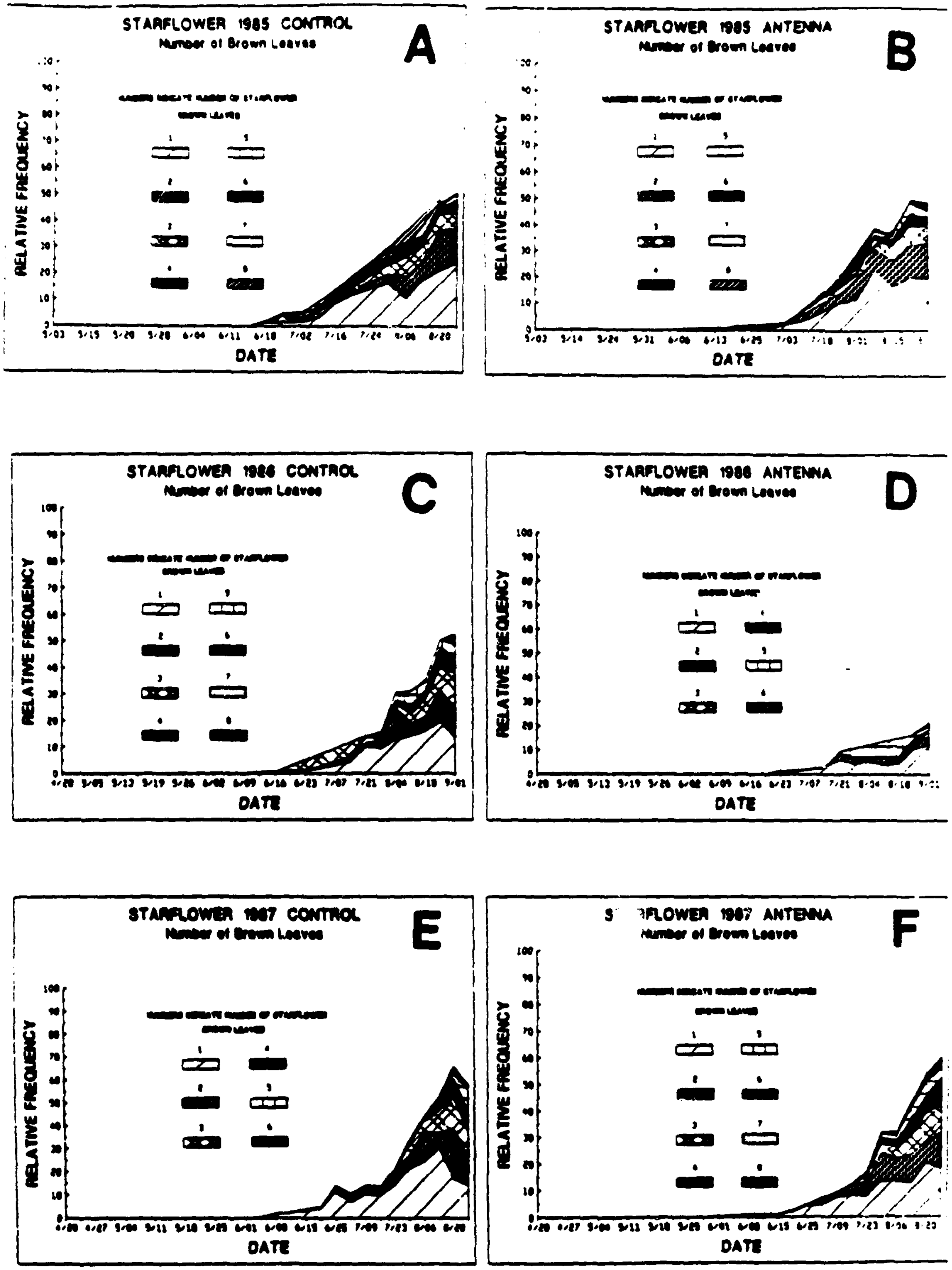
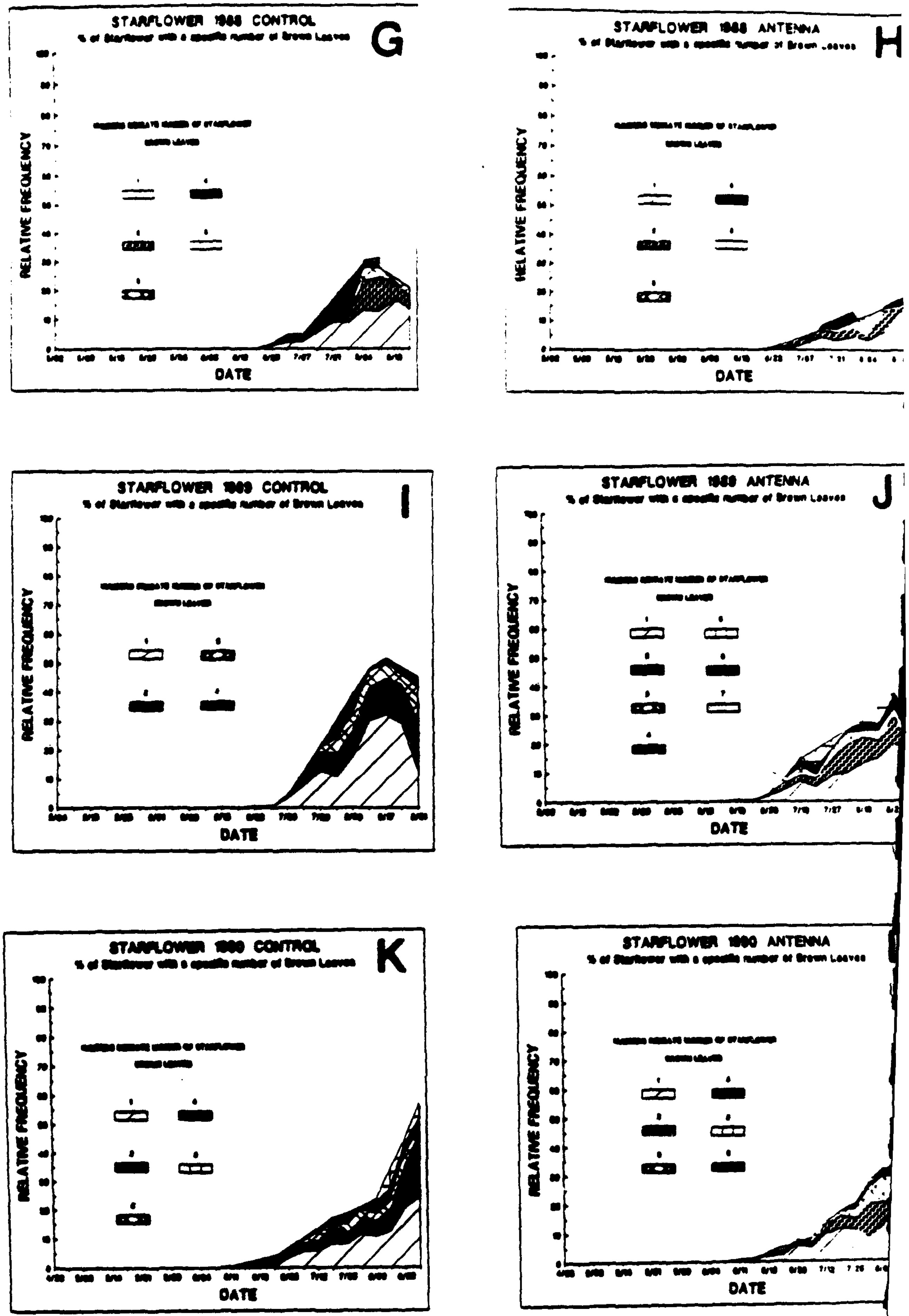
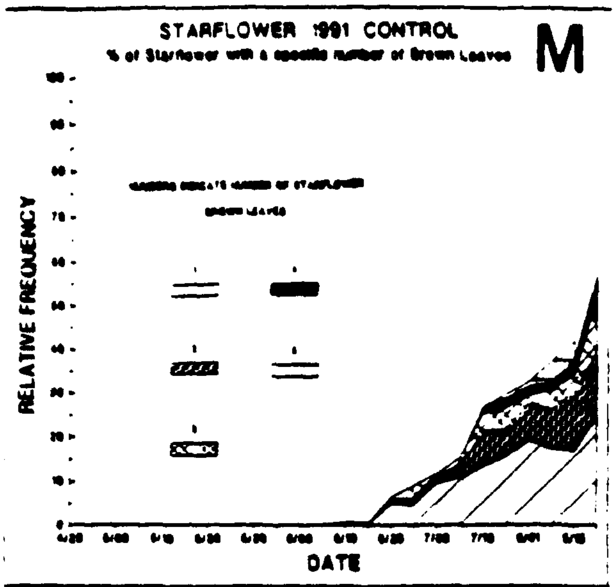
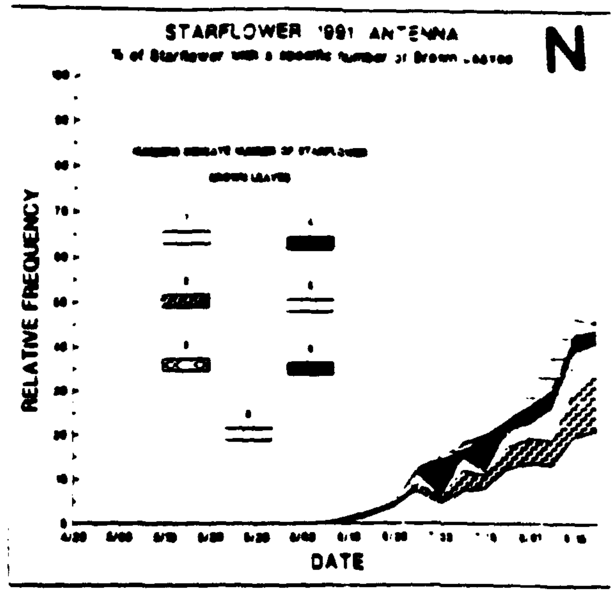

STARFLOWER 1991 CONTROL
M
RELATIVE FREQUENCY
DATE
STARFLOWER 1991 ANTENNA
N
RELATIVE FREQUENCY
DATE
STARFLOWER 1992 CONTROL
O
RELATIVE FREQUENCY
DATE
STARFLOWER 1992 ANTENNA
P
RELATIVE FREQUENCY
DATE

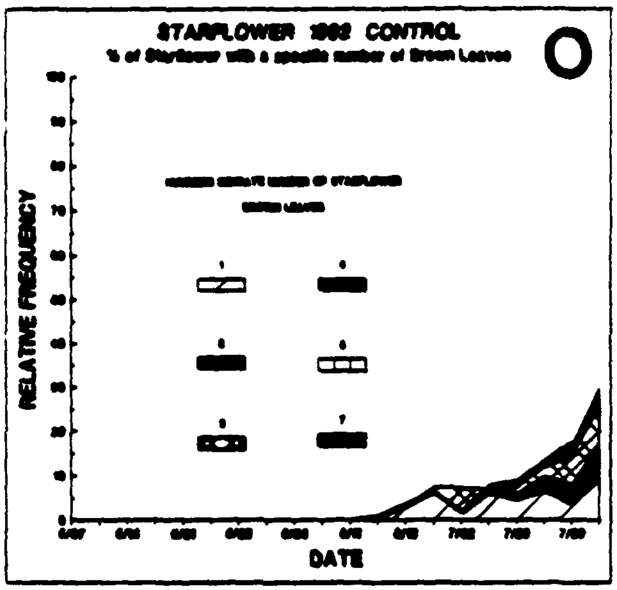
Figure 3.5: Relative frequency for number of plants with one or more brown leaves by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N), and 1992 (P).




STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Brown Leaves
G
RELATIVE FREQUENCY
DATE
STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Brown Leaves
H
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Brown Leaves
I
RELATIVE FREQUENCY
DATE
STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Brown Leaves
J
RELATIVE FREQUENCY
DATE
STARFLOWER 1990 CONTROL
% of Starflower with a specific number of Brown Leaves
K
RELATIVE FREQUENCY
DATE
STARFLOWER 1990 ANTENNA
% of Starflower with a specific number of Brown Leaves
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 CONTROL
% of Starflower with a specific number of Brown Leaves
M
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 ANTENNA
N
RELATIVE FREQUENCY
DATE


STARFLOWER 1992 CONTROL
% of Starflower with a specific number of Brown Leaves
O
RELATIVE FREQUENCY
DATE

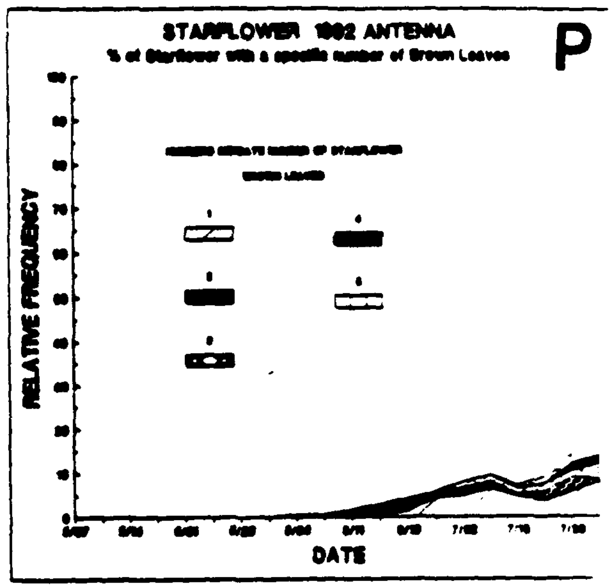
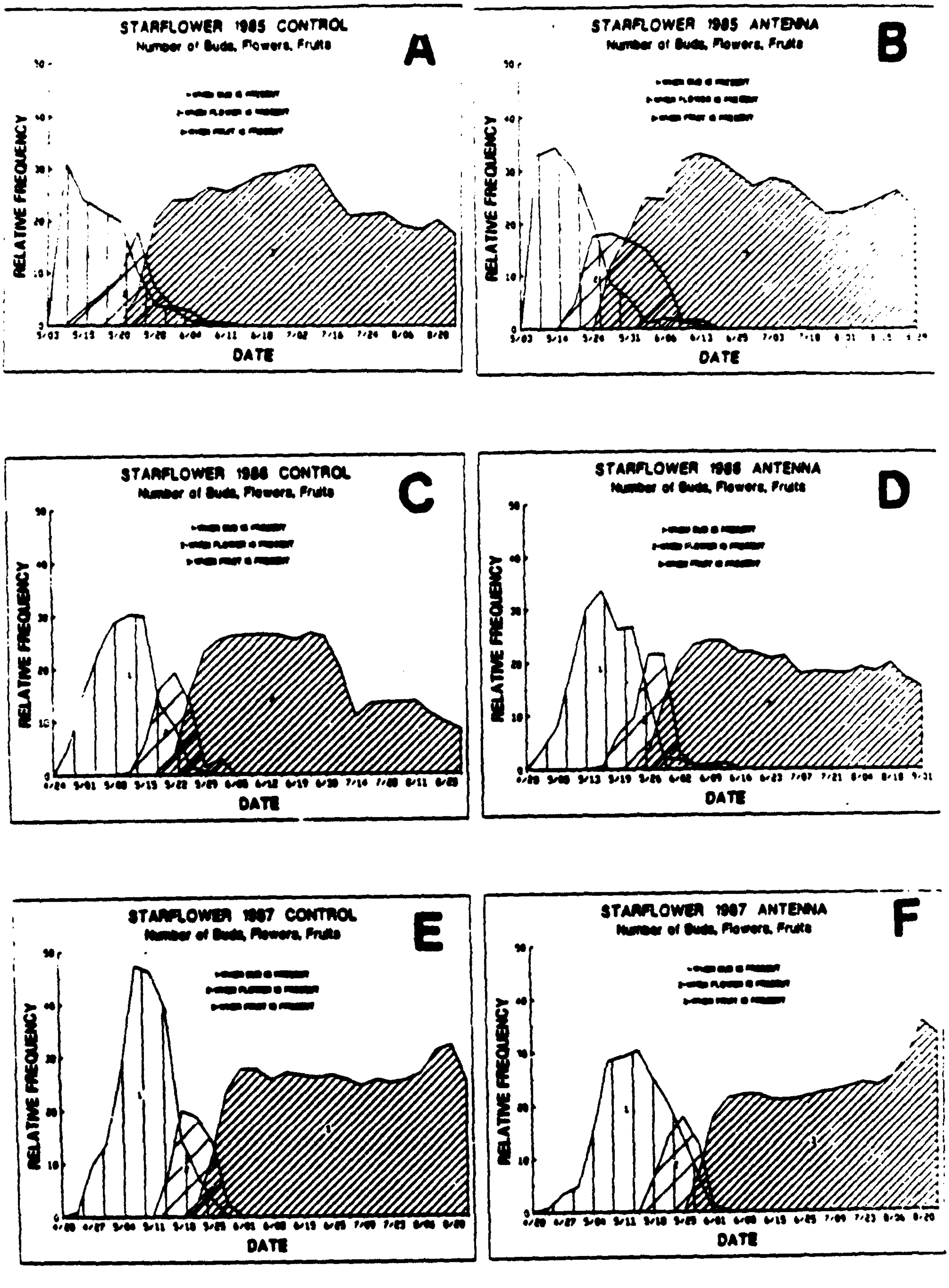
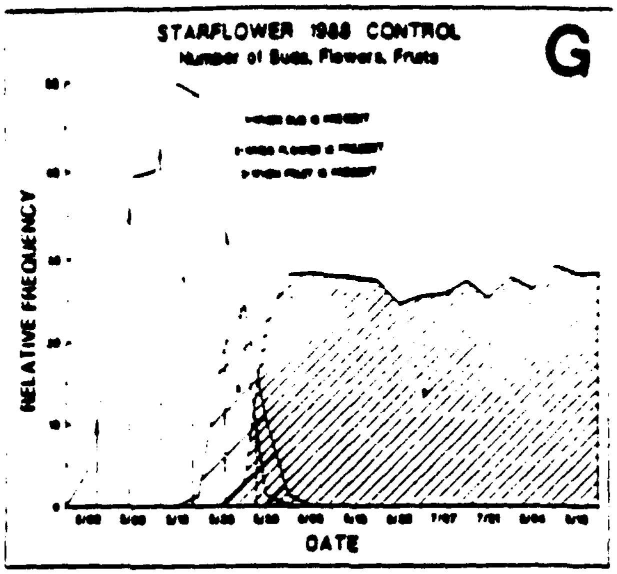
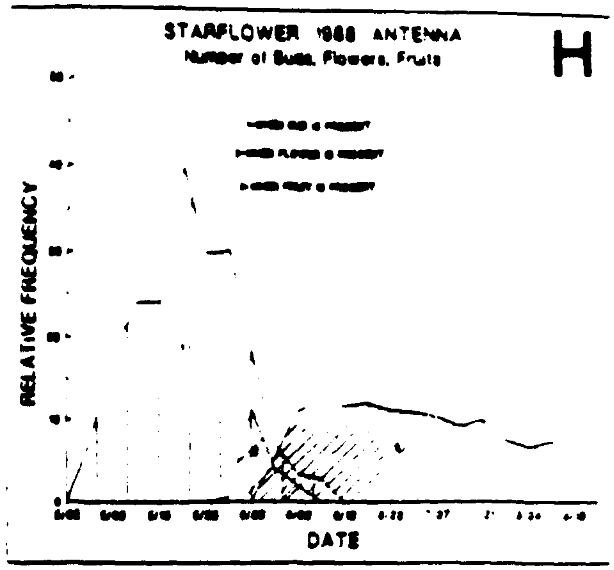
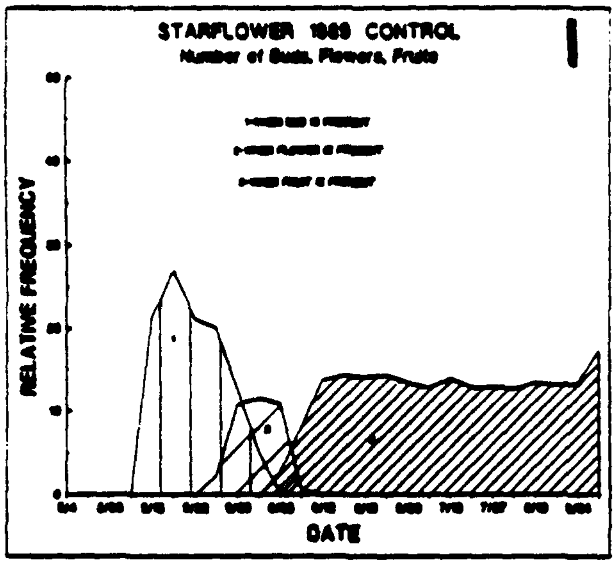

STARFLOWER 1992 ANTENNA
% of Starflower with a specific number of Brown Leaves
P
RELATIVE FREQUENCY
DATE

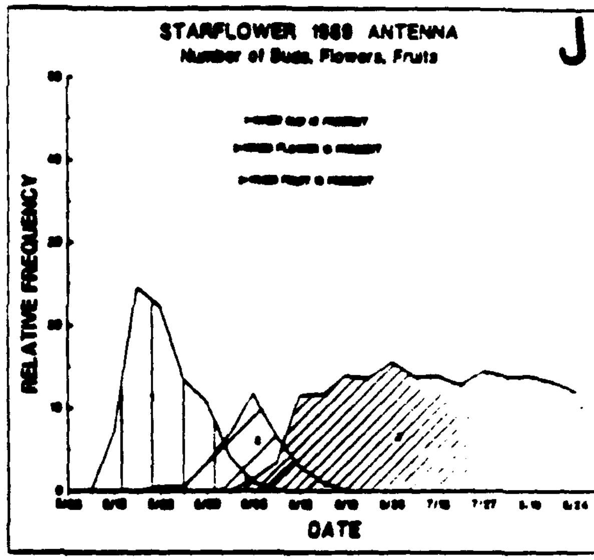
Figure 3.6: Comparison of the relative frequency and proportion of plants with one or more buds, flowers, and fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N), and 1992 (P).

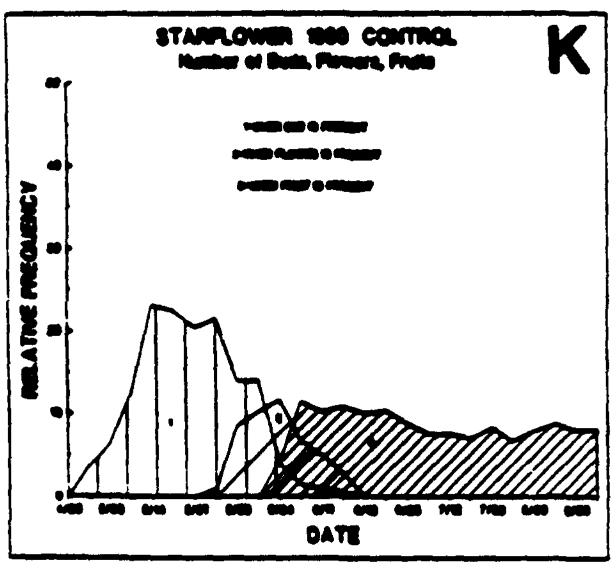


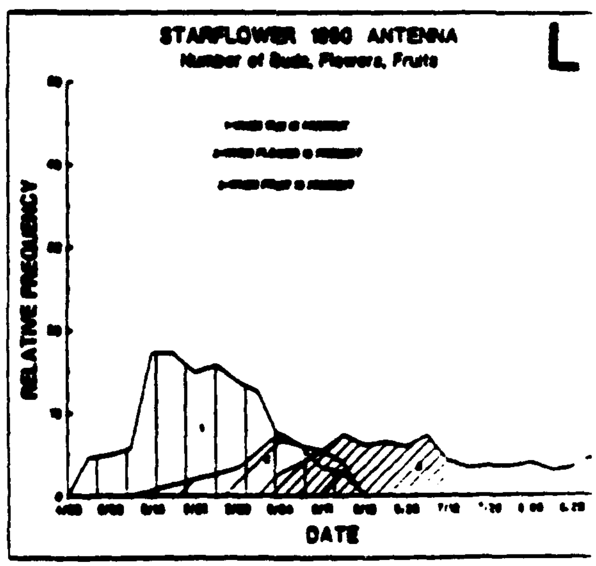

STARFLOWER 1988 CONTROL
Number of Buds, Flowers, Fruits
G
RELATIVE FREQUENCY
DATE

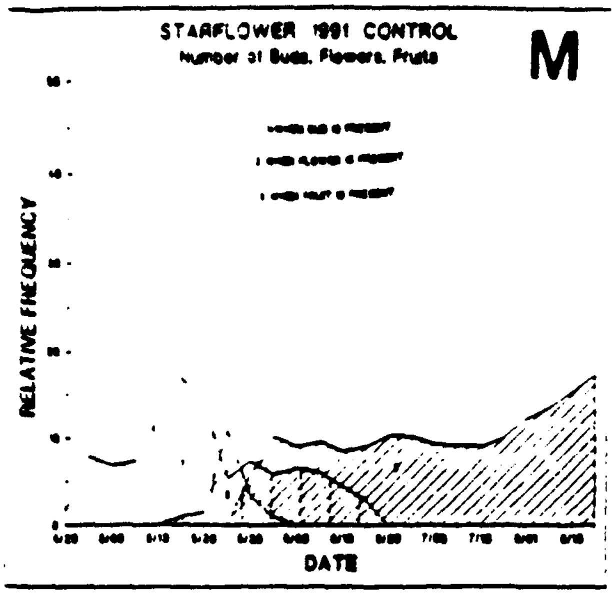

STARFLOWER 1988 ANTENNA
Number of Buds, Flowers, Fruits
H
RELATIVE FREQUENCY
DATE

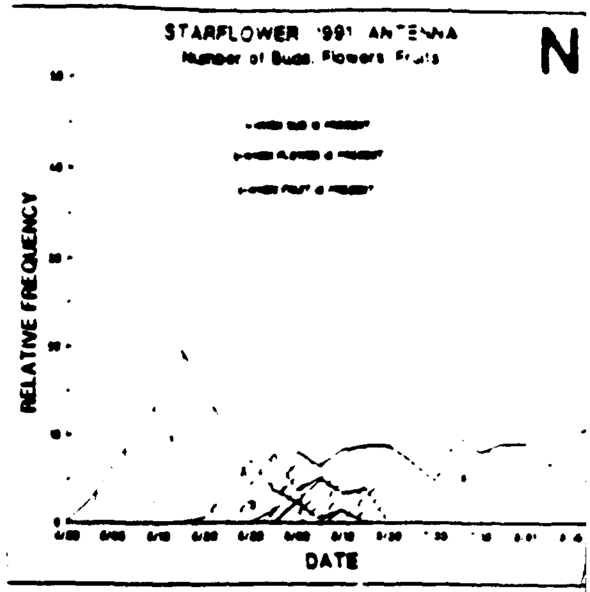

STARFLOWER 1989 CONTROL
Number of Buds, Flowers, Fruits
I
RELATIVE FREQUENCY
DATE

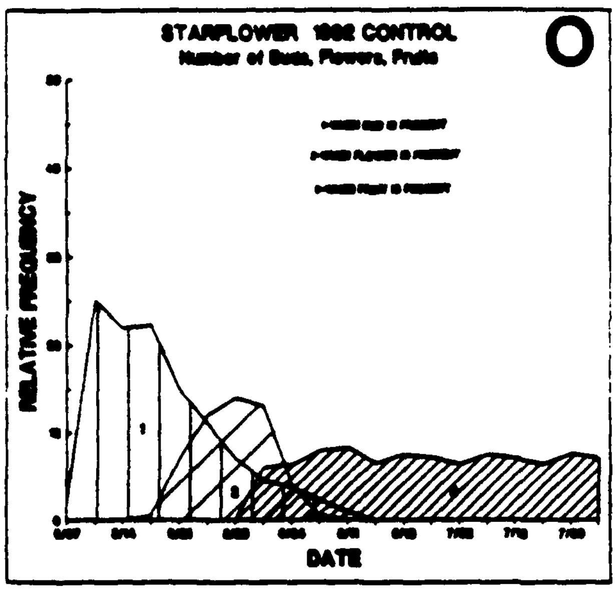

STARFLOWER 1989 ANTENNA
Number of Buds, Flowers, Fruits
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
Number of Buds, Flowers, Fruits
K
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 ANTENNA
Number of Buds, Flowers, Fruits
L
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 CONTROL
Number of Buds, Flowers, Fruits
M
RELATIVE FREQUENCY
DATE


N
RELATIVE FREQUENCY
DATE


STARFLOWER 1992 CONTROL
Number of Buds, Flowers, Fruits
O
RELATIVE FREQUENCY
DATE

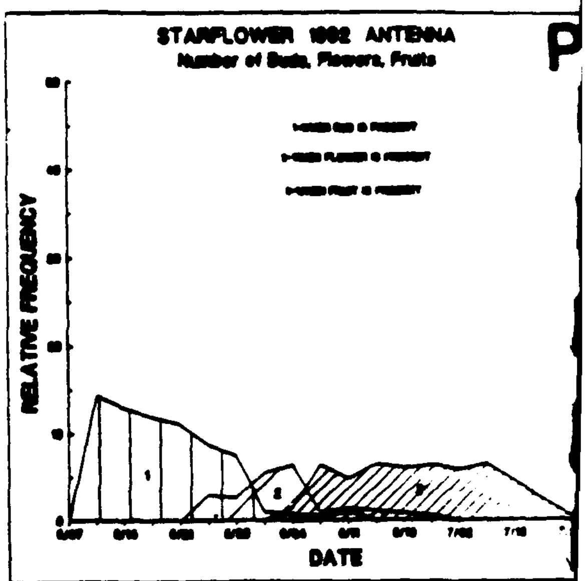
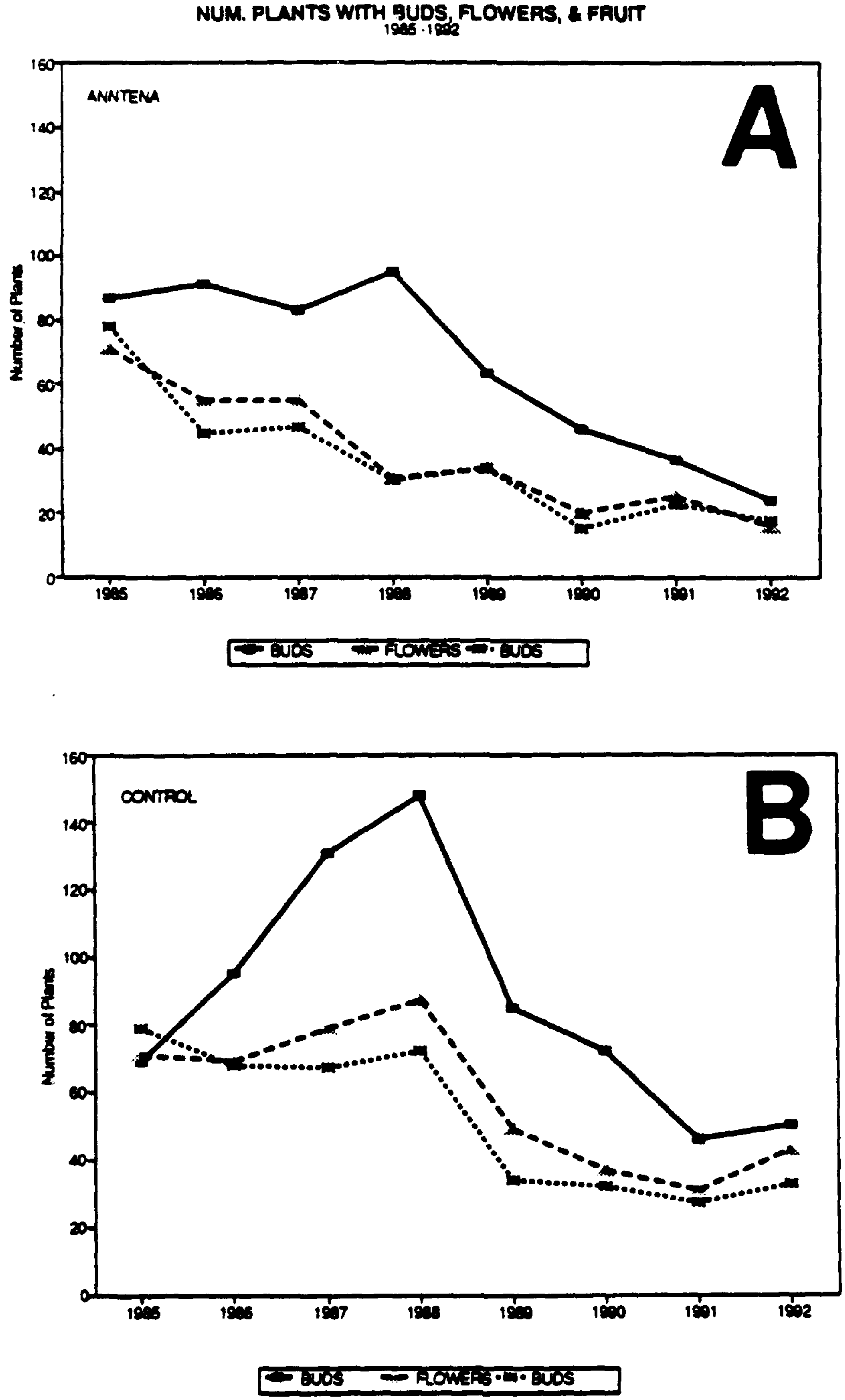

STARFLOWER 1992 ANTENNA
Number of Buds, Flowers, Fruits
P
RELATIVE FREQUENCY
DATE

Figure 4: Number of plants on the Antenna site (A) and the Control site (B) with buds, flowers, and fruit.



To determine if handling had a significant effect on stem length, leaf length, and leaf width on both the control and the antenna sites, three permanent plots (1 m^2) were randomly established in 1989 on each site approximately 1 m from the sampled transect at varying distances along the transect. All plants within the "unhandled" plots were measured on one occasion per year (the last measurment period for each year). Care was taken to ensure the least amount of handling occurred to plants on the "unhandled" plots. Mean stem lengths, leaf lengths, and leaf widths on both the "handled" plots and the "unhandled" plots on the control site and the antenna site were then statistically compared. In 1989, results indicated that there were no significant decreases ($p > 0.20$) in stem length, leaf length, and leaf width of "handled" plants on both the control site and the antenna site. In 1990 and 1992, similar results were determined. Due to problems in data acquisition, handling data collected in 1991 was lost. In 1989, 1990, and 1992, no significant interactions were determined among site and handling treatments.

Analysis of covariance (ANCOVA) was used to determine if climatic and microsite characteristics could be used to explain differences in stem expansion (cm/time period), leaf expansion (cm/time period), and leaf area expansion (cm^2/time period) between sites (antenna vs control), years, and site by years (Table 3.1). The same ANCOVA was used in 1992 as in 1991, 1990, 1989, 1988, and 1987. Because of the evident subplot variation along the sampling transect, additional information on basal area and canopy coverage of woody species within each subplot was taken in 1989. Basal area by species and total basal area were estimated for each subplot using a 10 factor prism. Canopy coverage on the ground and at 4.5 feet were measured using a densiometer. This same information was used for the 1990, 1991, and 1992 analyses.

Table 3.1. Analysis of Covariance table for stem expansion, leaf expansion, and leaf area expansion.

Source of Variation	df	SS	MS	F
Year	4	SS_y	MS_y	MS_y/MS_{e1}
Covariates	#	SS_{cy}	MS_c	MS_c/MS_{e1}
Error 1 (P/Y)	40-#	SS_{e1}	MS_{e1}	
Site	1	SS_s	MS_s	MS_s/MS_{e2}
Site by Year	4	SS_{sy}	MS_{sy}	MS_{sy}/MS_{e2}
Covariates	#	SS_{cs}	MS_{cs}	MS_{cs}/Ms_{e2}
Error 2 (SxP/Y)	40-#	SS_{e2}	MS_{e2}	

In the initial analysis of variance without covariates, stem expansion, leaf expansion, and area expansion on the antenna site were significantly different from the control site (Table 3.2A) Year and site/year interactions were also determined to be significantly different (Table 3.2A). Prior to ANCOVA, scatterplots of soil temperature degree days running total versus the response variables indicated that the variation in the response variables increased with increasing soil temperature (e.g.non-constant variance). This problem was solved by taking the natural log of soil temperature degree days running total. Correlations were then calculated between starflower measurements and climatic and microsite variables. The variables most highly correlated to stem length, leaf area, leaf length, and leaf width expansion were 1) maximum solar radiation (SOLMX) (r=-0.14, -0.38, -0.37, -0.40 respectively), 2) natural log of soil temperature degree days running total at 10 cm (LST10DRT) (r=0.17, 0.53, 0.58, and 0.66 respectively), 3) bigtooth aspen basal area (BTABA) (r=0.22, 0.30, 0.29, and 0.25 respectively), and 4) northern red oak basal area (NROBA) (r=-0.20, -0.30, -0.29, and -0.26 respectively). Interactions between climate variables and microsite variables were also highly correlated to stem length, leaf area, leaf length, and leaf width expansion (ie., LST10DRT/BTABA (r=-0.12, -0.21, -0.18, -0.16, respectively), and LST10DRT/NROBA (r=0.16, 0.30, 0.30, 0.24, respectively) SOLMX/BTABA (r= -0.20, -0.30, -0.32, -0.30, respectively)). Although not highly correlated to leaf area, leaf length, and leaf width expansion, the interaction SOLMX/NROBA (r=-0.04, -0.03, 0.01, -0.07, respectively) was used as a covariate to explain the high component of northern red oak trees on the control site. This year (1992), precipitation was added to the covariate analysis to account for the significant differences in precipitation between years (Element 1). Precipitation and its corresponding interaction with basal area estimates were not as highly correlated with stem length, leaf area, leaf length, leaf width as other ambient data (absolute r avlues ranged from 0.02 to 0.16) but added significant amounts of explained variation in the response variables when used in covariate analysis (Table 3.2B).

Table 3.2. Results of ANCOVA (p values) to determine significant differences in stem expansion (STEM), leaf length expansion (LGTH), leaf width (LWTH) expansion, and leaf area expansion (LAREA) between sites, years, and site by years.

A) No Covariates

Source of Variation	STEM	LGTH	LWTH	LAREA
Year	0.00	0.00	0.00	0.00
Site	0.00	0.00	0.00	0.00
Site by Year	0.00	0.00	0.00	0.00

B) Covariates for Stem Length (STEM), Leaf Length (LGTH), Leaf Width (LWTH), and Leaf Area (LAREA). Bigtooth Aspen Basal Area (BTABA) + Northern Red Oak Basal Area (NROBA) + Natural Log (Soil Temperature Degree Days Running Total at 10 cm)/BTABA + Natural Log (Soil Temperature Degree days Running Total at 10 cm)/NROBA + Maximum Solar Radiation/NROBA + Precipitation/NROBA.

Source of Variation	STEM	LGTH	LWTH	LAREA
Year	0.00	0.01	0.00	0.00
Site	0.81	0.99	0.77	0.87
Site by Year	0.00	0.03	0.03	0.69

The use of these covariates explained significant amounts of variation in leaf area, leaf length, and leaf width expansion between sites but not among years (Table 3.2B). These covariates also explained significant amounts of variation in site by year interactions for leaf area expansion but not for site by year interactions for leaf length and leaf width expansion.

Morphological Characteristics

Observations in the past years suggested a clonal difference between the population of starflower on the antenna site versus the population on the control site. In 1990, starflower plants and soils from each site were collected off the herbaceous transects and reciprocally transplanted on to the other site. Plants were randomly chosen from each site and placed in the same light regime on the other site. Plants were then measured in early September to determine if there were morphological differences between the two sites. In 1990, the transplant study indicated that there was a significant reduction ($p < 0.05$) in the stem length of plants taken from the control and planted on the antenna site versus average stem lengths on the control site. Number of leaves, leaf lengths, and leaf widths were not statistically different between the sites. At this time, there is no explanation for these results. In 1991, none of the transplants could be found on either site, thus this study was not continued in 1992. It is believed that the transplants on both sites did not produce a rhizome at the end of the growing season in 1990. This was probably due to transplanting shock and/or to other climatic factors.

A maximum of four buds per plant was observed on the control site but not the antenna site this year (Figure 3.1H). On both sites, the number of plants with two buds fluctuated considerably. This fluctuation was attributed to herbivores. Plants on the antenna site produced the same number of flowers as on the control site (Figures 3.2H). Plants with three fruit were only observed on the control site but not on the antenna site (Figures 3.3O and 3.3P). These results were opposite from results in 1991 and 1989. This year, both sites exhibited much different characteristics in the number of yellow leaves at various measurement periods during the growing season (Figures 3.4O and 3.4P). Reasons for this are unknown except that the climate from May to August was cold and rainy with intermitent dry/hot periods in May and early June which may have caused significant depletion of yellow leaves on certain plants. The percent of plants with brown leaves were somewhat similar between the antenna and the control sites and similar to results from 1988 and 1986 (Figures 3.5O and 3.5P). The effects of ELF fields on morphological characteristics are not evident at this time.

Using regression analysis, linear equations were fit to observations of leaf area using leaf length and leaf width measured on destructively sampled starflower plants off the herbaceous reserves for each year (1986-1992) on each site (Table 3.3).

Table 3.3. Leaf area (LA) equations for each site in each year and for all sites and all years using leaf width (Lw) and leaf length (Ll).

Site (Year)	Equation	$S_{y.x}$[1]
Control Site (1986)	LA = 0.09 + 0.55 (Lw x Ll)	0.20
Control Site (1987)	LA = 0.11 + 0.56 (Lw x Ll)	0.18
Control Site (1988)	LA = 0.40 + 0.52 (Lw x Ll)	0.68
Control Site (1989)	LA = 0.05 +.0.57 (Lw x Ll)	0.18
Control Site (1990)	LA = 0.08 + 0.56 (Lw x Ll)	0.16
Control Site (1991)	LA = 0.13 + 0.56 (Lw x Ll)	0.21
Control Site (1992)	LA = 0.15 + 0.57 (Lw x Ll)	0.22
Antenna Site (1986)	LA = 0.13 + 0.55 (Lw x Ll)	0.26
Antenna Site (1987)	LA = 0.13 + 0.56 (Lw x Ll)	0.34
Antenna Site (1988)	LA = 0.32 + 0.52 (Lw x Ll)	0.60
Antenna Site (1989)	LA = 0.05 + 0.56 (Lw x Ll)	0.24
Antenna Site (1990)	LA = 0.15 + 0.54 (Lw x Ll)	0.37
Antenna Site (1991)	LA = 0.12 + 0.54 (Lw x Ll)	0.35
Antenna Site (1992)	LA = 0.20 + 0.54 (Lw x Ll)	0.28

[1] Standard error of regression

The independent variable of leaf width x leaf length explained over 98 percent of the variation in leaf area for both sites in 1986, 1987, 1989, 1990, 1991, and 1992. Ninety-two and 96 percent of the variation in leaf areas was explained using the variable leaf width x leaf length for the control and the antenna sites, respectively, in 1988. Higher standard errors occurred with the development of the 1988 curves (Table 3.3). Possible causes of increased error in 1988 were attributed to inaccuracies in leaf length and leaf width measurements and/or leaf sampling techniques in the field.

Regression coefficients (intercepts and slopes) were tested to determine if there were significant differences ($p < 0.05$) between sites (antenna vs control) and among years. Site-year interactions were also examined. In 1992, significant yearly ($p < 0.001$) and site ($p < 0.001$) differences in both the slopes and the intercepts were observed. Intercepts for the antenna and control sites in 1988 were again significantly greater than for 1986, 1987, 1989, 1990, 1991 and 1992; the intercept for 1989 was significantly lower than all other years. Slopes for the antenna and control sites were significantly lower in 1988 than for 1986, 1987, 1989, 1990, 1991, and 1992. Again these differences may be due to inaccurate leaf sampling techniques. However, these differences may also be due increased solar radiation in 1988 compared with other years (Element 1, this report).

Summary

Differences in phenological events of starflower (bud break, flowering, fruiting, leafout, leaf senscence (yellow and brown)) between the antenna and control sites were not evident after the ELF antenna became operational (September, 1989). In 1992, significant variation in stem expansion, leaf length and width expansion, and leaf area expansion between the antenna and the control site can be explained using microsite basal areas, soil temperature degree days running total at 10 cm, maximum solar radiation, precipitation, and interactions between these variables. These covariates also explain significant variations in leaf area expansions among site by year interactions. There were, however, significant site by year differences for stem length, leaf length, and leaf width expansion. Our conclusion, at this time, is that ELF fields have not significantly influenced starflower on the antenna site.

Element 4. MYCORRHIZAE CHARACTERIZATION AND ROOT GROWTH

Mycorrhizae of plantation red pine seedlings have been chosen as sensitive biological indicators to reflect perturbations which might be caused by ELF fields. Mycorrhizae are symbiotic structures representing a finely balanced physiological relationship between tree roots and specialized fungi, providing mutual benefit to both partners of the symbiosis. Mycorrhizal fungi are obligately bound to their host requiring photosynthate from the tree for their energy source. In return, the matrix of mycorrhizal fungus mycelium which permeates the forest floor and mineral soil from colonized roots provides the host tree with minerals and water more efficiently than without its fungal partner. Although many types of mycorrhizae occur on these sites, this study will examine only ectomycorrhizae fungi formed on red pine root systems.

Mycorrhizal associations are a major part of a forest ecosystem and are likely to be sensitive indicators of subtle environmental perturbations. Mycorrhizal fungi are obligate symbionts, directly dependent on their partner's physiology for their health. Thus mycorrhiza formation and numbers will be sensitive to factors affecting either the fungus component or the host plant component.

Mycorrhizae have been selected for evaluation in other studies which require sensitive indicators of subtle environmental changes. Recent studies were designed to monitor the effects of acid rain on the forest ecosystem using mycorrhizal numbers as the parameter of assessment (Reich *et al.* 1985, Shafer *et al.* 1985, Stroo and Alexander 1985, Dighton and Skeffington 1987). Similar studies have examined mycorrhizae and how they were affected by ozone and air pollution (Kowalski 1987, Reich *et al.* 1985, Mejstrik and Cudlin 1987) and heavy metal buildup in soils (Jones and Hutchinson 1986). Extremely low frequency fields could detectably alter the more discriminating mycorrhizal fungus component. Data regarding mycorrhizae may also be used to substantiate responses seen in other measures of tree productivity.

Populations of mycorrhizae on each red pine plantation site are compared at monthly intervals during the growing season (May-October) and with corresponding monthly intervals during the growing season from previous years. The basic experimental units are individual red pine seedlings. Mycorrhizae are categorized into morphological types produced by different fungal associations on red pine seedlings. Changes in both the frequency of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling are quantified for analysis both within and among years as well as among sites. Data for analysis are expressed as the total number of mycorrhizae per gram of seedling root mass (oven dry weight (o.d.w.) 60°C). The working null hypothesis states that there are no differences in population densities of different types of mycorrhizal root tips on red pine seedlings at the Ground Antenna and Control sites, before or after the ELF Antenna becomes operational. Other changes that could occur are reflected by possible alternative hypotheses such as; 1) shifts in population species composition and 2) changes in the character of mycorrhizal morphology type.

Sampling and Data Collection

In conjunction with Element 2, Tree Productivity, fifteen red pine seedlings per site (five per plot per site) were sampled for six months (May-October) during the 1992 growing season, as was done the previous six years. Seedlings for mycorrhizal analysis were simultaneously measured for above- and belowground growth parameters and moisture stress. To retrieve mycorrhizae-bearing lateral roots, the seedling's root system was excavated using a shovel and produced a soil sample approximately 50 cm in diameter and 25 cm deep. This method was different than prior years due to the difficulty in adequately sampling major areas of seedling fine root biomass; thus, the soil sample area was enlarged. Red pine seedling fine (< 5mm) roots were extracted from this sample in the field to obtain approximately 30 to 60 cm of total root length. Lateral roots from each seedling with adherent soil were wrapped tightly in individual plastic bags, placed in a cooler and transported to the laboratory where they were refrigerated. Within two to three days the lateral roots were rinsed first in a small volume of distilled water (1:1 water to root/soil volume) for rhizosphere soil pH determination, then washed gently in tap water, placed in a fresh volume of tap water and refrigerated. Approximately 0.25 g roots (fresh weight) per sample were removed at this time for actinomycete enumeration (ELF, Litter Decomposition and Microflora Study). Counting mycorrhizal tips was begun immediately with counts completed within two weeks of field sampling.

A shallow white pan containing a small amount of water was used during the root sectioning and counting operation. The roots were cut to obtain 30 - 3 cm segments. As each 3 cm root segment was counted, its diameter and number of mycorrhizae were recorded. A mycorrhiza is defined, in this study, as a terminal mycorrhizal root tip at least 1.0 mm in length; hence a mature dichotomously branched mycorrhizal root tip would be tallied as two mycorrhizae. Upon completion of counting segments were collectively dried at 60°C to constant mass and weighed. Mycorrhiza counts for each 3 cm root segment are expressed as mycorrhizae per gram (o.d.w.) of dry root. This measure has been used in other root studies examining mycorrhizae dynamics in forest ecosystems (Harvey *et al.* 1987).

The most common mycorrhizae on these sites continue to be represented by fairly uniform morphologies. They range in color from a tan to a deep red-brown color and are formed primarily by *Thelephora terrestris* and/or *Laccaria laccata* (*sensu lato*, Fries and Mueller 1984). These mycorrhizae have been designated as Type 3 mycorrhizae. Many of the mycorrhizae have acquired a nearly black to deep jet-black color due to colonization by *Cenococcum graniforme*, an abundant mycorrhizal fungus in the original and surrounding hardwood forests, which were designated as Type 5 mycorrhizae. White to tan floccose forms are occasionally found, presumably colonized by *Boletus, Hebeloma, Paxillus* or *Suillus* spp., which have been designated as Type 6 mycorrhizae. Though variations occur within mycorrhizal morphology types, all fit within the grouping of these three main types. A dissecting microscope was used to distinguish mycorrhizal types. Morphology types were tallied separately and then totaled for each seedling. Non-mycorrhizal root tips were easily distinguishable as white root tips composed entirely of plant tissue, obviously lacking a fungal component.

Descriptions of Red Pine Mycorrhizal Morphology Types

Type 3 Mycorrhiza

Macroscopic: Light buff to dark red brown, sometimes nearly black, usually lighter at the apex; 2-10 mm long x 0.25-1.0 mm diameter; mono- or bipodal, occasionally multiply bifurcated and in mass forming coralloid clusters; plump and straight when short, but spindly and often crooked when long, usually somewhat constricted at the base.

Microscopic: Surface hyphae sparse, 2-3 um diameter, bearing clamps, setae scattered, often clustered in bunches of 4-8, mostly 50-80 um long; mantle 10-20 um thick, thinner over apex, hyphae forming conspicuous interlocking, "jig-saw puzzle-like" pattern; cortical cells red-brown except over apex where they are colorless; Hartig net hyphae bulbous and also forming interlocking pattern.

Comments: This is the most common type of mycorrhiza and was found originally on nursery red pine seedlings. The causal fungi, as evidenced by cultural isolation, are most often *Laccaria laccata* (*sensu lato*) and *Thelephora terrestris*, though other fungi may also produce similar mycorrhizae. It is worth noting that *L. laccata (sensu lato)* abounds in the surrounding forests and fruits abundantly on the plantation sites. This fungus might therefore be expected to maintain its dominance in the plantation seedlings. *Thelephora terrestris* has also been observed fruiting on the plantation sites.

Type 5 Mycorrhiza

Macroscopic: Black, sometimes with lighter apex; usually fuzzy with abundant attached, coarse hyphae; 1-3 mm long x 0.5-10 mm diameter; mono or bipodal, seldom multiply bifurcated; often appearing as if dark hyphae are enveloping Type 3 mycorrhizae.

Microscopic: Surface hyphae dark-brown to black, 3-6 um diameter, septate; setae arising from central stellate points of interlocking surface hyphae, setae 100 um or greater in length; mantle 10-30 um thick, mantle surface of coiled and interlocking hyphae; cortical cells dark and covered directly with hyphae of the same type observed with Type 3 mycorrhizae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This is a later successional stage mycorrhiza, appearing as a dark sheath over an earlier developed mycorrhiza. The causal fungus is *Cenococcum graniforme*, which is commonly isolated from these mycorrhizae. Hypogeous fruit bodies of *Elaphomyces* spp., the anamorph of *C. graniforme*, have been collected in the surrounding forest, indicating that adequate inoculum is available.

Type 6 Mycorrhiza

Macroscopic: White to light gray-brown, mottled and silvery; 2-5 mm long x 0.5-1.0 mm diameter; abundant loosely-bound surface hyphae often binding soil matter; mono- or bipodal often in large coralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing freed individual mycorrhizae to float.

Microscopic: Surface hyphae colorless, abundant, septate or not, 3-6 um diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 24-100 um thick, cortical cells red-brown covered with interlocking hyphae similar to Type 3; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This also appears to be a later successional stage mycorrhiza type forming a sheath over an earlier developed mycorrhiza. Presumably the responsible fungi colonize new root tips as well. Based on cultural characteristics of isolated fungi, the causal fungi probably belong to the families Boletaceae, Cortinariaceae or Paxillaceae. Fruiting bodies of these families were common in the original forest and fruit abundantly in the surrounding forest, providing adequate and readily available inoculum.

Statistical Analysis

Though red pine seedlings were outplanted on the study sites in June 1984, data from that year are not being compared with subsequent years for two reasons. First, 1984 was the year of plantation establishment; nursery seedlings are small and planting shock is known to have a significant effect on seedling root systems. Second, ambient weather and soil data was not available for 1984. For all years following 1984, total mycorrhizae per gram of dry root (o.d.w.) has been used to compare sites, years, and site by year interactions. A nested analysis of variance was used to test these factor levels. The error term used to test site differences was plot within site. The error term used to test yearly differences was month within year and the error term used to test site by year interactions was month within year by site. These error terms were used because of the occurrence of unequal variances in the total number of mycorrhizae per gram of dry root among plots and among months. We also made the following assumptions: 1) site differences were mainly due to plot differences, 2) yearly differences were mainly due to monthly variations, and 3) site by year differences were mainly due to monthly variations within year by site. A significance level of $p=0.05$ with the Student Newman Keuls's Multiple Range Test was used to detect significant differences among means. To facilitate this, data on total mycorrhizae per gram of dry root mass were analyzed using analysis of covariance, with weather and soil ambient variables applied as covariates.

Progress

Non-mycorrhizal root tips were not encountered in the 1992 season. Since 1985 non-mycorrhizal root tips declined, until 1987 when none were observed for the final month at the Ground and Control sites, and for the last four months at the Antenna site. Non-mycorrhizal roots were not encountered in 1988, 1989, nor in 1990. This steady decline in uncolonized root tips is likely a function of seedling maturation, and indicates that seedlings are becoming fully adapted to native soil microflora. Non-mycorrhizal root tips remain a morphological type of interest, and will continue to be monitored in 1993 (the last year of mycorrhizae sampling), in case (hypothetically) seedlings undergo a reversion in maturity due to ELF field effects.

Type 3 mycorrhizae in 1992 continued to be the major mycorrhizal type on red pine seedling root systems at all sites (Figures 4.1 and 4.2). This year, total numbers of mycorrhizae on the Control site were less than total number of mycorrhizae from the Antenna and Ground sites in May (Figure 4.1). After May, total number of mycorrhizae on the Control site increased steadily. Mean total number of mycorrhizae on the Ground site were approximately the same from May until July, then increased in August and September with a decrease in October. Mean total number of mycorrhizae on the Antenna site were similar to the Ground site except for an increase in October. Increases may be due to increased precipitation in after May or to soil nutrient fluctuations (see Element 2). Total number of mycorrhizal root tips in 1992 were not significantly different from numbers in 1987 and 1991. Total number of mycorrhizae in 1990 were not significantly different from total numbers in 1989.

Type 5 mycorrhizae decreased in June on the Control site but were stable from May to June on the Antenna site (Figure 4.3; note scale change on Y axis from Figures 4.1 and 4.2). Type 5 mycorrhizae increased on the Ground site (Figure 4.3). Statistical comparisons from year to year for any site and month demonstrate that numbers in 1992 were most like numbers in 1990. All three sites had similar numbers of Type 5 mycorrhizae in October. As with Type 3 mycorrhizae, site and month differences are attributed to fluctuations in increases in mean air temperatures and precipitation amounts in the preceding months.

Type 6 mycorrhizae are the least common type encountered on red pine seedlings for all study sites (Figure 4.4; note different scale of the Y axis compared with Figures 4.1, 4.2, and 4.3). Type 6 mycorrhizae were first observed in late 1984 on very few seedlings. In 1985 and 1986, no seedlings were found with Type 6 mycorrhizae. In 1987, the occurrence of Type 6 mycorrhizae were infrequent and sporadic (Figure 4.4); they were found on all sites (but not all months). In 1988, numbers of Type 6 mycorrhizae were similar to the previous year, but higher numbers are being recorded, especially later in the season. In only two months of 1988 were differences between sites significant: in May the Ground and Antenna sites had lower numbers of Type 6 mycorrhizae per gram than the Control site, and in September the Ground site had lower numbers than the Antenna site while not differing from the Control site. In 1989, however, numbers of Type 6 mycorrhizae declined with only the Control and Ground sites having similar numbers in May and the Control and Antenna sites having similar numbers in July (Figure 4.4). In 1990, numbers of Type 6 mycorrhizae significantly declined except for September when numbers increased on the Ground site. This later stage mycorrhizal type would be expected to develop sooner on the best of site (Control site), where tree growth had been advancing more quickly (see Element 2). In 1991 and in 1992, Type 6 mycorrhizae were not evident. Therefore, numbers of Type 6 mycorrhizae have decreased since early 1989. Reasons for this are unknown. Differences among months may be due to individual soil properties associated with each seedling sampled.

At this time, there does not appear to be any affect of ELF fields on the number of mycorrhizal root tips per gram

Figure 4.1: Yearly and monthly comparisons of the total number of mycorrhizal root tips (ECM) per gram of dry root.

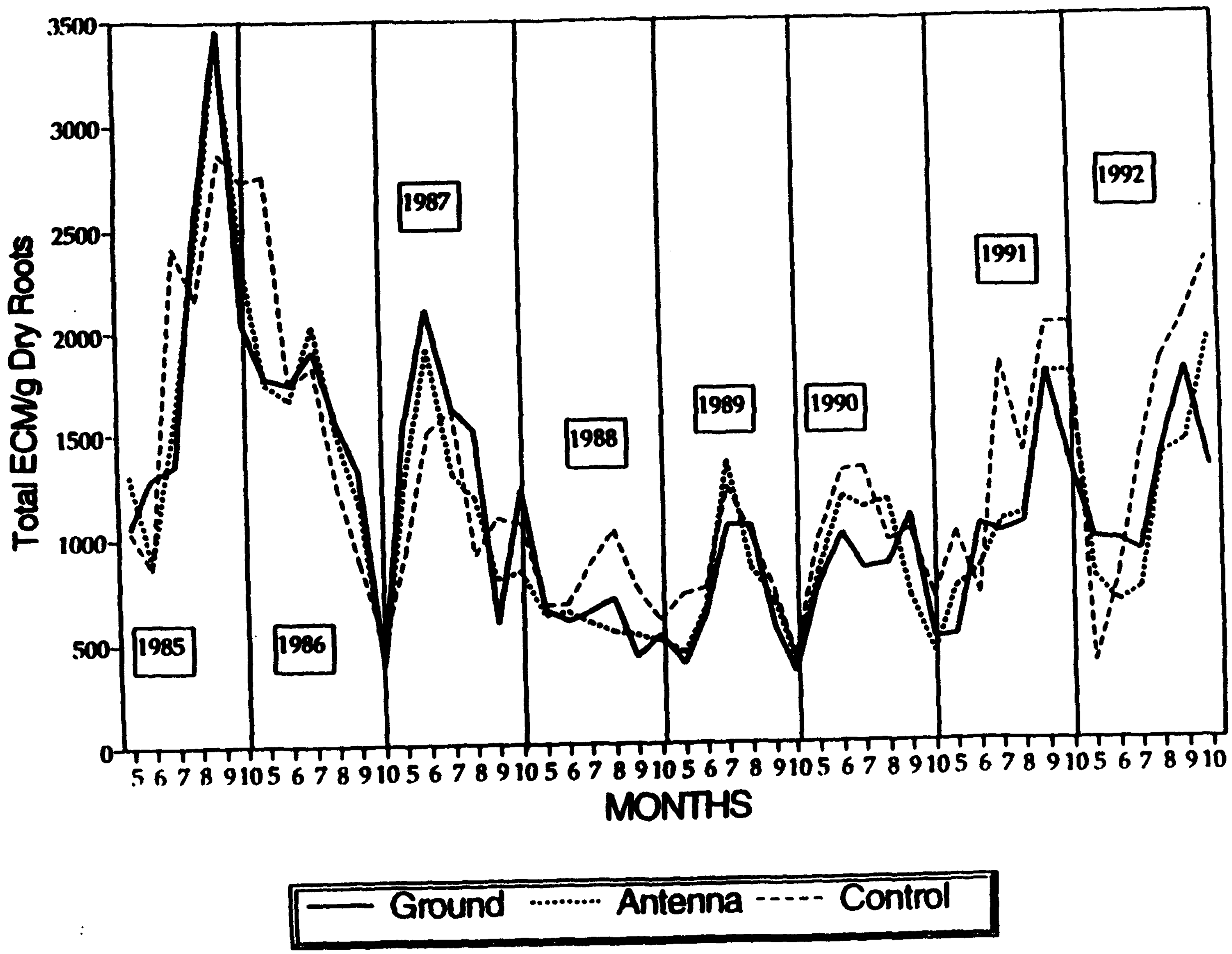


Figure 4.2: Yearly and monthly comparisons of the number of Type 3 mycorrhizal root tips (ECM) per gram of dry root.

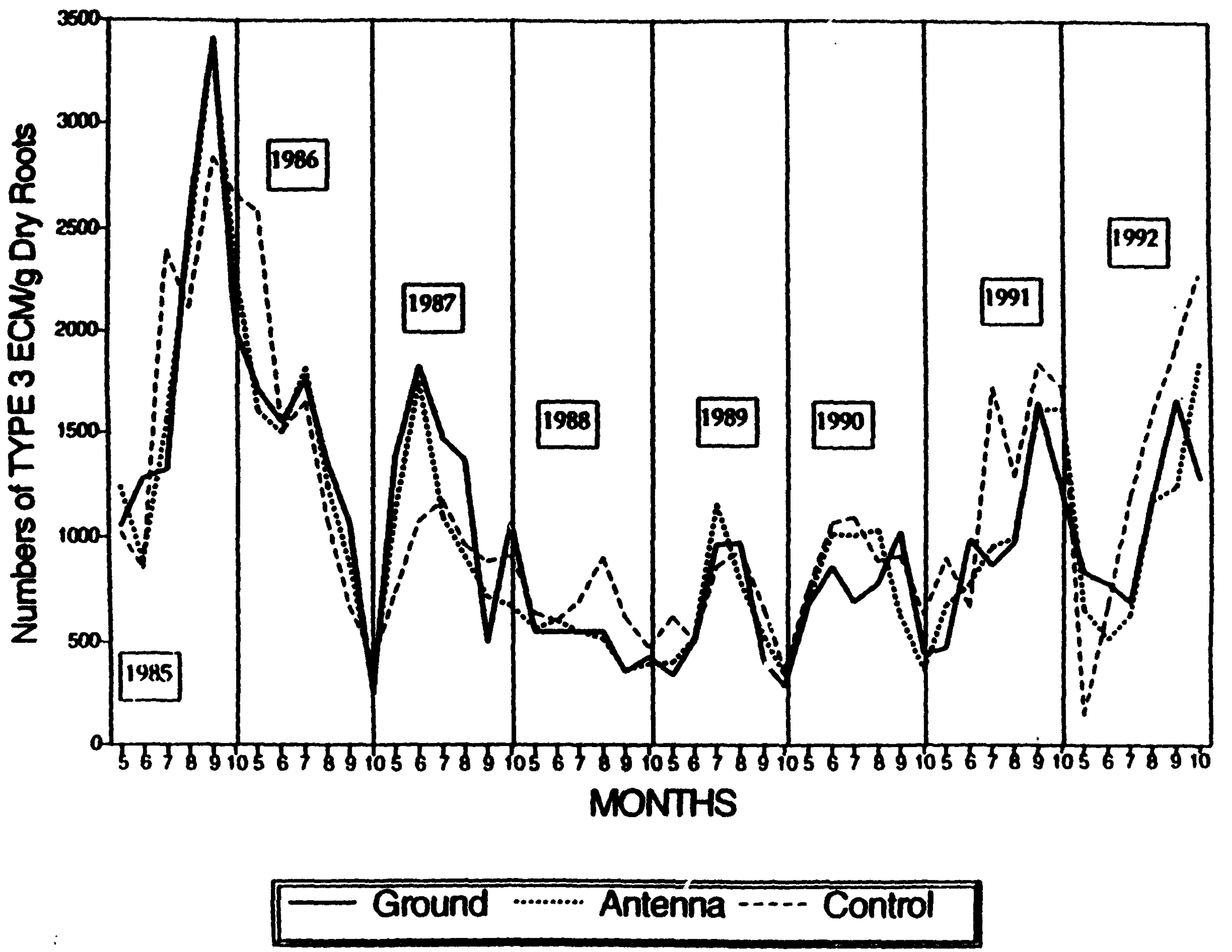


Figure 4.3: Yearly and monthly comparisons of the number of Type 5 mycorrhizal root tips (ECM) per gram of dry root.

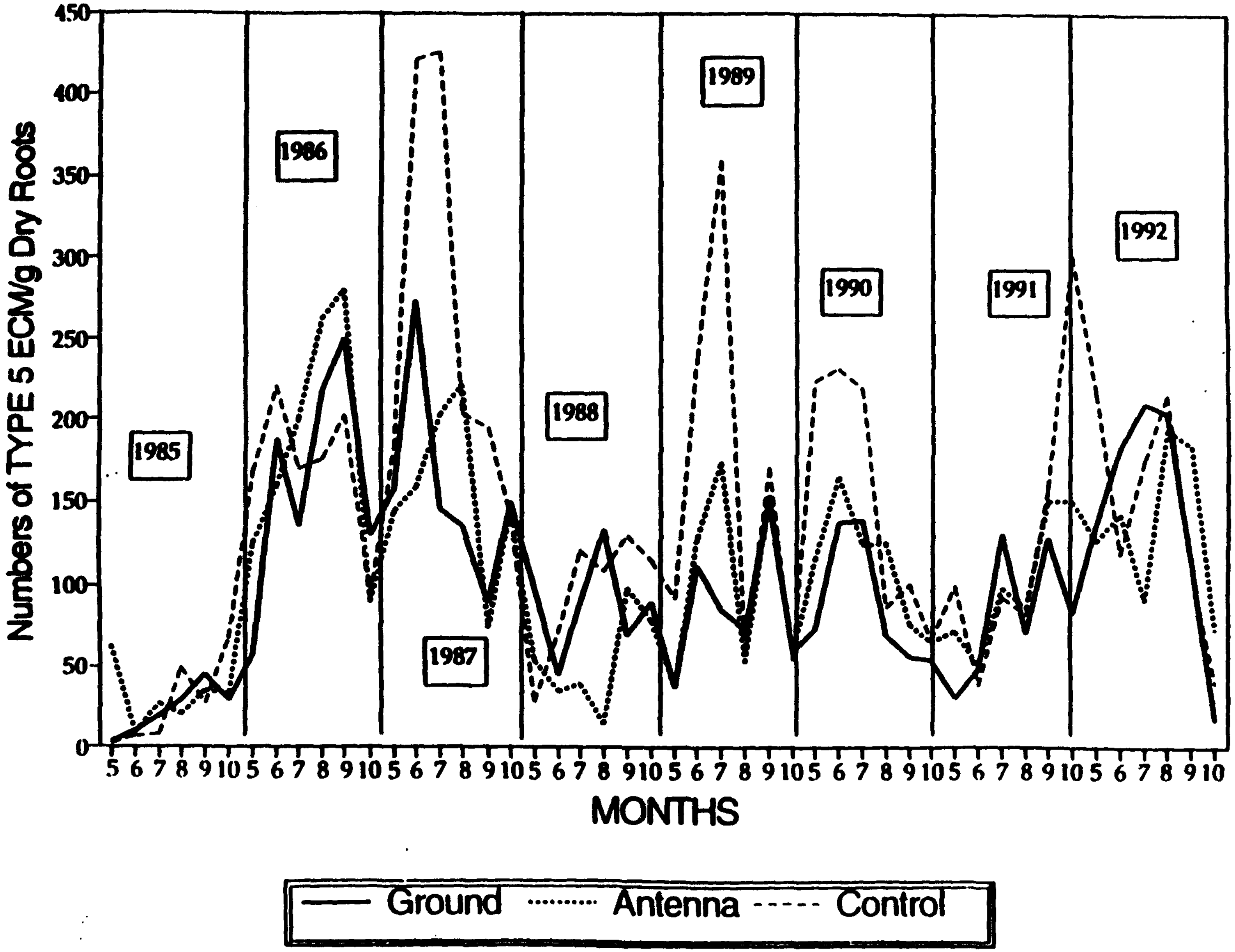
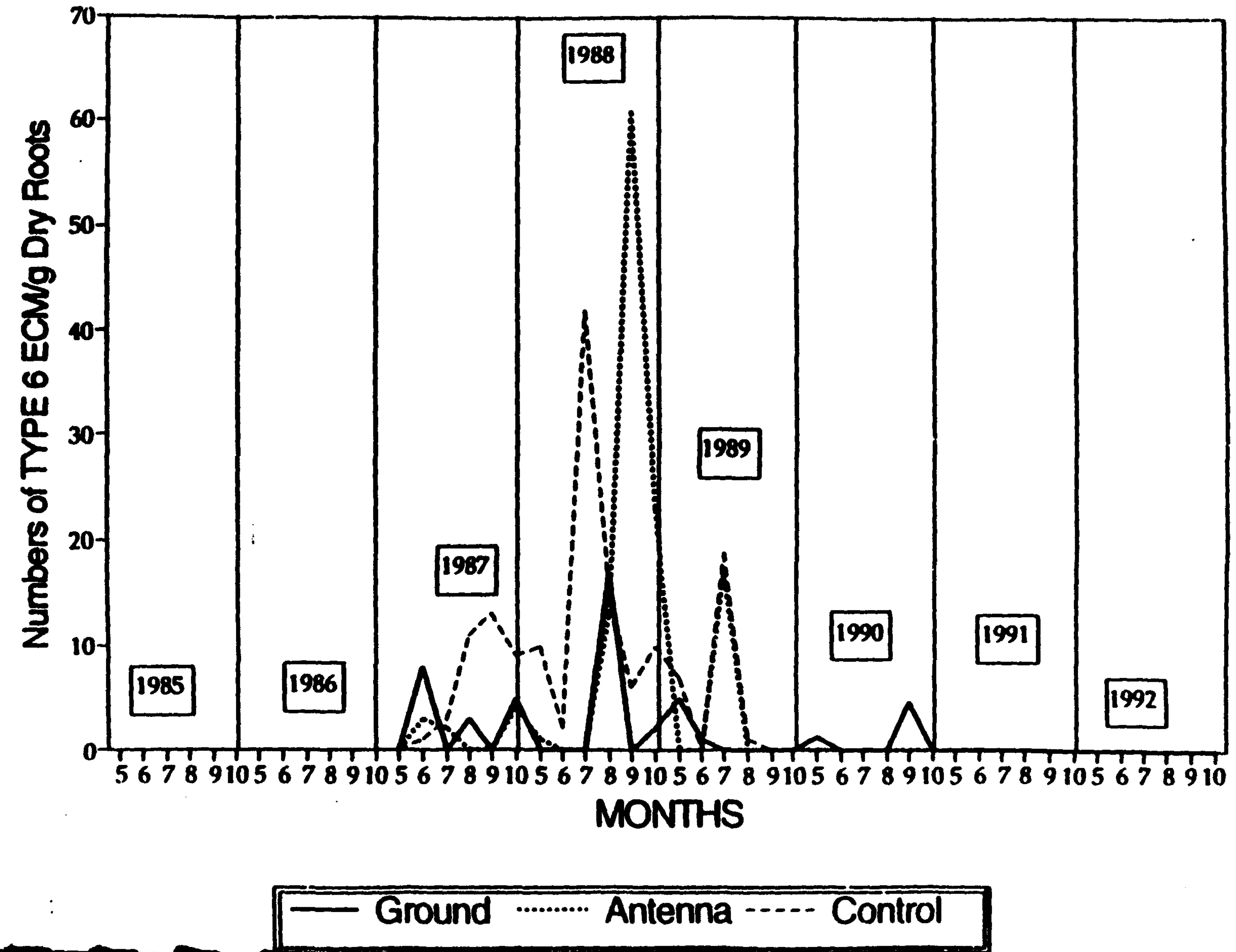


Figure 4.4: Yearly and monthly comparisons of the number of Type 6 mycorrhizal root tips (ECM) per gram of dry root.



of dry root. In 1989, site differences in total numbers of mycorrhizae and Type 3 mycorrhizae numbers were the least distinct of all years. If changes in mycorrhizal numbers, due to ELF fields, occur this should become evident during the 1993 sampling time.

Covariate Analysis

Covariate analysis was used to explain some of the differences in numbers of total mycorrhizae per gram dry root among sites, years, year by site interactions by taking into account the variation in ambient weather and soil conditions. Means and sums of ambient variables represent a period of approximately 30 days prior to each mycorrhizae sampling date. The complete list of ambient variables used in the analysis is shown in Table 4.1.

Correlations were performed to determine which ambient variables were most likely to serve as covariates. Correlation coefficients (r) for total mycorrhizae per gram of dry root with the ambient variables are in Table 4.1. Correlations were similar to those reported in 1991. The highest correlations were for number of days precipitation greater than 0.01 cm (PRC.01) and 0.10 cm (PRC.10), total precipitation (cm) (PRCTOT), minimum air temperature (ATMN), soil temperature at 5 cm running total (ST5DDRT), and soil temperature at 10 cm running total (ST10DDRT) (Table 4.1).

Analysis of variance (ANOVA) was performed with eight years of data (1985-1992) to detect differences among sites and among years, and their interactions, on total mycorrhizae per gram of dry root. Without covariates, mycorrhizal numbers were not significantly different ($p<0.05$) among sites and among site by year interactions (Table 4.2). Significant differences ($p<0.01$) among years were detected. Significantly fewer numbers of mycorrhizae occurred in years 1988, 1989, and 1990 compared with years 1985, 1986, 1987, 1991, and 1992. Differences may be due to the acclimation of seedlings to their habitat or to monthly and yearly changes in ambient conditions, as discussed above.

To test whether the addition of a covariate explained yearly differences in mycorrhizal numbers analysis of covariance (ANCOVA) was performed with the eight years of collected data. Table 4.2 lists probability (p) values (significance of the F statistic) after analysis of covariance, using five significantly correlated ($p<.01$) ambient parameters and age of the seedling. Age was used in the analysis this year to determine if the natural aging process of the seedling could explain significant amounts of variation in the number of mycorrhizae per gram of dry root. The addition of three variables, total precipitation (PRCTOT), soil temperature at 5 cm (ST5DDRT) and soil temperature at 10 cm running total (ST10DDRT), was also

Table 4.1. Pearson correlation coefficients (r) calculated for total mycorrhizae per gram of seedling root with ambient parameters for seven years (1985 through 1992).

Ambient Parameter	Correlation Coefficient
AT=mean daily air temperature	.0694**
ATMN=mean minimum daily air temperature	.0957**
ATMX=mean maximum daily air temperature	.0400NS
ATDD=mean air temperature degree days	.0400NS
ATDDRT=air temperature degree days running total	.0887**
ST5=mean soil temperature at 5 cm	.0692**
ST5MN=mean minimum soil temperature at 5 cm	.0639**
ST5MX=mean maximum soil temperature at 5 cm	.0743**
ST5DD=mean soil temperature at 5 cm degree days	.0620**
ST5DDRT=soil temperature at 5 cm degree days running total	.0986**
ST10=mean soil temperature at 10 cm	.0683**
ST10MN=mean minimum soil temperature at 10 cm	.0684**
ST10MX=mean maximum soil temperature at 10 cm	.0694**
ST10DD=mean soil temperature at 10 cm degree days	.0629**
ST10DDRT=soil temperature at 10 cm degree days running total	.0990**
PRCDAV=mean daily precipitation	.0505*
PRCMNDAV=mean minimum daily precipitation	.0665**
PRCMXDAV=mean maximum daily precipitation	.0582**
PRCTOT=total precipitation	.1197**
PRC.01=number of days precipitation events > 0.01 cm	.1275**
PRC.10=number of days precipitation events > 0.10 cm	.1452**
SM5=mean soil moisture at 5 cm	-.0222NS
SM5MN=mean minimum soil moisture at 5 cm	-.0205NS
SM5MX=mean maximum soil moisture at 5 cm	-.0189NS
SM10=mean soil moisture at 10 cm	-.0214NS
SM10MN=mean minimum soil moisture at 10 cm	-.0552**
SM10MX=mean maximum soil moisture at 10 cm	.0261NS
Seedling AGE	-.2024**

** Indicates significant correlation (0.001<p<0.01)
* Indicates significant correlation (0.01<p<0.05)
NS Indicates non-significant correlation (p > 0.05)

tested in the analysis. In all cases, although p values for site factors and site and year interactions changed, yearly differences could not be explained. The use of number of days, precipitation events are greater than 0.10 cm (PRC.10) in the covariate analysis produced significant year by site interactions.

Of the five ambient parameters used as covariates, the one that explains the most variation in total number of mycorrhizae was total precipitation (PRCTOT) (Table 4.2). This ambient parameter most likely to affected seedling root growth and mycorrhizal development because of the effect of drought on mycorrhizal fungi. It is believed that some fungi have the ability to enhance root processes during droughty periods. It appears, however, that on these sites mycorrhizal numbers increase with increases in precipitation. Monthly fluctuations within each growing season may be more important to mycorrhizal numbers than yearly differences in mean climatic data.

Table 4.2. Comparison of p values (significance of F) for total mycorrhizae per gram of seedling root data (1985 through 1991 after multiple analysis of covariance (ANCOVA) using some of the highly correlated (p<.001) ambient parameters.

COVARIATE	SITE	YEAR	YEAR x SITE
No Covariate	.084	.001	.111
AGE	.143	.001	.111
PRC.01[1/]	.192	.003	.091
PRC.10	.062	.005	.019
PRCTOT	.837	.004	.080
ATMN	.088	.000	.114
ST5DDRT	.127	.002	.150
ST10DDRT	.129	.002	.066
PRCTOT + ST5DDRT + ST10DDRT	.710	.003	.190

[1/]See Table 4.1 for key to abbreviations of ambient parameters.

Summary

Although there was a mean increase in mycorrhizae numbers from 1988 to 1992, no significant differences in mycorrhizae numbers per unit weight of seedling root among sites and among site by year interactions were detected using analysis of variance. There were signifcant differences in years; however, use of covariates did not reduce the differences among years. It may be that refinements in the analysis through the use of modeling appropriate temporal relationships between ambient data and seedling growth processes may help reduce differences among years.

The ELF Antenna system has been operational since the fall of 1989. If there were ELF effects on mycorrhizae numbers, the most important source of variation attributable to these effects would be the site by year interaction. If there was an effect, numbers of mycorrhizae from years 1990, 1991, and 1992 on the Antenna and/or Ground site(s) would be significantly different than the numbers on the Control site or from prior years information. This was not the case. Detection limits calculated with three years of data prior to the fully operational ELF Antenna (1985, 1986, 1987) indicated that an overall difference of approximately 10 to 15 percent was necessary to recognize a significant difference among sites, and an overall difference of approximately 15 to 25 percent would be necessary to identify a significant difference among years and among site by year interactions.

One more year of information on mycorrhizal numbers will be collected Summer, 1993. Findings, thus far, support the position that mycorrhizal symbiosis between tree roots and fungi can indeed be used as a sensitive indicator of subtle environmental changes.

Element 5. LITTER PRODUCTION

Litter fall and decomposition is important in the transfer of nutrients and energy within a vegetative community. The sensitivity of foliage production to both tree physiological changes and non-independent external climatic conditions make it a good indicator of possible ELF field effects on trees. Since litter samples can be gathered at frequent intervals, they provide an estimate of change in canopy production. Additionally, leaf samples taken during the growing season for nutrient analysis and weight determination would monitor nutrient accumulation and subsequent nutrient translocation from the foliage to the branches prior to leaf fall. This physiological process is also sensitive to environmental stress and would be a potential indicator of ELF field effects.

The objective of this element is to obtain information on total litter weight and nutrient content, and foliar nutrient levels of northern red oak during the growing season on the antenna and control plots prior to the operation of the ELF communication system. Two overall null hypotheses will be tested in this study.

H_0: There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

H_0: There is no difference in the foliar nutrient concentrations of northern red oak trees before and after the ELF antenna becomes operational.

Each year prior to an operational antenna (1984-1986), a baseline relationship of the ecological systems was determined whether there was any difference in the total weight of litter fall and foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for these analyses shown below (Table 5.1). Previous ELF annual reports have shown that no appreciable differences in these stand components were evident between these two sites prior to the onset of antenna operation.

Sampling and Data Collection

Five $1m^2$ meter litter traps are being used to monitor tree litter production on each permanent measurment plot at the antenna and the control sites. Litter was collected monthly during the summer and weekly after the onset of leaf fall in early September. Crown nutrient concentrations and translocation in northern red oak leaves are being examined by collecting foliage samples at both the antenna and control site during the summer months. An analysis of stem diameter data indicated that sampling trees of 15 cm, 21 cm and 32 cm

Table 5.1. ANOVA table for the analysis of litter components and foliar nutrier's

Source of Variation	df	SS	MS	F
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	1	SS_S	MS_S	$MS_Y/MS_{E(S)}$
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	# years	SS_Y	MS_Y	$MS_Y/MS_{E(Y)}$
Site x year	(1)(#yrs-1)	SS_{SXY}		MS_{SXY} $MS_{SXY}/MS_{E(Y)}$

would adequately represent the distribution of red oak on each site. Three trees of each diameter were located adjacent to the permanent measurement plots at each site to minimize disturbance. Leaf samples were obtained from near the top of the crown using a 12 gauge shotgun with a full choke.

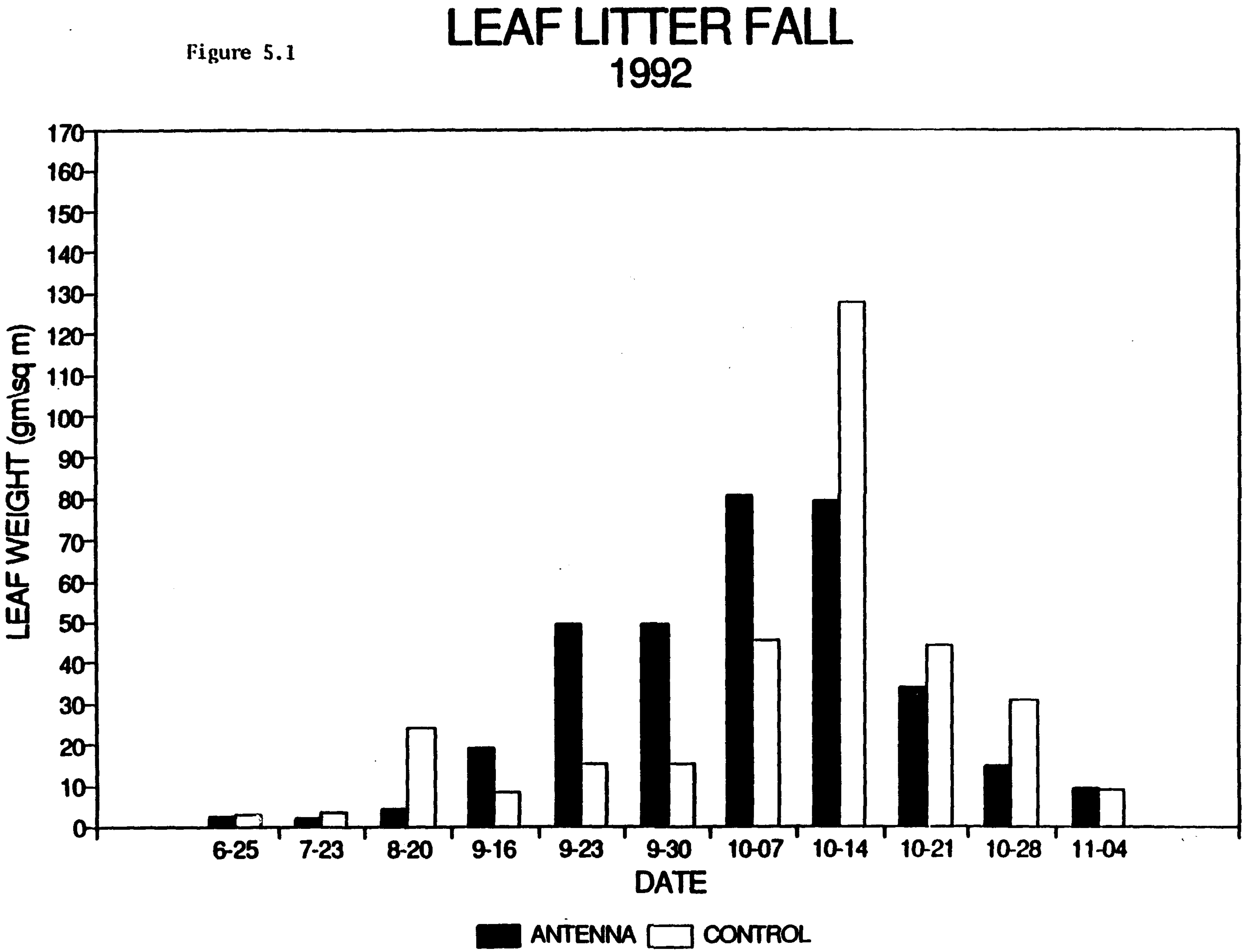
All litter and foliage samples were dried at 60°C in a forced draft oven. The litter was separated into leaves, wood, and miscellaneous categories and weighed. Leaf litter from a 0.25 m^2 compartment in each trap was separated by tree species. A representative subsample of ten leaves was taken from each foliage collection and weighed. All samples were ground to pass a 40 mesh sieve for subsequent N, P, K Ca and Mg analysis.

Progress

Litter weight

In 1992, the major litter fall in the ELF study area started between September 16 and September 23 and was completed by November 4 on both the antenna and control sites (Figure 5.1). Based on the previous 7-year average, this litter fall period began at an earlier date and continued longer into October (Figure 5.2a&b). As in past years, periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall. These differences in weekly leaf fall were related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control site (Table 5.2). Conversely, the control site has much higher numbers of northern red oak. Oak leaves remain on the trees longer than

Figure 5.1


LEAF LITTER FALL
1992
LEAF WEIGHT (gm\sq m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
6-25
7-23
8-20
9-16
9-23
9-30
10-07
10-14
10-21
10-28
11-04
DATE
ANTENNA
CONTROL

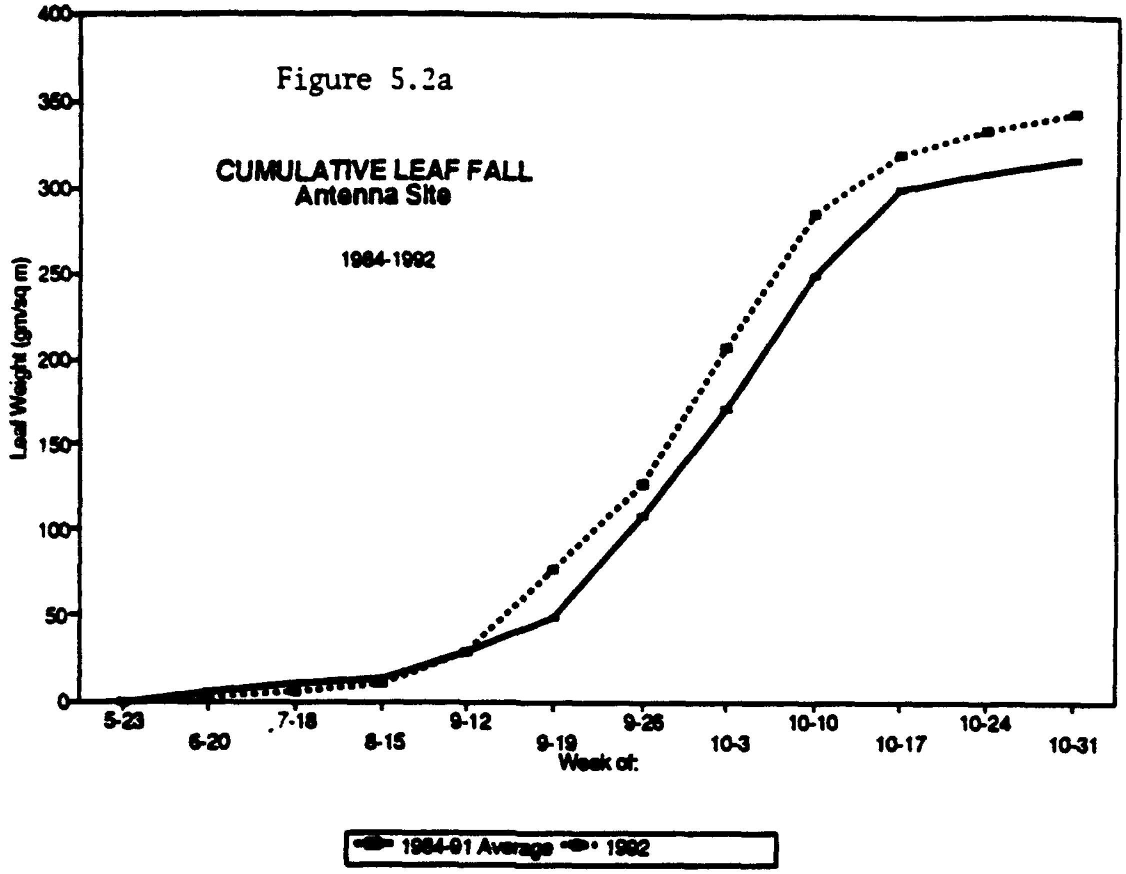


Figure 5.2a
CUMULATIVE LEAF FALL
Antenna Site
1984-1992
Leaf Weight (gm/sq m)
0
50
100
150
200
250
300
350
400
5-23
6-20
7-18
8-15
9-12
9-19
9-26
10-3
10-10
10-17
10-24
10-31
Week of:
1984-91 Average
1992

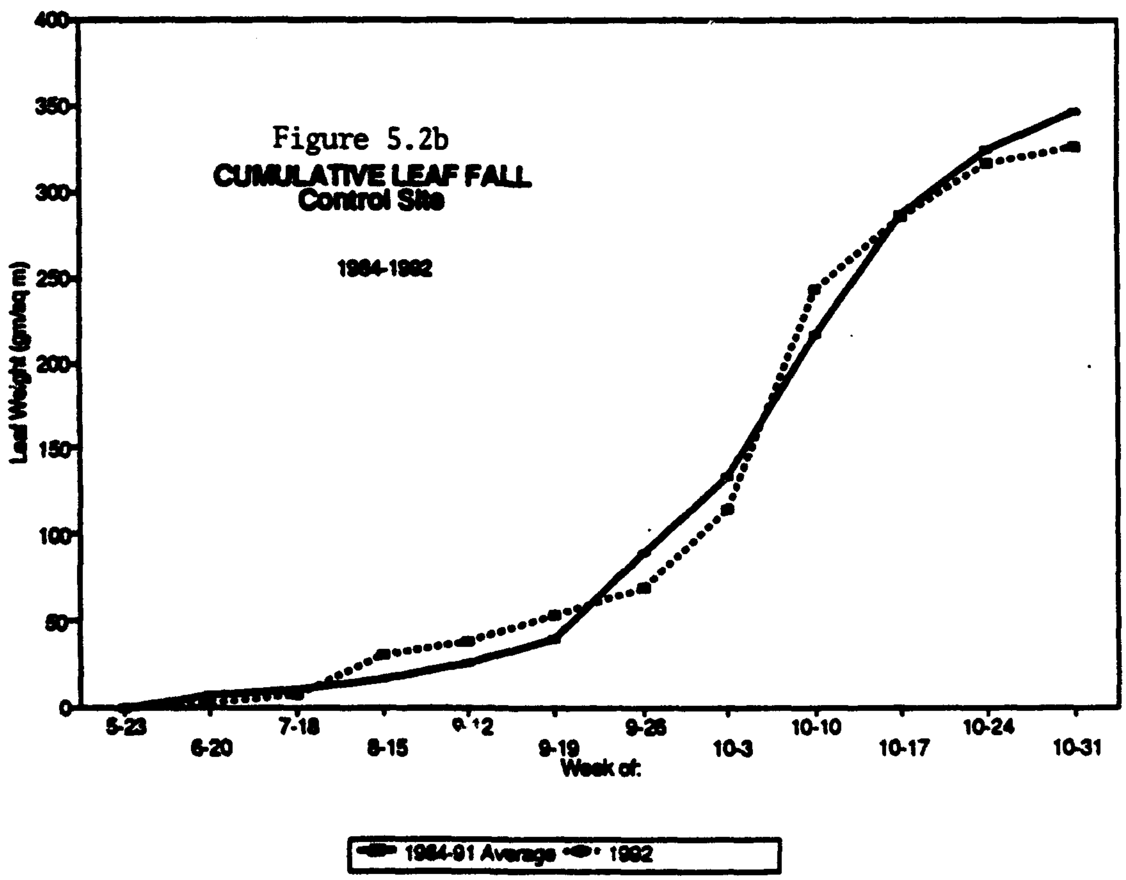


Figure 5.2b
CUMULATIVE LEAF FALL
Control Site
1984-1992
Leaf Weight (gm/sq m)
0
50
100
150
200
250
300
350
400
5-23
6-20
7-18
8-15
9-12
9-19
9-26
10-3
10-10
10-17
10-24
10-31
Week of:
1984-91 Average
1992

Table 5.2. Leaf litter fall by tree species at the antenna and control sites: 1985-1992.

Tree Species	Leaf Weight (g/m^2)								% of Total	
	1985	1986	1987	1988	1989	1990	1991	1992	1985-1991	1992
Antenna										
Red Maple	135	147	142	143	127	103	129	144	42	41
Red Oak	93	120	105	116	95	71	132	117	33	36
B. Aspen	45	52	46	56	18	32	59	51	14	15
Q. Aspen	1	1	2	3	2	1	3	5	<1	1
P. Birch	25	21	25	28	28	24	21	22	8	6
Red Pine	1	1	2	2	2	1	1	2	<1	<1
Control										
Red Maple	42	55	47	41	48	41	49	50	15	17
Red Oak	227	266	208	230	223	184	293	232	71	76
B. Aspen	14	17	13	12	16	17	16	11	5	4
Q. Aspen	11	9	8	13	10	3	7	5	3	2
P. Birch	19	22	26	26	20	13	9	8	6	2
Red Pine	0	0	0	0	0	0	0	0	0	0

either maple or aspen, and account for much of the litter fall variations between locations.

The weight of the litterfall leaf component on the antenna site in 1992 was higher than average, while the control site had lower than average weight (Table 5.3). This was mostly due to lower amounts of oak leaf litter, which is the major litter source on the control site. Big toothed aspen also showed a decline in leaf weight this year. The control site received significantly higher amounts of woody residue than the antenna site. Nearly all of this weight difference was due to one local thunderstorm in August, which blew down a number of trees on the control site. While strong yearly litterfall fluctuations continued on these sites, analysis of variance (ANOVA) using the eight year litterfall results showed no significant site or site x year interactions between the three litter components. Covariate analysis using stand and environmental variables that affect stand production rates was used to reduce litter fall variability among years, and improve detection limits between the antenna and control site. Similar to past years, soil and air temperature generally showed the highest correlations with litter production and gave the best results when used in the analyses of covariance (Table 5.4). The use of these covariates reduced variability in litter fall among years and lowered the P values between sites (Table 5.5).

Results of these data analyses have shown that all three litter components could be used to determine the effects of ELF fields on forest stands. However, the **a priori** detection limits for differences in foliage litter among years and between sites are much lower than with the wood and the miscellaneous litter fraction (Table 5.6), and so would be a more sensitive indicator of possible ELF effects. Given these limits and the results of the analysis of covariance, the lack of significance between the antenna and control sites for all three litter components indicate that the operational use of the ELF antenna in 1992 had no detectable effects on tree litter production.

Litter Nutrient Content

Total amounts of nutrients returned to the soil on each site reflect differences in both litter weight and nutrient concentrations (Table 5.7). Average nutrient concentrations of the various litter components and for individual tree species showed considerable variability between the two sites, but none were significantly different (Table 5.8 and 5.9). Covariate analysis using site and ambient factors listed in Table 5.10 was used to try and remove differences in litter nutrient concentrations among sites and years. As was noted in last year's report, significant site x year interactions for some litter components, either composited or for individual tree species, could not be removed by covariate analyses (Tables 5.11 and 5.12). Multiple range tests (SNK)

Table 5.3. Total litter fall at the antenna and control sites: 1984-1992

	Antenna	Control
	---------g/m^2--------	
<u>Leaves</u>		
1984	307 (66)	357 (102)
1985	347 (57)	352 (27)
1986	351 (49)	412 (87)
1987	332 (32)	319 (34)
1988	326 (45)	353 (53)
1989	305 (39)	344 (49)
1990	238 (25)	274 (38)
1991	348 (34)	379 (44)
1992	344 (61)	326 (49)
Average	322	346
<u>Wood</u>		
1984	44 (32)	54 (26)
1985	55 (31)	64 (33)
1986	43 (30)	58 (43)
1987	57 (38)	76 (38)
1988	53 (34)	62 (33)
1989	46 (40)	44 (33)
1990	57 (39)	88 (56)
1991	43 (36)	54 (70)
1992	78 (22)	253 (183)
Average	53	84
<u>Miscellaneous</u>		
1984	34 (24)	27 (14)
1985	52 (33)	45 (15)
1986	32 (8)	29 (11)
1987	33 (14)	28 (14)
1988	94 (64)	80 (35)
1989	97 (73)	64 (24)
1990	52 (16)	75 (23)
1991	30 (12)	25 (7)
1992	52 (22)	45 (23)
Average	54	43

<u>Collection Period</u>:
1984 - June 20, 1984 - Oct. 24, 1984
1985 - Oct. 25, 1984 - Oct. 23, 1985
1986 - Oct. 24, 1985 - Oct. 22, 1986
1987 - Oct. 23, 1986 - Oct. 21, 1987
1988 - Oct. 22, 1987 - Nov. 3, 1988
1989 - Nov. 4, 1988 - Nov. 1, 1989
1990 - Nov. 2, 1989 - Oct. 31, 1990
1991 - Nov. 1, 1990 - Oct. 30, 1991
1992 - Oct. 31, 1991 - Nov. 4, 1992

Numbers in parentheses are standard deviations.

were performed on these adjusted means to evaluate whether nutrient concentrations had changed in response to ELF antenna operation starting in 1987. These results showed that in all cases sic-ificant litter nutrient concentration differences existed between sites and years prior to antenna operation.

Table 5.4. Correlations between litter component weight and the covariates selected for inclusion in the analysis of covariance: 1985-1992

	Litter Component*		
Covariate	Foliage	Wood	Miscellaneous
Soil Temperature at 10 cm (April 1 - July 15)	--	---	-.28
Air Temperature Degree Days (August 16- September 15)	-.16	--	--

* Significant at the p=0.05 level

Table 5.5 Significance levels from the split plot analysis of covariance for litter components: 1985 - 1992

Factor	***Foliage***	***Wood***	***Miscellaneous***
	-----------p values----------		
Site	0.925	0.058	0.191
Years	0.000	0.000	0.000
Site x Years	0.085	0.000	0.195

Table 5.6. Detection limits of litter component weights between treatment sites and between years.*

Litter Component	Sites		Years		Year X Site	
	gm^2	%	g/m^2	%	g/m^2	%
Foliage	57.5	17.2	25.3	7.6	35.8	10.7
Wood	18.5	32.4	20.7	36.3	46.5	65.9
Miscellaneous	23.8	45.2	17.9	34.0	24.7	47.4

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

To further investigate these significant site x year interactions, covariate analyses were run using both environmental measurements and the ELF field exposure data for 1989, 1990, 1991, and 1992 (Appendix A). The inclusion of the various ELF field values did not alter or remove the site x year interactions found for litter nutrient concentrations. Since most leaf litter year x site detection levels are below twenty-five percent of the mean (Tables 5.13 and 5.14), these results indicate that differences in litter nutrient concentrations between the antenna and the control site are not attributable to low level ELF fields generated since 1989.

Red Oak Foliage Analyses

Nutrient concentrations in red oak foliage show considerable variability between the antenna and the control sites, but these generally reflect the nutrient status of the two sites before antenna transmissions began (Table 5.15). Results from covariate analyses using soil and climatic data sowed there were no significant site x year interactions for any foliage nutrient (Table 5.16). Nutrient detection limits for red oak foliage were generally quite good (under twenty -five percent) for all but P (Table 5.17). Consequently, these analyses were similar to the litter results, indicating that differences in red oak nutrient concentrations between the antenna and control site were not related to operation of the ELF antenna.

Table 5.7. Average nutrient content of litterfall at the antenna and control sites: 1985-1992

	Antenna		Control	
	1985-1991 (Average)	1992	1985-1991 (Average)	1992
	(kg/ha)			
Foliage				
N	23.3	24.6	24.0	24.6
P	4.6	4.9	6.2	5.1
K	11.1	13.1	14.7	13.9
Ca	35.8	51.7	39.5	51.1
Mg	5.8	5.7	6.0	5.2
Wood				
N	2.2	3.9	3.2	9.2
P	0.3	0.4	0.4	1.3
K	0.6	1.2	1.0	4.6
Ca	4.8	11.2	7.6	30.4
Mg	0.3	0.4	0.5	1.2
Miscellaneous				
N	6.3	6.4	4.9	5.1
P	0.7	1.1	0.6	0.6
K	2.1	3.6	1.9	1.4
Ca	3.6	8.4	4.3	8.4
Mg	0.5	0.4	0.4	0.3
Total				
N	31.9	34.9	32.1	38.9
P	5.5	6.4	7.2	7.0
K	13.8	17.9	17.6	19.9
Ca	44.2	65.9	51.4	89.9
Mg	6.6	6.5	6.9	6.7

Values in rows denoted by different letters are significantly different at the p=0.05 level.

Table 5.8. Average nutrient concentrations of litter components on the antenna and control sites: 1985-1992

	Antenna	Control
	(%)	
Foliage		
N	0.72 (0.13)	0.70 (0.10)
P	0.14 (0.03)	0.18 (0.07)
K	0.35 (0.08)	0.42 (0.07)
Ca	1.16 (0.21)	1.19 (0.20)
Mg	0.18 (0.03)	0.17 (0.02)
Wood		
N	0.46 (0.13)	0.48 (0.13)
P	0.05 (0.02)	0.06 (0.01)
K	0.12 (0.04)	0.15 (0.05)
Ca	1.01 (0.28)	1.19 (0.30)
Mg	0.06 (0.01)	0.07 (0.02)
Miscellaneous		
N	1.14 (0.24)	1.02 (0.19)
P	0.13 (0.04)	0.13 (0.05)
K	0.42 (0.18)	0.39 (0.18)
Ca	0.64 (0.23)	0.95 (0.50)
Mg	0.09 (0.02)	0.08 (0.01)

Numbers in parentheses are standard deviations.

Table 5.9. Average nutrient concentrations of tree litter on the antenna and control sites: 1985-1992

	Antenna	Control
	(%)	
Northern Red Oak		
N	0.73 (0.14)	0.66 (0.08)
P	0.13 (0.02)	0.17 (0.08)
K	0.33 (0.07)	0.40 (0.06)
Ca	1.06 (0.18)	1.11 (0.18)
Mg	0.12 (0.01)	0.15 (0.02)
Paper Birch		
N	0.83 (0.14)	0.81 (0.10)
P	0.17 (0.05)	0.18 (0.03)
K	0.42 (0.08)	0.54 (0.13)
Ca	1.48 (0.23)	1.30 (0.28)
Mg	0.27 (0.04)	0.28 (0.04)
Big Toothed Aspen		
N	0.81 (0.11)	0.73 (0.13)
P	0.13 (0.06)	0.15 (0.05)
K	0.38 (0.11)	0.50 (0.11)
Ca	1.42 (0.27)	1.59 (0.30)
Mg	0.27 (0.03)	0.22 (0.03)
Red Maple		
N	0.48 (0.06)	0.49 (0.09)
P	0.17 (0.04)	0.18 (0.02)
K	0.27 (0.09)	0.36 (0.10)
Ca	1.12 (0.14)	1.27 (0.18)
Mg	0.19 (0.02)	0.20 (0.03)

Numbers in parentheses are standard deviations.

Table 5.10. Covariates used in covariate analyses of litter nutrient concentrations among sites and year.

Soil Nutrients in September		
Soil N	-	a
Soil P	-	b
Soil K	-	c
Soil Ca	-	d
Soil Mg	-	e
Air temperature degree days		
in September	-	f
in October	-	g
Air temperature degree days running total		
to the end of September	-	h
to the end of October	-	i
Air temperature		
in September	-	j
in October	-	k
Soil temperature at 5 cm		
in September	-	l
in October	-	m
Soil temperature at 10 cm		
in September	-	n
in October	-	o
Soil temperature degree days at 5 cm running total		
to the end of September	-	p
to the end of October	-	q
Soil temperature degree days at 10 cm		
in September	-	r
in October	-	s
Soil temperature degree days at 5 cm		
in September	-	t
in October	-	u

Table 5.11. Results of covariate analyses of site and year differences in litter component nutrient concentration: 1985-1992

	N	P	K	Ca	Mg
	----------	----------	p value	----------	----------
<u>Leaf</u>	(ak)*	(cdk)	(dei) --	(k)	(acj)
Site	.164	.285	.603	.498	.904
Year	.011	.001	.000	.000	.063
Year x Site	.636	.001	.473	.541	.597
<u>Wood</u>	(af)	(o)	(dei)	(dj)	(cd)
Site	.600	.875	.469	.725	.046
Year	.001	.557	.006	.002	.006
Year x Site	.440	.854	.736	.064	.095
<u>Miscellaneous</u>	(l)	(acq)	(w)	(cjw)	(mu)
Site	.424	.720	.782	.569	.601
Year	.003	.000	.000	.000	.000
Year x Site	.023	.001	.000	.001	.061

*Variables used in COANOVA (see Table 5.10).

Table 5.12. Results of covariate analyses of site and year differences in leaf litter nutrient concentrations by species: 1985-1992*

	N	P	K	Ca	Mg
	p value				
Northern Red Oak	(ai)	(dk)	(ej)	(k)	(bi)
Site	.904	.478	.99[illegible]	.838	.647
Year	.012	.124	.000	.000	.000
Year x Site	.838	.558	.944	.029.	.001
Hazelnut and Paper Birch	(x)	(w)	(i)	(gk)	(j)
Site	.878	.325	.832	.812	.536
Year	.000	.000	.000	.000	.152
Year x Site	.929	.013	.002	.009	.589
Big Toothed Aspen	(qy)	(qo)	(gk)	(fh)	(cy)
Site	.537	.885	.469	.968	.484
Year	.000	.000	.011	.000	.035
Year x Site	.003	.012	.089	.595	.077
Red Maple	(cj)	(e)	(sy)	(hi)	(gk)
Site	.551	.670	.497	.622	.038
Year	.000	.000	.000	.000	.058
Year x Site	.024	.000	.319	.026	.392

*Variables used in COANOVA (see Table 5.10.).

Table 5.13. Detection limits for litter nutrient concentrations by component: 1985-1992

Component	Site		Year		Y x S	
	ppm	% of mean	ppm	% of mean	ppm	% of mean
Leaf						
Ca	1761	14.9	1058	9.0	1496	12.7
Mg	1006	57.3	121	6.9	171	9.7
K	1334	34.4	466	12.0	659	17.0
N	553	7.8	1132	15.9	1601	22.5
P	305	19.2	380	23.9	538	33.8
Wood						
Ca	4098	37.2	2488	22.6	3518	31.9
Mg	23	3.4	124	18.7	175	26.4
K	391	28.8	237	17.5	629	46.3
N	352	7.6	1122	24.1	1586	34.0
P	109	20.1	161	29.6	227	41.8
Misc						
Ca	4540	57.0	1652	20.7	2336	29.3
Mg	144	16.9	100	11.7	141	16.5
K	584	14.5	694	17.2	981	24.3
N	601	5.5	1835	16.9	2595	24.0
P	458	35.1	230	17.6	325	24.9

*The detection limits given are for differences at $p=0.05$ on covariate adjusted means.

Table 5.14. Detection limits for leaf litter nutrient concentrations by species: 1985-1992

Species	Site		Year		Y x S	
	ppm	% of mean	ppm	% of mean	ppm	% of mean
NRO						
Ca	597	5.5	394	3.6	557	5.1
Mg	521	38.8	72	5.4	102	7.6
K	666	18.2	481	13.2	680	18.6
N	1259	18.2	1129	16.3	1597	23.1
P	782	52.8	441	29.8	624	42.1
CCPB						
Ca	1514	10.9	993	7.2	1404	10.1
Mg	537	19.7	339	[illegible]	102	7.6
K	822	17.0	635	13.1	899	18.6
N	361	4.4	1106	[illegible]	1564	19.1
P	335	19.2	331	19.0	469	26.9
BTA						
Ca	3647	2.4	1494	1.0	2112	1.4
Mg	347	14.4	248	10.3	350	14.6
K	1465	33.5	690	15.8	976	22.3
N	1895	24.6	773	10.0	1094	14.2
P	689	49.3	370	26.5	523	37.5
RM						
Ca	984	8.2	733	6.1	1037	8.7
Mg	53	2.7	243	12.4	343	8.7
K	129	4.1	513	16.3	725	23.1
N	1039	21.8	395	8.3	558	11.7
P	320	18.3	188	10.8	266	15.3

*The detection limits given are for differences at $p=0.05$ on covariate adjusted means.

Table 5.15. Northern Red Oak foliage nutrient concentration for antenna and control sites: 1985 to 1992

	Antenna		Control	
	1985-1991	1992	1985-1991	1992
	(%)		(%)	
N	2.05	1.71	2.04	1.70
P	0.22	0.17	0.21	0.20
K	0.87	0.71	0.98	0.81
Ca	0.72	0.76	0.71	0.70
Mg	0.15	0.12	0.15	0.13

A factor in evaluating foliage nutrient concentrations is the weight of individual leaves, which could also change in response to ELF fields. Consequently, an analysis of variance was conducted on average yearly leaf weights from the antenna and the control sites (Table 5.18) No significant site, month, year, and diameter interactions were found.

Table 5.16. Results of covariate analyses for differences in foliage nutrient concentration: 1985-1992

	N (1)*	P (2)	K (3)	Ca (4)	Mg (5)
	----------	-------	p values	-------	----------
Site	.024	.093	.050	.235	.206
Year	.000	.531	.035	.002	.000
Year x Site	.113	.959	.849	.282	.412

* Covariates used

1 Average daily maximum air temperature, average daily maximum soil temperature at 5 cm, average daily maximum soil moisture at 10 cm, average daily maximum soil temperature 10 cm

2 Average daily soil temperature degree days at 10 cm running total, average daily minimum soil moisture at 5 cm, average daily maximum soil moisture at 10 cm

3 Average daily minimum soil temperature at 5 cm, average daily maximum air temperature, average daily and daily minmum soil moisture at 10 cm

4 Average daily maximum air temperature, average daily soil temperature at 10 cm

5 Average daily maximum air temperature, average daily minimun soil moisture at 10 cm, average daily soil temperature degree days at 10 cm

Table 5.17. Detection limits for Northern Red Oak foliage nutrient concentrations: 1985-1992*

	Site		Year		Year x site	
	ppm	% of mean	ppm	% of mean	ppm	% of mean
N	437	21.8	1962	9.7	2775	13.9
P	197	9.3	497	23.6	703	33.3
K	435	4.8	1084	12.1	1534	17.1
Ca	709	9.8	564	7.7	798	11.0
Mg	131	8.8	92	6.2	130	8.8

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Table 5.18. Analysis of variance results testing for differences in the average weight of ten leaf samples by site, tree diameter and sampling time (1985-92)

	p value
Site	.996
Diameter	.627
Site x Diameter	.218
Year	.000
Year x Site	.522
Year x Diameter	.566
Year x Diameter x Site	.115
Month	.000
Month x Site	.065
Month x Year	.082
Month x Year x Site	.113

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Appendix A: EM Field Measures

Each year, IITRI has taken measurements of 60 and 76 Hz transverse, longitudinal, and magnetic fields on each of the study plots at the ground, antenna, and control sites (see following report). Interpolation equations have been developed to estimate the maximum EM field exposure levels for specific locations within the study plots. The equations for the magnetic flux are given for each year following the IITRI report. These equations were used to calculate an average maximum exposure level for each plot (Table 1A-E). For 1991, when both legs of the antenna were operating, the measurements were not significantly different from those in 1989 or 1990 and the three years were combined. For the early 1991 growing season, when the EW antenna leg was not operating, a separate set of interpolation equations were developed.

In 1990, IITRI found that the patterns of the longitudinal field measurements were very complex and that the equations developed for use in this project in previous years were inadequate. IITRI provided digital data incorporating site maps and longitudinal field exposure contours for the antenna and ground sites. Through consultation between IITRI and MTU personnel, it was decided that the best way to estimate longitudinal field exposures was to utilize the contour lines developed by IITRI in 1990 and to scale the values from year to year according to the average longitudinal field exposure measurements for a plot. These procedures were used to estimate the mean exposure levels in Table 1. The magnetic flux information is incorporated into the 1991 analyses and the longitudinal field information will be incorporated into the analyses in the near future.

R
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799

16 October 1992

Dr. Glenn Mroz
Department of Forestry
Michigan Technical University
Houghton, MI 49931

Dear Dr. Mroz:

This letter documents the annual ELF electromagnetic (EM) field measurements taken by IITRI at your study sites on 19 and 20 June, and 3 and 15-17 October 1991. Descriptions are also given of the data-logger-based electric field monitoring systems which were installed at your Martell's Lake (Overhead and Buried) treatment study sites on 18-21 June. Graphs and summary tables of the data collected by these systems throughout 1991 are presented. The 1990-1991 measurement data from the fixed probes has been tabulated and compared graphically to the logger data and annual measurements.

Transmitter Operations - 1991

Since the fall of 1989, the NRTF-Republic has typically operated continuously and at full power using both antennas except for during scheduled weekly maintenance periods. Exceptions to this scenario were periods from 8 May through 12 July 1991 and from 23 December 1991 through 28 March 1992 when the EW antenna was de-energized for special repairs. The EM field intensities at your treatment study sites were dramatically reduced during these periods, as discussed in following sections. The 1991 transmitter operations have been summarized and will be presented in our annual measurement report. Daily transmitter log information for 1991 has already been provided to you.

Annual EM Measurements - 1991

Measurement Locations

In 1991, IITRI made annual EM field measurements at 50 locations within the study sites listed in Table 1. The annual (historic) measurement point locations, were unchanged from the 1990 EM field survey and are mapped in Figures 1 through 5. Figures 4 and 5 also identify data logger (E) and fixed probe (F) measurement locations, many of which coincide with the historic (H) measurement points.

TABLE 1. SITE NO. CROSS-REFERENCE
Upland Flora and Soil Microflora Studies

IITRI Site No.	Investigator's Site Name	Location				
		Township	:	Range	:	Section(s)
4T2	Martell's Lake (Overhead): ML	T45N	:	R29W	:	28
4T4	Martell's Lake (Buried): EP	T45N	:	R29W	:	28
4C1	Paint Pond Road Control	T41N	:	R32W	:	3
4S1	Red Maple Leaf Collection	T55N	:	R35W	:	21
4S2	Oak Leaf Collection	T41N	:	R32W	:	3
4S3	Pine Needle Collection	T54N	:	R34W	:	5

Measurement Protocol

IITRI characterizes three types of EM fields at each measurement point: the air electric field, earth electric field, and magnetic flux density. For each of these fields, a set of orthogonal, rms field intensity measurements is made and the rms field magnitude is calculated by vector addition. Measurements are taken at the ELF system center frequency of 76 Hz and, whenever possible, at the powerline frequency of 60 Hz.

This year the 76 Hz measurements were conducted at your treatment sites during full power transmitter operation using both antennas (normal condition), as well as during operation using the NS antenna only (special maintenance). Measurements of 60 Hz EM fields at your treatment sites were made during periods when the transmitters were off for maintenance. At your control site/oak leaf collection location, 76 Hz and 60 Hz measurements were taken during normal full power transmitter operation.

60 Hz EM Fields

Measured 60 Hz EM field intensities for 1983 through 1991 are presented in Tables 2 through 4. Treatment site measurements were taken in 1991 while the transmitters were off, and are representative of 60 Hz field levels present during maintenance periods. Measurements of 60 Hz EM fields during full power operation of the transmitters have been precluded each year at your treatment sites because of modulated transmitter operation during the site visits. However, measurements of 60 Hz fields were taken at other study treatment sites during non-modulated transmitter operation in 1989. They indicate that 60 Hz EM field intensities present with the transmitters on are comparable to those with the transmitters off.

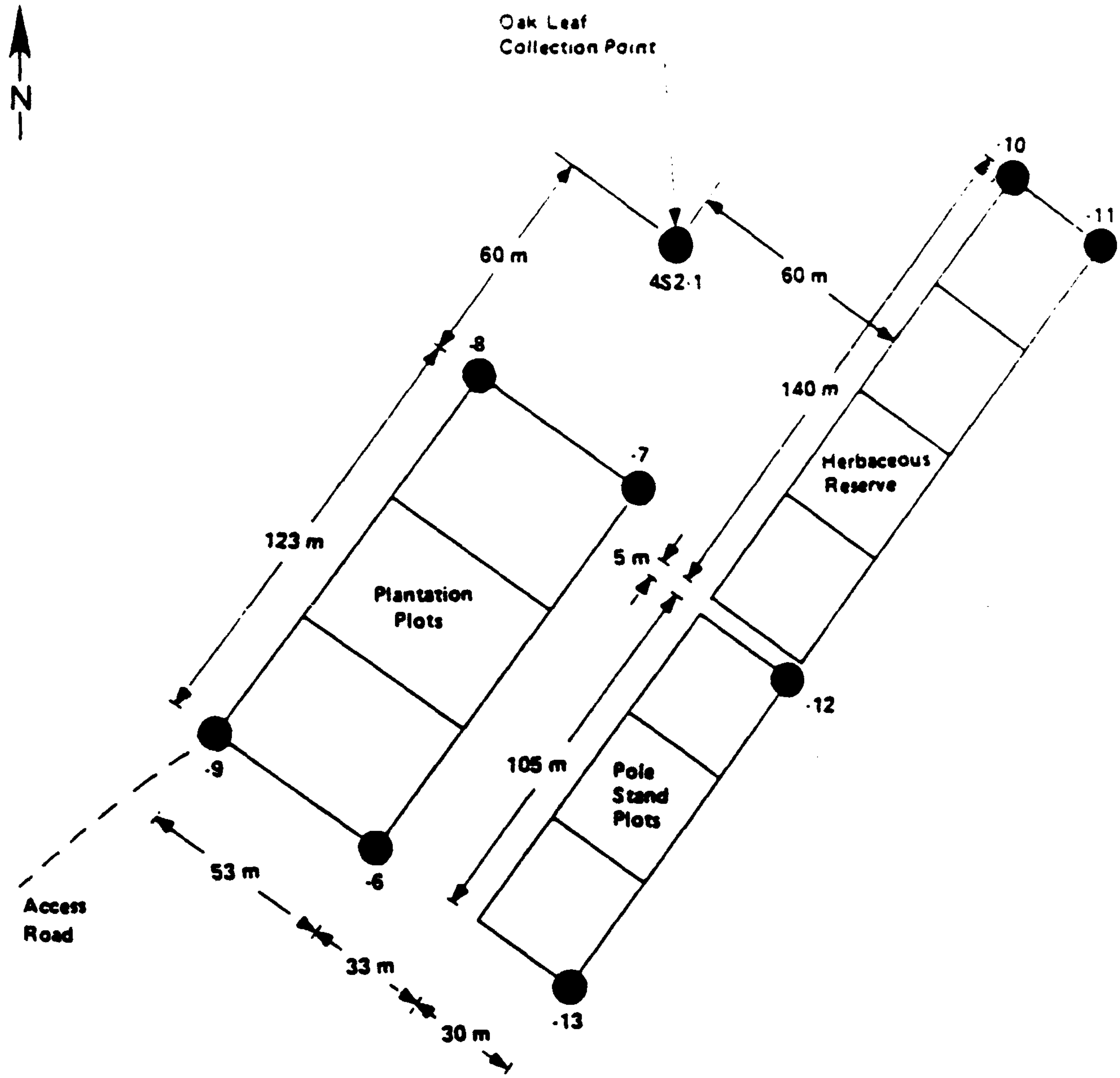

FIGURE 1. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

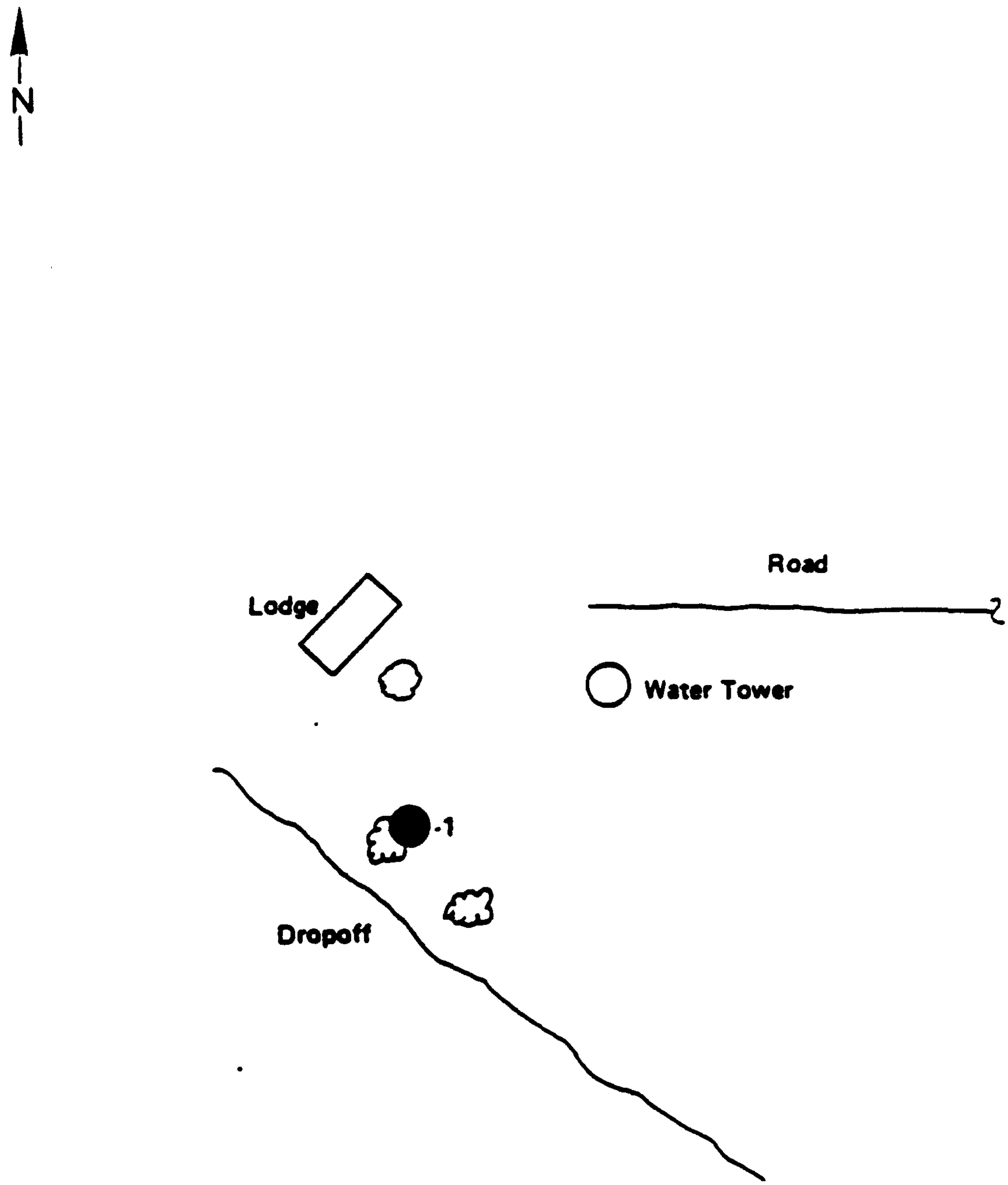

FIGURE 2. MEASUREMENT POINT AT RED MAPLE LEAF COLLECTION SITE; 4S1-1.

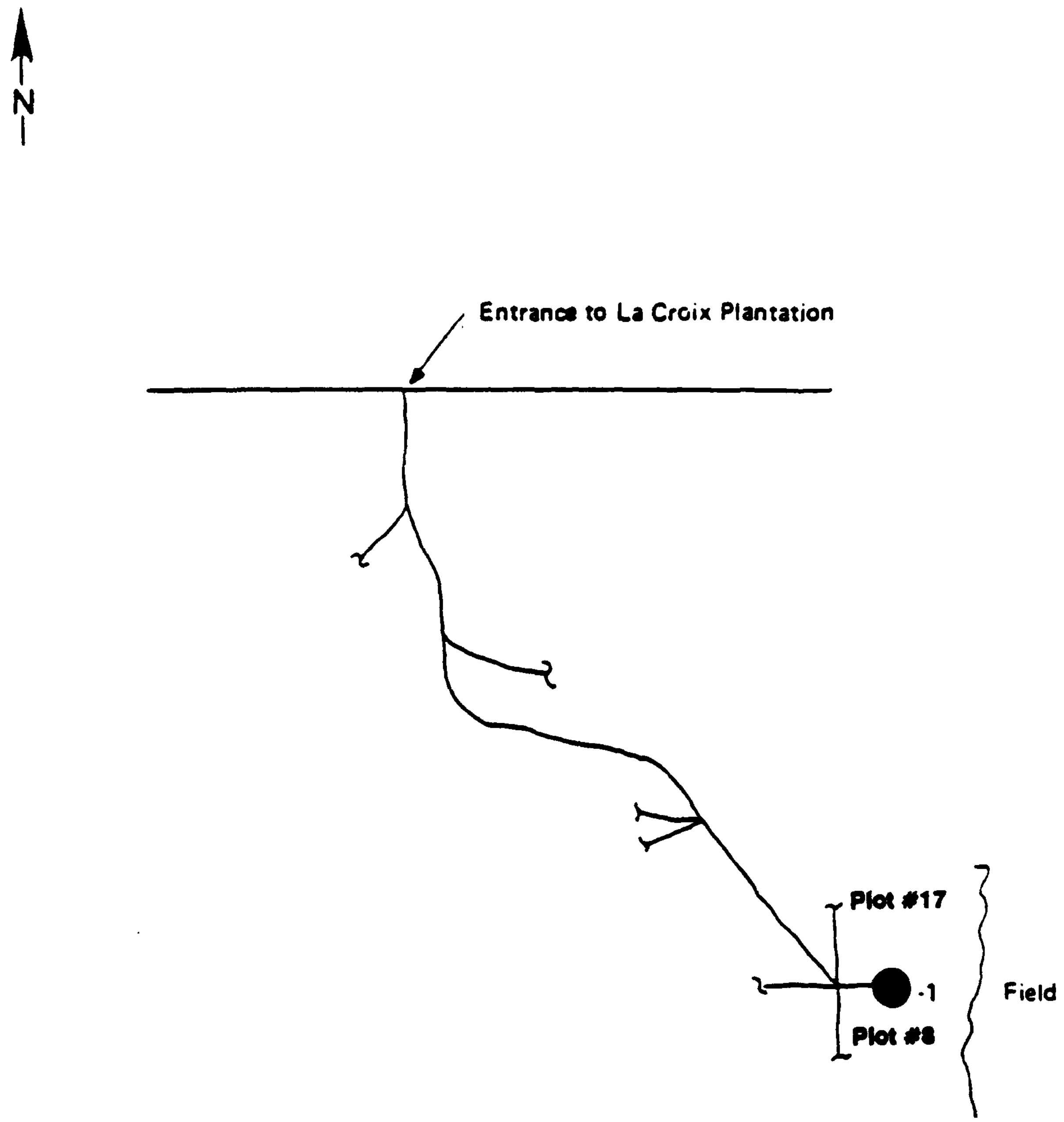

FIGURE 3. MEASUREMENT POINT AT THE PINE NEEDLE COLLECTION SITE; 4S3-1.

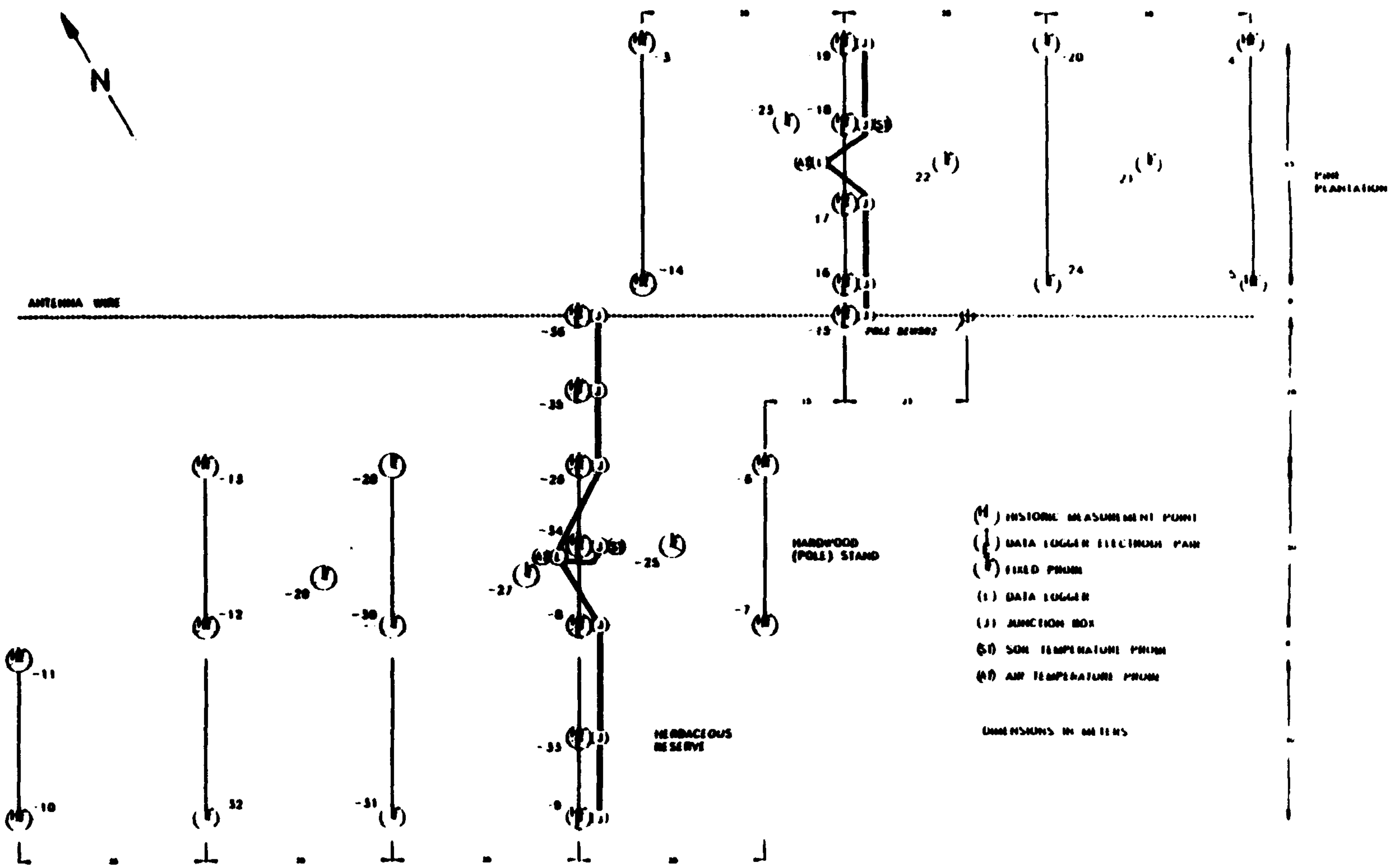

FIGURE 4. MTU ANTENNA SITE MARTELL'S LAKE (OVERHEAD) MEASUREMENT POINTS; 412 3 THROUGH 36

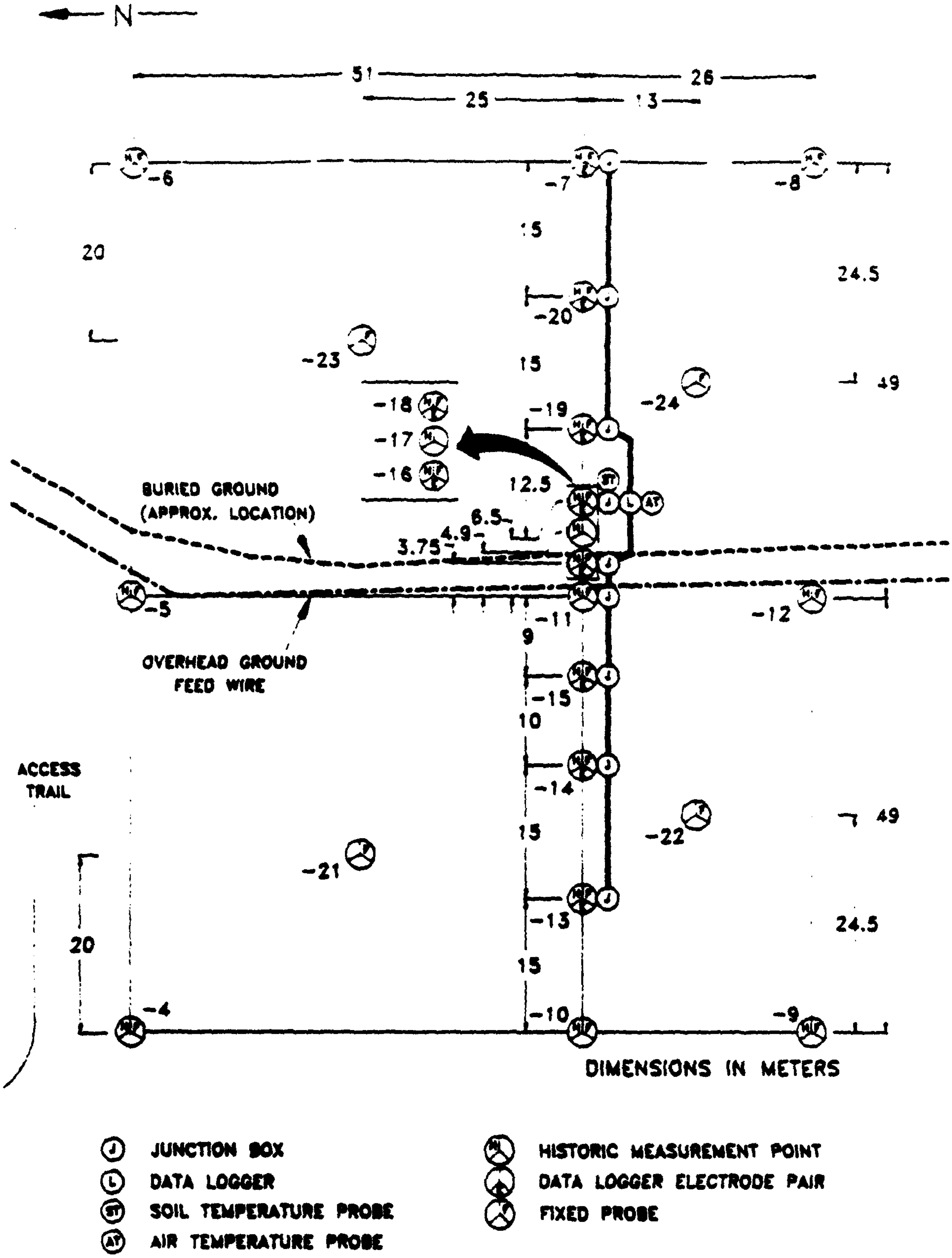

FIGURE 5. MTU GROUND SITE–MARTELL'S LAKE (BURIED):EP MEASUREMENT POINTS 4T4–4 THROUGH –24.

4C1-6	-	0.003	<	<	<	<	<[a]	<[b]	<[a]
4C1-7	-	0.006	<	<	<	<	<[a]	<[b]	<[a]
4C1-8	-	0.004	<	<	<	<	<[a]	<[b]	<[a]
4C1-9	-	0.002	<	<	<	<	<[a]	<[b]	<[a]
4C1-10	-	-	<	<	<	<	<[a]	<[b]	<[a]
4C1-11	-	-	<	<	<	<	<[a]	<[b]	<[a]
4C1-12	-	-	<	<	<	<	<[a]	<[b]	<[a]
4C1-13	-	-	<	<	<	<	<[a]	<[b]	<[a]
4T2-3	-	0.001	<	<	<	0.002	#[a]	#[a]	/
4T2-4	-	-	<	<	<	0.001	#[a]	#[a]	/
4T2-5	-	-	<	<	<	0.011	#[a]	#[a]	/
4T2-6	-	-	<	<	<	<0.001	#[a]	#[a]	/
4T2-7	-	-	<	<	<	<0.001	#[a]	#[a]	/
4T2-8	-	-	<	<	<	/	#[a]	#[a]	/
4T2-9	-	-	<	<	<	<	#[a]	#[a]	/
4T2-10	-	-	<	<	<	<	#[a]	#[a]	/
4T2-11	-	-	<	<	<	<	#[a]	#[a]	/
4T2-12	-	-	<	<	<	/	#[a]	#[a]	/
4T2-13	-	-	<	<	<	<0.001	#[a]	#[a]	/
4T2-14	-	-	<	<	<	0.011	#[a]	#[a]	/
4T2-15	-	-	-	-	-	-	#[a]	#[a]	/
4T2-16	-	-	-	-	-	-	#[a]	#[a]	/
4T2-17	-	-	-	-	-	-	#[a]	#[a]	/
4T2-18	-	-	-	-	-	-	#[a]	#[a]	/
4T2-19	-	-	-	-	-	-	#[a]	#[a]	/
4T2-26	-	-	-	-	-	-	-	#[a]	/
4T2-33	-	-	-	-	-	-	-	#[a]	/
4T2-34	-	-	-	-	-	-	-	#[a]	/
4T2-35	-	-	-	-	-	-	-	#[a]	/
4T2-36	-	-	-	-	-	-	-	#[a]	/

TABLE 2. 60 Hz AIR ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]	1989	1990	1991
4T4-4	-	0.003	<	<	<0.001	<0.001	#[d]	#[d]	/
4T4-5	-	-	<	<	0.006	0.003	#[d]	#[d]	/
4T4-6	-	-	<	<	<	<	#[d]	#[d]	/
4T4-7	-	-	<	<	<	<	#[d]	#[d]	/
4T4-8	-	-	<	<	<	<	#[d]	#[d]	/
4T4-9	-	-	<	<	<	<	#[d]	#[d]	/
4T4-10	-	-	<	<	<	<	#[d]	#[d]	/
4T4-11	-	-	<	<	0.010	0.009	#[d]	#[d]	/
4T4-12	-	-	-	<	0.005	0.007	#[d]	#[d]	/
4T4-13	-	-	-	-	-	-	#[d]	#[d]	/
4T4-14	-	-	-	-	-	-	#[d]	#[d]	/
4T4-15	-	-	-	-	-	-	#[d]	#[d]	/
4T4-16	-	-	-	-	-	-	#[d]	#[d]	/
4T4-17	-	-	-	-	-	-	#[d]	#[d]	/
4T4-18	-	-	-	-	-	-	#[d]	#[d]	/
4T4-19	-	-	-	-	-	-	#[d]	#[d]	/
4T4-20	-	-	-	-	-	-	#[d]	#[d]	/
4S1-1	-	-	-	-	0.013	0.033	0.011[b]	0.017[b]	0.018[b]
4S2-1	-	-	-	-	<	<	<[d]	<[b]	<[d]
4S3-1	-	-	-	-	<0.001	<0.001	<0.001[b]	<0.001[b]	/

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.
< = measurement est. <0.001 V/m based on earth E-field.

PM-91 (10/82)

TABLE 3. 60 Hz EARTH ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]	1989	1990	1991
4C1-6	-	0.022	0.016	0.005	0.043	0.023	0.016[d]	0.024[b]	0.012[d]
4C1-7	-	0.143	0.123	0.077	0.178	0.118	0.030[d]	0.039[b]	0.043[d]
4C1-8	-	0.104	0.117	0.077	0.131	0.078	0.018[d]	0.063[b]	0.020[d]
4C1-9	-	0.011	0.019	0.024	0.034	0.032	0.023[d]	0.023[b]	0.018[d]
4C1-10	-	-	0.090	0.088	0.118	0.106	0.054[d]	0.041[b]	0.030[d]
4C1-11	-	-	0.160	0.107	0.132	0.146	0.066[d]	0.068[b]	0.048[d]
4C1-12	-	-	0.104	0.101	0.075	0.093	0.042[d]	0.042[b]	0.033[d]
4C1-13	-	-	0.040	0.030	0.046	0.065	0.025[d]	0.039[b]	0.014[d]
4T2-3	-	0.51	0.39	0.194	0.27	0.28	#[d]	#[d]	0.52[b]
4T2-4	-	-	0.27	0.24	0.30	0.25	#[d]	#[d]	0.59[b]
4T2-5	-	-	0.43	0.32	0.20	0.20	#[d]	#[d]	0.77[b]
4T2-6	-	-	0.66	0.46	0.192	0.22	#[d]	#[d]	0.84[b]
4T2-7	-	-	0.42	0.52	0.197	0.28	#[d]	#[d]	0.71[b]
4T2-8	-	-	0.47	0.190	0.22	/	#[d]	#[d]	0.79[b]
4T2-9	-	-	0.49	0.31	0.183	0.25	#[d]	#[d]	0.62[b]
4T2-10	-	-	0.44	0.32	0.155	0.166	#[d]	#[d]	0.71[b]
4T2-11	-	-	0.51	0.40	0.31	0.43	#[d]	#[d]	0.72[b]
4T2-12	-	-	0.47	0.38	0.24	/	#[d]	#[d]	0.73[b]
4T2-13	-	-	0.76	0.31	0.31	0.25	#[d]	#[d]	0.87[b]
4T2-14	-	-	0.61	0.29	0.35	0.21	#[d]	#[d]	0.78[b]
4T2-15	-	-	-	-	-	-	#[d]	#[d]	1.01[b]
4T2-16	-	-	-	-	-	-	#[d]	#[d]	0.66[b]
4T2-17	-	-	-	-	-	-	#[d]	#[d]	0.93[b]
4T2-18	-	-	-	-	-	-	#[d]	#[d]	0.73[b]
4T2-19	-	-	-	-	-	-	#[d]	#[d]	0.64[b]
4T2-26	-	-	-	-	-	-	-	#[d]	0.61[b]
4T2-33	-	-	-	-	-	-	-	#[d]	0.75[b]
4T2-34	-	-	-	-	-	-	-	#[d]	0.81[b]
4T2-35	-	-	-	-	-	-	-	#[d]	0.73[b]
4T2-36	-	-	-	-	-	-	-	#[d]	0.60[b]

TABLE 3. 60 Hz EARTH ELECTRIC FIELD INTENSITES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]	1989	1990	991
4T4-4	-	0.72	0.42	0.186	0.56	0.079	#[d]	#[d]	0.40[b]
4T4-5	-	-	0.58	0.58	4.3	1.12	#[d]	#[d]	3.1[b]
4T4-6	-	-	0.22	0.16	0.61	0.188	#[d]	#[d]	0.35[b]
4T4-7	-	-	0.44	0.29	0.64	0.22	#[d]	#[d]	0.28[b]
4T4-8	-	-	0.42	0.193	0.40	0.23	#[d]	#[d]	0.27[b]
4T4-9	-	-	0.50	0.21	0.27	0.073	#[d]	#[d]	0.31[b]
4T4-10	-	-	0.42	0.22	0.29	0.063	#[d]	#[d]	0.23[b]
4T4-11	-	-	0.40	0.60	2.7	1.27	#[d]	#[d]	4.1[b]
4T4-12	-	-	-	0.75	3.4	1.35	#[d]	#[d]	0.34[b]
4T4-13	-	-	-	-	-	-	#[d]	#[d]	0.22[b]
4T4-14	-	-	-	-	-	-	#[d]	#[d]	0.53[b]
4T4-15	-	-	-	-	-	-	#[d]	#[d]	1.29[b]
4T4-16	-	-	-	-	-	-	#[d]	#[d]	4.4[b]
4T4-17	-	-	-	-	-	-	#[d]	#[d]	/
4T4-18	-	-	-	-	-	-	#[d]	#[d]	4.6[b]
4T4-19	-	-	-	-	-	-	#[d]	#[d]	1.17[b]
4T4-20	-	-	-	-	-	-	#[d]	#[d]	0.27[b]
4S1-1	-	-	-	-	8.5	12.2	11.6[b]	15.7[b]	9.1[b]
4S2-1	-	-	-	-	0.155	0.109	0.032[d]	0.068[b]	0.060[d]
4S3-1	-	-	-	-	0.65	1.73	0.73[b]	0.87[b]	0.69[b]

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.

TABLE 4. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]	1989	1990	1991
4C1-6	-	0.003	0.003	0.003	0.002	0.003	0.002[d]	0.002[b]	0.001[d]
4C1-7	-	0.003	0.002	0.001	0.003	0.002	0.001[d]	0.002[b]	0.001[d]
4C1-8	-	0.003	0.003	0.002	0.003	0.002	0.001[d]	0.002[b]	0.002[d]
4C1-9	-	0.003	0.003	0.002	0.001	0.002	0.002[d]	0.002[b]	0.001[d]
4C1-10	-	-	0.002	0.002	0.002	0.002	0.002[d]	0.002[b]	0.001[d]
4C1-11	-	-	0.002	0.002	0.002	0.002	0.001[d]	0.002[b]	0.001[d]
4C1-12	-	-	0.002	0.003	0.001	0.002	0.001[d]	0.002[b]	0.001[d]
4C1-13	-	-	0.002	0.003	0.001	0.003	0.002[d]	0.002[b]	0.001[d]
4T2-3	-	0.002	0.001	0.001	0.003	0.005	#[d]	#[d]	0.004[b]
4T2-4	-	-	0.001	0.001	0.003	0.006	#[d]	#[d]	0.005[b]
4T2-5	-	-	0.001	0.007	0.017	0.030	#[d]	#[d]	0.029[b]
4T2-6	-	-	0.001	0.006	0.006	0.014	#[d]	#[d]	0.017[b]
4T2-7	-	-	0.001	0.004	0.004	0.007	#[d]	#[d]	0.010[b]
4T2-8	-	-	0.001	0.002	0.004	/	#[d]	#[d]	0.010[b]
4T2-9	-	-	0.001	0.003	0.003	0.005	#[d]	#[d]	0.007[b]
4T2-10	-	-	0.001	0.003	0.003	0.005	#[d]	#[d]	0.007[b]
4T2-11	-	-	0.001	0.004	0.005	0.007	#[d]	#[d]	0.009[b]
4T2-12	-	-	0.002	0.004	0.005	/	#[d]	#[d]	0.010[b]
4T2-13	-	-	0.001	0.005	0.008	0.013	#[d]	#[d]	0.016[b]
4T2-14	-	-	0.002	0.011	0.018	0.029	#[d]	#[d]	0.035[b]
4T2-15	-	-	-	-	-	-	#[d]	#[d]	0.043[b]
4T2-16	-	-	-	-	-	-	#[d]	#[d]	0.033[b]
4T2-17	-	-	-	-	-	-	#[d]	#[d]	0.016[b]
4T2-18	-	-	-	-	-	-	#[d]	#[d]	0.009[b]
4T2-19	-	-	-	-	-	-	#[d]	#[d]	0.004[b]
4T2-26	-	-	-	-	-	-	-	#[d]	0.015[b]
4T2-33	-	-	-	-	-	-	-	#[d]	0.008[b]
4T2-34	-	-	-	-	-	-	-	#[d]	0.012[b]
4T2-35	-	-	-	-	-	-	-	#[d]	0.030[b]
4T2-36	-	-	-	-	-	-	-	#[d]	0.042[b]

TABLE 4. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]	1989	1990	1991
4T4-4	-	0.004	0.002	0.001	0.003	0.003	#[d]	#[d]	0.003[b]
4T4-5	-	-	0.002	0.006	0.010	0.017	#[d]	#[d]	0.008[b]
4T4-6	-	-	0.002	0.001	0.004	0.007	#[d]	#[d]	0.002[b]
4T4-7	-	-	0.001	0.001	0.004	0.005	#[d]	#[d]	0.002[b]
4T4-8	-	-	0.002	0.001	0.004	0.005	#[d]	#[d]	0.002[b]
4T4-9	-	-	0.002	0.001	0.002	0.003	#[d]	#[d]	0.001[b]
4T4-10	-	-	0.001	0.001	0.002	0.002	#[d]	#[d]	0.001[b]
4T4-11	-	-	0.002	0.002	0.012	0.019	#[d]	#[d]	0.008[b]
4T4-12	-	-	-	0.002	0.010	0.016	#[d]	#[d]	0.006[b]
4T4-13	-	-	-	-	-	-	#[d]	#[d]	0.001[b]
4T4-14	-	-	-	-	-	-	#[d]	#[d]	0.001[b]
4T4-15	-	-	-	-	-	-	#[d]	#[d]	0.003[b]
4T4-16	-	-	-	-	-	-	#[d]	#[d]	0.012[b]
4T4-17	-	-	-	-	-	-	#[d]	#[d]	0.013[b]
4T4-18	-	-	-	-	-	-	#[d]	#[d]	0.009[b]
4T4-19	-	-	-	-	-	-	#[d]	#[d]	0.003[b]
4T4-20	-	-	-	-	-	-	#[d]	#[d]	0.002[b]
4S1-1	-	-	-	-	0.035	0.043	0.052[b]	0.052[b]	0.032[b]
4S2-1	-	-	-	-	0.003	0.002	0.002[d]	0.001[b]	0.001[d]
4S3-1	-	-	-	-	0.036	0.095	0.028[b]	0.030[b]	0.035[b]

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

\- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.

As expected, the measured 60 Hz EM field intensity values change from year to year. The primary causes of 60 Hz EM field temporal variations at all study sites are changes in powerline load conditions and in soil conductivity, both of which are difficult to quantify. The 60 Hz EM field intensities at your treatment sites are also affected somewhat by the ELF transmitter configurations because of the closeness of these sites to the EW antenna and ground terminal. Regardless of cause, however, the percent changes in 60 Hz EM field intensities are about the same for both control and treatment sites.

Overall, the 60 Hz EM field intensities measured at your study sites in 1991 are within expected ranges. Despite the year-to-year changes in 60 Hz EM field levels, the 76 Hz EM fields at your treatment sites have consistently dominated the 60 Hz EM fields at all study sites. Further, the ratio of 60 Hz EM fields between your treatment and control sites continue to meet exposure criteria guidelines established at the beginning of the Ecological Monitoring Program.

76 Hz EM Fields - Annual Measurements

Normal Operation - Both Antennas

The 76 Hz measurement data taken during 1991 along with data from earlier years, are listed in Tables 5 through 7. The energized antenna elements and currents at the time of measurement are given below the year in the column headings of the tables. The annual increases in field magnitudes from 1986 through 1989 track the yearly increases in antenna currents as the NRTF-Republic progressed through various testing phases to full power operation. The 1991 measurement values for full power operation with both antennas are consistent with those obtained in 1990 and 1989 under the same antenna conditions. They are also proportional to measurements taken in earlier years at lower currents.

Special Maintenance Period - NS Antenna Only

As mentioned earlier, the extended shutdown of the EW antenna for repairs had a significant impact on the 76 Hz EM exposure levels at your treatment sites located along the SEW antenna element and ground 5. A complete set of EM field measurements was made at both treatment sites under this operating condition. These data are also presented in Table 5-7. It was found that the EM exposures at all locations at the treatment sites were reduced to about one-third of those with both antennas energized. The relatively high levels along the de-energized EW antenna are caused by cross coupling from the energized NS antenna.

TABLE 5. 76 Hz AIR ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1986				1987		1988		1989	1990	1991	
	NS 4 A	NEW 6 A	SEW 6 A	SEW 10 A, EX	NS 15 A	EW 15 A	NS 75 A	EW 75 A	B 150 A	B 150 A	NS 150 A	B 150 A
4C1-6	<	<	<	•	<	<	<	<	<	<	/	/
4C1-7	<	<	<	•	<	<	<	<	<	<	/	/
4C1-8	<	<	<	•	<	<	<	<	<	<	/	/
4C1-9	<	<	<	•	<	<	<	<	<	<	/	/
4C1-10	<	<	<	•	<	<	<	<	<	<	/	/
4C1-11	<	<	<	•	<	<	<	<	<	<	/	/
4C1-12	<	<	<	•	<	<	<	<	<	<	/	/
4C1-13	<	<	<	•	<	<	<	<	<	<	/	/
4T2-3	<	<	0.004	0.007	0.002	0.014	0.006	0.125	0.142	0.110	0.047	0.122
4T2-4	<	<	0.005	0.008	0.001	0.014	0.017	0.113	0.149	0.122	0.041	0.095
4T2-5	0.018	<	0.092	0.153	0.003	0.23	0.033	2.6	1.31	1.16	0.30	1.08
4T2-6	<	<	0.005	0.008	0.003	0.013	0.014	0.142	0.138	0.148	0.051	0.123
4T2-7	<	<	0.007	0.012	0.001	0.018	0.020	0.165	0.173	0.177	0.044	0.150
4T2-8	<	<	0.004	0.007	0.002	0.012	/	/	0.124	0.112	0.045	0.103
4T2-9	<	<	0.005	0.008	0.002	0.010	0.019	0.137	0.116	0.119	0.031	0.110
4T2-10	<	<	0.004	0.007	0.002	0.011	0.020	0.112	0.113	0.076	0.034	0.112
4T2-11	<	<	0.003	0.005	0.002	0.012	0.010	0.130	0.22	0.180	0.042	0.132
4T2-12	<	<	0.002	0.003	0.002	0.014	/	/	0.095	0.096	0.041	0.086
4T2-13	<	<	0.005	0.008	0.002	[illegible]	0.010	0.121	0.125	0.130	0.036	0.125
4T2-14	0.030	<	0.155	0.26	0.003	0.186	0.026	2.5	1.66	1.94	0.23	1.68
4T2-15	-	-	-	-	-	-	-	-	2.3	1.67	0.32	0.58
4T2-16	-	-	-	-	-	-	-	-	1.92	1.84	0.46	1.17
4T2-17	-	-	-	-	-	-	-	-	0.69	0.59	0.075	0.27
4T2-18	-	-	-	-	-	-	-	-	0.28	0.21	0.039	0.152
4T2-19	-	-	-	-	-	-	-	-	0.107	0.105	0.029	0.092
4T2-26	-	-	-	-	-	-	-	-	-	0.182	0.059	0.136
4T2-33	-	-	-	-	-	-	-	-		0.141	0.042	0.146
4T2-34	-	-	-	-	-	-	-	-		0.144	0.041	0.129
4T2-35	-	-	-	-	-	-	-			0.24	0.101	0.38
4T4-36	-	-								4.7	0.94	4.7

TABLE 5. 76 Hz AIR ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1986				1987		1988		1989	1990	1991	
	NS 4 A	NEW 6 A	SEW 6 A	SEW 10 A, EX	NS 15 A	EW 15 A	NS 75 A	EW 75 A	B 150 A	B 150 A	NS 150 A	B 150 A
4T4-4	<	<	0.006	0.010	0.002	0.005	0.008	0.028	0.067	0.058	0.015	0.071
4T4-5	0.033	0.008	0.20	0.33	0.019	0.27	0.089	1.31	4.8	3.8	1.37	4.4
4T4-6	0.006	<	0.023	0.038	0.002	0.021	0.011	0.064	0.175	0.117	0.040	0.186
4T4-7	<	<	0.006	0.010	0.002	0.015	0.008	0.090	0.133	0.129	0.026	0.33
4T4-8	<	<	0.008	0.013	0.002	0.016	0.007	0.083	0.145	0.145	0.032	0.130
4T4-9	<	<	0.008	0.015	0.001	0.008	0.009	0.047	0.095	0.072	0.017	0.130
4T4-10	<	<	0.007	0.012	0.001	0.001	0.011	0.057	0.112	0.085	0.026	0.107
4T4-11	<	0.005	0.38	0.63	0.025	0.43	0.20	4.4	5.0	4.6	1.37	4.8
4T4-12	0.055	0.005	0.43	0.72	0.017	0.30	0.150	2.1	4.5	3.8	1.26	4.6
4T4-13	-	-	-	-	-	-	-	-	0.26	0.21	0.042	0.28
4T4-14	-	-	-	-	-	-	-	-	0.88	0.84	0.194	0.90
4T4-15	-	-	-	-	-	-	-	-	2.7	2.6	0.51	2.8
4T4-16	-	-	-	-	-	-	-	-	5.9	5.4	1.68	6.7
4T4-17	-	-	-	-	-	-	-	-	4.5	4.3	1.28	5.7
4T4-18	-	-	-	-	-	-	-	-	4.8	3.8	1.24	4.9
4T4-19	-	-	-	-	-	-	-	-	1.16	0.96	0.25	1.15
4T4-20	-	-	-	-	-	-	-	-	0.32	0.183	0.067	0.47
4S1-1	-	-	-	-	<	<	<	<	<	<	<	<
4S2-1	-	-	-	-	<	<	<	<	<	<	<	<
4S3-1	-	-	-	-	<	<	<	<	<	<	<	<

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.
A = amperes.

\- = measurement point not established.
/ = measurement not taken.
< = measurement est. <0.001 V/m based on earth E field.
* = data cannot be extrapolated.

TABLE 6. 76 Hz EARTH ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1986				1987		1988		1989	1990	1991	
	NS 4 A	NEW 6 A	SEW 6 A	SEW 10 A, EX	NS 15 A	EW 15 A	NS 75 A	EW 75 A	B 150 A	B 150 A	NS 150 A	B 150 A
4C1-6	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.005	0.030	0.028	/	0.026
4C1-7	<0.001	<0.001	<0.001	*	0.005	0.006	0.024	0.023	0.091	0.085	/	0.079
4C1-8	<0.001	<0.001	<0.001	*	0.004	0.004	0.017	0.016	0.076	0.067	/	0.069
4C1-9	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.006	0.030	0.022	/	0.028
4C1-10	<0.001	<0.001	<0.001	*	0.005	0.004	0.026	0.023	0.087	0.079	/	0.089
4C1-11	<0.001	<0.001	<0.001	*	0.006	0.005	0.028	0.028	0.113	0.103	/	0.101
4C1-12	<0.001	<0.001	<0.001	*	0.004	0.003	0.016	0.016	0.068	0.072	/	0.053
4C1-13	<0.001	<0.001	<0.001	*	0.002	0.002	0.012	0.011	0.051	0.044	/	0.037
4T2-3	1.31	0.22	6.3	10.5	1.36	15.2	7.7	76	131	140	22	126
4T2-4	1.05	0.22	5.0	8.3	1.70	10.7	6.2	68	135	129	44	134
4T2-5	1.18	0.24	5.3	8.8	1.46	12.7	8.2	62	86	105	41	123
4T2-6	1.11	0.27	4.4	7.3	2.2	12.4	10.4	56	105	101	39	114
4T2-7	1.13	0.23	5.3	8.8	1.31	9.7	8.8	71	90	89	28	94
4T2-8	1.32	0.25	5.7	9.5	1.81	15.8	/	/	141	135	40	139
4T2-9	1.17	0.21	5.1	8.5	1.46	13.7	7.1	63	119	125	40	121
4T2-10	0.97	0.22	4.1	6.8	1.84	10.5	8.1	50	96	91	35	98
4T2-11	1.14	0.21	5.0	8.3	2.2	10.7	9.6	122	182	170	38	155
4T2-12	1.06	0.21	4.3	7.2	1.93	13.5	/	/	99	114	45	119
4T2-13	1.12	0.64	5.4	9.0	1.74	14.9	8.2	71	138	144	36	142
4T2-14	1.07	0.175	5.1	8.5	1.66	14.3	6.6	56	124	121	42	138
4T2-15	-	-	-	-	-	-	-	-	73	82	32	82
4T2-16	-	-	-	-	-	-	-	-	88	86	33	92
4T2-17	-	-	-	-	-	-	-	-	104	105	29	107
4T2-18	-	-	-	-	-	-	-	-	95	99	29	124
4T2-19	-	-	-	-	-	-	-	-	107	107	31	103
4T2-26	-	-	-	-	-	-	-	-	-	210	57	189
4T2-33	-	-	-	-	-	-	-	-		113	41	130
4T2-34	-	-	-	-	-	-	-	-		152	36	127
4T2-35	-	-	-	-	-		-			136	45	137
4T2-36	-			-						155	44	133

PH-91 (10/92)

TABLE 6. 76 Hz EARTH ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No.,	1986				1987		1988		1989	1990	1991	
Meas. Pt.	NS 4 A	NEW 6 A	SEW 6 A	SEW 10 A, EX	NS 15 A	EW 15 A	NS 75 A	EW 75 A	B 150 A	B 150 A	NS 150 A	B 150 A
4T4-4	0.33	0.181	1.46	2.4	1.63	3.7	7.2	16.5	42	31	10.2	25
4T4-5	13.8	2.0	81.	135.	14.0	194.	68	910	2100	1670	510	1790
4T4-6	1.22	0.22	6.2	10.3	2.2	12.9	10.3	62	140	117	29	141
4T4-7	0.94	0.175	5.5	9.2	2.0	14.1	9.1	62	119	135	30	101
4T4-8	0.91	0.188	5.3	8.8	1.36	10.7	6.8	65	106	113	31	111
4T4-9	0.29	0.130	1.32	2.2	1.08	3.0	7.5	18.1	47	42	4.5	18
4T4-10	0.29	0.169	1.63	2.7	1.35	3.9	5.1	16.0	39	43	8.1	30
4T4-11	0.59	1.82	89.	148.	10.7	178.	50	850	1870	1890	630	2200
4T4-12	21.	2.2	118.	197.	13.8	260.	40	760	1950	1600	380	1380
4T4-13	-	-	-	-	-	-	-	-	64	56	15.2	59
4T4-14	-	-	-	-	-	-	-	-	220	200	59	320
4T4-15	-	-	-	-	-	-	-	-	760	760	220	820
4T4-16	-	-	-	-	-	-	-	-	3000	3800	690	3300
4T4-17	-	-	-	-	-	-	-	-	130	30	/	/
4T4-18	-	-	-	-	-	-	-	-	3200	3600	1000	4100
4T4-19	-	-	-	-	-	-	-	-	750	880	196	880
4T4-20	-	-	-	-	-	-	-	-	200	163	49	200
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/	/	/
4S2-1	-	-	-	-	0.005	0.005	0.026	0.026	0.126	0.103	/	0.097
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/	/	/

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.
A = amperes.

\- = measurement point not established.
/ = measurement not taken.
* = data cannot be extrapolated.

TABLE 7. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No.,	1986				1987		1988		1989	1990	1991	
Meas. Pt.	NS 4 A	NEW 6 A	SEW 6 A	SEW 10 A, EX	NS 15 A	EW 15 A	NS 75 A	EW 75 A	B 150 A	B 150 A	NS 150 A	B 150 A
4C1-6	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	0.001	0.003	0.003	/	0.003
4C1-7	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	<0.001	0.002	0.002	/	0.002
4C1-8	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	<0.001	0.002	0.002	/	0.002
4C1-9	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	0.001	0.003	0.003	/	0.003
4C1-10	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	<0.001	0.002	0.002	/	0.002
4C1-11	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	<0.001	0.002	0.002	/	0.002
4C1-12	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	<0.001	0.002	0.002	/	0.002
4C1-13	<0.001	<0.001	<0.001	•	<0.001	<0.001	0.001	0.001	0.003	0.003	/	0.003
4T2-3	0.047	0.001	0.22	0.37	0.008	0.55	0.040	2.8	5.7	5.9	1.69	5.5
4T2-4	0.049	0.001	0.24	0.40	0.008	0.57	0.041	2.9	5.8	5.9	1.74	5.7
4T2-5	0.197	<0.001	1.00	1.67	0.011	2.4	0.061	12.4	24	27	6.9	23
4T2-6	0.058	0.001	0.44	0.73	0.006	1.16	0.020	5.0	10.3	11	3.0	10.3
4T2-7	0.046	0.001	0.22	0.37	0.006	0.59	0.024	2.6	5.4	5.8	1.63	5.4
4T2-8	0.045	0.001	0.22	0.37	0.006	0.59	/	/	5.6	5.8	1.67	5.3
4T2-9	0.029	0.001	0.138	0.23	0.007	0.38	0.027	1.72	3.4	3.6	0.96	3.3
4T2-10	0.033	0.001	0.149	0.25	0.006	0.39	0.027	1.78	3.5	3.7	1.14	3.4
4T2-11	0.043	0.001	0.21	0.35	0.006	0.56	0.025	2.6	5.0	5.3	1.54	4.9
4T2-12	0.047	0.001	0.23	0.38	0.006	0.61	/	/	5.6	5.9	1.71	5.7
4T2-13	0.086	<0.001	0.43	0.72	0.005	1.14	0.020	5.1	10.1	10.8	3.1	10.4
4T2-14	0.21	<0.001	1.03	1.72	0.012	2.5	0.061	11.9	25	28	7.7	26
4T2-15	-	-	-	-	-	-	-	-	33	36	9.6	32
4T2-16	-	-	-	-	-	-	-	-	28	29	7.8	26
4T2-17	-	-	-	-	-	-	-	-	13.6	13.9	3.9	13.0
4T2-18	-	-	-	-	-	-	-	-	8.6	8.6	2.4	7.7
4T2-19	-	-	-	-	-	-	-	-	5.9	6.0	1.73	5.7
4T2-26	-	-	-	-	-	-	-	-	-	10.5	2.8	9.7
4T2-33	-	-	-	-	-	-	-			4.2	1.21	3.8
4T2-34	-	-	-	-	-	-	-			7.4	2.1	7.0
4T2-35	-	-	-	-	-	-	-			21	5.9	20
4T2-36	-			-	-					36	10.0	33

TABLE 7. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1986				1987		1988		1989	1990	1991	
	NS 4 A	NEW 6 A	SEW 6 A	SEW 10 A, EX	NS 15 A	EW 15 A	NS 75 A	EW 75 A	B 150 A	B 150 A	NS 150 A	B 150 A
4T4-4	0.019	<0.001	0.096	0.160	0.005	0.24	0.027	1.15	2.5	2.3	0.63	2.3
4T4-5	0.114	0.001	0.57	0.95	0.008	1.40	0.033	6.9	13.9	13.3	4.2	13.7
4T4-6	0.045	0.001	0.22	0.37	0.008	0.53	0.034	2.7	5.3	5.1	1.60	5.3
4T4-7	0.038	0.001	0.186	0.31	0.008	0.45	0.033	2.3	4.4	4.1	1.30	4.4
4T4-8	0.035	0.001	0.179	0.30	0.007	0.43	0.033	2.1	4.2	4.1	1.25	4.2
4T4-9	0.025	0.21	0.118	0.197	0.005	0.29	0.027	1.41	2.8	2.7	0.79	2.8
4T4-10	0.022	<0.001	0.116	0.193	0.005	0.27	0.027	1.33	2.7	2.6	0.75	2.8
4T4-11	0.161	0.001	0.80	1.33	0.011	1.89	0.042	8.9	18.7	19.1	5.9	18.3
4T4-12	0.115	0.001	0.58	0.97	0.010	1.37	0.041	7.1	14.5	13.4	4.4	14.0
4T4-13	-	-	-	-	-	-	-	-	2.7	3.8	1.12	4.0
4T4-14	-	-	-	-	-	-	-	-	7.0	7.0	2.0	7.4
4T4-15	-	-	-	-	-	-	-	-	11.9	12.0	3.4	11.5
4T4-16	-	-	-	-	-	-	-	-	18	14.6	5.2	14.7
4T4-17	-	-	-	-	-	-	-	-	14.3	13.6	4.3	13.8
4T4-18	-	-	-	-	-	-	-	-	16.8	15.7	5.0	15.8
4T4-19	-	-	-	-	-	-	-	-	9.8	9.1	2.8	9.7
4T4-20	-	-	-	-	-	-	-	-	5.9	5.4	1.76	5.9
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/	/	/
4S2-1	-	-	-	-	<0.001	<0.001	0.001	<0.001	0.002	0.001	/	0.002
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/	/	/

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.
A = amperes.
\- = measurement point not established.
/ = measurement not taken.
* = data cannot be extrapolated.

Measurements were not made at your control site with the EW antenna shutdown. However, 76 Hz EM field contributions from the NS and EW antennas are known to be of similar magnitude at this site. This is evidenced by the 1987 and 1988 measurements during individual antenna operation. EM exposures at the control site, therefore, were likely reduced to about one-half of their normal levels when only the NS antenna was operating. While the actual amount of exposure reduction at the control site is unknown, any reduction in the EM fields here is desirable from the standpoint of maintaining proper EM exposure ratios.

Fixed Probe Measurements, 1990-1991

Regular measurements at the fixed electric field probes, which were established at numerous locations at your treatment sites in 1990, are still being conducted. Fixed probe measurements locations are designated by an "F" in the measurement point symbols in Figures 4 and 5. All fixed probe locations established in 1990 are still in use. The fixed probe measurement set was expanded in 1991 to include the electrode pairs monitored by the data loggers. Data for all fixed probe measurements in 1990 and 1991 are presented in Tables 8 through 11. Measurements made during shutdown of the EW antenna are labeled "NS Only" in the column headings. Summary statistics were computed for each probe for each year. Statistics for 1991 do not include data for NS operation only.

Data Logger Measurements, 1991

Figures 4 and 5 also show the layouts of the three data logger monitoring systems that were installed at your treatment sites on 18-21 June 1991. Two systems monitor the pine plantations at the antenna and ground sites, while the third monitors the antenna site hardwood stand and herbaceous reserve. Each system includes an array of earth electric field probes, a soil temperature probe and an air temperature probe. The electric field probe arrays are laid out on transects perpendicular to the antenna or ground wire. The probe locations are the same as those used during annual measurements along these transects. Soil temperature probes are located at the field probe closest to each logger and sense at a depth of 5 inches. Air temperature probes are located on the underside of the data logger housing in order to shield them from direct sunlight. Each probe output is measured and recorded hourly by the data logger.

Daily averages of the hourly earth electric field intensity measurements for 1991 are plotted in Figures 6-8. Weather related parameters that might be expected to impact the

TABLE 8. 1990 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Antenna Site Fixed Test Points

Test Point	Measurement Date												Summary Statistics		
	6/28	7/10	7/24	8/07	8/21	9/04	9/18	10/02	10/22	11/07	12/05	12/21	Mean	S.D.	Coeff. of Variab.
412-3	140	135	139	145	142	141	139	141	143	147	153	157	144	6.0	0.042
412-4	129	128	124	125	126	127	126	126	126	125	120	121	125	2.5	0.020
412-5	105	99	97	94	102	99	104	105	111	108	110	106	101	5.0	0.049
412-6	101	100	96	97	100	94	96	97	106	104	104	105	100	3.9	0.039
412-7	89	86	84	82	80	84	81	85	87	87	88	83	85	2.7	0.032
412-8	135	130	142	143	132	138	133	137	141	143	141	145	138	4.7	0.034
412-9	125	122	119	116	120	118	117	119	122	122	136	141	123	7.4	0.060
412-10	91	87	88	88	87	89	88	92	97	95	96	98	91	4.0	0.043
412-11	170	168	160	158	168	165	168	168	177	171	123	125	160	16.8	0.105
412-12	114	144	113	114	110	110	106	108	114	116	154	163	122	18.8	0.154
412-13	144	142	144	145	144	146	146	143	147	146	156	160	147	5.2	0.035
412-14	121	115	117	113	118	117	122	124	127	126	122	125	121	4.3	0.036
412-16	91	88	85	81	90	91	90	96	97	99	94	95	91	5.0	0.054
412-19	107	106	106	103	106	105	106	106	107	107	105	106	106	1.10	0.010
412-20	107	107	102	108	107	105	106	107	111	110	114	121	109	4.7	0.043
412-21	143	139	122	132	139	142	139	140	149	144	141	144	140	6.6	0.047
412-22	98	92	91	85	93	86	89	93	90	89	85	85	90	3.9	0.043
412-23	114	108	109	107	112	109	115	115	126	122	113	115	114	5.4	0.047
412-24	120	121	114	112	117	117	120	123	127	126	128	123	121	4.8	0.040
412-25	115		117	121	116	114	115	114	118	120	129	129	119	5.2	0.044
412-26	210	200	200	210	210	199	198	197	210	220	230	220	210	9.4	0.045
412-27	118	112	124	130	119	116	115	116	129	133	124	131	122	6.9	0.056
412-28	151	151	153	157	152	153	152	153	149	151	152	149	152	2.0	0.013
412-29	55	55	61	63	53	53	54	53	53	59	53	54	56	3.4	0.060
412-30	106	105	113	122	110	107	112	113	115	124	120	122	114	6.3	0.055
412-31	94	96	98	99	99	100	101	100	102	102	103	104	100	2.8	0.028
412-32	75	73	73	72	74	74	75	74	75	73	72	75	74	1.10	0.015

Table 9. 1991 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Antenna Site Fixed Test Points

Test Point	Measurement Date																	Summary Statistics*		
						NS Antenna Only														
	1/4	1/18	2/19	3/18	4/25	5/29	6/21	7/8	7/25	8/16	8/28	9/9	9/30	10/11	10/23	11/8	12/6	Mean	S.D.	Coeff of Variab
412-3	147	144	146	153	152	48	49	49	153	159	160	150	150	148	149	149	140	150	5.1	0.034
412-4	112	117	112	128	131	44	44	43	135	136	138	139	136	130	135	124	129	129	8.9	0.069
412-5	108	111	132	130	111	35	34	35	118	112	108	118	120	120	119	122	122	118	7.1	0.061
412-6	112	119	113	112	109	38	37	40	109	121	120	112	113	116	114	114	116	114	3.6	0.031
412-7	95	101	102	97	97	27	26	26	83	84	84	87	90	89	91	90	93	92	5.9	0.065
412-8	149	150	150	146	147	43	42					137	134	139	140	144	153	145	5.9	0.041
412-9	137	134	141	138	128	37	38						165	164	156		140	145	12.7	0.088
412-10	100	99	98	101	100	35	35	35	96	102	103	95	103	103	105	103	102	101	2.8	0.028
412-11	139	131	136	128	167	50	41	55	173	144	106	167	166	165	162	172	119	148	21	0.143
412-12	161	162	165	151	132	39	45	39	124	131	132	129	120	123	124	136	160	139	16.1	0.115
412-13	180	169	167	149	139	41	43	41	150	149	146	148	147	149	150	149	149	153	10.6	0.070
412-14	113	121	119	126	131	39	39	39	128	128	133	127	133	130	135	123	128	127	5.8	0.046
412-15										58	60	65	66	64	65	63	59	63	2.9	0.046
412-16	81	85	87	100	101	33	34					108	118	114	120		100	101	13.1	0.129
412-17										99	92	111	109	111	111	111	100	106	7.0	0.066
412-18										118	116	112	108	110	110	110	103	111	4.3	0.039
412-19	98	103	99	106	104	33	33					107	116	101	108	124	103	106	7.3	0.069
412-20	129	122	123	121	117	39	39	38	116	113	114	112	112	114	114	113	106	116	5.6	0.048
412-21	141	128	135	140	145	57	52	54	144	135	82	140	131	130	127	132	120	131	15.1	0.116
412-22	86	89	94	91	109	43	40	43	98	86	86	99	104	94	97	88	94	94	6.7	0.072
412-23	106	107	108	120	117	40	35	39	116	116	114	129	129	127	129	123	107	118	8.4	0.071
412-24	121	130	132	133	133	37	36	36	122	115	120	124	124	125	126	118	124	125	5.4	0.043
412-25	138	135	132	125	107	28	15	4.5	88	69	76	57	61	65	63	124	103	96	30	0.31
412-26	250	240	230	220	230	67	62			200	192	220	210	210	210	240	240	220	15.8	0.071
412-27	149	146	146	134	138	37	30	37	129	135	131	122	126	132	130	155	130	136	9.2	0.068
412-28	178	168	164	154	153	52	55	54	162	167	155	156	153	157	153	153	150	159	7.6	0.048
412-29	70	70	78	73	72	15	14	15	64	66	66	54	54	58	56	64	58	65	7.3	0.114
412-30	130	129	131	124	128	40	38	40	116	125	67	107	114	121	120	132	120	119	16.0	0.134
412-31	103	104	105	104	98	37	39	38	106	97	91	108	108	107	109	103	100	103	4.9	0.047
412-32	58	63	61	77	80	28	28	28	76	74	74	82	79	77	80	76	84	74	7.7	0.104
412-33										114	138	116	116	114	117	126	122	120	7.7	0.064
412-34										97	100	118	110	111	112	114	119	110	7.4	0.067
412-35											162	155	155	161	158	179	163	162	7.6	0.047
412-36											128	142	140	136	135	136	142	137	4.6	0.033

* Summary statistics do not include data measured during operation of the NS antenna only

TABLE 10. 1990 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Ground Site Fixed Test Points

Test Point	Measurement Date												Summary Statistics		
	6/28	7/18	7/24	8/07	8/21	9/04	9/18	10/2	10/22	11/7	12/5	12/21	Mean	S.D.	Coeff of Variab
4T4-4	31	29	27	28	31	31	32	32	12	9	8.7	8.3	23	9.9	0.42
4T4-5	1670	1800	1830	1950	2100	2000	2000	1980	1720	1740	1980	1910	1900	134	0.071
4T4-6	117	115	115	125	136	138	141	143	148	140	142	140	133	11.4	0.086
4T4-7	135	132	130	132	137	135	137	139	144	146	145	149	138	6.0	0.043
4T4-8	113	108	105	106	109	105	108	109	112	113	109	111	109	2.7	0.025
4T4-9	42	42	42	43	42	43	43	44	18	20	20	22	35	10.7	0.31
4T4-10	32	30	30	30	30	29	32	33	35	37	37	37	33	3.0	0.090
4T4-11	1890	1940	2200	2300	2000	2100	2000	2000	2200	2200	2400	2500	2200	185	0.086
4T4-12	1600	1610	1700	1820	1850	1820	1900	1960	1820	1770	1820	1860	1790	104	0.058
4T4-21	109	107	91	97	122	127	131	134	146	135	132	136	122	16.5	0.135
4T4-22	148	137	139	148	153	154	159	169	177	174	170	165	158	12.8	0.081
4T4-23	330	340	330	350	380	370	390	400	410	380	370	390	370	25	0.069
4T4-24	360	360	340	340	390	380	410	430	430	420	420	420	390	32	0.081

TABLE 11. 1991 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Ground Site Fixed Test Points

Test Point	Measurement Date																	Summary Statistics*		
						NS Antenna Only														
	1/4	1/18	2/19	3/18	4/25	5/29	6/21	7/8	7/25	8/16	8/28	9/13	9/30	10/10	10/23	11/6	12/6	Mean	S.D.	Coeff. of Variab
4T4-4	6.8	7.1	8.3	10.3	9.2	10.6	9.9	10.4	11.1	11.3	11.5	12.8	12.6	12	13	12	11	10.6	2.0	0.185
4T4-5	2100	2100	2200	2200	1850	480	480	410	1780	1780	1850	1910	1900	1900	1850	1460	1580	1890	210	0.109
4T4-6	131	131	135	135	100	32	29	30	123	125	133	140	141	143	141	132	110	130	11.8	0.091
4T4-7	136	147	135	155	134	37	36										145	142	7.7	0.054
4T4-8	108	112	109	115	108	30	29	29	110	102	102	105	105	108	108	112	110	108	3.6	0.033
4T4-9	25	25	27	26	22	8.0	7.1	7.8	18.2	17.9	18.5	17.9	18.6	19	19	16	19	21	3.5	0.168
4T4-10	37	36	33	27	30	9.4	8.6	9.0	32	31	24	32	33	34	34	36	30	32	3.5	0.109
4T4-11	2600	2800	3200	2900	2400	550	550	480	2000	2200	2400	2100	2100	2100	2200	1790	2000	2300	390	0.167
4T4-12	2500	2300	2600	2700	1890	470	450	380	1550	1520	1580	1700	1800	1900	1830	1400	1520	1910	420	0.22
4T4-13													76	79				78	1.5	0.019
4T4-14												260	220	230	230	200	270	310	128	0.42
4T4-15										640	850	790	790	790	800	710	750	760	60	0.079
4T4-16										3500	3600	3100	3100	3200	3300	3400	3600	3300	194	0.058
4T4-18										4100	4400	4100	4200	4400	4400	4500	5000	4400	270	0.062
4T4-19												750	780	820	840	710	700	770	55	0.072
4T4-20																	220	220	0.0	0.0
4T4-21	128	123	120	149	92	39	34	33	113	89	100	124	130	128	130	111	98	117	16.5	0.141
4T4-22	154	148	143	161	123	52	44	46	133	149	152	156	152	157	160	151	129	148	11.2	0.076
4T4-23	390	380	400	390	310	91	88	83	340	370	390	400	390	400	400	340	320	370	30	0.081
4T4-24	450	440	450	470	350	115	104	100	370	350	360	410	430	430	430	310	370	400	49	0.121

*Summary statistics exclude data measured during operation of the NS antenna only

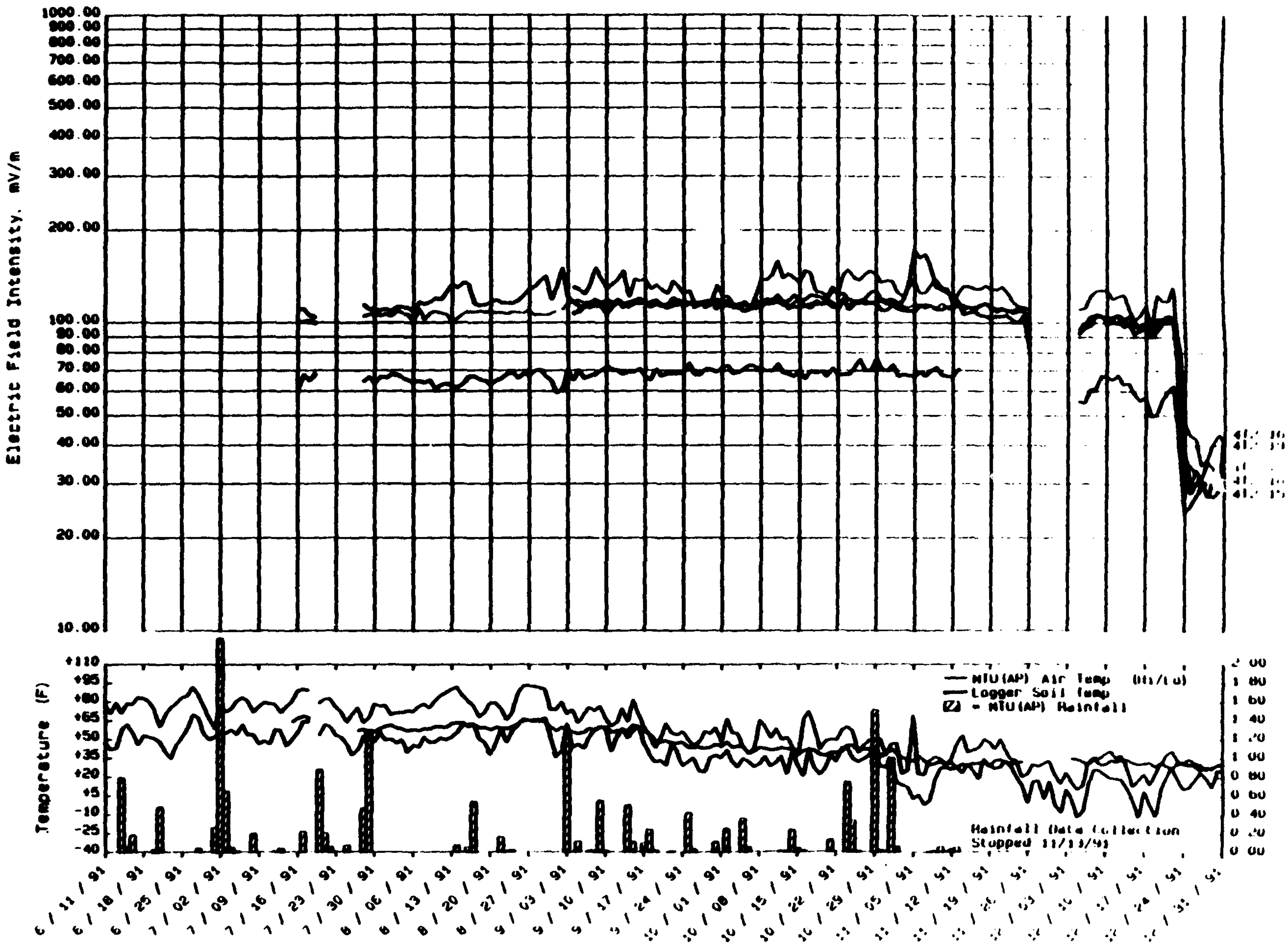

FIGURE 6 DAILY AVERAGE EARTH ELECTRIC FIELD INTENSITIES AT THE ANTENNA SITE PINE PLANTATION, 412 19, 18, 17, 16, 15

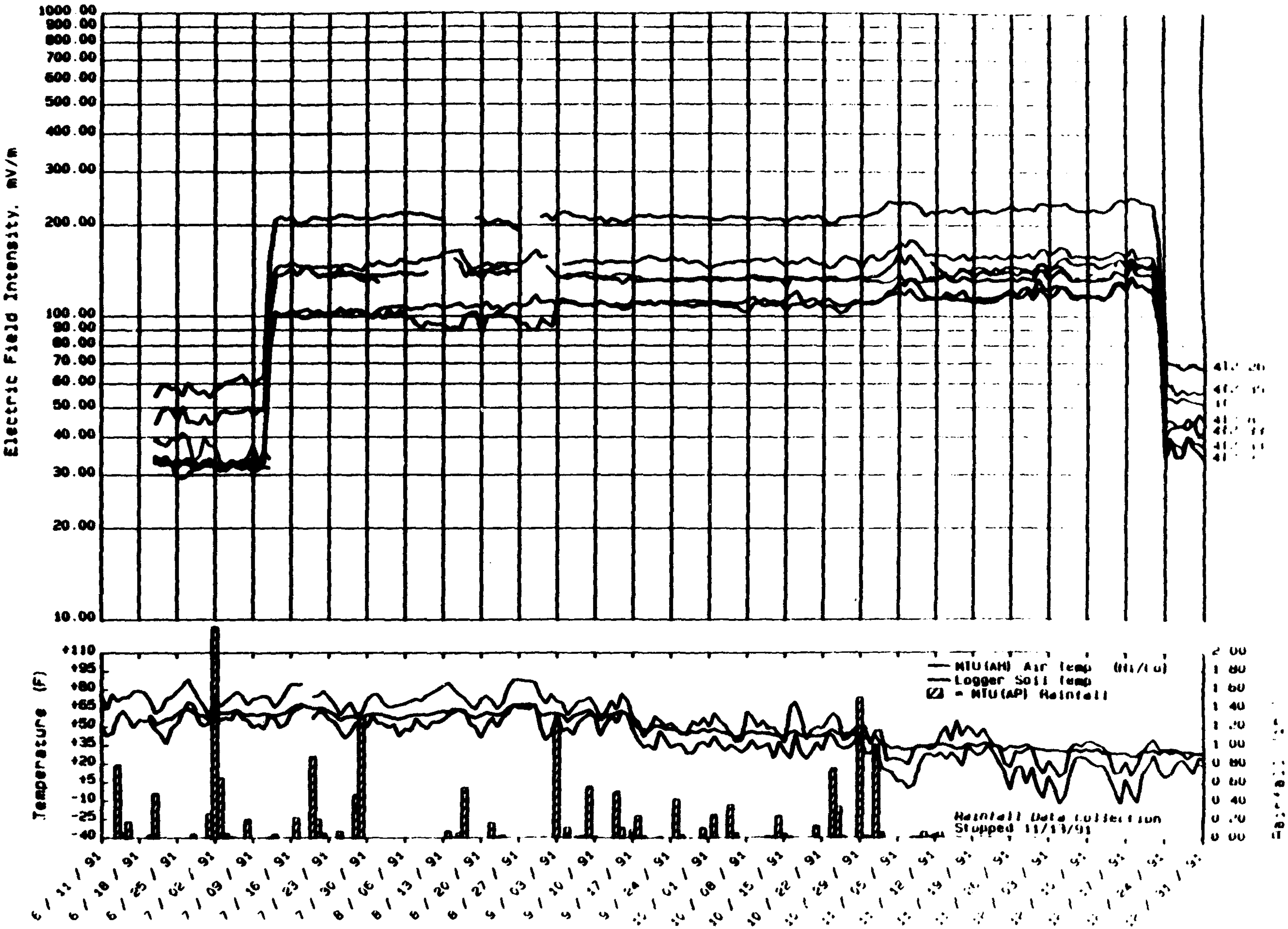

FIGURE 7 DAILY AVERAGE EARTH ELECTRIC FIELD INTENSITIES AT THE ANTENNA SITE
HARDWOOD STAND, 412.9, 33.8, 44.26, ...

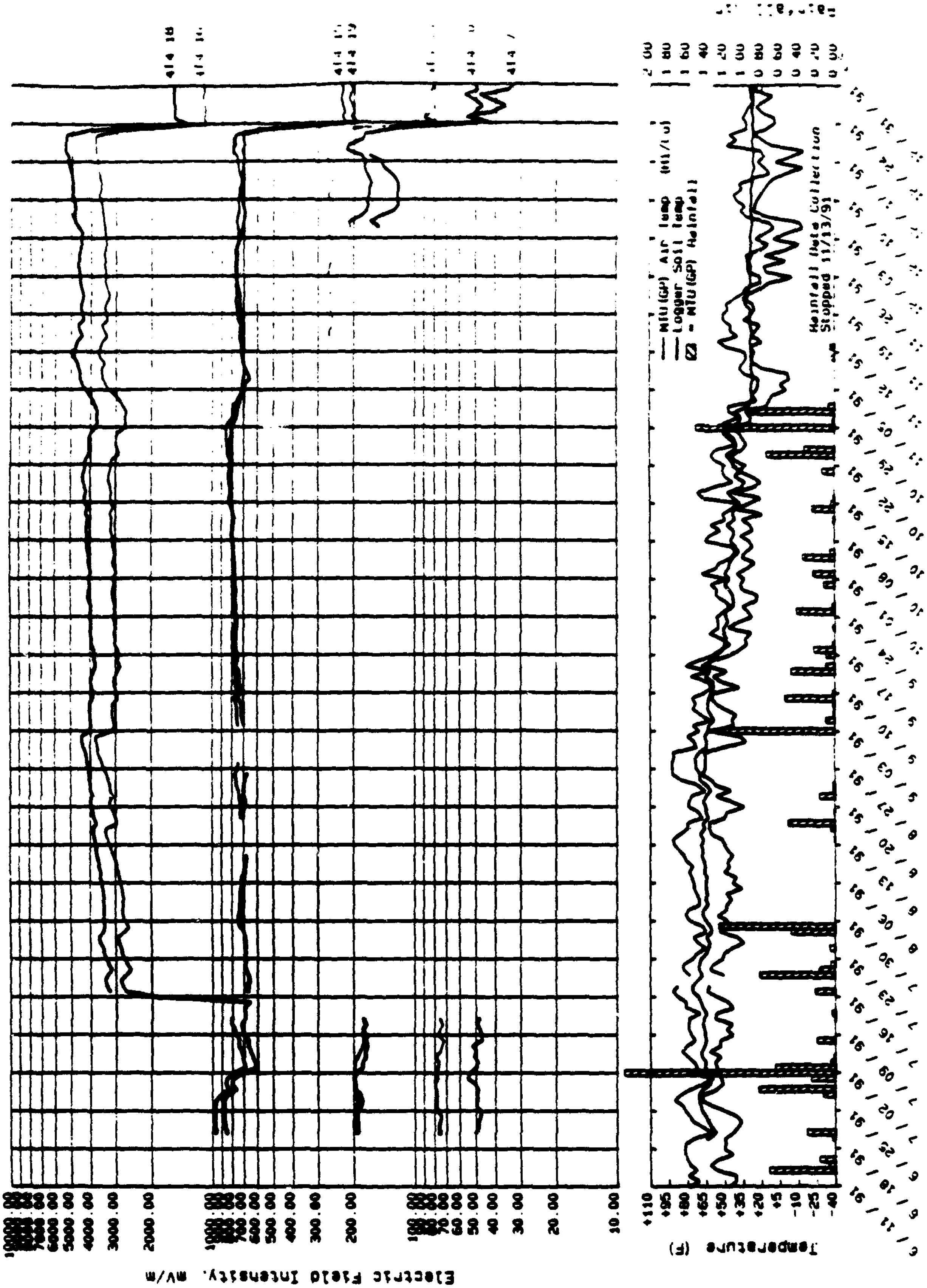

FIGURE 8 DAILY AVERAGE EARTH ELECTRIC FIELD INTENSITIES AT THE GROUND SITE PINE PLANTATION, 414 7, 20, 19, 18, 16, 15, 14

electric field intensity levels are on a separate grid below the main plot. The soil temperatures presented were taken by the IITRI data loggers, while the air temperature and rainfall data are from the MTU ambient monitoring system. The source of the MTU weather data is noted parenthetically in the legend. An "A" or "G" is used to designate the antenna or ground site and a "P" or "H" is used to designate pine plantation or hardwood stand.

Two major shifts in the electric field intensity levels can be seen in Figures 6-8. The low field levels prior to 12 July and following 23 December correspond to periods when the EW antenna was shutdown. As previously discussed, shutdown of the EW antenna reduced the EM field levels by about a factor of 3. Several gaps in the electric field data are also shown in these figures. These are not periods when the transmitters were off. Rather, they reflect data lost as a result of data logger or electrode failures or by procedure errors made when offloading the data from the logger computers. At the ground site system, measurements from three electrode sets (4T4-7,14,20) were confounded by the data logger input protection devices. The problem began when the EW antenna came back on line on 13 July, but was not discovered and corrected until the fall.

Analysis of Measurement Data

Air Electric Field and Magnetic Flux Density Profiles

Profiles of the 76 Hz air electric field and magnetic flux density along transects perpendicular to the antenna and ground ROW's appear in Figures 9-12. Each figure has multiple profiles relating to normal operation with both antennas for the years 1989-1991 and one profiles for the period of NS operation only in 1991. The historic measurement points which comprise each profile are identified just above the horizontal axis. Measurement points 4T2-26 and 33 through 36 were not established in 1989 and this profile is therefore missing for that year.

The air electric fields in the pine plantations at both the antenna and ground sites decrease in a uniform fashion with increasing distance from the antenna or ground feed wire. The field profiles for the antenna site pine plantation have decreased slightly each year. This is because the air electric field at this site, which is set up by the potential difference between the antenna wire and ground surface, is being increasingly shielded by the growing pine trees. The same effect is not seen at the ground site because the buried ground wire, which is the main contributor to the air electric field here, creates a potential difference between trees that is less affected by the tree height. At the ground site there

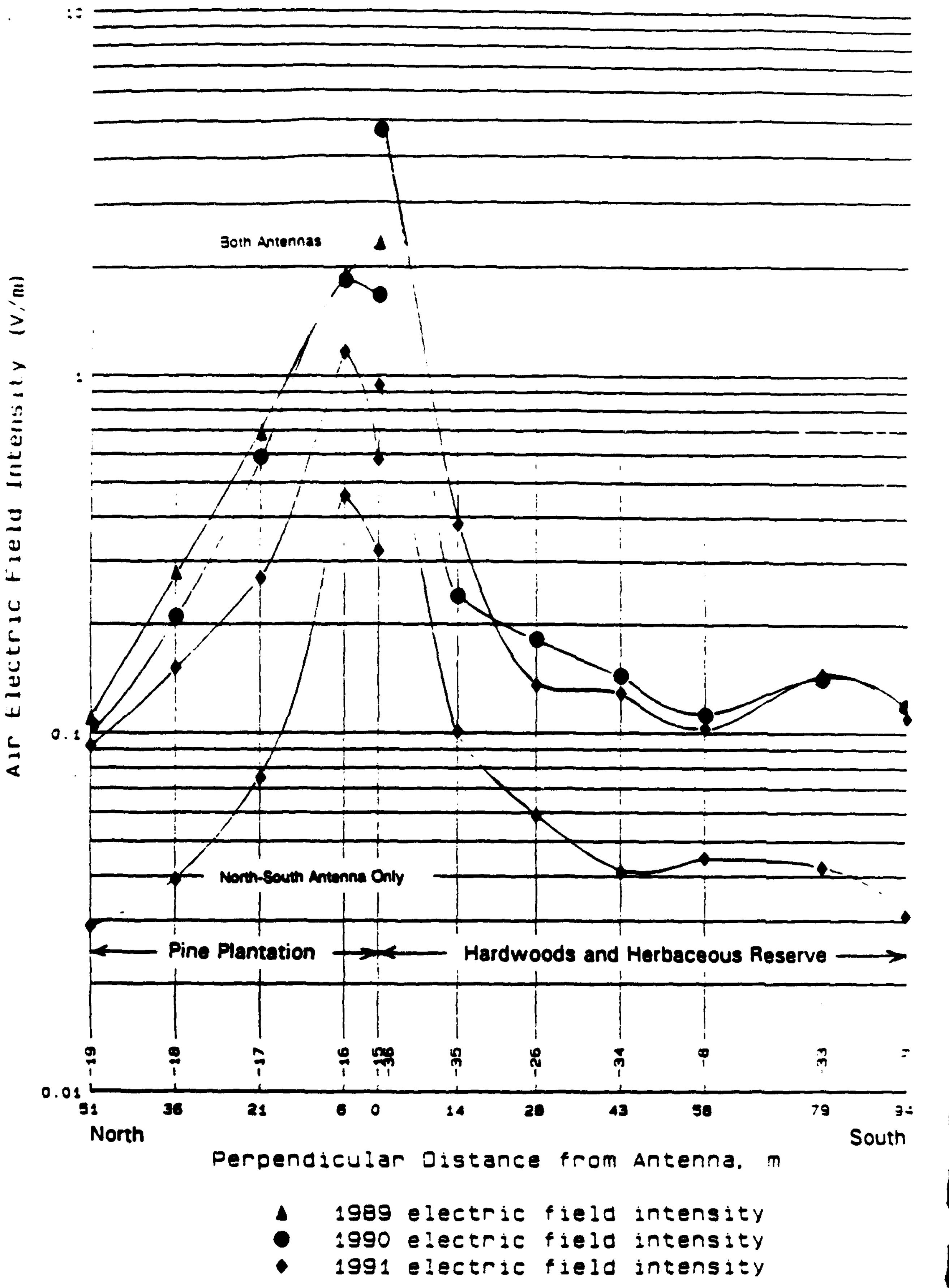

FIGURE 9. 76 Hz AIR ELECTRIC FIELD PROFILES
MARTELL'S LAKE (OVERHEAD): ML; 4T2-8, 9, 15-19, 26, 33-36

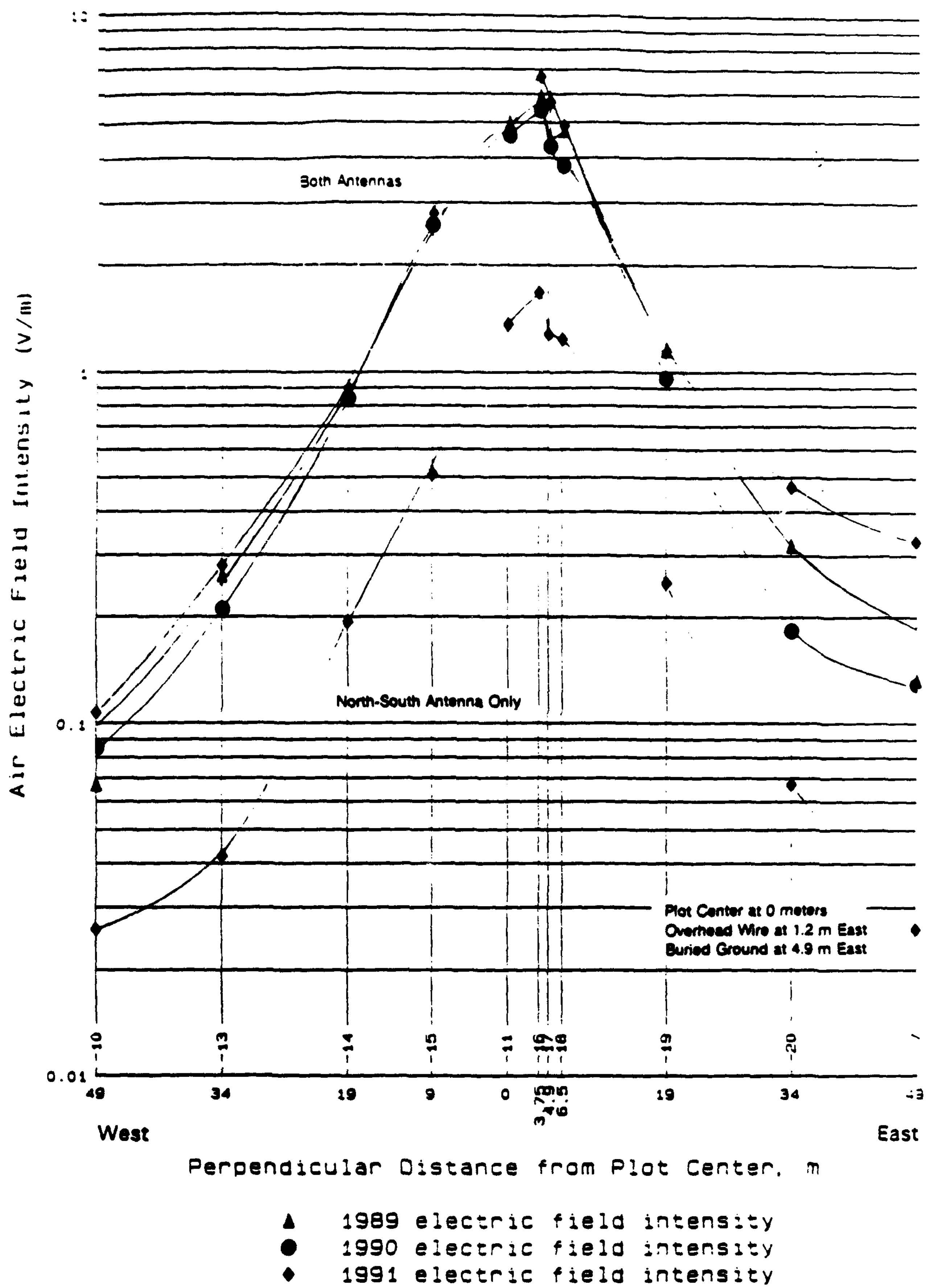

FIGURE 10. 76 Hz AIR ELECTRIC FIELD PROFILES
MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

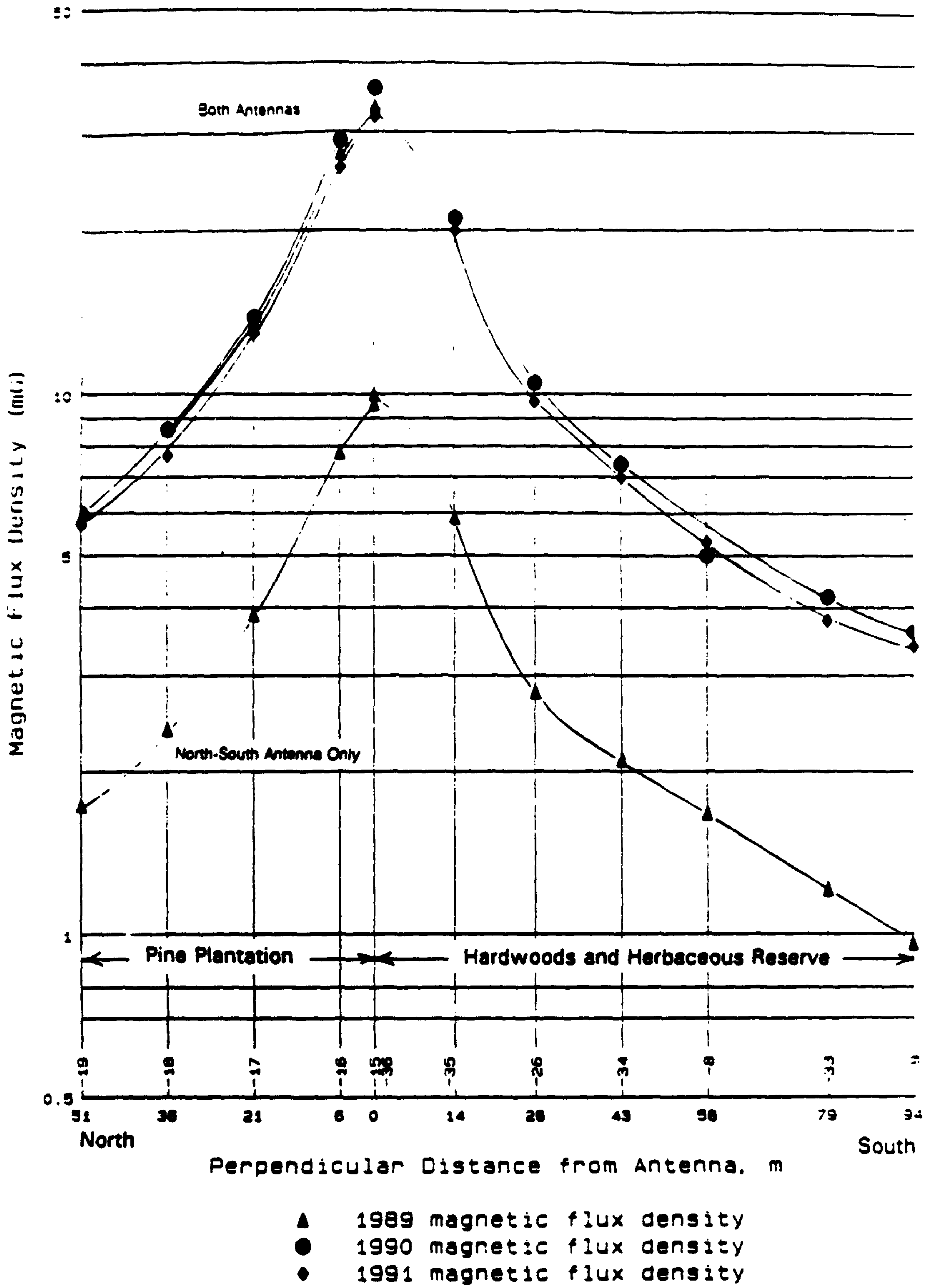

FIGURE 11. 76 Hz MAGNETIC FLUX DENSITY PROFILES
MARTELL'S LAKE (OVERHEAD): ML: 4T2-8, 9, 15-19, 26, 33-3

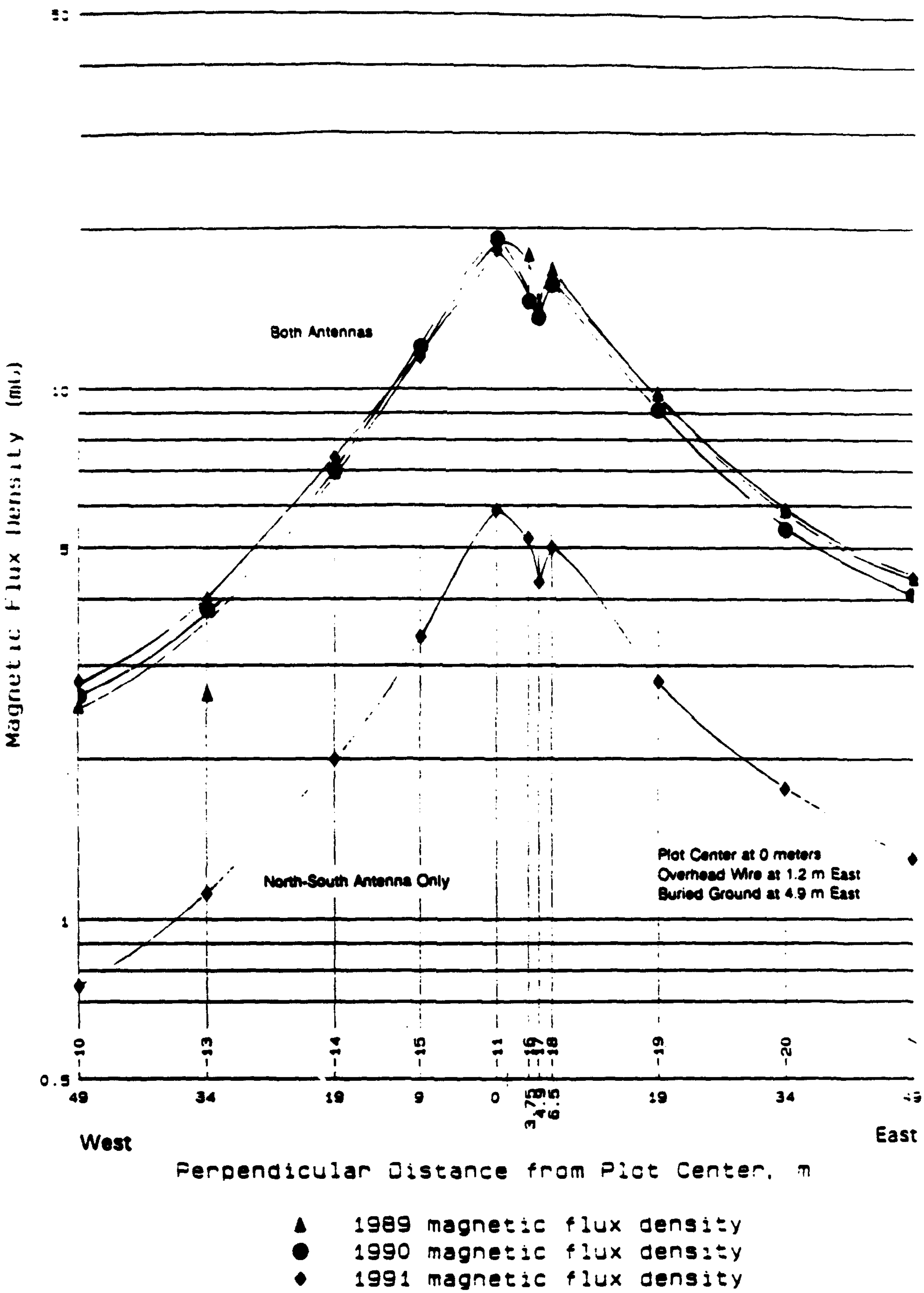

FIGURE 12. 76 Hz MAGNETIC FLUX DENSITY PROFILES
MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

is also a dip in the field profiles near the plot center, which occurs in all years.This is caused by an interaction between and partial cancellation of the fields produced by the overhead and buried ground wires. The profiles for both sites may be used to provide good estimates of the air electric field intensity at any point in the pine plantations by graphical interpolation, given the distance of the point from the antenna or ground wires.

The air electric field profile for the pole stand and herbaceous reserve plots is not as uniform as that for the pine plantations. The air electric field, normally set up by the potential difference between the antenna wire and the earth, is shielded by the tall trees at these plots. The air electric fields which do appear at these plots are the byproduct of the earth electric field, which creates potential differences between the trees. The air field profiles for these plots are therefore subject to the same variables that affect the earth electric field. The earth electric fields vary greatly and unpredictably across the pole stand and herbaceous reserve plots as discussed in the following paragraphs. The air electric field intensities at other points on these plots can therefore only be bounded using the historic profile data.

The magnetic flux density is dependent only on the distance of the measurement point from the source. The profiles for this field are therefore the most predictable and stable of those measured. As shown in Figures 11 and 12, the fields decrease uniformly with increasing distance from their sources. At the ground site, a dip in the magnetic flux density profile near the plot center, similar to that seen for the air electric field, occurs in all years. This again, is caused by an interaction between and partial cancellation of the fields generated by the overhead and buried ground wires. These profiles may be used to estimate the magnetic flux density at any point at your treatment sites with very good accuracy.

<u>Earth Electric Field Intensity Profiles</u>

Statistical summaries of the 1991 earth electric field data from the data loggers and fixed probes are presented in Tables 12 and 13, together with corresponding annual measurements. Table 12 summarizes data for the period 13 July - 23 December when both antennas were operating. Table 13 covers the period 29 May - 11 July when only the NS antenna was operating. Most fixed probe locations listed in these tables were not established until 16 August and therefore do not have data presented for them in Table 13.

TABLE 12. 1991 EARTH ELECTRIC FIELD STATISTICAL SUMMARY
FOR THE PERIOD OF 13 JULY - 23 DECEMBER
BOTH ANTENNAS ACTIVATED

Location	DATA LOGGER				FIXED PROBE				ANNUAL
	# Data Points	Mean mV/m	STD mV/m	Coeff. of Variab.	# Data Points	Mean mV/m	STD mV/m	Coeff. of Variab.	mV/m
ANT/HWD									
4T2-36	2943	136	9.3	0.069	7	137	4.6	0.033	133
4T2-35	3543	154	10.9	0.071	7	162	7.6	0.047	137
4T2-26	3468	220	14.3	0.066	8	210	14.0	0.066	189
4T2-34	3653	108	11.5	0.106	8	110	7.4	0.067	127
4T2-8	3305	138	9.9	0.071	6	141	6.1	0.043	133
4T2-33	3540	113	9.2	0.082	8	120	7.7	0.064	130
4T2-9	926	136	8.3	0.061	4	156	10.0	0.064	121
ANT/PIN									
4T2-15	2913	67	9.8	0.145	8	63	2.9	0.046	82
4T2-16	2273	115	16.4	0.142	5	112	7.3	0.065	92
4T2-17	3175	111	10.9	0.099	8	106	7.0	0.066	107
4T2-18	3206	114	13.0	0.114	8	111	4.3	0.039	124
4T2-19	2231	129	18.3	0.142	6	110	7.9	0.072	103
GND/PIN									
4T4-7	315	135	16.9	0.126	1	145			101
4T4-20	396	181	19.0	0.105	1	220			200
4T4-19	3222	750	49	0.065	6	770	55	0.072	880
4T4-18	3563	4100	490	0.118	8	4400	270	0.062	4100
4T4-16	3644	3100	480	0.155	8	3300	194	0.058	3300
4T4-15	3255	750	43	0.058	8	760	60	0.079	820
4T4-14	837	260	12.8	0.048	6	240	22	0.095	320
4T4-13					2	78	1.5	0.019	59

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TABLE 13. 1991 EARTH ELECTRIC FIELD STATISTICAL SUMMARY
FOR THE PERIOD OF 29 MAY - 11 JULY
NORTH-SOUTH ANTENNA ONLY ACTIVATED

Location	DATA LOGGER				FIXED PROBE				ANNUAL
	# Data Points	Mean mV/m	STD mV/m	Coeff. of Variab.	# Data Points	Mean mV/m	STD mV/m	Coeff. of Variab.	mV/m
ANT/HWD									
4T2-36	456	36	5.9	0.162					44
4T2-35	456	48	6.5	0.135					45
4T2-26	456	59	6.3	0.107	2	65	2.5	0.039	57
4T2-34	456	32	3.3	0.104					36
4T2-8	455	33	3.3	0.100	2	43	0.50	0.012	40
4T2-33	456	33	3.0	0.091					41
4T2-9	442	32	2.9	0.088	2	38	0.50	0.013	40
ANT/PIN									
4T2-15									32
4T2-16					2	34	0.50	0.015	33
4T2-17									29
4T2-18									29
4T2-19					2	33	0.0	0.0	31
GND/PIN									
4T4-7					2	37	0.50	0.014	30
4T4-20	453	50	7.9	0.159					49
4T4-19	453	192	12.0	0.063					196
4T4-18	453	850	109	0.129					1000
4T4-16	453	770	102	0.133					690
4T4-15	453	185	13	0.071					220
4T4-14	453	76	6.2	0.081					59
4T4-13									15.2

The means of the fixed probe and data logger measurements along with the annual earth electric field intensity measurements listed in Tables 12 and 13 are plotted as electric field profiles in Figures 13 and 14. Each figure has one set of profiles for normal operation with both antennas and one set for NS operation only. Error bars (+/- one standard deviation) are plotted for the data logger mean values.

Both tables show good agreement between the three measurement sets. The means at the fixed probe locations, which employ the same electrodes as the data loggers, are typically within one standard deviation of the logger measurement means. The annual measurement values also closely track the logger and fixed probe means, even though these measurements are taken with a separate probe at a slightly offset position from the fixed probe.

The earth electric field at your treatment sites is influenced by several factors, making it very difficult to predict. At your antenna site the field shows both increases and decreases with increasing distance from the antenna. Such irregularities are the result of varying terrain elevations and differences in soil conductivity.

The earth electric field at your ground site has a null over the buried ground wire, with relatively high peaks on both sides of the wire. This is characteristic of the earth electric field near an ELF ground wire. The field at the ground site falls off much more uniformly than at the antenna site, indicating that the soil conductivity is much more uniform here.

Because the earth electric field behaves unpredictably across your treatment sites, the historic, data logger, and fixed probe data will not provide very accurate estimates of the earth fields at other points at these sites. The data is useful, however, for studies of temporal field variations and for the bracketing of field exposures over the sites.

Temporal Variability of the Earth Electric Field

The logger data, together with weather data collected by your monitoring systems, has been used to analyze temporal variations in the earth electric field and to look for possible correlations with temperature and/or rainfall. Such correlations are expected because of the dependence of the earth electric field on soil conductivity which can in turn be affected by temperature and/or rainfall. It is important to understand, however, that the mathematical dependence of the earth electric field on soil conductivity varies with location at your treatment sites. The earth electric field at a point near a ground terminal is

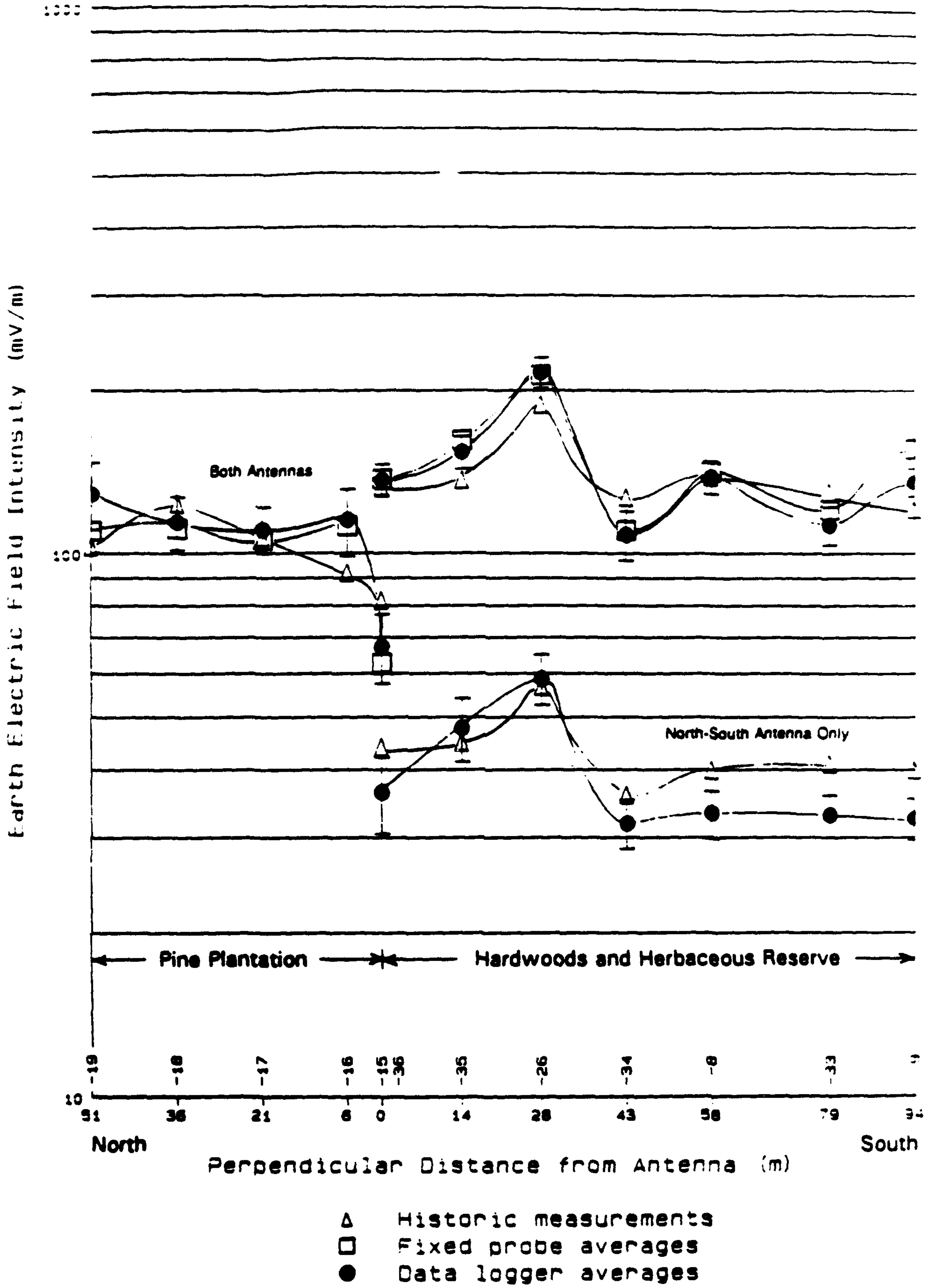

FIGURE 13. COMPARISON OF 76 Hz EARTH ELECTRIC FIELDS AT SITE 4
ERROR BARS ARE +/- ONE STD. DEV. OF THE LOGGER DATA

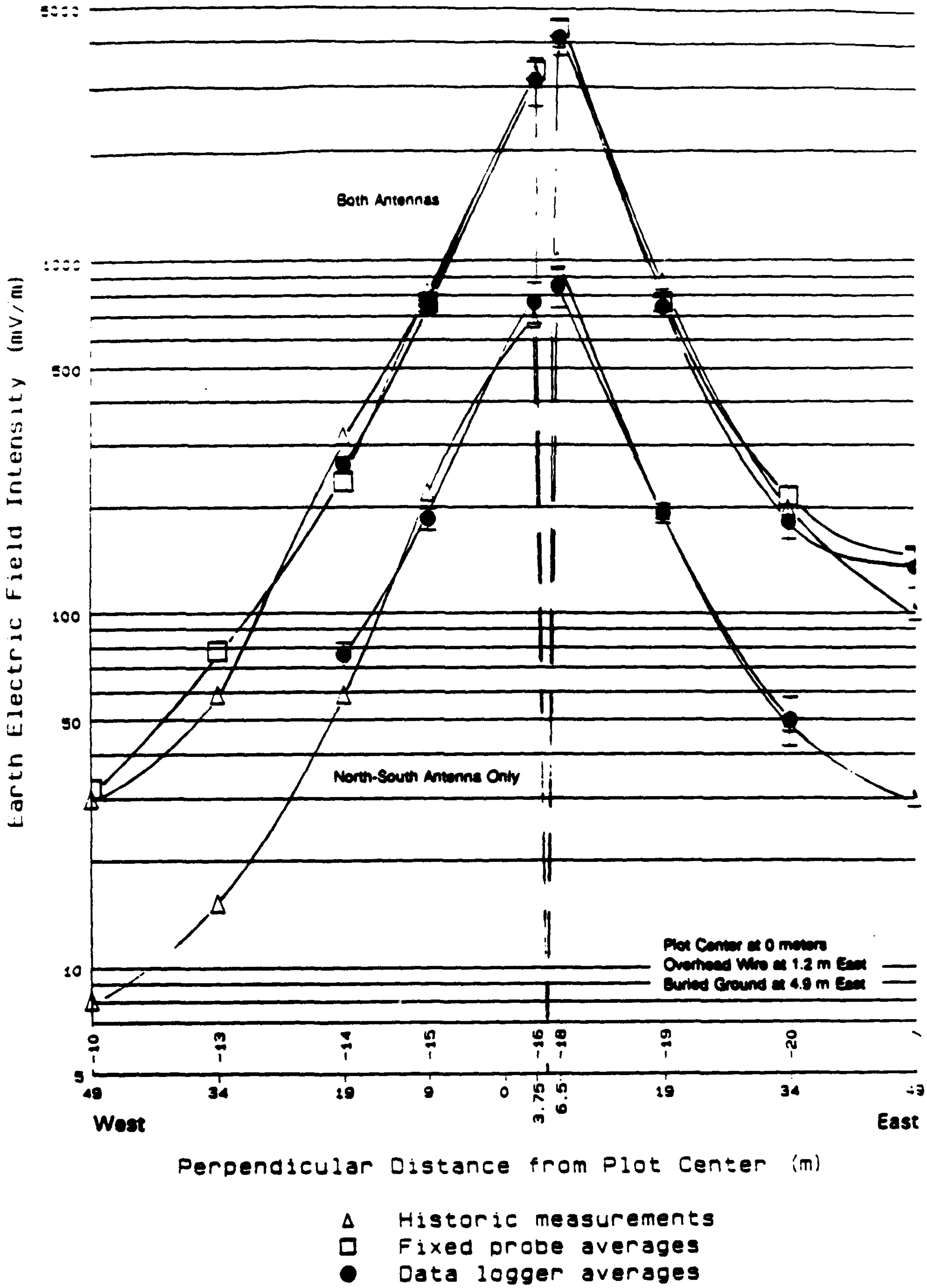

FIGURE 14. COMPARISON OF 76 Hz EARTH ELECTRIC FIELDS AT SITE ...
ERROR BARS ARE +/- ONE STD. DEV. OF THE LOGGER DATA.

the result of current conducted from the buried ground wire and is inversely proportional to the surface conductivity. The earth electric fields at your antenna site are induced by the magnetic field and are inversely proportional to the logarithm of the bulk earth conductivity. More distant locations at your ground site exhibit a combinatic . of these influences. Furthermore, non-homogenious soil conditions, which were addressed in the discussions of spatial variability may also impact the uniformity of temporal variations across your treatment sites. With this in mind, the following paragraphs give examples of seasonal, rainfall induced, and diurnal variations in the earth electric field and provide estimates of the level of variation for each case.

The daily average electric field data shown in Figures 6-8 increase slightly for most probes from the summer to winter months - a phenomenon that has also been observed for several years at grounds seasonal monitoring data logger sites in Wisconsin. This is caused by an increasing resistivity of the soil with decreasing temperatures and by electrolyte changes of the freezing soil. Monthly electric field averages for each logger probe at your sites are given in Table 14. This table indicates that earth electric field intensities increased at all probe locations for which data was taken between June/July to late December for NS antenna operation. Likewise, electric field intensities increased at most probe sites during operation of both antennas over the period from late July and early December. The seasonal field increases over these periods were typically between 10 and 30%. However, an increase as great as 65% occurred at probe 4T4-18 near the buried ground wire.

Shorter term variations in the earth electric field can also be seen in Table 14, by examination of the percent variability of the hourly data (std./mean X 100%) corresponding to each monthly period. This variability is typically only 5-10%. One source of the variability is rainfall. Hourly electric field measurement data for location 4T4-18 are plotted together with weather data in Figure 15. Decreases of about 10% in electric field intensity can be seen to occur following rainfall on 20 July and 28 July. Earth electric field changes following rainfall were generally less than 10% at other locations away from the buried ground wire. As an example, data plotted in Figure 16 for the same period for antenna site location 4T2-26 shows no change in the electric field following the rain events. Any change here is either masked by other measurement variability or is below the data logger resolution.

TABLE 14. 1991 76 Hz EARTH ELECTRIC FIELD INTENSITY AVERAGES (mV/m)
Upland Flora and Soil Microflora Studies Data Logger Measurements

Location	NS Antenna Only		Both Antennas						NS
	Jun 20-30	Jul 1-11	Jul 13-31	Aug 1-31	Sep 1-30	Oct 1-31	Nov 1-30	Dec 1-22	Dec 24-31
ANT/HWD									
4T2-9	33 8.5%	32 9.1%					135 6.6%	136 5.6%	37 17.3%
4T2-33	33 9.1%	33 9.1%	103 6.9%	108 5.7%	111 3.8%	112 5.4%	119 6.9%	122 7.5%	43 17.9%
4T2-8	33 10.6%	33 9.7%	138 5.3%	138 4.5%	133 4.7%	133 3.8%	142 8.2%	149 6.6%	45 15.3%
4T2-34	32 10.9%	32 10.0%	102 7.4%	97 11.6%	109 7.1%	108 7.6%	115 5.7%	121 7.8%	38 19.2%
4T2-26	57 10.2%	60 10.7%	210 3.3%	210 4.8%	210 5.5%	210 6.6%	230 5.4%	230 4.4%	88 3.4%
4T2-35	47 14.0%	48 13.1%	146 5.1%	152 6.3%	152 5.7%	151 7.2%	160 6.6%	160 6.2%	57 10.9%
4T2-36	38 16.3%	34 14.4%	136 7.4%	142 8.7%	135 4.9%	132 5.4%	137 6.7%	142 6.4%	53 13.2%
ANT/PIN									
4T2-19					131 13.5%	134 15.7%	127 10.2%	118 12.7%	41 26%
4T2-18			111 10.5%	120 11.3%	118 11.9%	114 9.0%	112 8.7%	102 9.1%	30 30%
4T2-17			104 7.0%	107 8.0%	115 8.5%	116 8.6%	113 8.9%	100 9.6%	32 33%
4T2-16					115 9.0%	120 9.1%	120 19.2%	100 10.2%	34 29%
4T2-15			65 11.5%	66 11.7%	69 13.3%	71 14.7%	68 13.6%	81 17.1%	28 31%
GND/PIN									
4T4-7								135 12.5%	42 31%
4T4-20	49 15.3%	50 16.6%						181 10.5%	51 22%
4T4-19	196 4.2%	188 7.3%	700 4.3%	710 3.1%	760 3.2%	820 3.7%	740 3.8%	710 2.8%	210 6.4%
4T4-18	940 6.2%	760 7.2%	3400 4.2%	3800 7.1%	4000 4.2%	4100 4.3%	4500 6.4%	4900 6.1%	1550 8.0%
4T4-16	850 5.3%	680 8.7%	2400 3.4%	3100 9.0%	3100 7.4%	3100 5.1%	3400 8.2%	3600 4.4%	1110 3.6%
4T4-15	190 5.3%	180 7.7%	680 4.1%	720 4.0%	770 1.9%	800 2.9%	730 4.7%	750 2.4%	230 3.6%
4T4-14	77 7.8%	76 8.3%					280 4.8%	270 4.7%	84 13.0%
4T4-13									

Percent variability (mean/std. X 100%) is given below each of the electric field averages.

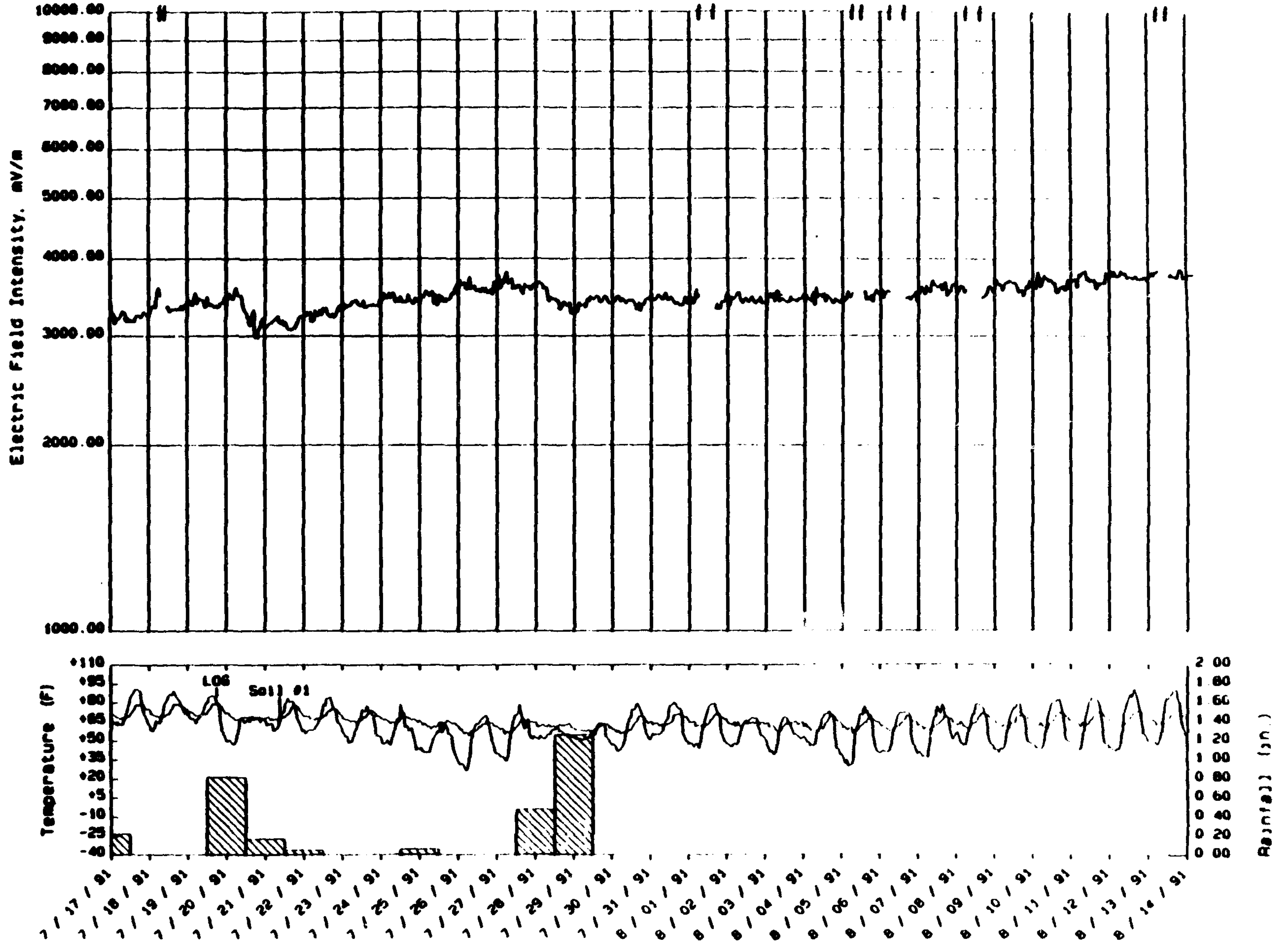

FIGURE 15. HOURLY EARTH ELECTRIC FIELD INTENSITIES AT THE GROUND SITE PINE PLANTATION; MEASUREMENT POINT 4T4-1B

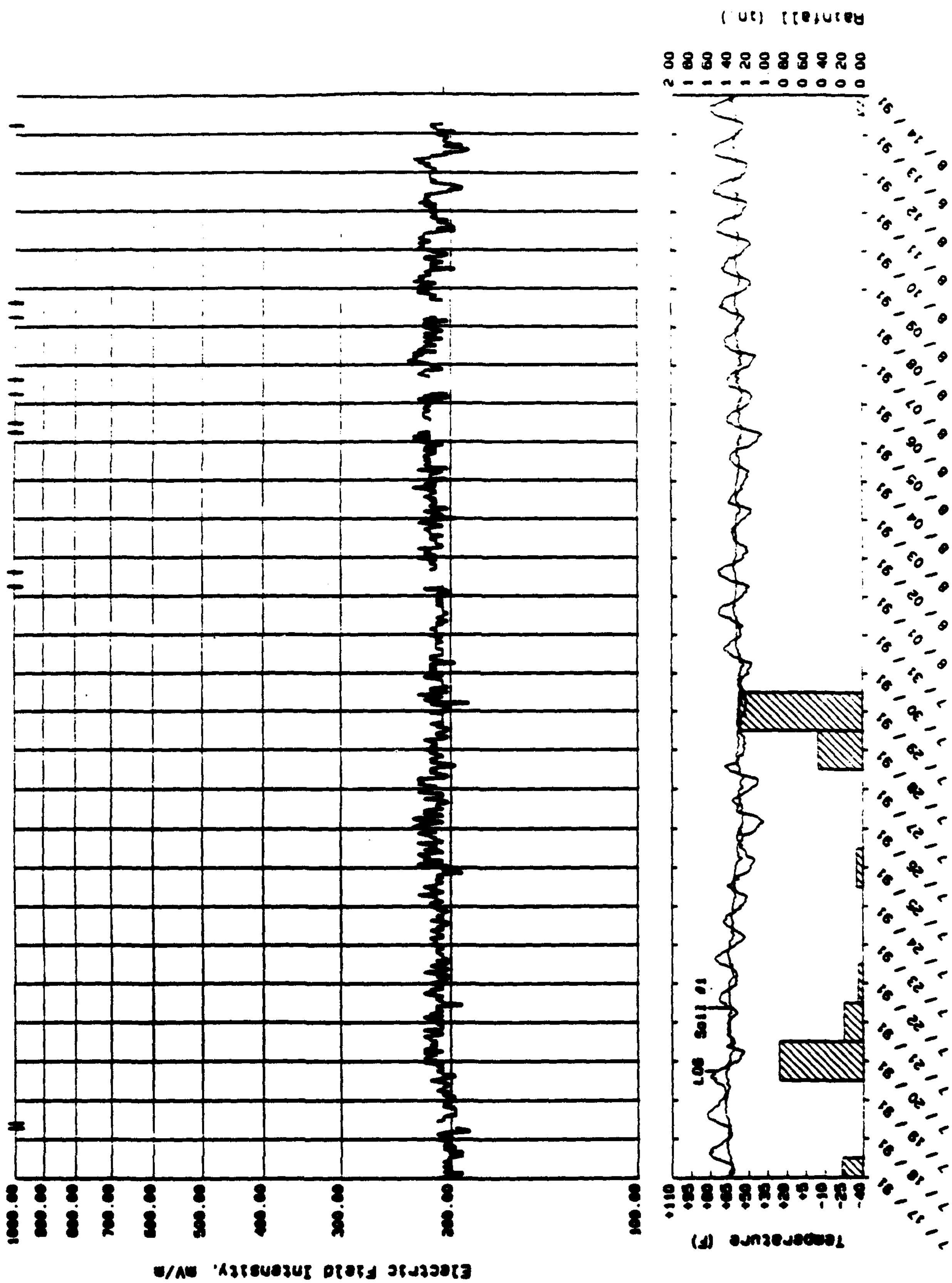

FIGURE 16. HOURLY EARTH ELECTRIC FIELD INTENSITIES AT THE ANTENNA HARDWOOD STAND: MEASUREMENT POINT 412-26

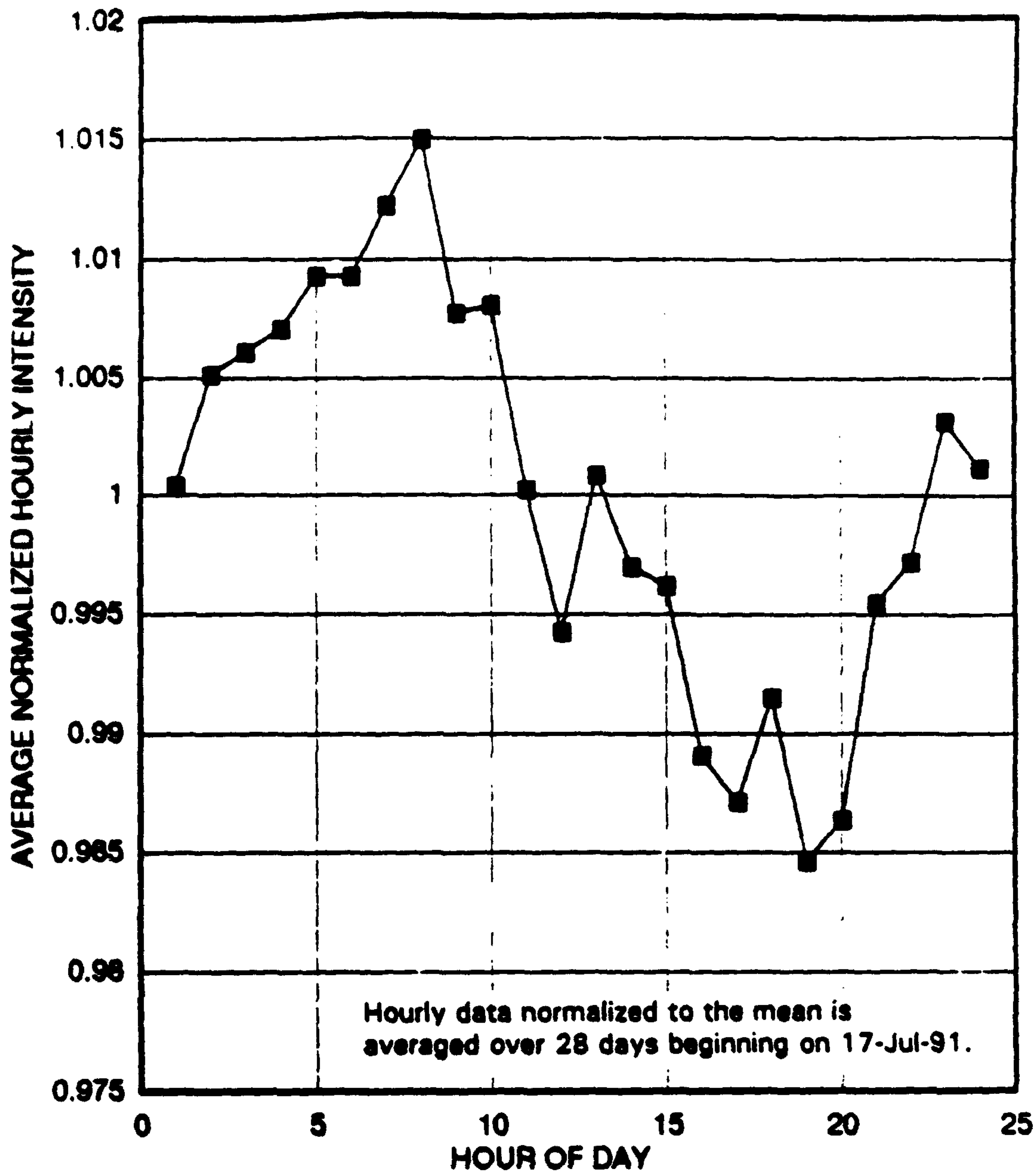

FIGURE 17. EARTH ELECTRIC FIELD DIURNAL CYCLE AT THE GROUND SITE PINE PLANTATION; MEASUREMENT POINT 4T4-18.

All hourly data logger measurement data were also examined for diurnal variations. Again, such variations were most apparent near the buried ground wire and are illustrated in the hourly data presented in Figure 15. To clarify the diurnal pattern, the data plotted in this figure was averaged by hour of day for the 28 day period. The hourly averages are plotted in Figure 17. A clear peak in the average field intensity is visible at 8:00 A.M. and a null at 8:00 P.M. for this probe and time period. The daily variation is about 3.5%.

Similar analyses were done for several other probes at both your antenna and ground sites. While diurnal variations were not identified for all locations and/or time periods, they were observed with some regularity at both sites. For example, diurnal variations similar to that for location 4T4-18, are evident in Figure 16 after 7 August (location 4T2-26 in the antenna site hardwood stand). When present, diurnal variations were typically less than 5%.

All hourly data logger electric field data has been plotted. However, it is not presented here because of its volume (approx. 130 plots). It can be made available to you in hardcopy or software format if you wish to review it further.

<u>1992 Schedule</u>

The NRTF-Republic is expected to continue full-time 150 ampere operation, except during scheduled maintenance periods in 1992. The annual EM measurements are expected to be conducted in the fall of 1992. If you require any special engineering assistance or EM measurements in addition to those normally conducted or already discussed above, please inform us immediately so that these activities may be scheduled.

Sincerely,

IIT RESEARCH INSTITUTE

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Research Engineer
(312) 567-4622

James R. Gauger
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DPH:bjm

Table 1A. Estimated maximum yearly exposure levels by plot for control hardwood sites for 1985-1991.

	1985	1986	1987	1988	1989	1990	1991
60 Hz							
Transverse (V/m)							
Plot 1	0.0000	0.0000	0.0000	0.0000			
Plot 2	0.0000	0.0000	0.0000	0.0000			
Plot 3	0.0000	0.0000	0.0000	0.0000			
Longitudinal (mV/m)							
Plot 1	0.0490	0.0490	0.0490	0.0490			
Plot 2	0.0614	0.0614	0.0614	0.0614			
Plot 3	0.0738	0.0738	0.0738	0.0738			
Magnetic Flux (mG)							
Plot 1	0.0020	0.0020	0.0020	0.0020			
Plot 2	0.0020	0.0020	0.0020	0.0020			
Plot 3	0.0020	0.0020	0.0020	0.0020			
76 Hz							
Longitudinal EW (mV/m)							
Plot 1	0.0000	0.0000	0.0030	0.0090	0.0410	0.0410	0.0410
Plot 2	0.0000	0.0000	0.0030	0.0120	0.0500	0.0500	0.0500
Plot 3	0.0000	0.0000	0.0030	0.0150	0.0590	0.0590	0.0590
Magnetic Flux (mG)							
Plot 1	0.0000	0.0000	0.0000	0.0000	0.0024	0.0024	0.0024
Plot 2	0.0000	0.0000	0.0000	0.0000	0.0024	0.0024	0.0024
Plot 3	0.0000	0.0000	0.0000	0.0000	0.0024	0.0024	0.0024

Table 1B. Estimated maximum yearly exposure levels by plot for control plantation sites for 1985-1991.

	1985	1986	1987	1988	1989	1990	1991
60 Hz							
Transverse (V/m)							
Plot 1	0.0000	0.0000	0.0000	0.0051			
Plot 2	0.0000	0.0000	0.0000	0.0051			
Plot 3	0.0000	0.0000	0.0000	0.0051			
Longitudinal (mV/m)							
Plot 1	0.5126	0.3522	0.2869	0.2828			
Plot 2	0.5126	0.3522	0.2869	0.2828			
Plot 3	0.5126	0.3522	0.2869	0.2828			
Magnetic Flux (mG)							
Plot 1	0.0011	0.0048	0.0077	0.0130			
Plot 2	0.0009	0.0046	0.0075	0.0128			
Plot 3	0.0007	0.0044	0.0073	0.0126			
76 Hz							
Longitudinal (mV/m)							
Plot 1	0.0000	0.0000	0.0030	0.0100	0.0420	0.0420	0.0420
Plot 2	0.0000	0.0000	0.0030	0.0130	0.0520	0.0520	0.0520
Plot 3	0.0000	0.0000	0.0030	0.0160	0.0630	0.0630	0.0630
Magnetic Flux (mG)							
Plot 1	0.0000	0.0000	0.0000	0.0000	0.0024	0.0024	0.0024
Plot 2	0.0000	0.0000	0.0000	0.0000	0.0024	0.0024	0.0024
Plot 3	0.0000	0.0000	0.0000	0.0000	0.0024	0.0024	0.0024

Table 1C. Estimated maximum yearly exposure levels by plot for antenna hardwood sites for 1985-1991.

	1985	1986	1987	1988	1989	1990	1991
60 Hz							
Transverse (V/m)							
Plot 1	0.0000	0.0000	0.0000	0.0038			
Plot 2	0.0000	0.0000	0.0000	0.0038			
Plot 3	0.0000	0.0000	0.0000	0.0038			
Longitudinal (mV/m)							
Plot 1	0.4939	0.3558	0.2849	0.2963			
Plot 2	0.4939	0.3558	0.2849	0.2963			
Plot 3	0.4939	0.3558	0.2849	0.2963			
Magnetic Flux (mG)							
Plot 1	0.0013	0.0040	0.0058	0.0097			
Plot 2	0.0011	0.0039	0.0056	0.0095			
Plot 3	0.0009	0.0037	0.0054	0.0093			
76 Hz							
Longitudinal (mV/m)							
Plot 1	0.0000	7.8000	19.7200	106.7500	185.0800	187.3800	192.3700
Plot 2	0.0000	6.5700	16.6000	89.8700	155.8200	157.7600	161.9600
Plot 3	0.0000	5.4900	13.8700	75.0700	130.1500	131.7700	135.2800
Magnetic Flux (mG)							
Plot 1	0.0000	0.3060	0.8000	3.6530	7.9700	7.9700	7.9700
Plot 2	0.0000	0.3060	0.8000	3.6530	7.9700	7.9700	7.9700
Plot 3	0.0000	0.3060	0.8000	3.6530	7.9700	7.9700	7.9700

Table 1D. Estimated maximum yearly exposure levels by plot for antenna plantation sites for 1985-1991.

	1985	1986	1987	1988	1989	1990	1991
60 Hz							
Transverse (V/m)							
Plot 1	0.0000	0.0000	0.0000	0.0051			
Plot 2	0.0000	0.0000	0.0000	0.0051			
Plot 3	0.0000	0.0000	0.0000	0.0051			
Longitudinal (mV/m)							
Plot 1	0.5126	0.3522	0.2869	0.2828			
Plot 2	0.5126	0.3522	0.2869	0.2828			
Plot 3	0.5126	0.3522	0.2869	0.2828			
Magnetic Flux (mG)							
Plot 1	0.0011	0.0048	0.0077	0.0130			
Plot 2	0.0009	0.0046	0.0075	0.0128			
Plot 3	0.0007	0.0044	0.0073	0.0126			
76 Hz							
Longitudinal (mV/m)							
Plot 1	0.0000	6.4600	16.3400	88.4200	153.3100	155.2200	159.3500
Plot 2	0.0000	6.4500	16.3000	88.2500	153.0200	154.9200	159.0500
Plot 3	0.0000	6.8100	17.2000	93.1100	161.4400	163.4500	167.8000
Magnetic Flux (mG)							
Plot 1	0.0000	0.4430	1.1300	5.2780	11.7010	11.7010	11.7010
Plot 2	0.0000	0.4430	1.1300	5.2780	11.7010	11.7010	11.7010
Plot 3	0.0000	0.4430	1.1300	5.2780	11.7010	11.7010	11.7010

Table 1E. Estimated maximum yearly exposure levels by plot for ground plantation sites for 1985-1991.

	1985	1986	1987	1988	1989	1990	1991
60 Hz							
Transverse (V/m)							
Plot 1	0.0000	0.0000	0.0004	0.0004			
Plot 2	0.0000	0.0000	0.0002	0.0002			
Plot 3	0.0000	0.0000	0.0003	0.0003			
Longitudinal (mV/m)							
Plot 1	0.3519	0.3519	1.7587	0.6104			
Plot 2	0.2851	0.2851	0.9544	0.4879			
Plot 3	0.3185	0.3185	1.1674	0.5491			
Magnetic Flux (mG)							
Plot 1	0.0016	0.0016	0.0058	0.0093			
Plot 2	0.0015	0.0015	0.0047	0.0067			
Plot 3	0.0015	0.0015	0.0052	0.0080			
76 Hz							
Longitudinal (mV/m)							
Plot 1	0.0000	22.2800	49.0000	198.7800	461.9600	406.3600	417.5100
Plot 2	0.0000	10.1800	22.3900	90.8300	211.0900	185.6800	190.7800
Plot 3	0.0000	13.5000	29.6900	120.4300	279.8700	246.1900	252.9500
Magnetic Flux (mG)							
Plot 1	0.0000	0.2680	1.4650	7.0400	10.9900	10.9900	10.9900
Plot 2	0.0000	0.0060	0.7560	3.8050	10.9120	10.9120	10.9120
Plot 3	0.0000	0.2860	1.1100	5.4210	9.6200	9.6200	9.6200

1986 Regression Output:

Constant		0.413401
Std Err of Y Est		0.065915
R Squared		0.951806
No. of Observations		9
Degrees of Freedom		6
X Coefficient(s)	-0.00592	1.449598
Std Err of Coef.	0.004479	1.185233

1987 Regression Output:

Constant		1.09875
Std Err of Y Est		0.152989
R Squared		0.953923
No. of Observations		9
Degrees of Freedom		6
X Coefficient(s)	-0.01606	2.915353
Std Err of Coef.	0.010395	2.750936

1988 Regression Output:

Constant		5.740808
Std Err of Y Est		0.547943
R Squared		0.97487
No. of Observations		9
Degrees of Freedom		6
X Coefficient(s)	-0.08476	12.69044
Std Err of Coef.	0.037231	9.852722

1991ns Regression Output:

Constant		4.915485
Std Err of Y Est		0.587383
R Squared		0.904997
No. of Observations		17
Degrees of Freedom		14
X Coefficient(s)	-0.08199	-0.05436
Std Err of Coef.	0.007469	0.066066

1989-91 Regression Output:

Constant		16.41759
Std Err of Y Est		1.879233
R Squared		0.911485
No. of Observations		17
Degrees of Freedom		14
X Coefficient(s)	-0.27282	-0.1837
Std Err of Coef.	0.023897	0.211366

Figure 1. Magnetic flux interpolation equations for the ground site.

$$mG = a_0 + a_1 X + a_2 / X$$

1986

Regression Output:		
Constant		0.306765
Std Err of Y Est		0.03114
R Squared		0.991864
No. of Observations		12
Degrees of Freedom		9
X Coefficient(s)	-0.00248	4.360294
Std Err of Coef.	0.000535	0.266561

1987

Regression Output:		
Constant		0.85487
Std Err of Y Est		0.101768
R Squared		0.984606
No. of Observations		12
Degrees of Freedom		9
X Coefficient(s)	-0.00685	9.885593
Std Err of Coef.	0.001747	0.871151

1988

Regression Output:		
Constant		3.543742
Std Err of Y Est		0.304458
R Squared		0.994488
No. of Observations		12
Degrees of Freedom		9
X Coefficient(s)	-0.02727	52.81739
Std Err of Coef.	0.005226	2.606209

1991

Regression Output:		
Constant		2.63242
Std Err of Y Est		0.443738
R Squared		0.964369
No. of Observations		20
Degrees of Freedom		17
X Coefficient(s)	-0.0239	30.79394
Std Err of Coef.	0.005775	2.919799

1989-91ns

Regression Output:		
Constant		8.752003
Std Err of Y Est		1.449636
R Squared		0.967304
No. of Observations		56
Degrees of Freedom		53
X Coefficient(s)	-0.08037	110.1662
Std Err of Coef.	0.011356	5.618626

Figure 2. Magnetic flux interpolation equations for the antenna site.

$$mG = a_0 + a_1 X + a_2 / X$$

1987	Regression Output:		
	Constant		0.002354
	Std Err of Y Est		0.001095
	R Squared		0.550002
	No. of Observations		8
	Degrees of Freedom		6
	X Coefficient(s)	1.08E-05	
	Std Err of Coef.	3.98E-06	

1988	Regression Output:		
	Constant		0.008121
	Std Err of Y Est		0.003474
	R Squared		0.851595
	No. of Observations		8
	Degrees of Freedom		6
	X Coefficient(s)	7.41E-05	
	Std Err of Coef.	1.26E-05	

1989-91	Regression Output:		
	Constant		0.036443
	Std Err of Y Est		0.01161
	R Squared		0.83388
	No. of Observations		24
	Degrees of Freedom		22
	X Coefficient(s)	0.000256	
	Std Err of Coef.	2.44E-05	

Figure 3. Longitudinal field interpolation equations for the control site.

$$mV/m = a_0 + a_1 Y$$

Appendix B: Climatic Monitoring Information

Table 1a. Replacement equations for missing ambient data 1992.

1992 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Air Temperature Antenna Plantation Plots				
1	$Y = 0.987(X_1)+.543$	10.4	.148	.983	$Y\pm.30$
2	$Y = 0.905(X_1)+.624$	9.7	.146	.980	$Y\pm.30$
3	$Y = 0.979(X_1)+.354$	10.1	.132	.986	$Y\pm.27$

X_1 = average daily air temperature at ground site
Y = average daily air temperature at antenna site plantation plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Air Temperature Antenna Hardwood Plots				
1-3	$Y = 1.013(X_1)+.575$	10.7	.170	.978	$Y\pm.35$

X_1 = average daily air temperature at ground site
Y = average daily air temperature at antenna site

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Temperature Antenna Plantation Plots (5 cm)				
1	$Y = 1.10-3.407(X_1)$	8.1	.154	.951	$Y\pm.31$
2	$Y = .981+.6265(X_1)$	10.9	.059	.991	$Y\pm.12$
3	$Y = 1.08-.3667(X_1)$	10.9	.109	.974	$Y\pm.22$

X_1 = average daily soil temperature 5 cm at ground site
Y = average daily soil temperature 5 cm at antenna plantation plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Temperature Antenna Hardwood Plots (5 cm)				
1	$Y = 0.882-.5366(X_1)$	8.7	.068	.985	$Y\pm.14$
2	$Y = 0.918-.9294(X_1)$	8.7	.093	.974	$Y\pm.19$
3	$Y = 0.900-.7330(X_1)$	8.7	.075	.982	$Y\pm.15$

X_1 = average daily soil temperature 5 cm on ground site
Y = average daily soil temperature 5 cm on antenna hardwood plots

Table 1b. Replacement equations for missing ambient data 1992.

1992 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Moisture (%) Antenna Plantation Plots (5 cm)				
1	$Y = .255+7.734(X_1)$	12.2	.142	.260	$Y\pm.29$
2	$Y = 1.57-12.18(X_1)$	15.2	.589	.439	Y+1.2

X_1 = average daily soil moisture 5 cm at ground site
Y = average daily soil moisture 5 cm at antenna plantation plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Moisture (%) Antenna Hardwood Plots (5 cm)				
1	$Y = 0.525+8.044(X_1)$	17.2	.194	.445	$Y\pm.40$
2	$Y = 0.455+7.291(X_1)$	15.2	.281	.223	$Y\pm.58$
3	$Y = 0.875-1.543(X_1)$	13.7	.282	.503	$Y\pm.59$

X_1 = average daily soil moisture 5 cm on ground site
Y = average daily soil moisture 5 cm on antenna hardwood plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Temperature Antenna Plantation Plots (10 cm)				
1	$Y = 0.862+.1684(X_1)$	8.6	.162	.899	$Y\pm.33$
2	$Y = 0.903+1.901(X_1)$	10.7	.096	.966	$Y\pm.19$
3	$Y = 1.050-0.529(X_1)$	9.7	.066	.987	$Y\pm.14$

X_1 = average daily soil temperature 10 cm at ground site
Y = average daily soil temperature 10 cm at antenna plantation plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Temperature Antenna Hardwood Plots (10 cm)				
1	$Y = 0.897-0.663(X_1)$	8.1	.059	.986	$Y\pm.12$
2	$Y = 0.948-1.158(X_1)$	8.1	.072	.981	$Y\pm.15$
3	$Y = 0.922-.911(X_1)$	8.1	.059	.987	$Y\pm.12$

X_1 = average daily soil temperature 10 cm at ground site
Y = average daily soil temperature 10 cm at antenna hardwood plots

Table 1c. Replacement equations for missing ambient data 1992.

1992 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Moisture (%) Antenna Plantation Plots (10 cm)				
1	$Y = 1.281-7.414(X_1)$	11.5	.211	.647	$Y\pm.43$

X_1 = average daily soil moisture 10 cm at ground site
Y = average daily soil moisture 10 cm at antenna hardwood plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Soil Moisture (%) Antenna Hardwood Plots (10 cm)				
1	$Y = 0.921-1.000(X_1)$	10.7	.144	.372	$Y\pm.38$
3	$Y = 0.728+1.022(X_1)$	12.0	.144	.673	$Y\pm.29$

X_1 = average daily soil moisture 10 cm at ground site
Y = average daily soil moisture 10 cm at antenna hardwood plots

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Relative Humidity Ground Site				
	$Y = .9597-1.12(X_1)$	67.0	.436	.897	$Y\pm.87$

X_1= daily relative humidity at antenna site
Y = daily relative humidity at ground site

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Control Average Vegetation Temperature (30 cm)				
	$Y = .970+.432(X)$	14.6	.036	.994	$Y\pm.07$

X_1 = average daily air temperature Control air temperature in hardwoods
Y = average vegetation temperature at control site

Table 1c. Replacement equations for missing ambient data 1992.

1992 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
	Control Daily Precipitation				
	Y = .757+.112(X)	0.3	.034	.515	Ẏ±.07
	Control Average Relative Humidity				
	Y =1.389-29.7(X)	69.3	1.01	.787	Y±2.0

Control Daily Precipitation:

X_1 = total daily precipitation Crystal Falls DNR
Y = total daily precipitation control

Control Average Relative Humidity:

X_1 = average daily relative humidity Crystal Falls DNR
Y = average dialy relative humidity control

Appendix C: Hardwood Growth Modeling Manuscript

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Seasonal shoot growth of planted red pine predicted from air temperature degree days and soil water potential

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ABSTRACT

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On-site climatic measurements were used to model red pine (*Pinus resinosa* Ait.) shoot elongation. Three study sites each consisting of three 0.2-ha plots were cleared and planted with red pine. Shoot growth was measured weekly for 2 years. Incremental seasonal growth of the leading shoot was estimated using a difference form of a modified Chapman-Richards growth function. Weekly growth was estimated as a function of air temperature degree days (4.4°C basis), soil water potential, and total expected seasonal growth. An example using the model compares varying site and climatic conditions and their effect on the pattern of seedling height growth during the growing season as well as their effect on the total amount of height growth realized at the end of the growing season.

INTRODUCTION

The timing or pattern of growth of a species is important to forest managers when considering silvicultural treatments. Perala (1985) cited the importance of timing of shoot growth for such silvicultural treatments as insect surveys, foliar application of herbicides, and the pruning and shearing of Christmas trees. To describe the phenology of shoot elongation on red pine (Pinus resinosa Ait.), Perala (1985) found that climatic conditions were more useful predictors than calendar date. Using regional climatic information to calculate air temperature degree days, he explained much of the variation in the timing and amount of shoot elongation among sites. He speculated that much of the unexplained variation may be due to other climate-dependent factors such as soil moisture content or differences in microclimate between his red pine measurement plots and weather stations. To refine the understanding of the relative contributions of temperature and soil moisture in describing shoot elongation, this paper focuses on a growth model that was developed using site-specific, rather than regional, measures of both air temperature and soil water potential.

METHODS

Site description

Data were taken from three young red pine plantations located in the central Upper Peninsula of Michigan. Site 1 is in Iron County (46°20′N, 88°10′W). Sites 2 and 3 are both in Marquette County (46°20′N, 88°10′W). Before clearcutting, all three sites supported primarily undisturbed second-growth northern hardwood vegetation and were classified in the *Acer–Quercus–Vaccinium* habitat type (Coffman et al., 1983). All three sites are within the same regional ecosystem, suggesting comparable climate as well as geology (Iron District, Crystal Falls Subdistrict; Albert et al., 1986). The sites are subject to the climatic influences of the Great Lakes and have a short growing season of 87 days. The soils, though morphologically similar in surface horizons, were classified differently. Site 1 is an Alfic Haplorthod, sandy, mixed, frigid; site 2 is an Entic Haplorthod, sandy, mixed, frigid; and site 3 is a Typic Dystrocept, sandy, mixed, frigid (US Dep. Agric. Soil Conservation Service, 1975). Although they are classified differently, previous studies have indicated similar overstory productivity on these soil types (Shetron, 1972).

Tree measurements

In June 1984 the study sites were cleared of existing vegetation by whole-tree harvesting. Three permanent measurement plots (46 m×46 m) were then established at each site. These areas were immediately planted (3-0 red pine seedlings from a local seed source and obtained from the USDA Forest Service Toumey Nursery in Watersmeet, MI) on a 1 m×1 m spacing. One hundred of the red pine seedlings were randomly selected from each plot and permanently marked for measurements. Weekly shoot measurements were made to the nearest 1 mm on each of the marked red pine seedlings. Measurements were made from the meristematic tip or the tip of the new terminal bud to the center of the whorl of lateral branches beneath the bud. These weekly measurements began in mid-April while shoots were still dormant and continued until mid-July when shoot elongation was completed. Only the 1986 and 1987 growing seasons are included in this study because respective climatic data for the 1985 season are unavailable. In 1986, there were 14 weeks of shoot growth measurements and in 1987 there were 18 weeks of shoot

TABLE 1

Average stand characteristics for the red pine plantations on the three sites during the 1986 and 1987 growing seasons

	Site 1	Site 2	Site 3
Average total height (cm) at beginning of 1986	28.33	23.92	22.73
Average weekly incremental shoot growth (cm) for 1986	1.81	1.23	1.17
Average weekly incremental shoot growth (cm) for 1987	1.97	1.49	1.66
Average seasonal shoot growth (cm) for 1986	23.35	17.53	16.32
Average seasonal shoot growth (cm) for 1987	35.21	26.55	29.48
Average accumulated degree days for 1986	1021.53	998.23	953.73
Average accumulated degree days for 1987	1379.63	1288.67	1262.37

growth measurements. Seasonal shoot growth averaged from 16.3 to 35.2 cm over these 2 years (Table 1).

Ambient measurements

A Handar 540A* ambient monitoring platform was located in a cleared area at each of the three study areas. Each ambient monitoring platform contained sensors to measure precipitation, air temperature, relative humidity, and solar radiation. The three plots within each site were equipped with thermistor resistance sensors to measure air temperature at 2 m above the ground. They were also equipped with thermistor resistance sensors for soil temperature and 0–5 V differential floating sensors for soil moisture at depths of 5 cm and 10 cm. Three-hour averages were calculated for each variable, transmitted, and recovered via the GEOS East satellite and telephone lines each night. From these data, cumulative air temperature degree days were calculated on a 4.4°C basis (40°F), which is a common temperature for shoot growth studies (Perala, 1985). This heat unit approach has been in use for some time to explain plant and temperature relationships (Wang, 1960). The calculation is as follows:

$$\text{ATDD} = (\Sigma \text{ADT} - 4.4)$$

where the summation is on a weekly basis, and ATDD is air temperature de-

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gree days and ADT is average daily air temperature. These daily values were summed to coincide with the weekly shoot growth measurements. Average accumulated degree day totals for each growing season at each site are found in Table 1.

Soil water potential was determined to estimate moisture stress (Richards, 1965). Although soil moisture content gives a measurement of the amount of water contained in the soil, it does not reflect the degree to which plants can utilize this water. The potential determines to a large extent the availability of water to plants. Using methodology described by Richards (1965), curves were developed that relate soil water potential to the moisture content for each plot. Soil water potential values (−MPa) were estimated using these curves and daily field soil moisture content; they were averaged over 7 days to correspond to the weekly shoot growth measurements. Average seasonal values for each site are found in Table 1.

Growth model

The amount of shoot growth expected in a given week is estimated using a difference form of a modified Chapman–Richards growth function (Pienaar and Turnbull, 1973) and the cumulative air temperature degree days at the beginning and the end of the week. Soil temperature degree days at depths of 5 and 10 cm were considered, but preliminary screening showed that air temperature degree days (on a 4.4°C basis) explained more of the variation between sites. A negative exponential component modifies the expected growth based on soil water potential (Zahner, 1968). Moisture was assumed possibly to be limiting if soil water potential levels were above 0.101 −MPa (1 atm). Above this point there is no free water in the soil. Soil water potential was estimated at depths of 5 and 10 cm based on soil moisture content measurements at these depths. The model incorporating soil water potential at the 10 cm depth explained more of the variation (higher R^2 and lower mean square error) in height growth than the model incorporating soil water potential at the 5 cm depth.

The model performs dynamically through the differential accumulations of air temperature degree days and is modified by soil water potential. The form of the model is as follows:

$$g_t = \{[1-\exp(-b_1 AT_{2t})]^{b_2} - [1-\exp(-b_1 AT_{1t})]^{b_2}\} (G)\{\exp[b_3(M_t - 0.101)]\} \quad (1)$$

where g_t is the amount of shoot growth (0.1 cm) occurring in week t, G is the expected total shoot growth (0.1 cm) in the growing season (this may be estimated from site index curves), AT_{1t} is the cumulative air temperature degree days (4.4°C) to the beginning of week t, AT_{2t} is the cumulative air temperature degree days (4.4°C) to the end of week t, M_t is the average soil water potential for week t (if actual soil water potential is less than 0.101 – MPa, M was set to 0.101 – MPa for model development), b_1 and b_2 are estimated coefficients for the air temperature degree days component, and b_3 is the estimated coefficient for the moisture stress component.

Data were fitted by nonlinear regression using the SAS subroutine NLIN (SAS Institute, 1985) to a full model containing the moisture stress component as well as a reduced model composed only of accumulated air temperature degree days. This procedure was carried out for each growing season on each site. Significant differences ($P<0.05$) were assumed between sites or years if asymptotic 95% confidence intervals for respective coefficients did not overlap.

RESULTS AND DISCUSSION

The reduced growth model containing only the air temperature degree days component was fitted to data from each site during each study year. Significant differences ($P<0.05$) between study years were found for estimates of b_2 for each of the three study sites. To account for these yearly differences, the data were then fitted to the full growth model containing the soil water potential component. On sites 2 and 3 in 1987, however, average soil water potential never exceeded 0.101 – MPa. For this reason, the model was not fitted to data from these two sites during that year. Results from these analyses indicate significant differences ($P<0.05$) among sites and years for both b_2 and b_3. Estimates of b_3, the coefficient of the soil water potential component, were significantly different from zero in all cases, indicating its usefulness in the overall growth model.

Red pine has deterministic growth, thus the amount of growth in a given growing season is in part determined by the size of the terminal bud which is formed during the preceding year (Olofinboba and Kozlowski, 1973). The high R^2 (0.89) showed that shoot growth is not solely dependent on bud size and that the current year's weather is also very important.

Perala (1985) contended that the duration of shoot growth varies with amount of total seasonal growth. Thus, as total shoot growth increases, the duration of growth also increases. This concept affects the interpretation of the coefficients b_1 and b_2 in the growth model and could account for the site and year differences found in the b_2 estimates. These two coefficients were rewritten as follows:

$$b_i = b_{i1} G^{b_{i2}} \quad (2)$$

where b_i may either be b_1 or b_2. The parameters b_{i1} and b_{i2} are now used to estimate b_1 or b_2. The effect of seasonal shoot growth on the coefficient b_2 was

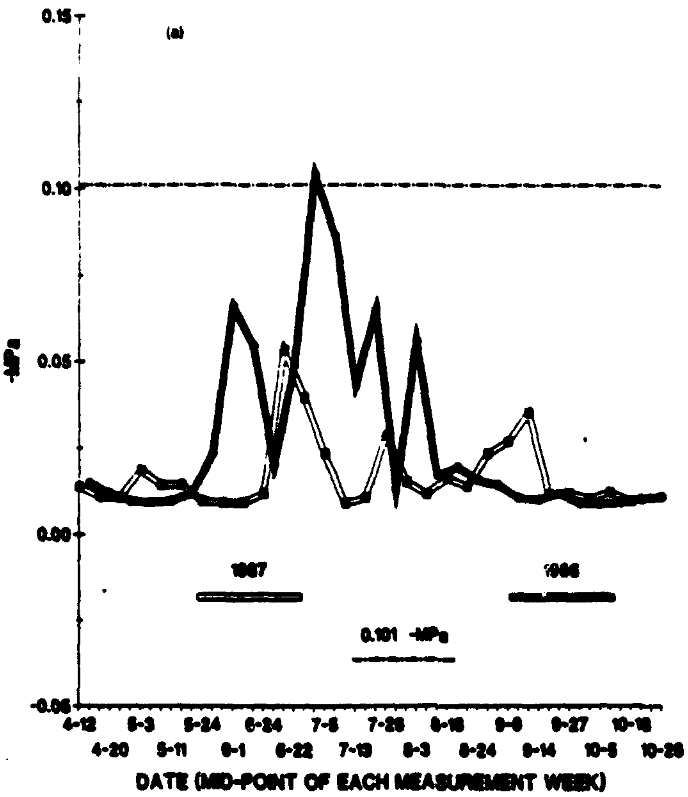

Fig. 1. Soil water potential (−MPa) at 10 cm for (a) site 1, (b) site 2, and (c) site 3.

found to be highly significant, but not on the coefficient b_1. Using these results, the model form was rewritten as follows:

$$g_t = \{[1-\exp(-b_1 AT_{2t})]^{b_{21} G^{b_{22}}} - [1-\exp(-b_1 AT_{1t})]^{b_{21} G^{b_{22}}}\} (G)\{\exp[b_3(M_t - 0.101)]\} \quad (3)$$

where b_2 has been redefined as $b_2 = b_{21} G^{b_{22}}$ and all other variables are as previously defined. Fitting this new model to data for each site within each study year eliminated yearly differences in the coefficient estimates at each site.

With yearly differences accounted for, study years were combined and coefficient estimates for each study site were examined. Estimates of b_3, the coefficient associated with soil water potential were significantly different from zero ($P<0.05$) for sites 1 and 3. At site 2 this was not the case. Low soil moisture is a relatively infrequent occurrence at the study sites except possibly during the month of July (Albert et al., 1986). During the 1987 red pine

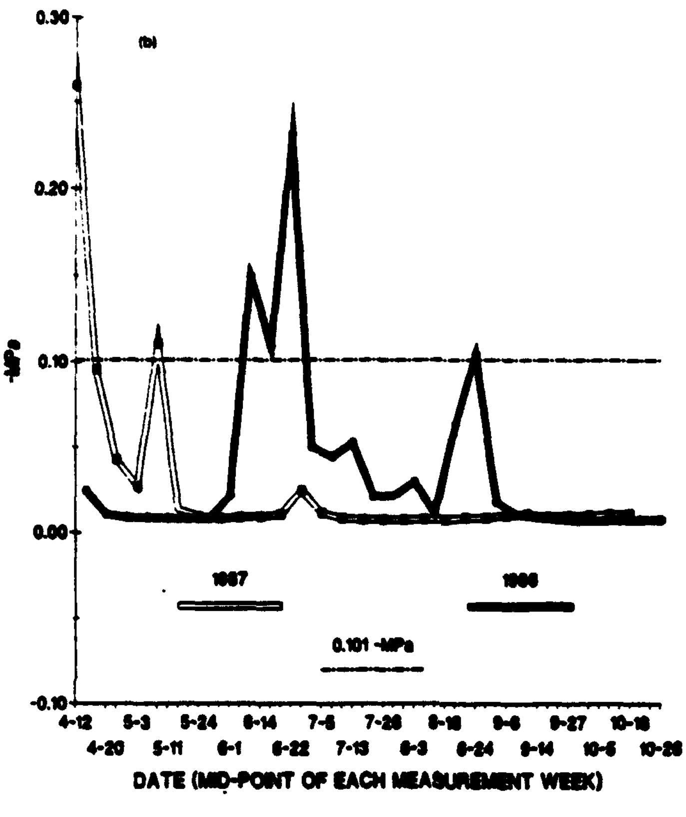

Fig. 1. Continued.

growing season, average weekly soil water potential never exceeded 0.101 –MPa at either site 2 or site 3; site 1 had several weeks where average soil water potential was above 0.101 –MPa (Figs. 1(a), (b), and (c). In 1987, site 2 again had adequate soil moisture (1 week had an average above 0.101 –MPa). This fact could account for the coefficient not being significantly different from zero ($P<0.05$) at this site. The significance of b_3 at the other two sites indicates the importance of this component to the overall model.

When study years were combined, there was one significant difference ($P<0.05$) in the coefficient estimates among sites. The estimate of b_{22} at site 1 was slightly different (asymptotic 95% confidence intervals do not overlap, but 99% confidence intervals do) from the respective estimates at sites 2 and 3. Nevertheless, based on these results, we concluded that there was sufficient justification for combining the study sites for a single set of coefficient estimates (Table 2) for the final growth model (Eqn. (3)). Predicted and ob-

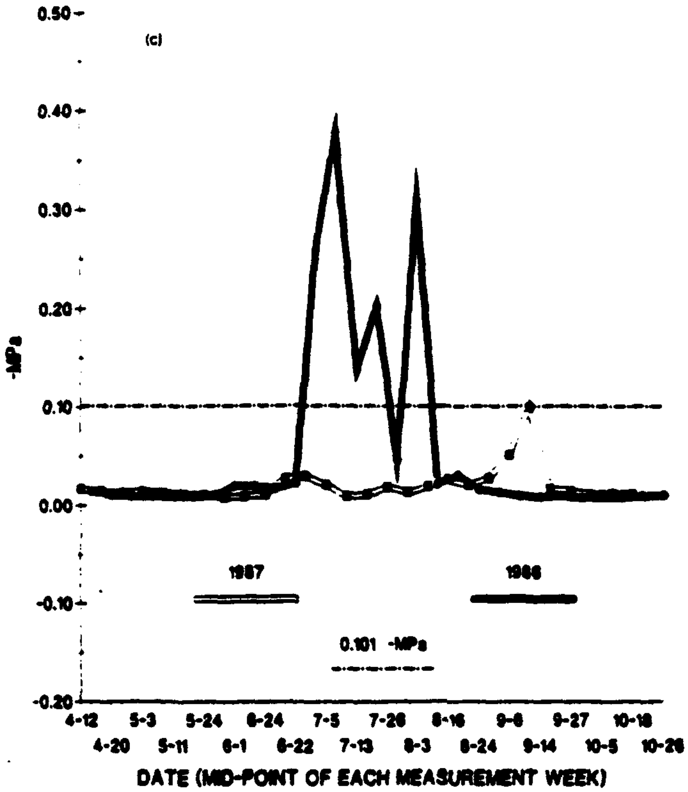

Fig. 1. Continued.

TABLE 2

Summary statistics for the final model with sites and study years combined

	Coefficient estimate	Asymptotic 95% confidence interval
b_1	0.0069	(0.0068, 0.0070)
b_{21}	1.7595	(1.5262, 1.9928)
b_{22}	0.4024	(0.3633, 0.4413)
b_3	−1.7601	(−2.1119, −1.4083)

% variation explained: 88.6%

served average shoot growth are given for each of the three sites in Figs. 2(a)–(c). The differences in observed vs. predicted shoot growth early in the growing season can be attributed to bud swell before elongation. By the middle of

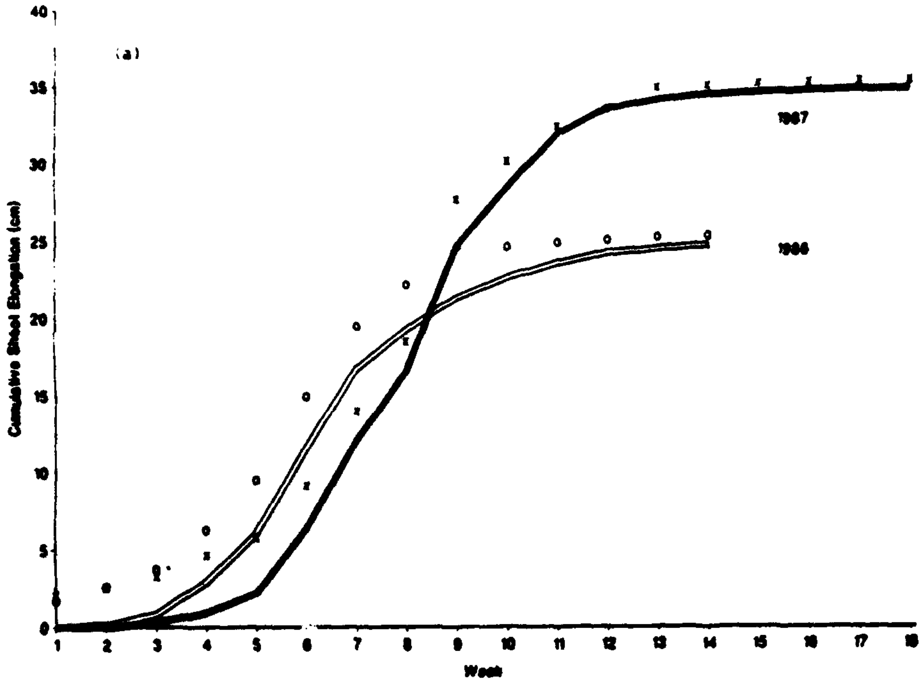

Fig. 2. Predicted and observed average red pine shoot growth (cm) for (a) site 1, (b) site 2, and (c) site 3, where observed average shoot growths are denoted by single points and predicted average shoot growth are denoted by lines.

the growing season, especially in 1987, few differences exist between the observed and predicted averages.

Predicted height growth

Using this model, a series of site and weather conditions were used to simulate and compare the predicted pattern of seedling height growth during the growing season as well as the total amount of seedling height growth realized at the end of the season. Eight comparisons were made utilizing the range of conditions observed on the study sites. A high-quality site (simulated by setting potential growth to be 30 cm) and a low-quality site (simulated by setting potential growth to be 15 cm) were compared under the following conditions:

(1) hot growing season (1400 degree days accumulated by the end of the growing season);

(2) cold growing season (900 degree days accumulated by the end of the growing season);

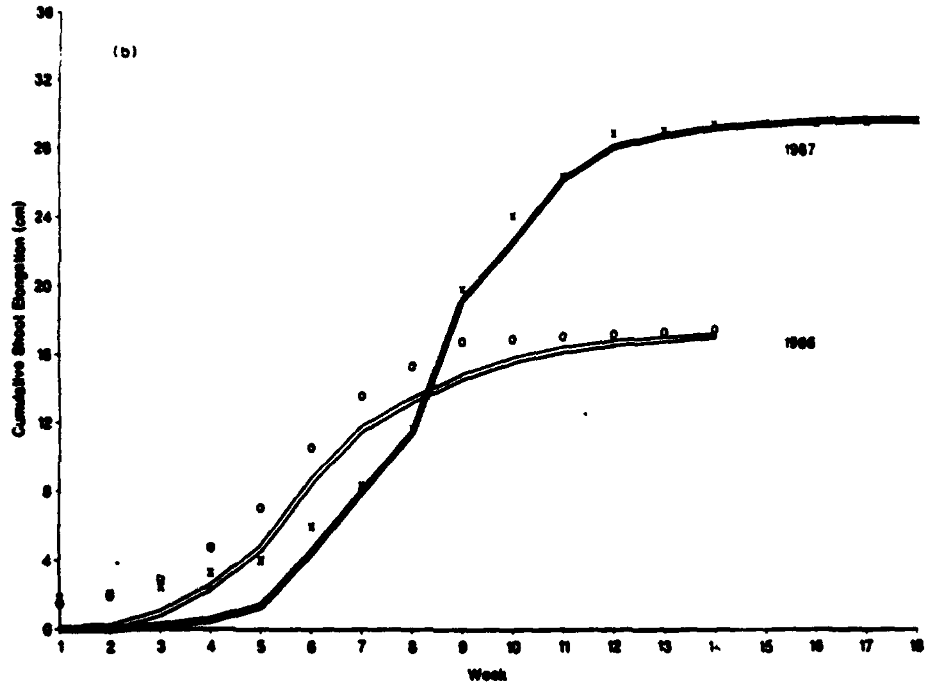

Fig. 2. Continued.

(3) wet growing season (soil water potential 0.101 – MPA or lower);

(4) dry growing season (soil water potential of 0.55 – MPA for the weeks in June and July, 0.101 – MPA or less for all other weeks).

The pattern or timing of height growth was similar for both high- and low-quality sites. Height growth started and ended earlier during a hot growing season than during a cold growing season. There was generally a 2–3 week lag in the timing of height growth during a cold vs. a hot growing season, where height growth started and ended sooner during a hot year. At either site during a hot growing season, height growth during a dry year generally ended half a week earlier than during a wet year (Table 3). The greatest amount of height growth was achieved on the high-quality site, regardless of the climatic conditions. There was little difference in the total height growth at either site during a wet growing season. The greatest reduction in total height growth occurred when the growing season was both cold and dry (Table 3), when height growth was reduced by up to 50%. Figures 3(a) and (b) depict the height growth pattern for each of the simulated weather conditions on the two sites.

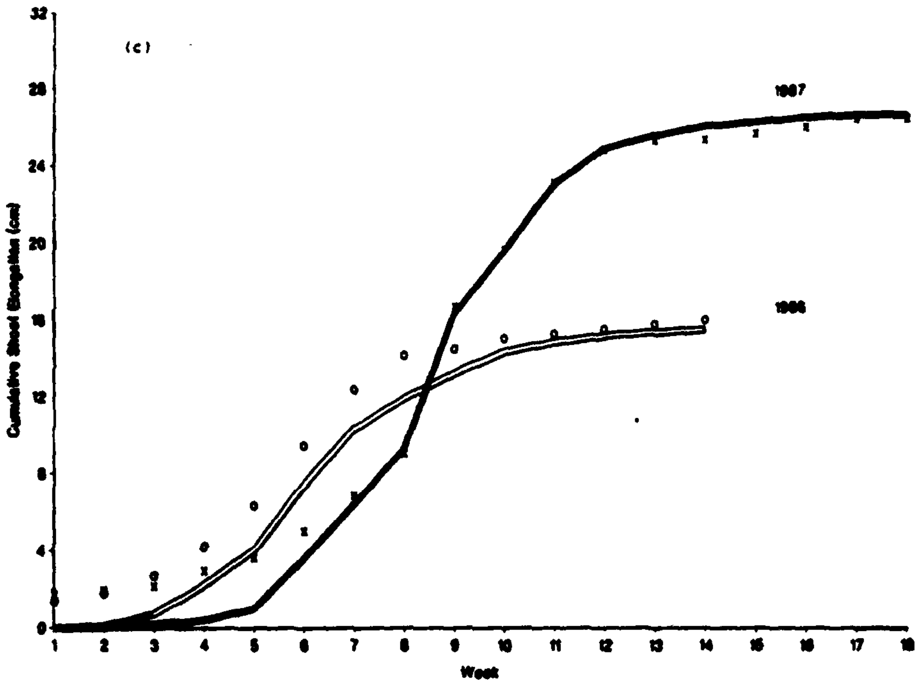

Fig. 2. Continued.

TABLE 3

Results from simulations using the shoot growth model with varying temperature and moisture regimes at the high- and low-quality sites[a]

	No. of weeks to achieve approximately		Total amount of growth (cm)
	50% growth	90% growth	
High-quality site			
Hot, wet[b]	7	10	29.99
Hot, dry[b]	6–7	9	21.16
Cold, wet[b]	10	14	29.64
Cold, dry[b]	10	14	15.84
Poor-quality site			
Hot, wet	7	10	14.99
Hot, dry	6–7	9	11.36
Cold, wet	9	13	14.86
Cold, dry	9	13	8.57

[a]A high-quality site has a potential growth (*G*) of 30 cm and a low-quality site has a *G* of 15 cm.
[b]The temperature regimes simulated include hot (1400 degree days accumulated) and cold (900 degree days accumulated) and the moisture regimes simulated include wet (soil water potential 0.101 – MPA or less) and dry (soil water potential 0.55 – MPa for weeks in June and July, 0.101 – MPa or less for all other weeks).

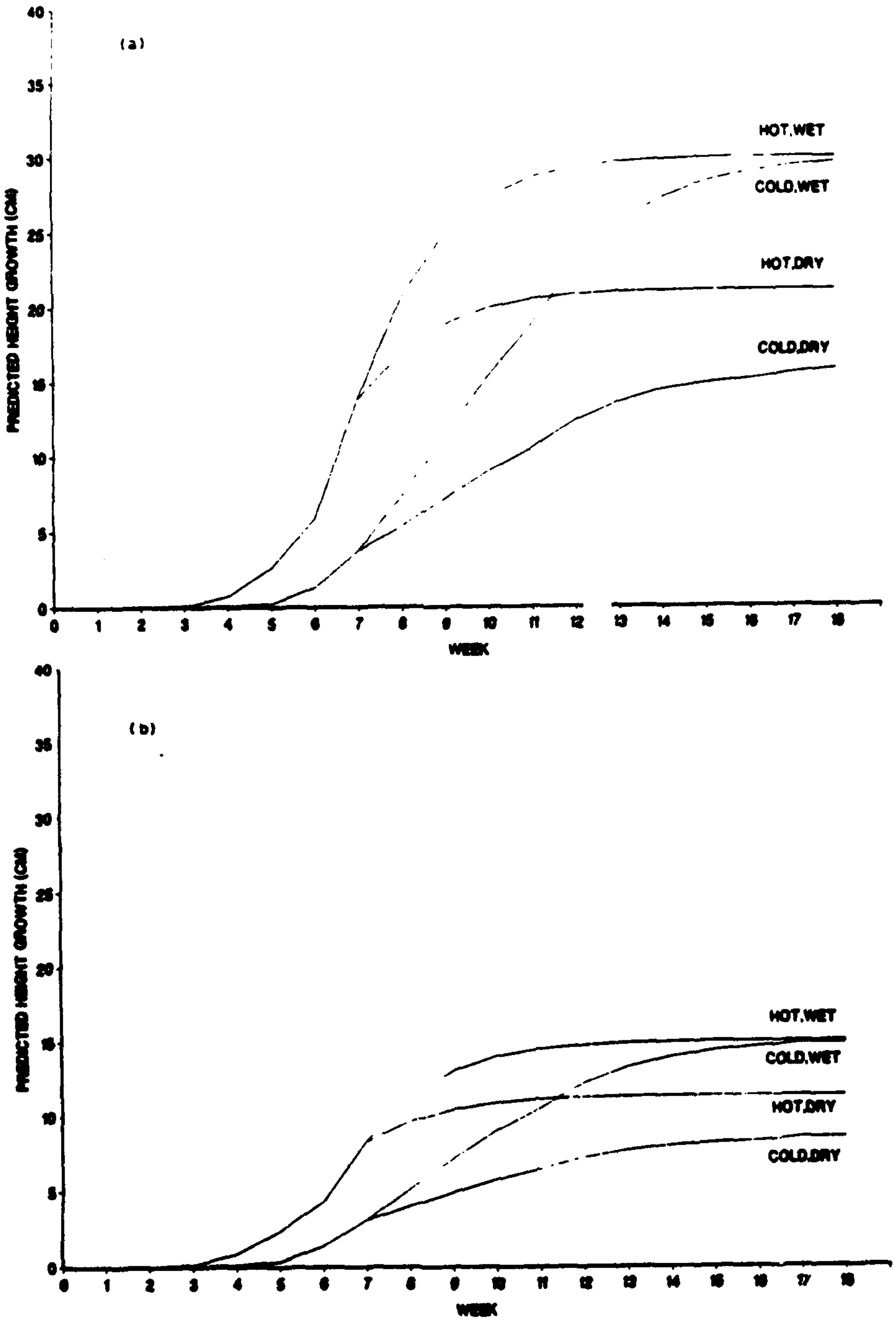

Fig. 3. Predicted shoot growth on (a) high-quality site (potential growth of 30 cm) and (b) low-quality site (potential growth of 15 cm) for simulated combinations of temperature (1400 (hot) vs. 900 (cold) total degree day accumulations) and moisture (soil water potential 0.101 – MPa or less (wet) for all weeks vs. soil water potential of 0.55 – MPa (dry) for weeks in June and July and 0.101 – MPa or less all other weeks).

SUMMARY AND CONCLUSIONS

Earlier work by Perala (1985) used air temperature degree days to predict red pine shoot growth with data collected from local weather stations. This study used site-specific data, with similar results. Cumulative air temperature degree days was the dominant factor in predicting the amount of shoot growth of red pine at any point in time during the growing season. However, differences among study sites and between study years were found. By redefining one coefficient in terms of total seasonal growth to account for the relationship of duration of shoot growth to total seasonal growth and by adding soil water potential to the model, these differences were eliminated. This allowed the development of a single set of coefficient estimates for a red pine shoot growth model (Eqn. (3)).

An example comparing various site and weather conditions and their effect on the pattern and the amount of seedling height growth during the growing season found that high-quality sites yielded the greater amounts of total growth regardless of the weather conditions, and for any site, a hot and wet growing season yielded the greatest amount of total height growth. The timing or pattern of growth during the growing season was affected by varying weather conditions. For any given site, during a hot, dry year, growth ends earlier than with any other set of conditions. During a cold year, growth ends later than during warm years. This example provides a general illustration of the model predictions; with this model a manager has a means of determining when and how much shoot growth occurs during the growing season, thus allowing for improved management planning.

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Modeling diameter growth in local populations: a case study involving four North American deciduous species

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ABSTRACT

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Many existing models representing the growth of forest overstory species as a function of environmental conditions make a number of assumptions which are inappropriate when applied to local populations. For example, maximum tree diameter and height are often assumed to be constant limiting factors for a given species even though growth functions can often be localized by utilizing information in the forest growth and yield literature to make site-specific estimates of these values. Most existing models also use an annual timestep which may be inappropriate when attempting to model the growth response of individual trees to environmental conditions. In this study, a model utilizing a weekly timestep is described and applied to four widespread North American deciduous tree species. Because response to environmental conditions can vary regionally as a result of genetic heterogeneity, the resulting model should not be considered as universally appropriate for these species. This study illustrates methods which can be utilized to develop models for application to local populations.

A number of recent studies have utilized information from forest growth models and existing forest monitoring data to investigate the effects of environmental stresses on forest productivity. Examples include the work by Holdaway (1987) investigating the regional effects of acidic deposition on forests in the northcentral USA, and work by Botkin et al. (1989) projecting the

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possible effects of climate change on the forests of Michigan. These and similar studies utilize growth models to study the effects of an imposed environmental factor against a background of natural variability in climate and other factors.

There are a number of existing models which attempt to describe annual diameter growth as a function of tree and stand characteristics while accounting for the effect of site physical, chemical, and climatic properties. Diameter growth functions of the JABOWA (Botkin et al., 1972) and FORET (Shugart and West, 1977) models and models of the type described by Reed (1980) and Shugart (1984) are examples. There have been a number of models developed recently but many of these utilize the growth functions based on the methods presented in these earlier papers. In any case, most models are based on certain species-specific characteristics (such as maximum observed diameter and height) and observations relating site physical, chemical, and climatic conditions to species productivity (such as the climatic conditions at the limits of the species' geographic range).

Productivity here is defined as annual aboveground overstory biomass accumulation. While monitoring of actual biomass production over time is not feasible in field situations, it is relatively easy to accurately and precisely measure cambial development. There is a strong relationship between a tree's diameter at breast height and total tree biomass (Crow, 1978). Furthermore, cambial activity is strongly related to climatic variation, competition from neighboring trees, and site physical and chemical properties (Spurr and Barnes, 1980; Smith, 1986). For these reasons, diameter increment was chosen as the response variable representing biomass increment.

The diameter growth functions of the JABOWA and FORET models were tested by Fuller et al. (1987) on the two study sites described below and found to perform poorly when compared to actual field measurements. For all species on the sites, the models proved to be poorer predictors of individual tree diameter increment than simply using the mean diameter growth of the stands. Desanker and Reed (1993) extended these comparisons over a total of seven growing seasons and also included the growth functions from the STEMS (Belcher et al., 1982) and FOREST (Ek and Monserud, 1974) growth models. Average differences of at least 200% between observed and predicted diameter increments were observed for each of the models for at least 1 year, with some differences as high as 3000%. Clearly, such errors are unacceptable when attempting to evaluate the effects of forest stress factors which may impact growth by less than 100%. Desanker and Reed (1993) conclude that forest growth models can not simply be taken off the shelf and applied to any site (even within the geographic range of the models) without somehow adjusting for local site conditions.

There are several reasons for the inaccuracy of the predictions made by these models. An annual timestep may not be adequate when attempting to quantify the effects of environmental stress on forest productivity. Charles-Edwards et al. (1986) indicate that the amount of time for individual plant growth processes to stabilize following a pertubation in the nutrient status of the rooting environment is on the order of 10^5 s (a few days) and the recovery time of a natural system on the order of 10^9 s (many years). It is illogical to use a timestep which is longer than the recovery time of the system of interest, whether that system is an individual plant or plant community. It is also counterproductive to use a timestep that is many orders of magnitude less than the recovery time of the system of interest. Since the interest here involves individual plants and their response to competition from neighboring plants as well as environmental factors, an intermediate timestep of 1 week was utilized in developing a diameter growth model of the type described by Reed (1980).

Models of the type described above may also perform poorly on specific sites because the species attributes they utilize are not applicable across the entire geographic range of a species. The maximum expected diameter and height for a species is dependent on genotype and site conditions and is not constant over the entire range of the species. There is a great amount of information in the forest growth and yield literature relating tree growth and development to site quality class or site index which can be utilized to make forest growth models more site specific.

A diameter growth model using site-specific species attributes and observed relationships between diameter growth, competition, and site physical, chemical, and climatic properties is presented below for two study sites in Upper Michigan. The purpose is to develop a model which can be used to estimate the effects of an imposed environmental factor against a background of natural environmental variability in a local population. The relationships given here reflect the genotypes and environmental conditions on the study sites and can not be expected to extend over the entire geographic ranges of these species. The methodology for identifying and quantifying these relationships is applicable to other study sites and species.

METHODS

Site description

The two study sites are located in the central Upper Peninsula of Michigan. Site 1 is at 46°10′N, 88°30′W and Site 2 is at 46°20′N, 88°10′W. Both sites have relatively undisturbed second growth deciduous vegetation consisting principally of red maple (*Acer rubrum*, L.) and northern red oak (*Quercus rubra*, L.) with minor components of quaking aspen (*Populus tremuloides*, Michx.), bigtooth aspen (*Populus grandidentata*, Michx.), and paper birch (*Betula papyrifera*, Marsh.). The sites are both characterized as the *Acer-*

Quercus-Vaccinium habitat type (Coffman et al., 1983). The soil at Site 1 is classified as an alfic haplorthod, sandy, mixed, frigid; the soil at Site 2 is classified as an entic haplorthod, sandy, mixed, frigid (USDA Soil Conservation Service, 1975). Past studies have documented similar northern deciduous forest productivity on these two soil types (Shetron, 1972). Both sites are within the same regional ecosystem (Iron District, Crystal Falls Subdistrict (Albert et al., 1986). The study sites are typical of forests on well-drained sandy soils of the region.

Field measurements

Measurement of radial increment was accomplished using a band dendrometer as described by Cattelino et al. (1986). The dendrometer bands were read weekly to the nearest 0.008 cm of diameter. Dendrometer bands of this type have the ability to measure diurnal shrinking and swelling of the tree bole which introduces some variability into the measurements. By standardizing the day of the week and approximate time of day to make measurements, and by following individual trees over a number of years, the negative effects of this measurement variability are minimized while the positive effects of being able to detect growth pattern across the season are maximized. Readings began in early April and continued through the growing season until over 50% of leaf fall had taken place. There were 274 trees banded on Site 1 and 197 trees banded on Site 2 prior to the 1985 growing season. Weekly measurements were made over the 1985, 1986, 1987, and 1988 growing seasons. Locations of the individual trees were mapped on a Cartesian coordinate system with a 0.1 m resolution (Reed et al., 1989). Stand conditions at the beginning of the modeling efforts (1986) are given in Table 1.

The second category of field measurements include climate and soil properties which may affect plant growth processes. Each study site was equipped with a remote data collection platform located in a cleared area adjacent to the site. The main data collection platform contained sensors measuring precipitation, air temperature, relative humidity, and solar radiation; each of three 30 m×35 m plots at each site contained sensors measuring air temperature, soil temperature, and soil moisture content at 5 and 10 cm depths. Sensors were queried every 30 min and computed into 3 h mean values by the platform microprocessor. Precipitation data are logged once every 3 h. Data were retrieved eight times daily via NOAA satellite transmissions. These daily climatologic and soil data were then summarized into weekly averages to coincide with the dendrometer band readings for analysis. Physical descriptions of each pedogenic soil horizon were made at the beginning of the study. The upper 15 cm of mineral soil were sampled monthly during the growing season for determination of nutrient levels.

TABLE 1

Stand characteristics at the beginning of the study (1986)

Species	Average diameter (cm)	Average height (m)	Average basal area (m^2 ha^{-1})	Density (stems ha^{-1})	Site index (m @ 50 years)	Age (years)
Site 1						
Northern red oak	20.82	22.24	20.00	556	22	52
Paper birch	16.30	20.63	2.92	127	18	54
Aspen	22.82	23.51	3.33	79	20	55
Red maple	11.85	16.31	0.52	48	18	45
Site 2						
Northern red oak	22.69	17.62	6.57	143	21	47
Paper birch	20.42	19.62	0.86	25	20	55
Aspen	25.37	20.27	2.43	48	21	50
Red maple	15.23	16.43	7.78	410	17	42

GROWTH MODEL FORMULATION

The basic growth model formulation follows the conceptual model described by Botkin et al. (1972) and Reed (1980). In the model, the diameter growth during a given week, d_t, is represented as a function of tree, stand, climate, and site physical and chemical factors. These factors are incorporated in four model components: (1) annual potential growth (PG); (2) the adjustment of annual potential growth to account for intertree competition (IC); (3) the adjustment of annual potential growth to account for site physical, chemical, and annual climatic properties (SPC); (4) the seasonal growth pattern and further adjustment of annual potential growth to account for weekly climatic factors (SGP_t).

Each of the last three components is expressed as a proportion of the annual potential growth and the weekly diameter growth is expressed as the product of the four components

$$d_t = PG \times IC \times SPC \times SGP_t \qquad (1)$$

Annual potential growth

In the above formulation, annual potential growth is defined as the amount of diameter growth that a tree could achieve if no environmental variables limit growth. Fuller (1986) identified the model form given by Botkin et al. (1972) for use on these study sites. A slightly modified form of this model is used to represent potential growth (PG) on the study sites

TABLE 2

Coefficient estimates (and associated asymptotic 95% confidence limits for statistically estimated coefficients) for the four species

	Species			
	Northern red oak	Paper birch	Aspen	Red maple
Annual potential diameter growth component				
Site index (m @ 50 years)				
Site 1	22.0	19.8	18.3	17.7
Site 2	20.7	20.7	20.1	17.1
H_{max} (cm)				
Site 1	2416	2278	2204	2105
Site 2	2359	2324	2287	2077
D_{max} (cm)				
Site 1	73	60	60	52
Site 2	72	61	60	51
b_2				
Site 1	62.438	71.367	68.900	75.692
Site 2	61.722	71.705	71.667	76.078
b_3				
Site 1	0.42766	0.59472	0.57417	0.72781
Site 2	0.42863	0.58775	0.59722	0.74587
G	200.78 (174.45, 227.10)	139.23 (69.25, 209.22)	112.92 (98.08, 127.76)	133.47 (117.63, 149.31)

Intertree competition component				
a	0.0557 (0.0443, 0.0671)	0.0431 (0.0150, 0.0712)	0.1206 (0.0919, 0.1493)	0.0352 (0.0290, 0.0414)
Site physical, chemical and climatic factor component				
c_0	−3.32 (−12.75, 6.31)	0	−47.28 (−59.55, −35.02)	−40.35 (−33.93, −46.77)
c_1	−0.0045 (−0.0056, 0.0034)	−0.0025 (−0.0044, −0.0007)	0.0356 (−0.0429, −0.0283)	0.0890 (0.0696, 0.1084)
c_2	0.1081 (−0.0514, 0.2671)	0	0.3456 (0.1429, 0.5503)	0.1498 (0.0695, 0.2302)
c_3	0	−37.26 (−56.11, −18.42)	0	12.71 (6.47, 18.95)
Seasonal growth pattern component				
d_1	809.67 (762.75, 856.60)	725.75 (586.83, 765.68)	713.97 (693.07, 734.87)	761.11 (740.06, 782.16)
d_2	1.4351 (1.3595, 1.5107)	2.1470 (2.1132, 2.7207)	2.2878 (2.1597, 2.4159)	2.1322 (2.0256, 2.2388)
d_3	−0.5125 (−0.7882, −0.2367)	−0.3278 (−0.5708, −0.0849)	0	−0.5005 (−0.7133, −0.2876)

$$PG = \frac{GD(1 - D/D_{max})}{274 + 3b_2D - 4b_3D^2} \quad (2)$$

where D is tree diameter at breast height (DBH; cm), D_{max} is the maximum observed tree diameter for a species (cm), and G, b_2, and b_3 are species-specific constants. Botkin et al. (1972) included height and the species' maximum height (both in centimeters) in their model formulation; because of the difficulty in precisely measuring height and annual height growth in mature deciduous individuals, these variables were not directly included in the model formulation in this study. To insure logical predictions are obtained when D is near D_{max} (to insure that PG = 0 when $D = D_{max}$ and $H = H_{max}$), Botkin et al. (1972) imposed the following constraints on b_2 and b_3

$$b_2 = 2(H_{max} - 137)/D_{max} \quad (3)$$

$$b_3 = (H_{max} - 137)/D_{max^2} \quad (4)$$

These constraints were imposed on b_2 and b_3 in this study as well to retain the logical behavior of PG.

Fuller (1986) and Desanker and Reed (1993) found that the model with the values of the coefficients given by Botkin et al. (1972) performed poorly on the study sites and required re-estimation. As discussed by Botkin et al. (1972), Reed et al. (1990), and Desanker and Reed (1993), this is at least partly because H_{max} and D_{max} are site specific. Ek et al. (1984) gave an expression relating total tree height to DBH, site index, and stand basal area for each of the four species in this study. By using the observed site indices from the study plots and assuming an asymptotic stand basal area, the equations given by Ek et al. (1984) were utilized to estimate D_{max} and H_{max} for the study plots. An asymptotic basal area of 32 m^2 ha^{-1} was chosen; basal areas exceeding this in mixed species stands of this type are possible on small plots, but very rare on the stand level. The final estimates of D_{max} and H_{max} are not sensitive to small changes in the selected asymptotic basal areas but can change dramatically when unrealistically high or low asymptotic basal areas are selected. Numerical procedures were used to solve the equations to find the diameter which would lead to insignificant (<0.01 m) height growth; that diameter was taken as D_{max} for the site and the corresponding height was taken as H_{max}. The resulting estimates of D_{max} and H_{max} were used to fix b_2 and b_3 in the model as defined in the limiting relationships given above (Table 2).

Botkin et al. (1972) set G to produce approximately two-thirds of the maximum diameter at one-half of the maximum age. In this study, G was statistically estimated using non-linear regression techniques (Table 2). For paper birch and aspen, asymptotic 99% confidence intervals around the estimated values of G included the values used by Botkin et al. (1972) and Shugart and

West (1977) for these species. For red maple and northern red oak, this was not the case. The value of G incorporates various proportional relationships between total tree biomass increment, leaf area, and leaf biomass (Botkin et al., 1972). Therefore, it is not surprising that site-specific values may be required for some species.

Intertree competition

In the formulation of Botkin et al. (1972), and in following revisions by Shugart and West (1977) and others, the effect of intertree competition on diameter growth is represented in two ways. The first is through a model component representing light availability, which is based on tree height, the height of all other trees in the stand, and shade tolerance (two tolerance classes were used). The second is through a factor representing competition for moisture and nutrients which is simply a ratio of basal area for the stand to maximum stand basal area expected for the cover type.

On these study sites, Holmes (1988) did not find a significant ($P > 0.05$) relationship between plot basal area and individual tree diameter growth. The comparison of the height of an individual tree to all other trees on a plot was also judged to be inappropriate, especially since these study plots measure 30 m × 35 m and contain trees which are not measurably affecting each other.

Holmes and Reed (1991) used map information from the study plots to evaluate the performance of numerous individual tree competition indices for each of the four species. The competition indices used here are not necessarily those that were most highly correlated with individual tree diameter growth but they do perform well in the modeling efforts, especially in the combined model when other environmental factors are considered. A simple competition index given by Lorimer (1983) performed well for northern red oak, paper birch, and red maple. This index is given by

$$CI_i = \sum (DBH_j/DBH_i) \qquad (5)$$

where CI_i is the value of the competition index for the ith (subject) tree, DBH_i is the diameter of the subject tree, DBH_j is the diameter of the jth competitor, and the summation is over all trees within 7.62 m of the subject tree. Holmes and Reed (1991) found that the relationship between Lorimer's competition index and diameter growth did not differ between sites or across years (1985–1987) for northern red oak, paper birch, and red maple.

For aspen, the least shade tolerant of the four species in this study, the competition index given by Bella (1971) proved to be highly related to observed diameter growth. This index includes additional information regarding the distance to neighboring trees

$$CI_i = \sum [(a_{ij}/A_i) \times (DBH_j/DBH_i)^3] \qquad (6)$$

where CI_i is the value of the competition index for the ith (subject) tree. DBH_i is the diameter of the subject tree. DBH_j is the diameter of the jth competitor. A_i is the area of the influence zone (as defined by the open grown crown radius given by Ek (1974)) of the ith tree, and a_{ij} is the area of the overlap of the influence zones of the ith tree and the jth competitor. As with Lorimer's index and the other three species, the relationship between Bella's index and aspen diameter growth did not differ between sites or across years (1985–1987).

A negative exponential relationship was assumed between diameter growth and increasing competition. In the diameter growth model, this is represented by

$$IC = e^{-(a \times CI)} \tag{7}$$

where IC is the intertree competition component of the diameter growth model, a is the coefficient to be estimated for each species, and CI is the value of the competition index for the respective tree. There were no significant differences between sites in the estimated value of a (Table 2).

Site physical, chemical and climatic factors

For environmental factors such as moisture, temperature, and soil nutrient levels, there is expected to be a range of values where a species responds positively to increased amounts of the factor, a range of values where the factor is adequate for the species and there is little response to increases or decreases, and a range of values where the species responds negatively to increased amounts (Spurr and Barnes, 1980; Reed et al., 1990). Reed et al. (1992) describe an intensive variable screening procedure that was used to identify a set of environmental variables for each species which were correlated, either positively or negatively, with diameter growth on the study sites. These variables were selected to be as independent of each other as possible; the environmental factors selected were used in an analysis of covariance and accounted for significant differences in diameter growth between sites and among years.

A component was added to the diameter growth model to represent the effect of site physical, chemical, and climatic factors on growth. The environmental factors were accounted for in the model by a linear function constrained to produce the proportion of potential growth which might be expected

$$SPC = \frac{(DBH + c_0 + c_1 X_1 + c_2 X_2 + c_3 X_3)}{DBH} \tag{8}$$

where SPC is the effect of physical, chemical, and climatic factors on diameter growth and DBH is tree diameter. The particular environmental factors

(X_k) and the associated constants (c_k) are species specific. The factors identified in this study were total seasonal air temperature growing degree days (April–September) on a 4.4°C basis for northern red oak, paper birch, and aspen, and air temperature degree days through May for red maple, July soil potassium concentration (p.p.m.) in the upper 15 cm of mineral soil for aspen and red maple, and soil water holding capacity (cm/cm) at a depth of 5–10 cm for red maple and at a depth of 10–30 cm for paper birch. The intercept (c_0) was not significant ($P > 0.05$) for northern red oak and paper birch and was removed from the model for these two species (Table 2).

Seasonal growth pattern and effect of weekly climatic conditions

Fuller et al. (1987) found that cumulative total air temperature degree days (4.4°C basis) was the most significant environmental factor impacting the timing of diameter growth for all four species on both sites. Reed et al. (1990) modeled the proportion of annual growth expected in a given week using a difference form of a modified Chapman–Richards growth function and the cumulative air temperature degree days at the beginning and end of the week. This requires the implicit assumption that each species will respond to temperature up to a point and that further increases in degree days will not lead to increased growth.

Increased air temperature leads to increased plant respiration and evaporation which may result in decreased levels of soil moisture. The expected growth, given the cumulative air temperature degree days, will not be achieved if moisture is limiting. In the model, average soil water potential (−MPa) at a depth of 5 cm is used to indicate the level of moisture stress. At a value of water potential less than 0.101 −MPa, water is freely available to plants and is not assumed to be limiting. At potentials greater than 0.101 −MPa, moisture may limit growth to some extent; plant response is assumed to be a simple exponential function of increasing soil water potential. If the observed average soil water potential for a week is less than 0.101 −MPa, a value of 0.101 −MPa was used in the estimation procedure.

The model component representing weekly growth combines the effects of cumulative air temperature degree days at the beginning (ATD_{t_1}) and end (ATD_{t_2}) of week t and average soil water potential at 5 cm in week t (SWP_t)

$$SGP_t = [e^{-(ATD_{t_1}/d_1)^{d_2}} - e^{-(ATD_{t_2}/d_1)^{d_2}}] \times [e^{-d_3(SWP_t - 0.101)}] \qquad (9)$$

where SGP_t is the proportion of potential total annual growth expected in week t. The coefficients d_1, d_2, and d_3 are species-specific coefficients and are estimated statistically using non-linear regression techniques (Table 2).

Combined model

The combined model, incorporating all four model components discussed above, was fitted to data from both sites for the 1986 and 1987 growing seasons. This allowed the examination of site differences in the coefficients due to tree and climatic differences in the 1986 and 1987 growing seasons. There were no differences in any coefficient by site so the data were combined to estimate the coefficients for each species. Data from the 1988 growing season were used for testing, but were not used in estimating the coefficients. Predictions of total seasonal diameter growth were made for each tree and compared with the observed growth values. A studentized test on the average residual found no evidence of bias in the combined model for any species except for aspen (Table 3). In other words, the average residual was not different from zero ($P>0.10$) for northern red oak, paper birch, and red maple. For aspen, the average residual was different from zero ($P=0.01$), indicating a significant underprediction of observed growth by the combined model. This result is probably a consequence of a number of factors, including the small sample size for aspen, the extreme genetic diversity found in aspen in the Lake States, and the clonal growth of aspen (Fowells, 1965).

The standard error of the residuals in the estimation data is analogous to the square root of the mean squared error in ordinary linear regression. The standard error of the residuals in the estimation data set is less than the measurement increment (0.008 cm) for all species except aspen (Table 3). This implies that the model prediction is within the measurement precision for those species and further improvement is unlikely.

The proportion of variation explained in total annual diameter growth

TABLE 3

Diameter growth model performance for each species when predicting total seasonal growth (sites and years combined)

Species	Proportion of variation explained[1]	Average residual (cm)	Standard error of residuals (cm)	$H_o: \mu_R=0$ $H_a: \mu_R \neq 0$
Northern red oak	0.443	0.0128 (6.4%)	0.0079	NS
Paper birch	0.724	0.0037 (6.1%)	0.0075	NS
Aspen	0.286	0.0328 (16.9%)	0.0105	$P=0.01$
Red maple	0.512	0.0010 (1.0%)	0.0041	NS

[1]Proportion of variation explained is calculated as follows

$$PVE=\frac{\Sigma(Y_i-\bar{Y})^2-\Sigma(Y_i-\hat{Y}_i)^2}{\Sigma(Y_i-\bar{Y})^2}$$

where Y_i is the observed growth for the ith tree; $\hat{Y}_i$ is the predicted growth for the ith tree; $\bar{Y}$ is the average growth for all trees of the same species as the ith tree.

(Table 3) is analogous to R^2 in linear regression, and for all four species is in the range found by other studies in deciduous species (e.g. Harrison et al., 1986). Further improvement in these values may not be possible at the study sites because of the precision of the field measurements and the rates of observed growth.

Residual analysis

The analysis of the model's ability to predict growth is divided into two components: total annual growth and seasonal pattern of growth. The predicted total annual growth is obtained by summing the weekly growth predictions over the entire growing season. The predicted seasonal growth pattern is determined by the cumulative growth to any given week during the growing season.

Total annual growth

Annual residuals, by site, are given for each species in Table 4. These comparisons involve the sum of the predicted weekly diameter growth over a season compared with the total observed growth during the season. As mentioned previously, the data from 1986 and 1987 were used in model estimation; the data from 1988 were not used in estimation. The 1988 comparisons between the observed and predicted values can, in some ways, be interpreted as a test of the model under new conditions. While the same trees measured in previous years are remeasured, the particular combination of weather conditions in 1988 are unique. Thus, while not being an independent test of the model, the 1988 comparisons can provide insight into model performance under conditions other than those in the estimation data set.

As seen in Table 4, for northern red oak and paper birch, the studentized 95% confidence limits for each of the 3 years on both sites include zero, indicating no significant deviation in growth from that predicted by the model. For red maple, the studentized 95% confidence intervals for both sites in 1986 and 1987 include zero, indicating unbiased model predictions during the years from which the estimation data were obtained. In 1988, there was a large negative residual at each site, and the residuals were not different between sites. This indicates that the model did not adequately represent the growing conditions in 1988 and that some factor or combination of factors led to a reduced average diameter growth rate for red maple which was not seen in previous years but which was apparent at both sites.

In searching for differences in environmental factors between 1988 and previous years, the major difference appears to be related to moisture. Average air temperature at 2 m above the ground and average precipitation are not significantly different between years (Table 5), but relative humidity and soil water potential at 5 cm were significantly different in 1988 than in pre-

TABLE 4

Performance of the diameter growth model in predicting total seasonal growth by site and year for each species

Site	Year	Number of observations	Average residual (cm)	Standard error of residuals (cm)	Studentized 95% confidence interval
Northern red oak					
1	1986	61	−0.0069	0.0103	−0.0275, 0.0137
	1987	62	0.0135	0.0112	−0.0089, 0.0359
	1988	62	−0.0178	0.0113	−0.0414, 0.0048
2	1986	20	0.0204	0.0251	−0.0321, 0.0776
	1987	22	0.0797	0.0323	−0.0125, 0.1469
	1988	23	0.0250	0.0202	−0.0169, 0.0669
Paper birch					
1	1986	10	0.0047	0.0162	−0.0139, 0.0413
	1987	10	0.0007	0.0086	−0.0188, 0.0202
	1988	10	0.0270	0.0270	−0.0200, 0.0740
2	1986	3	0.0191	0.0241	−0.0846, 0.1228
	1987	3	−0.0083	0.0153	−0.0711, 0.0605
	1988	3	−0.0048	0.0207	−0.0939, 0.0843
Aspen					
1	1986	30	0.0033	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	−0.0240, 0.0304
	1988	28	0.0533	0.0184	−0.0048, 0.0411
2	1986	11	0.0282	0.0193	−0.0143, 0.0707
	1987	11	0.0599	0.0227	0.0099, 0.1099
	1988	10	0.1175	0.0175	0.0779, 0.1571
Red maple					
1	1986	10	0.0307	0.0143	−0.0016, 0.0630
	1987	10	0.0095	0.0129	−0.0197, 0.0387
	1988	10	−0.0852	0.0243	−0.1402, −0.0302
2	1986	70	−0.0019	0.0059	−0.0136, 0.0098
	1987	80	0.0002	0.0064	−0.0125, 0.0129
	1988	84	−0.0771	0.0053	−0.0876, −0.0666

vious years. This indicates the possibility of increased moisture stress in 1988. Red maple is a widespread tree species found on many types of sites; it is characteristic of bottomland, swampy, and moist sites but it often occurs under drier conditions (Fowells, 1965; Harlow and Harrar, 1969). Reduced moisture availability on the study sites in 1988, as indicated by soil water

TABLE 5

Average April–October weather conditions on the two study sites

Variable	Site	Year		
		1986	1987	1988
Air temperature				
(°C 2 m	1	12.9	13.5	13.3
aboveground)	2	12.0	12.7	12.5
Soil temperature				
(°C at 5 cm depth)	1	11.7	12.3	11.6
	2	11.2	11.8	11.2
Precipitation				
(cm)	1	36.6	53.4	44.7
	2	34.2	56.1	53.1
Relative humidity				
(%)	1	-	70.0	62.5
	2	-	84.1	80.1
Soil moisture				
(% at 5 cm)	1	14.1	10.9	10.6
	2	10.4	10.8	9.5

potential at 5 cm, could be the cause of the reduced growth compared with previous years. This emphasizes the necessity of data collection over a longer time period in order to fully evaluate the effect of climatic conditions on tree growth.

Aspen is the only species for which there is a mixed response between the two sites (Table 4). The residuals of total annual aspen diameter growth at Site 1 have increased over the 3 year study period while they have remained relatively constant at Site 2. Both sites are located adjacent to a cleared area but the average distance from the edge to the individual aspen trees is roughly equal for the two sites. In addition, there is no difference in crown position between individuals at both sites; the aspen individuals in these mixed stands all tend to be dominant or codominant individuals. There was also no significant difference in total leaf biomass produced at Site 1 between 1988 and previous years. Taken together, these factors indicate that the aspen at Site 1 could not be responding to an increased light environment in 1988. There is a greater red maple component at Site 1 than at Site 2, and the aspen could be responding to reduced competition from red maple because of the reduction in red maple growth described above. If so, this is happening at Site 1 and not at Site 2 and it is happening in the absence of increased light.

To summarize the total annual growth comparisons, the model performed well for two species (northern red oak and paper birch) at both sites for all 3 years. For one species (red maple), the model did not perform well in 1988 at either site. It is possible that this is a result of decreased moisture availability compared with previous years. These results emphasize the fact that each year represents a unique combination of environmental conditions, and an extended sampling period is needed to fully understand the relationships between tree productivity and climate. For the fourth species (aspen), there is a divergence in model performance between the two sites. The cause of this is not obvious at this time but there does not appear to be a simple environmental or competitive explanation based on the available information from the sites.

Seasonal growth pattern

Seasonal growth pattern is driven in the model by cumulative air temperature degree days and soil water potential on a weekly basis. Differences between estimated and observed seasonal growth patterns are examined using the Kolmogorov–Smirnov procedure to compare the observed and predicted cumulative growth percentages for each week. If an environmental variable affecting seasonal growth pattern is not included in the model, the observed pattern should differ from the predicted pattern. An illustration of the observed and predicted growth pattern is given in Fig. 1.

For northern red oak, there were no significant differences ($P>0.05$) between the observed and predicted seasonal diameter growth patterns at either site in any of the 3 years. This indicates that there is no significant deviation from the seasonal diameter growth pattern predicted by the model.

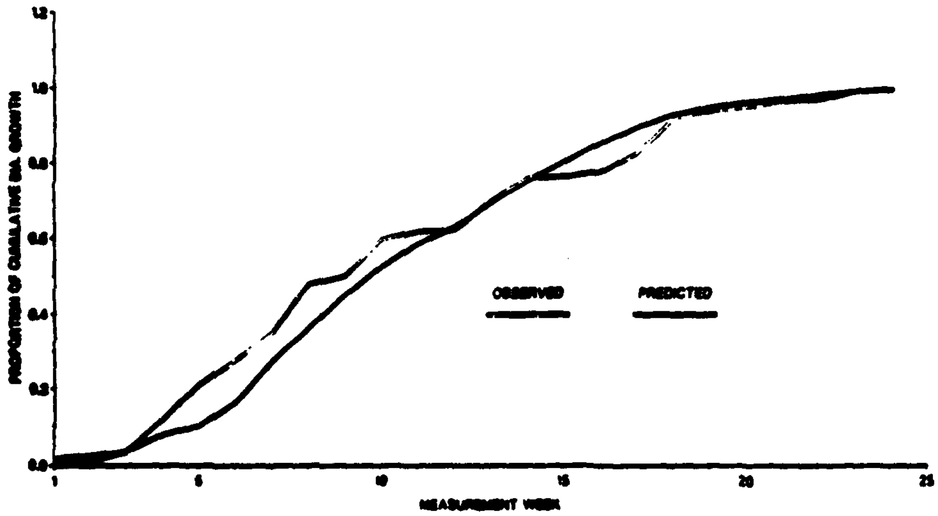

Fig. 1. Observed and predicted seasonal growth patterns for northern red oak on Plot 2, Site 2 in 1988.

For paper birch at Site 1, there were no significant differences between the observed and predicted seasonal growth pattern in any of the 3 years. At Site 2, there were significant differences ($P < 0.05$) between the observed and predicted seasonal growth patterns on one plot in all 3 years and in a second plot in 1987 and 1988; there were no differences on the third plot. It is not clear that these differences are the result of any seasonal difference in climatic conditions between the two sites. The overall effect was that the model predicted a lower proportion of growth early in the year compared with what was observed. As discussed earlier, the overall net effect did not include a difference in total annual growth. The differences may largely be a consequence of small numbers of trees being included in the plot level comparisons.

There were no significant differences ($P > 0.05$) between the observed and predicted seasonal growth patterns for red maple at Site 1 with the exception of one plot in 1986 and another plot in 1988. At Site 2, there was a significant difference ($P < 0.05$) on one plot in 1988 but not in 1986 or 1987 and no differences for the other two plots. There does not seem to be any pattern to these differences. For the majority of plots and years there was no difference between the observed and predicted seasonal growth patterns.

For aspen, there was a significant difference ($P < 0.05$) between the observed and predicted seasonal growth pattern for only one plot in 1 year (1988) at Site 1. This plot only contains a single aspen individual and, while this difference could be related to the increased aspen growth at Site 1, unless this difference is repeated in the future and found on other plots at Site 1 there is no real evidence of a systematic inadequacy in the model's prediction of seasonal diameter growth pattern. At Site 2, there were no differences ($P < 0.05$) between observed and predicted aspen seasonal growth pattern with the exception of one plot in 1986. In 1986, the studentized 95% confidence intervals for the total annual growth residuals did not include zero and this may be having an influence on the evaluation of seasonal growth pattern. This difference was not repeated in later years and, since it only occurred on one plot, does not seem to indicate a serious problem with the model.

In the seasonal growth pattern evaluations, comparisons were made on a plot basis (using the three plots at each site) rather than on the site level. There were a number of instances where individual plots differed in observed and predicted seasonal growth pattern for single years, but paper birch at Site 2 was the only case where differences between the observed and predicted patterns were noted on all or most of the plots. Even here, there were no apparent climatic differences which seemed to have caused the model performance to deteriorate. Whatever the cause, it was not sufficient to be associated with an overall decrease of model performance in estimating total annual growth as discussed above.

CONCLUSIONS

Many existing models which represent tree growth as a response to climate contain assumptions which may be adequate on a regional basis but which cause poor model performance on many individual sites. Species' maximum diameters and heights, for example, are utilized in many of these models and, while it is well known that these are site dependent, this fact is not recognized in most existing growth models. Another example is a species' response to climate. From provenance trials it is well known for many species that genetic material from different locations within a species' geographic range responds differently to climatic conditions at a given site (Carter, 1991). In many existing models a species' growth response to a given heat sum is assumed to be constant, even though differences in heat sum are used to represent different sites. There are many problems, therefore, in utilizing existing models to project the response of local tree populations and ecosystems to changing environmental conditions.

For many species and localities, traditional forest growth and yield information can be utilized in localizing the dimensional limits in existing models. Because of the problems encountered when applying existing models to local populations, it is important to localize such models when applying them to historical data to investigate impacts of historical climatic or pollutant exposure conditions. In this study, methods were developed and illustrated which utilize height/diameter models from the literature to develop expressions for maximum tree height and diameter as a function of site index and maximum stand basal area. Such methods of localizing existing growth models could be developed for many species in much of the world.

An annual timestep may not be sufficient for modeling tree response to environmental conditions. Ecosystem level response to a shift in environmental conditions may be on the order of several years while an individual tree's response to changes in environmental conditions, such as moisture or nutritional status, is on the order of a few days. Also, the timing of events such as drought during the growing season is as critical as their intensity in determining their effect on tree growth. The amounts and timing of precipitation and the temperature pattern within a given year interact to make each year a unique combination of environmental factors affecting plant communities. For these reasons, a weekly timestep was utilized in modeling seasonal growth pattern and, by summation, total annual diameter growth on the study sites.

In this study, over two sites and 3 years, the model of seasonal and annual diameter growth performed well for two of the four species. For a third species, there was a growth reduction at both sites in the third year, most likely a result of a combination of temperature and precipitation leading to a reduction in available water during the growing season. For the fourth species, there was an unexplained differential in model performance between the two sites. These results emphasize the need for site-specific information collected annually over an extended period in order to fully understand and quantify the effects of environmental factors on forest productivity.

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:
LITTER DECOMPOSITION AND MICROFLORA
The Michigan Study Site

ANNUAL REPORT 1993

SUBCONTRACT NUMBER: E06549-84-C-002

MICHIGAN TECHNOLOGICAL UNIVERSITY
HOUGHTON, MICHIGAN

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ABSTRACT

The ninth year of litter decomposition study has nearly been completed with red pine, northern red oak, and red maple leaf litter in hardwood stands (control and antenna sites) and red pine plantations (control, antenna, and ground sites). The sample units consist of bagged bulk leaf samples of each litter species, for determination of dry matter mass loss. All 1993 samples have been retrieved, and nearly all of these have been processed for statistical analysis. Analysis of the complete 1985 - 1993 data set also awaits receipt of the 1993 weather data, for calculation of our weather-related covariates.

Precision in the data sets has been higher for the hardwood stands than for the plantations. The hardwood stands have provided more stable environments among years for litter mass loss study than have the rapidly developing pine plantations. This is an important consideration with respect to our objective of detecting possible effects of increasing ELF EM field exposures.

Of the three study litter species, pine and oak have provided more precise data than maple. Maple litter fragments to a greater extent than do either pine or oak litter.

Two types of ANACOV model have been used to evaluate site-year interactions. The traditional Effects Model ANACOV examines data sets for differences among years, sites, and months, with blocking by plot nested within site, and for site-year interaction. The mathematically equivalent Means Model ANACOV looks for differences among categorical "siteyears" (e.g., control-1985, antenna-1985, ground-1985, control-1986, etc.). When differences exist among siteyears, multiple comparisons are used to explain site trends among years.

Our principle objectives are 1) to use ANACOV to explain differences among years and sites, and site-year interactions, using covariates unrelated to ELF field exposures, and 2) to evaluate the temporal patterns of remaining differences relative to ELF EM field variables. We recognize that the utility of ecologically appropriate covariates may be compromised if their temporal distribution patterns can not be shown to be statistically independent of ELF EM field variables.

Covariates have explained many differences among sites, years, months, and siteyears. We have settled on a set of covariates based on seasonal inputs of energy and moisture to the decomposition system. This set of covariates expresses the seasonal effects of energy inputs with respect to concurrent precipitation inputs. One additional covariate corrects for the differences among years in monthly sample collection dates.

Analysis of the siteyear patterns in the hardwood stands (for all three litter species) suggests that ELF EM fields may slightly accelerate the rate of litter decomposition. Throughout the first eight years of study, the annual patterns of litter mass loss have tended to be similar for both study hardwood stands. Nevertheless, ANACOV indicates that decomposition progressed more quickly at the control site than at the overhead antenna site through 1987, but more quickly at the antenna site than at the control site from 1988 through 1992. This tendency was not statistically significant for all years, and was most pronounced for oak litter. Final analysis with the pivotal 1992/93 experiment awaits availability of the necessary weather data.

The Armillaria root disease epidemics in all three plantations have been documented since their onset in 1986. Armillaria root disease is easily diagnosed, permitting accurate mapping as the basis for statistical modeling. Sampling is accomplished by taking census of each plantation periodically. Pathogenic *Armillaria* genets (individuals) have killed from 8 to 43 percent of the red pine plantation populations to which they have access. Documented Lake States epidemics of Armillaria root disease in red pine have peaked after 10 years of activity. Nevertheless, relatively little root disease mortality developed in 1992 and 1993. The combination of markedly cool wet weather and increased seedling size may have had the combined effect of reducing seedling vulnerability.

The monomolecular rates of disease progress for all *Armillaria* genets large enough to have killed at least 10 seedlings were compared among plantations by ANOVA, and with each other by the Tukey-Kramer method for unplanned comparisons. Although no significant differences in disease progress rates were found among plantations, many significant differences were detected among genets by comparing disease progress rates (regression slopes). Rates of disease progress ranged similarly in all three plantations, and were only correlated with seedling size at the control site. Area occupied by each genet remains to be determined in the near future. The numbers and basal areas of stumps (potential *Armillaria* foodbases) on an area basis will then be tested for correlation with genet disease progress rates. Nevertheless, our results currently suggest 1) significant and similar variation in virulence among the pathogenic *Armillaria* genets occurring in the three study plantations, and 2) no detectable effect of ELF EM field exposures on rate of Armillaria root disease progress.

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EXECUTIVE SUMMARY

Maple, oak, and pine leaf litter decomposition have been studied from 1985 through 1993. Pine mycorrhiza-associated streptomycete bacteria populations were studied from 1985 through 1991. The ongoing Armillaria root disease epidemics in the three study pine plantations have been documented since their onset in 1986.

Litter Decomposition: We are studying litter decomposition in both the red pine plantations and their neighboring hardwood stands. Hardwood stands and plantations present very different environments for decomposition. Our oak, maple, and pine foliar litter substrates differ in composition, favoring different components of the decomposer community. Maple litter decays fastest (with considerable fragmentation), providing the most variable data. Pine litter decays most slowly, providing the least variable data, and oak litter is intermediate. Very small changes in decompositon progress are statistically detectable for all three species in both stand types.

The statistical technique employed is to compare decomposition progress on the three sites (control, overhead antenna, and antenna ground) over a period including both pre-and post-treatment years. Because climatic conditions vary among sites and years, the decomposition data must be adjusted for temperature and precipitation variation using covariate analysis (ANACOV). Covariates have explained many differences among sites, years, and months, and much of the site-year interaction. The site-year interaction measures whether the relationship between sites changes with time. Because of the pre- and post-treatment design, insignificant site-year interactions imply no ELF effect. Further, significant site-year interactions imply an ELF effect only if they mimic the temporal pattern of ELF exposures among the study sites. We are using a set of seasonal covariates which permits expression of the seasonal effects of energy inputs with respect to concurrent precipitation inputs.

One additional covariate corrects for the differences among years in monthly sample collection dates.

Some differences in decomposition progress among sites and years, and site-year interactions, remain unexplained by ANACOV. These differences are being evaluated in light of what we know about ELF EM field exposures at the study sites. Analysis of the site-year patterns in the hardwood stands (for all three litter species) suggests that ELF EM fields may accelerate litter decomposition. The pattern of differences between the antenna and control hardwood stands appears to have reversed in 1988. The difference resulting from the reversal is not statistically significant for all years, and was most pronounced for oak litter. Issues under consideration include 1) whether or not a true change in decomposition rate has developed at the antenna site and/or at the control site, 2) the actual magnitude of any rate change(s), and 3) the biological significance and potential ramifications of such changes. These issues will be addressed in light of analysis of the complete data set, which awaits the availability of 1993 weather data.

Mycorrhizoplane Streptomycetes: There is no indication of any ELF EM field effect through 1991 on red pine mycorrhiza-associated streptomycete bacteria populations. ANACOV has explained all differences among sites and months, as well as the site-year interaction, for numbers of streptomycete morphotypes. Morphotype numbers have decreased in all three plantations since their establishment in 1984. We suspect that this decrease is associated with the establishment of red pine monocultures on sites which formerly supported more diverse mixed hardwood/conifer forests. ANACOV has also explained the differences among sites and the site-year interaction for total streptomycete numbers. Levels have not followed a recognizable pattern over the years.

Obtaining sufficient statistical power to detect effects of ELF

EM fields has been a major difficulty. A change in streptomycete levels of 26 to 50 percent between two site/year combinations would be detected only 50 percent of the time. Large detectable differences for morphotype numbers (20 to 37 percent for site-year combinations) are less of a problem, because the numbers detected are very low. Nevertheless, ranging from 2 to 4 morphotypes per sample, shifts of this magnitude would likely involve declines in abundance (or outright loss) of several of the approximately 20 streptomycete morphotypes observed over the past six years.

Armillaria Root Disease Epidemiology: Pathogenic Armillaria genets have killed from 8 to 43 percent of the accessible red pine plantation populations. The disease progress rates for pathogenic Armillaria genets in the three plantations were compared by ANOVA. Although significant differences were not found among plantations, many significant differences were found among genets by comparing disease progress rates (regression slopes). Rates of disease progress ranged similarly in all three plantations, and were inversely correlated with seedling size at the control plantation (but not at the other two plantations). The numbers and basal areas of stumps (potential Armillaria foodbases) on an area basis remain to be tested for correlation with genet disease progress rates. Nevertheless, our results currently suggest 1) significant and similar variation in virulence among the pathogenic Armillaria genets occurring in the three study plantations, and 2) no detectable effect of ELF EM fields on rate of Armillaria root disease progress.

INTRODUCTION

Background

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF EM fields cause fundamental changes in forest health. This research program includes two separate yet highly integrated projects, the Upland Flora Studies project and the Litter Decomposition and Microflora project. Work elements of the Litter Decomposition and Microflora project have examined 1) rates of litter decomposition in both hardwood stands and red pine plantations, 2) mycorrhizoplane streptomycete population dynamics on red pine plantation seedlings, and 3) Armillaria root disease epidemiology in the red pine plantations. These work elements have shared the same field sites with the Upland Flora Studies project. In fact, the Armillaria root disease work element is adopted from the Upland Flora Studies project. These three work elements have complemented and extended the program of the Upland Flora Studies project. The information obtained is being used for comparison of pre-operational and operational status of the study variables on both treatment and control sites, to evaluate possible ELF EM field effects on the local forest ecosystem.

We believe that the research programs representing all three work elements are biologically and statistically defensible. However, only the litter decomposition study has provided preliminary evidence of possible ELF EM field effects, whereas the mycorrhizoplane streptomycete and the Armillaria root disease epidemiology studies have not. The 1993 Annual Report examines the degree of success achieved by research in all three work elements to date, and outlines plans for conclusion of the litter decomposition and Armillaria root disease work elements in 1994.

Objectives

The overall objectives of these work elements are to determine the impacts of ELF EM fields on:

1) rates of litter decomposition for three important local tree species (red maple, northern red oak, and red pine),

2) overall levels and taxonomic richness of mycorrhizoplane streptomycete populations, and

3) rates of Armillaria root disease progress in red pine plantations.

Ultimately, the question of whether ELF EM fields impact these segments of forest communities will be answered by testing various hypotheses (Table 1) based on the results of relatively long-term studies.

Table 1. Critical null hypotheses which will be tested to fulfill objectives of the ELF environmental monitoring program Litter Decomposition and Microflora project.

I. Differences in the level of foliar litter decomposition unexplained by ANACOV (among hardwood stands or among plantations, among years, and among "siteyears") for each study litter species, are not explainable using spatial and temporal factors of ELF electromagnetic field exposure.

II. There is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations on the plantation red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

III. There is no difference in the representation of different identifiable strains of mycorrhizoplane streptomycetes on the plantation red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

IV. There is no difference in the rate of Armillaria root disease progress in the study red pine plantations that cannot be explained using factors unaffected by ELF antenna operation.

PROJECT DESIGN

Overview of Experimental Design

Emphasis has been placed on development of a statistically rigorous experimental design capable of separating potentially subtle ELF EM field effects from the natural variability associated with soil, vegetational, climatic and temporal factors. Consequently, in order to most effectively test our hypotheses, we have fully integrated our studies with those of the Upland Flora Studies project, permitting us to take full advantage of both that project's basic field design and the extensive data collected by that project on the tree, stand and site factors which influence or regulate the processes and populations we are measuring (Table 2). The measurements made and the associated analyses are discussed more thoroughly in the following sections. The experimental designs integrate direct measures with site variables, and are a common thread through the work elements of both projects due to shared components of the field design.

Because of the similarity in analyses, an understanding of this experimental design is essential. However, the rationale and progress for measurements in each work element of this study are necessarily unique and will be discussed separately in the following sections.

Experimental Design and Electromagnetic Exposure

The EM fields associated with the ELF system are different at the overhead antenna and ground locations. Therefore, the general approach of the study required plots to be located along a portion of the overhead antenna, at a ground terminal, and at a control location some distance from the antenna. IITRI has measured 76 hz electric field intensities at the three study sites since 1986 when antenna testing began; background 60 hz

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Litter Decomposition and Microflora project, the objective each group of measurements relates to, and the work elements which address the necessary measurements and analyses.

Hypothesis Number	Related Objective	Measurements	Work Elements
I	1	**Monthly determinations of dry matter loss, from bulk leaf litter samples of oak, maple, and pine**[2]; climatic and biotic variables, litter nutrient and lignin contents	1,(1),(5)[1]
II	2	**Monthly counts of streptomycetes associated with Type 3 red pine seedling mycorrhizae**; climatic variables	2,(1)
III	2	**Monthly counts of numbers of streptomycete morphotypes associated with Type 3 red pine seedling mycorrhizae**; climatic variables, sample processing delay	2,(1)
IV	3	**Monthly mapping and identification of <u>Armillaria</u> cultures isolated from red pine seedling mortality**; climatic variables, ELF EM field strength, seedling size, hardwood stump population characteristics	3,(1),(2)

[1] Numbers in parentheses refer to work elements in the Upland Flora Studies project.

[2] Bold print designates the response variable; other variables listed are covariates.

field intensities were measured at all sites in 1985. Three types of EM field are measured: magnetic (mG), longitudinal (mV/m), and transverse (V/m).

The most general experimental design for the Upland Flora Studies project is a split-plot in space and time. Each site (control, antenna, and ground) is subjected to a regime of ELF field exposures and is subdivided into two stand types: pole-sized hardwood stands and red pine (*Pinus resinosa* Ait.) plantations. Both stand types at each field site are divided into three contiguous plots to control variation. The time factor is the number of years in which the experiment is conducted for pre-operational and operational comparisons, or the number of sampling periods in one season for year to year comparisons. It is necessary to account for time since successive measurements are made on the same whole units over a long period of time without re-randomization. A combined analysis involving a split-plot in space and time is made to determine both the average treatment response (site difference) over all years, and the consistency of such responses from year to year.

Each site follows this design with one exception. There is no pole-sized hardwood stand type at the ground unit, because the necessary buffer strips would have placed the hardwood stand type too far from the grounded antenna for meaningful exposure. Thus one treatment factor (hardwood stands) is eliminated at the ground site. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. Where analyses are conducted on only one stand type, the stand type treatment factor is irrelevant and is not included in the analysis. This is the case for all studies of the Litter Decomposition and Microflora project. All other factors remain unchanged.

Analysis of Covariance

Analysis of variance (ANOVA) and analysis of covariance (ANACOV) are used in our studies to determine effects of treatments on decomposition progress, streptomycete population levels and morphotype numbers, and rates of Armillaria root disease progress. Treatments in the case of litter decomposition include year, individual plantation or hardwood stand, and monthly sampling date. For streptomycete population dynamics, treatments include year, plantation, and monthly sampling date. For rate of root disease progress, the only treatment is the individual plantation. The statistical design employed for all three work elements reported here is a factorial design with blocking and covariates. The factors included in the design vary somewhat by experiment. They include year, month, site, and blocking for the litter decomposition and streptomycete studies. Site and blocking (see below) are the only factors included in the design for root disease study. In this special case, time is accounted for in calculating the rate constant. In the litter decomposition work element, separate analyses are conducted for the hardwood and pine plantation stand types, to satisfy the assumptions required by the ANOVA and ANACOV models.

The experiments conducted in the Litter Decomposition and Microflora project are not split-plot experiments across time, a design frequently used in the Upland Flora Studies project. A split-plot design across time requires repeated measurements on the same experimental unit. In contrast, the experimental units in the litter decomposition and streptomycete work elements are destructively sampled to obtain the required measurements; the experimental units in the root disease work element are the 18 naturally-occurring pathogenic Armillaria genets present in the three study plantations (3, 6, and 9 in the antenna ground, overhead antenna, and control plantations).

Blocking is employed to control variability. In the root disease models, for example, the three plots comprising each plantation are blocks, and each contains four quarter-plot experimental units. The blocking employed produces an unbalanced incomplete block design (i.e., not all ELF treatments can be represented in each block). The incomplete block design is dictated by the spatial separation of the ELF treatments.

Our experimental design directly controls experimental error to increase precision. Indirect or statistical control can also reduce variability and remove potential sources of bias through the use of covariate analysis. This involves the use of variables (covariates) which are related to the variable of interest (variate). Covariate analysis removes the effects of an environmental source of variation that would either inflate the experimental error or inappropriately increase the variability explained by the treatments. Identification of covariates which are both biologically meaningful and independent of treatment effects is one of the most important steps in our current analysis. Variables must be unaffected (both directly and indirectly) by ELF EM fields in order to be legitimately used as covariates to explain (with respect to ELF EM fields) any non-ELF-induced differences in response variables among years or sites. The independence of the ambient conditions covariates are tested by the Upland Flora Studies project.

Covariates under examination differ among the dependent variables considered (Table 2). For the litter decomposition studies, we have recently developed a set of seasonal cumulative (rather than annual cumulative) weather-related covariates which better reflect the seasonal interaction between energy and moisture inputs to the decomposition process. We have also developed another effective covariate for these studies, based on the deviation (in days) between a standard set of retrieval dates and each actual retrieval date. These new covariates are both biologically meaningful and statistically significant without violating the assumptions required for ANACOV. They also do the best job of explaining treatment differences detected by ANOVA. As in previous reports, mycorrhizoplane streptomycete analyses use climatic variables computed as annual running totals of air or soil temperature degree days, total precipitation, and/or numbers of precipitation events. Covariates are currently being incorporated into the Armillaria root disease progress analysis.

The adjusted treatment means presented for each ANACOV model employ the arc sin square root transformation of raw data (for litter decomposition, as X_r, the proportion of dry matter mass remaining), or the log10 transformation of raw data (for mycorrhizosphere streptomycete levels and morphotype numbers). The adjusted treatment means are adjusted for the covariate(s) used, and represent the transformed data after the treatment means have been adjusted for the effect of the covariate(s). Throughout the ANACOV discussion, differences detected between means are <u>after</u> the effect of the covariate(s) has been considered. Thus, for example, when it is stated that decomposition failed to progress during a given month, the interpretation should be that the covariate(s) adequately explained any change that may have occurred during that month.

Testing for ELF EM Field Effects

ELF EM field intensities appear to be affected by vegetative and soil factors. Also, timing and intensity of ELF EM field treatments have varied through various phases of antenna testing prior to full antenna operation. The antenna was activated for low-level intermittent testing during the 1987 and 1988 growing seasons, and achieved fully operational status late in 1989. Therefore, hypothesis testing examines differences in response variables between fully operational years vs. intermittent testing years vs. pre-operational years, as well as among antenna, ground, and control sites within years.

In the litter decomposition study, ANACOV models nearly always indicate significant site-by-year interactions. Furthermore, these interactions are highly significant. The interpretation of the site-by-year interaction is that the year must be known to predict the site effect, and conversely the site must be known to predict the year effect. In this case, explaining the main effect of year or site does not necessarily indicate that no ELF EM field effect is occurring. Furthermore, it can be hard to interpret the interaction term to understand if the effect follows the same pattern as the ELF EM field exposure, or if it is only random variation due to microclimatic factors not represented in the analysis.

An alternative ANACOV model, the means model, has been formulated to address this problem. In this representation, each combination of the factor levels is included as a separate treatment. Thus, the two treatments and the interaction term are combined into one treatment, which we call Siteyear; individual treatment levels include Overhead-1985, Overhead-1986, ... , Overhead-1992, Ground-1985, Ground-1986, ... , Ground-1992, Control-1985, Control-1986, ..., and Control-1992. This approach is mathematically equivalent to the effects model, but it allows more detailed analysis of the treatment combinations. The means model was demonstrated in the Annual Report 1990 (pages 33-36), using the bulk pine experiment. The means model allows us to analyze the information at a much more disaggregated level than does the effects model.

Detection Limits and Statistical Power

Because of the variability inherent in ecosystem studies, coupled with the expected subtle nature of any perturbations due to ELF EM field exposure, a quantitative assessment of the level of precision achieved by each study is central to likelihood of perturbation detection. Two different measures were considered to make this evaluation: statistical power and detection limits.

Power is defined as the likelihood that a particular statistical test will lead to rejection of the null hypothesis if the null hypothesis is false. Exact calculation of power requires 1) knowledge of the alpha level (Type I error), 2) knowledge of the parameters of the distribution of the variable of interest under the null hypothesis, 3) specification of a given alternative parameter value, and 4) knowledge of the probability of detecting a change of the chosen magnitude (also called beta or Type II error level). In a t-test, for example, to determine power one must know the alpha level (commonly 0.05), the value of the test statistic under the null hypothesis (zero, if the test is to determine whether two means are different), the degree of difference in the means which is considered biologically important (e.g., 10 percent difference), and the proportion of the time this change would be detected (e.g., a 90 percent chance that a 10 percent change would be detected). The last two values are difficult for scientists to agree upon in ecological studies, because it is often a matter of judgement. Quantitative knowledge of ecological relationships is often poor, and certain knowledge may be lacking (e.g., whether a ten percent difference in a parameter is important where a five percent difference is not). While it is possible to construct curves showing power for a number of alternative hypotheses, one is still left with the question of how much of a difference is important.

An alternative procedure is the a posteriori calculation of the detection limit (i.e., the percent difference between two means which results in a specified chance of correctly rejecting the null hypothesis for a given alpha level). This is really just another way of wording a power statement. Use of the detection limit allows reviewers to evaluate the test in light of their own views of what percent difference is important. A detection limit is not exact, since it is an a posteriori test, depending on the data used in the test procedure and the procedure itself. The detection limits presented in this annual report were calculated from the results of ANACOV models and the least square means procedure employed by the SAS Proc GLM software.

In summary, calculation of statistical power has the advantage of being exact, but the disadvantage for ecological studies of requiring specification of the degree of change and probability of detection considered important. The calculation of detection limits has the advantage of not requiring specification of an alternative (power is fixed at 50 percent), but the disadvantage of being an *a posteriori* calculation, and therefore not exact. We feel that the detection limit provides the same information as statistical power, and that the detection limit is more suitable for ecological studies since specification of an exact alternative hypothesis is not required.

Calculations of Detection Limits

The following example uses the mycorrhizoplane streptomycete levels ANACOV for all 7 study years (1985 - 1991). Two points need to be made before the examples are presented:

1) In ANACOV, the variance and standard error for each effect level (*e.g.*, year) is different. This happens because the mean of the values of each covariate representing each effect level is not the grand mean for that covariate. The closer the representative covariate values representing each effect level are to their grand mean, the lower the variability (standard error) will be for the corresponding LSMEAN.

2) Our analytical approach is based on the ability to determine whether or not two sample means are statistically different. The process for determining if two sample-based means are different is outlined below.

General Approach: Because the standard error of the LSMEAN varies, it seems reasonable to evaluate the power for more than one effect level (*e.g.*, year). We have chosen to evaluate the power of two LSMEANs for each effect, the one with the lowest variability and the one with the highest variability. In addition, we have chosen to make each comparison with another hypothetical, equally-variable LSMEAN. This should provide a reasonable range of detection limit estimates for the effect considered.

The least variable LSMEAN: Considering the Year effect in the streptomycete levels ANACOV, 1989 had an LSMEAN of 5.4516 and a standard error of 0.03224. The size of the test is 5 percent ($\alpha = 0.05$), and the power of the test is 50 percent ($\beta = 0.50$):

$$Z = (LSMEAN1 - LSMEAN2) / (SE_{LSMEAN1}^2 + SE_{LSMEAN2}^2)^{0.5}$$

Because $\alpha = 0.05$, the Z value is 1.96. Therefore,

$$1.96 = (LSMEAN1 - LSMEAN2) / (0.03224^2 + 0.03224^2)^{0.5}, \text{ and}$$

$$\begin{aligned} LSMEAN1 - LSMEAN2 &= 1.96 * (0.03224^2 + 0.03224^2)^{0.5} \\ &= 1.96 * 0.04559 \\ &= 0.08936 \end{aligned}$$

Therefore, for another LSMEAN to be different from 1989 (assuming it has the same variance, and using Tukey's HSD multiple range test), it would need to have a value outside the range: 5.4516 ± 0.08936. It follows that LSMEANs outside the range

$$5.3622 \leq LSMEAN \leq 5.5410$$

would be significantly different from the 1989 mean.

The detection limit statement for this interval would be: If two actual effects level means ($\log_{10}$-transformed data) differ by 0.08936, then there is a 50 percent chance that this difference will be found if $\alpha = 0.05$.

Since the dependant variable is transformed, the interval above is more biologically meaningful if translated back to the original units. Unfortunately, the transformation back to the original units does not preserve the interpretation of the detection limits. This occurs, in part, because the mean of the transformed dependent variable does not, upon reverse transformation, equal the mean of the original dependent variable (i.e., the mean of the dependent variable is not invariate under non-linear transformation). We will complete the back-transformation process to give an estimate in biologically meaningful units of the detection limits, but must emphasize that this results in a biased approximation of the actual detection limits. Furthermore, the direction and magnitude of the bias are unclear.

$$10^{5.3622} \leq (\text{observed value} = 10^{5.4516}) \leq 10^{5.5410}, \text{ or}$$

$$230{,}250 \leq (\text{observed value} = 282{,}879) \leq 348{,}498$$

Note that the interval, when transformed back to the original units, is not symmetric about the 1989 LSMEAN. That is, the lower limit is closer to the mean than the upper limit.

The detection limit can also be approximately expressed as a proportion of the back-transformed LSMEAN, as:

$$0.5 * (348{,}498 - 230{,}250) / 282{,}879 = 0.2090$$

The Most Variable LSMEAN: The most variable year in the streptomycete levels ANACOV was 1985, with an LSMEAN of 5.3288 and a standard error of the LSMEAN of 0.05699. (Note: One reason for the larger LSMEAN standard error for 1985 is the smaller initial sample size used in 1985.) The same process followed above is used to establish the "low estimate" of power using these values.

$$LSMEAN1 - LSMEAN2 = 1.96 * (0.05699^2 + 0.05699^2)^{0.5} = 0.15798$$

It follows that LSMEANs outside the following range would be significantly different from the 1985 mean.

$$5.1708 \leq LSMEAN \leq 5.4868$$

The detection limit statement for this interval would be: If two actual effects level means (log_{10}-transformed data) differ by 0.15798, then there is a 50 percent chance that this difference will be found if $\alpha = 0.05$.

Back-transformed to the original streptomycete colony-forming units, the interval above becomes[1]:

$$148{,}184 \leq (\text{observed value} = 213{,}206) \leq 306{,}761$$

As a proportion of the back-transformed LSMEAN, the detection limit is approximately[1]:

$$0.5 * (306{,}761 - 148{,}184) / 213{,}206 = 0.3719$$

In this report, detection limits will be expressed both as 1) the detection limit difference in transformed units (e.g., 0.08936 and 0.15798, for 1989 and 1985, respectively), and 2) a proportion of the back-transformed LSMEAN[1] (e.g., 0.2090 and 0.3719, for 1989 and 1985, respectively).

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[1] See the above discussion concerning bias resulting from this non-linear transformation.

WORK ELEMENTS

The work elements of the Litter Decomposition and Microflora project acknowledge the three diverse study areas included within this project. Data from work elements of the "Trees" project are used to test each hypothesis posed by this project (Table 2). The following sections present a synopsis of the study rationale, measures, and analytical results for each work element of this project.

ELEMENT 1: LITTER DECOMPOSITION

Introduction

Knowledge of key decomposition processes and their rates is essential to conceptualization of ecosystem dynamics. Organic matter decomposition is primarily accomplished by microorganisms, whose activities are regulated by the environment. Environmental factors which disrupt decomposition processes detract from the orderly flow of nutrients to vegetation. As a new and anthropogenic environmental factor, ELF EM fields merit investigation for possible effects on the litter decomposition subsystem.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar 1978). Conversely, dry matter mass loss is a useful measure of the impact of environmental perturbations on the integrated activities of the litter biota. The methods employed in these studies integrate the activities of all but the largest soil fauna, and ELF EM fields represent one possible cause of environmental perturbation.

Studies of litter decomposition also extend the usefulness of litter production data collected in the course of forest vegetation studies. Knowledge of litter biomass production and nutrient content provide one link between the overstory and forest floor components of the forest ecosystem.

The forest vegetation at all three study sites is classified in the *Acer-Quercus-Vaccinium* habitat type (Coffman *et al*. 1983). The two hardwood species selected for study, northern red oak (*Quercus rubra*) and red maple (*Acer rubrum*), are common to both of the hardwood stand subunits. Red pine (*Pinus resinosa*) was selected as the conifer species for study because 1) it exists as scattered mature specimens throughout the area, and 2) the study plantations were established with red pine. These three study species represent a range of decomposition strategies and rates.

Nine years of maple, oak, and pine leaf litter decomposition study have been completed at the ground, antenna, and control study sites. The litter decomposition study element involves evaluation of the potential for subtle ELF EM field effects on the activities of communities of interacting microorganisms. Underway since 1985, this work has spanned two pre-operational years and three (possibly four, including 1991) years of intermittent antenna testing, but only two fully operational years. The 1992/93 data set is essential to provide sufficient data for evaluation of the possibility of ELF EM field effects on these aspects of forest health.

The decision to continue data collection for the litter decomposition work element is based on the following criteria:

1. evidence in the current database suggesting possible ELF EM field effects on the response variable, and
2. subtle changes in decomposition rate can be detected (generally, detection limits below ten percent suggest sufficient precision to detect subtle responses to ELF EM field effects).

Methods

Litter decomposition is being quantified as percent change over time in dry matter mass. We are currently prototyping the laboratory methods for determining X_m on an ash-free basis for use as the independent variable in our models. If resources permit (and we think they may), the final report will use ash-free X_m as the response variable (at least for critical treatments such as oak in the hardwood stands). Dry matter mass loss from freshly fallen foliar litter samples has been widely used as a measure of fully integrated litter decomposition

(Jensen 1974, Millar 1974, Witkamp and Ausmus 1976, Fogel and Cromack 1978). Experiments in this project are conducted annually and focus on decomposition progress during the year following autumn litterfall. Bulk foliage samples of all three litter species for the ninth year of study have been recovered from the field.

A single parent litter collection, from a single location, is made for each study species in order to avoid the effects of possible differences in substrate quality associated with geographically different litter sources. Ratios of fresh to dry matter mass and initial nutrient content are determined for random samples taken at regular intervals during field sample preparation from each of the annual pine, oak, and maple litter parent collections. All mass loss data are based on 30°C dry masses. Samples destined for the field are pre-weighed and enclosed in nylon mesh envelopes (3 mm openings) constructed to lie flat on the ground.

All samples were placed in the field in December, and subsets were retrieved at approximately monthly intervals from early May to early November. Snow cover at the study sites dictated the earliest and latest possible recovery dates from the plantation subunits. The experimental design used throughout the study was as follows. Two clusters of samples were placed on each of the three plots comprising each plantation and hardwood stand type. One envelope per species was retrieved each month from each of the 6 clusters per plantation or hardwood stand.

Raw data were expressed as the proportion (X_m) of original dry matter mass remaining over time. Sufficient samples were recovered each month to permit analysis of differences in dry matter losses between sites, years, and monthly sampling dates by ANACOV. Dry matter mass loss data were transformed to the arc sin square root of X_m, to homogenize variances prior to ANACOV (Steel and Torrie 1980).

Throughout the study, all bulk litter samples have been either ground for nutrient analysis or archived for possible future nutrient analysis. The residual portion of every ground sample, beyond the portion required for nutrient analysis, has been archived for future reference. Bulk standard samples representing the parent litter collections have been analyzed for percent N, P, K, Ca, and Mg content. However, we have suspended nutrient analysis of retrieved samples, in order to devote available resources to mass loss studies. Discontinuation of nutrient analyses on retrieved samples is also justified by the tenability of nutrient data as covariates. If decomposition is at all affected by ELF EM field exposure, it is quite likely that sample nutrient content would also be affected. The use of covariates whose levels may be influenced by the experimental treatment (i.e., ELF EM field exposure) could mask the presence of ELF effects in the analysis.

All ANACOVs have been conducted on the mainframe computer, using PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985). In all statistical analyses, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$, regardless of the statistical test employed. Multiple range comparisons among significant differences detected by ANACOV are identified by the Least Square Means pairwise comparison option, within PROC GLM.

The almost uniformly significant year-by-site interactions are especially interesting, because they may indicate an ELF effect on decomposition rate. In order to explain significant year-by-site interactions, two types of ANACOV model have been used. First, the traditional Effects Model ANACOV examines the data set for significant differences among years, sites, and months, as well as for significant year-by-site interaction. Second, the mathematically equivalent Means Model ANACOV looks for significant differences among "siteyears" (e.g., control1985, antenna1985, ground1985, control1986, etc.). When significant differences exist among siteyears, multiple comparisons can be used to identify site trends among years. Our principle objectives have been 1) to use ANACOV to explain differences among years and sites, and year-by-site interactions, using covariates unrelated to ELF field exposures, and 2) to evaluate the temporal patterns of remaining unexplained differences relative to ELF EM field variables.

Covariates have proven useful for explaining differences among sites, years, and months, and siteyears. Since 1991, we have used a set of covariates based on seasonal inputs of energy and moisture to the decomposition system. This set of covariates permits expression of the differential seasonal effects of energy inputs with respect to concurrent precipitation inputs. One additional covariate corrects for the differences among years in monthly sample collection dates.

It is possible for a treatment to display a non-causative but statistically significant correlation with covariates. This would result in a classic case of multicolinearity, causing a reduction in the power of statistical tests involving both the covariate and the treatment (see Judge et al. 1982 for a complete discussion of the issue). This does not, however, seem to be a problem for this study, because of the small differences that are detected as statistically significant.

Whenever ANACOV is used, there is concern for whether or not the covariate values can be affected by the treatment under investigation (in this case, ELF EM field exposure). Where this type of effect occurs, some of the observed response which should be allocated to the treatment may possibly be allocated to the covariate. Thus, if a covariate and the treatment are correlated, and if the correlation could have been caused by the treatment, it would be inappropriate to use that covariate. Nevertheless, it is frequently the case that a covariate value could not reasonably be affected by the treatment. This is most clearly true in any case where the covariate is measured before the treatment is applied, but is often clearly true even if the covariate is measured during or after treatment application. We can argue strongly that this is true for our weather covariates. Operation of the Michigan ELF antenna is expected to have only subtle, if any, effects on biotic communities, but there seems no plausible argument for any effect of ELF EM fields on the basic weather pattern at the treatment sites. Thus, our precipitation and temperature covariate patterns cannot be caused by ELF.

1992/93 Study

Fresh-fallen red pine litter was again collected on netting in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its remoteness from interfering ELF EM fields. Red maple litter was similarly collected seven miles from Houghton, for the same reasons. Northern red oak litter was collected northeast of the control plantation plot 3. Bulk pine sample envelopes measured 22 cm x 28 cm, and contained 10 g (air dry) of the parent collection. Bulk maple and oak sample envelopes measured 44 cm x 28 cm, and contained 15 g (air dry) of the parent collection.

The experimental design remained unaltered. Eight bulk litter envelopes of each species were placed together at two locations on each of the three plots comprising each subunit. One bulk envelope per species was retrieved each month from each of these 6 locations per subunit.

Description of Progress

1992/93 Study

Tables 3 through 5, respectively, present mean dry matter mass loss summaries (raw, untransformed data) for the bulk pine, oak and maple foliage samples retrieved in 1993 (by sampling date, site and stand type), along with standard deviations and minimum

Table 3. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1993, for **bulk red pine** foliar litter samples disbursed in December, 1992.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
9 May	0.91	0.01	2	0.90	0.03	3
5 June	0.91	0.01	2	0.90	0.01	1
5 July	0.84	0.03	4	0.87	0.01	1
1 August	0.84	0.02	3	0.83	0.01	1
4 September	0.80	0.05	7	0.75	0.03	4
2 October	0.76	0.02	2	0.75	0.02	3
31 October	na[d]	na	na	na	na	na

Table 3. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
9 May	0.90	0.01	1	0.90	0.01	1
5 June	0.88	0.03	3	0.89	0.02	2
5 July	0.86	0.02	2	0.88	0.01	2
1 August	0.83	0.01	2	0.84	0.02	2
4 September	0.78	0.01	2	0.78	0.01	2
2 October	0.75	0.03	4	0.76	0.03	4
31 October	na	na	na	na	na	na

Table 3. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
9 May	0.91	0.02	2
5 June	0.90	0.02	2
5 July	0.85	0.04	5
1 August	0.84	0.03	3
4 September	0.78	0.03	4
2 October	0.76	0.04	5
31 October	na	na	na

a/ Proportion ($X = M_1/M_0$), where M_0 and $_1$ represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

d/ data not yet available

Table 4. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1993, for **bulk northern red oak** litter samples disbursed in December, 1992.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
9 May	0.92	0.02	2	0.93	0.02	2
5 June	0.92	0.02	2	0.92	0.02	2
5 July	0.85	0.01	1	0.88	0.02	2
1 August	0.84	0.01	2	0.85	0.01	2
4 September	0.79	0.03	4	0.77	0.02	3
2 October	0.72	0.03	5	0.73	0.02	2
31 October	na[d]	na	na	na	na	na

Table 4. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
9 May	0.94	0.02	3	0.93	0.02	2
5 June	0.93	0.03	3	0.92	0.02	2
5 July	0.89	0.03	3	0.90	0.01	2
1 August	0.84	0.04	5	0.86	0.02	3
4 September	0.77	0.03	4	0.77	0.02	3
2 October	0.76	0.04	5	0.75	0.02	3
31 October	na	na	na	na	na	na

Table 4. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
9 May	0.94	0.02	2
5 June	0.92	0.01	1
5 July	0.87	0.02	2
1 August	0.83	0.01	2
4 September	0.80	0.04	6
2 October	0.74	0.04	5
31 October	na	na	na

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

d/ data not yet available

Table 5. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1993, for bulk red maple litter samples disbursed in December, 1992.

Sampling Date	Antenna Unit: Plantation Mean[a]	Plantation S.D.[b]	Plantation %[c]	Hardwood Stand Mean	Hardwood Stand S.D.	Hardwood Stand %
9 May	0.80	0.01	2	0.81	0.03	4
5 June	0.76	0.02	2	0.78	0.02	2
5 July	0.71	0.02	4	0.74	0.02	3
1 August	0.67	0.03	5	0.69	0.03	5
4 September	0.66	0.03	5	0.67	0.03	5
2 October	0.62	0.01	2	0.62	0.05	8
31 October	na[d]	na	na	na	na	na

Table 5. (cont)

Sampling Date	Control Unit: Plantation Mean	Plantation S.D.	Plantation %	Hardwood Stand Mean	Hardwood Stand S.D.	Hardwood Stand %
9 May	0.82	0.03	4	0.82	0.04	5
5 June	0.78	0.03	4	0.78	0.03	4
5 July	0.74	0.04	5	0.76	0.01	2
1 August	0.69	0.03	5	0.73	0.04	5
4 September	0.68	0.03	5	0.67	0.03	5
2 October	0.61	0.03	4	0.65	0.02	3
31 October	na	na	na	na	na	na

Table 5. (cont)

Sampling Date	Ground Unit: Plantation Mean	Plantation S.D.	Plantation %
9 May	0.81	0.03	3
5 June	0.78	0.03	4
5 July	0.72	0.04	5
1 August	0.70	0.02	3
4 September	0.65	0.02	4
2 October	0.63	0.02	3
31 October	na	na	na

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

d/ data not yet available

detectable differences (based on 95 percent confidence intervals for sample means). The data show that the following shifts in sample means should be detectable ($\alpha = 0.05$).

A. Plantation Subunits:

Pine - 5%; Oak - 5%; Maple - 5%

B. Hardwood Stand Subunits:

Pine - 4%; Oak - 3%; Maple - 5%

Figures 1 and 2 present comparisons of monthly dry matter mass loss progress for bulk pine fascicles during the 1992/93 study in the red pine plantation and hardwood stand types, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 % confidence intervals. Figures 3 and 4, and 5 and 6, present analogous comparisons for bulk oak and maple leaf samples, respectively.

1985 through 1993 Studies

We are not able to present an analysis of the complete litter decomposition data set (1985 - 1993) in this 1993 Annual Report, because 1) data for the November sample retrieval are not yet completely processed, and 2) we have not yet received the weather data with which to construct our weather-related covariates. Because the 1985 - 1993 analysis will take the same form as that presented for 1985 - 1992 in the 1992 Annual Report, we present a brief summary of that earlier analysis here. We anticipate having the 1985 - 1993 analysis completed in time for inclusion in the project's final report.

Mean dry matter mass loss values for each year, litter species, and month (through 1992), along with their associated coefficients of variation (CV), were presented in Tables 6 through 10 of the 1992 Annual Report (for the ground plantation, antenna plantation and hardwood stand, control plantation and

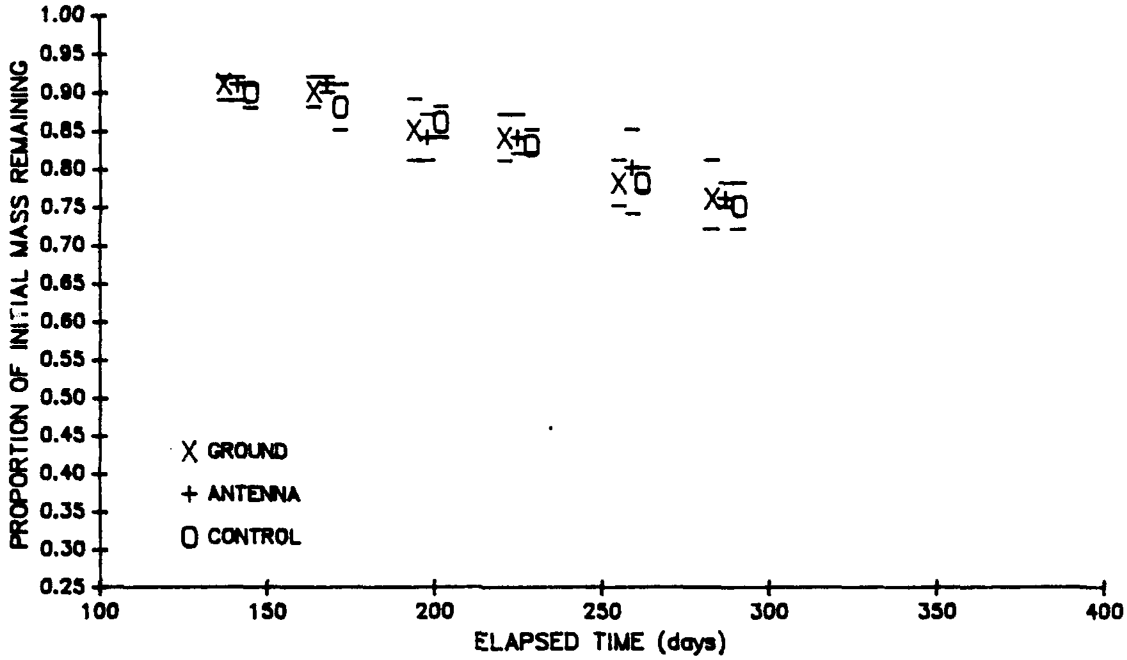

FIGURE 1. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the three plantation subunits during the 1992–1993 experiment.

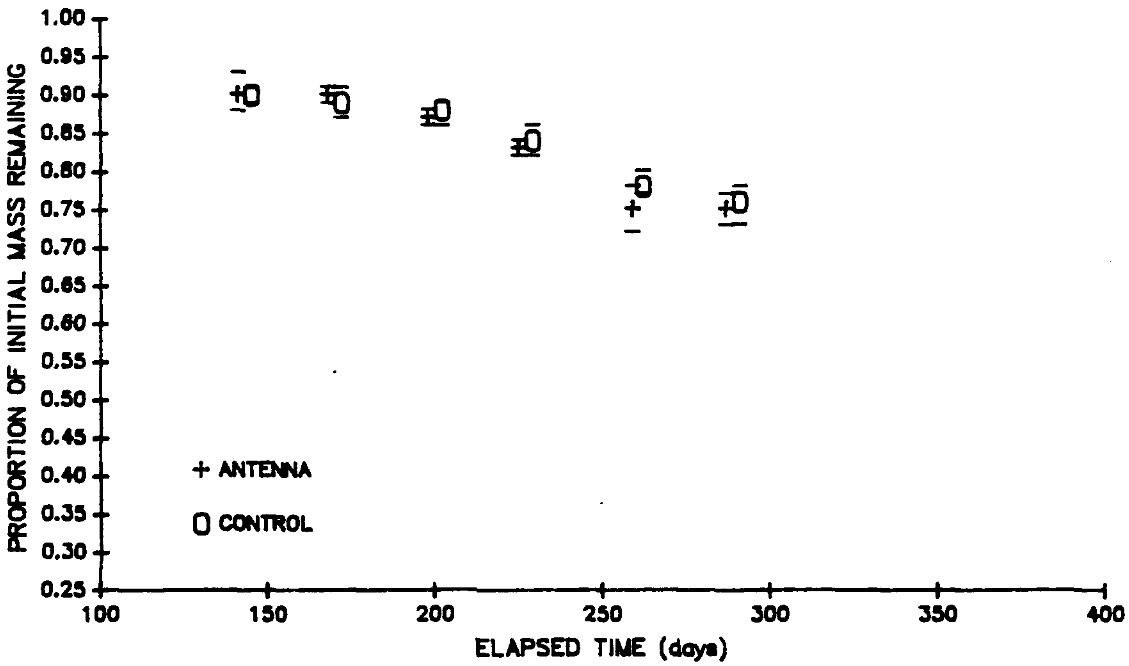

FIGURE 2. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the two hardwood stand subunits during the 1992–1993 experiment.

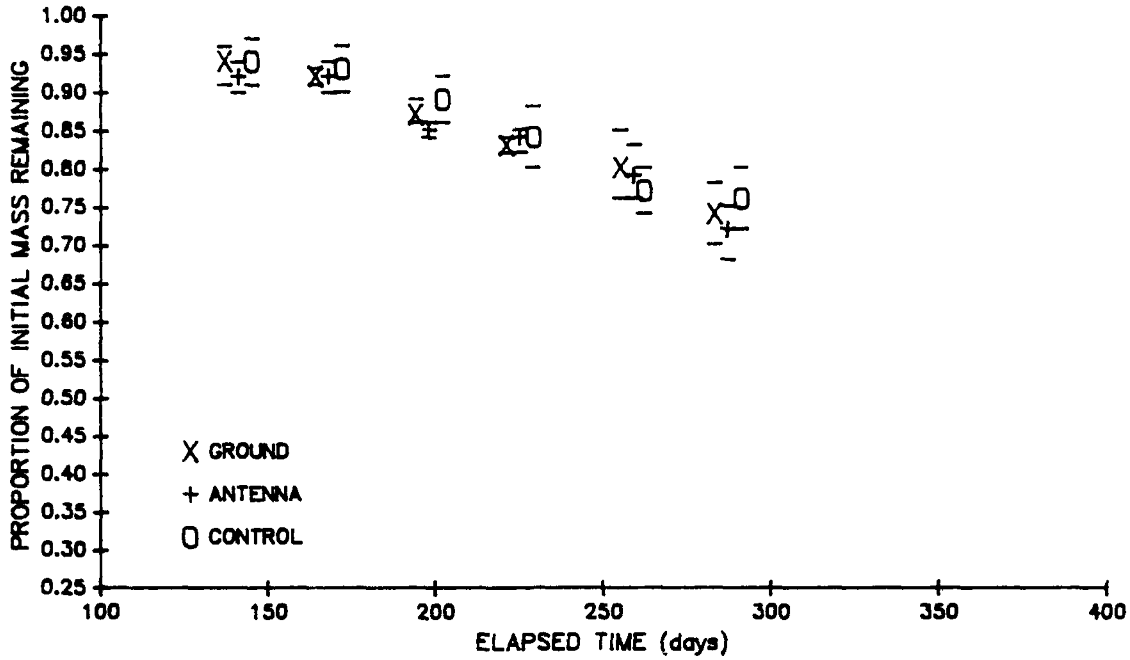

FIGURE 3. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the three plantation subunits during the 1992–1993 experiment.

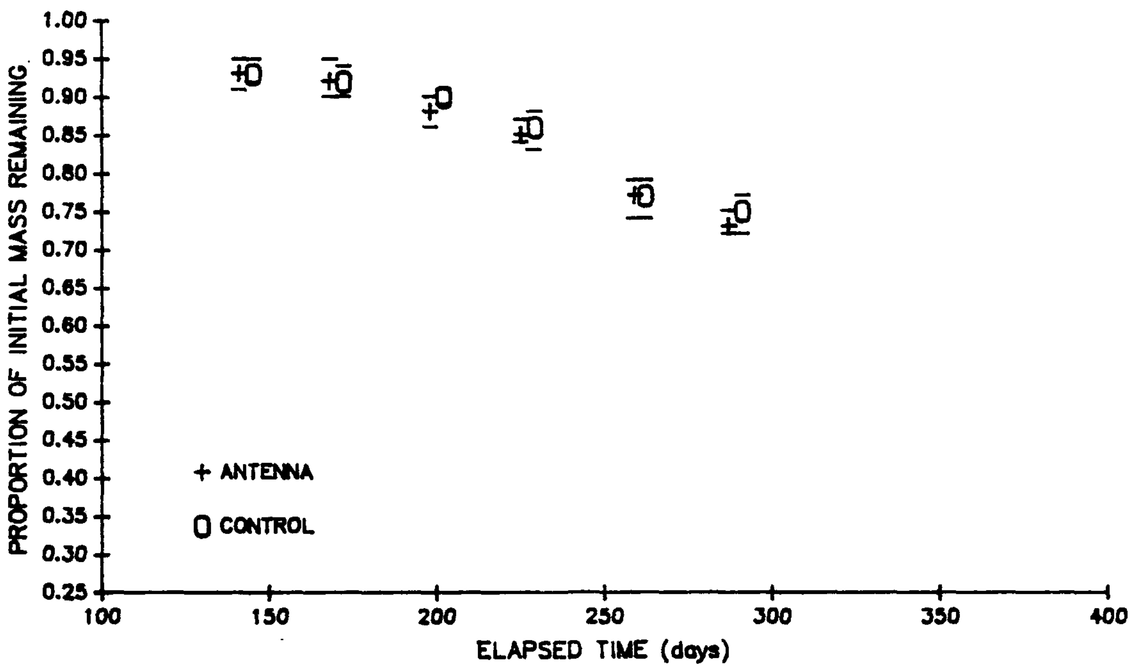

FIGURE 4. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1992–1993 experiment.

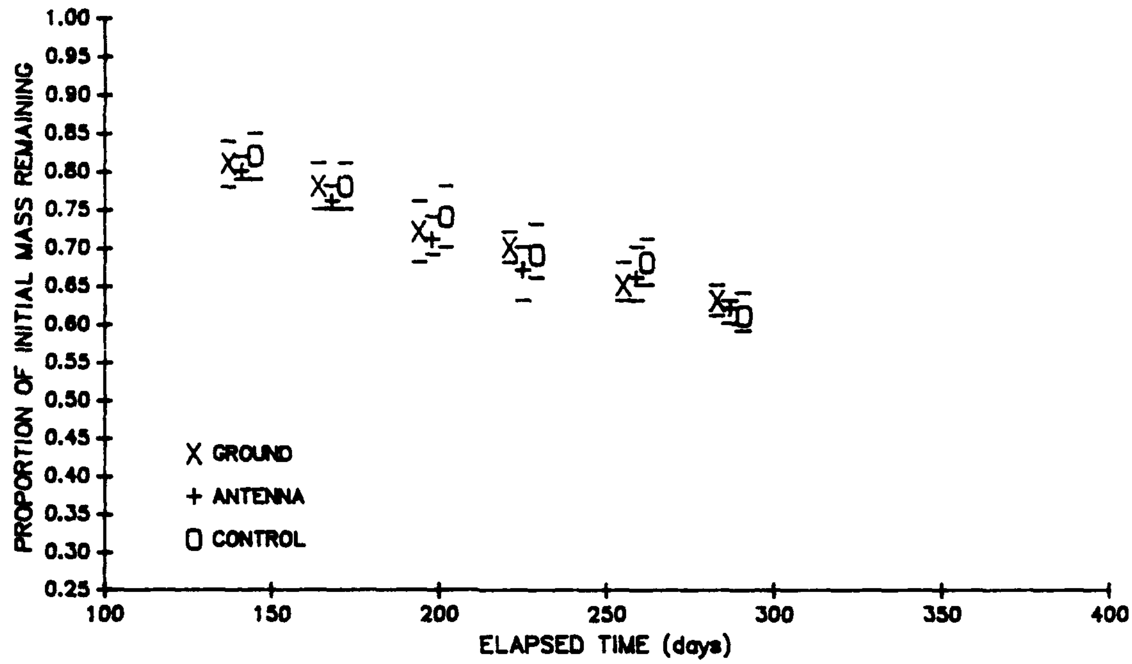

FIGURE 5. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the three plantation subunits during the 1992–1993 experiment.

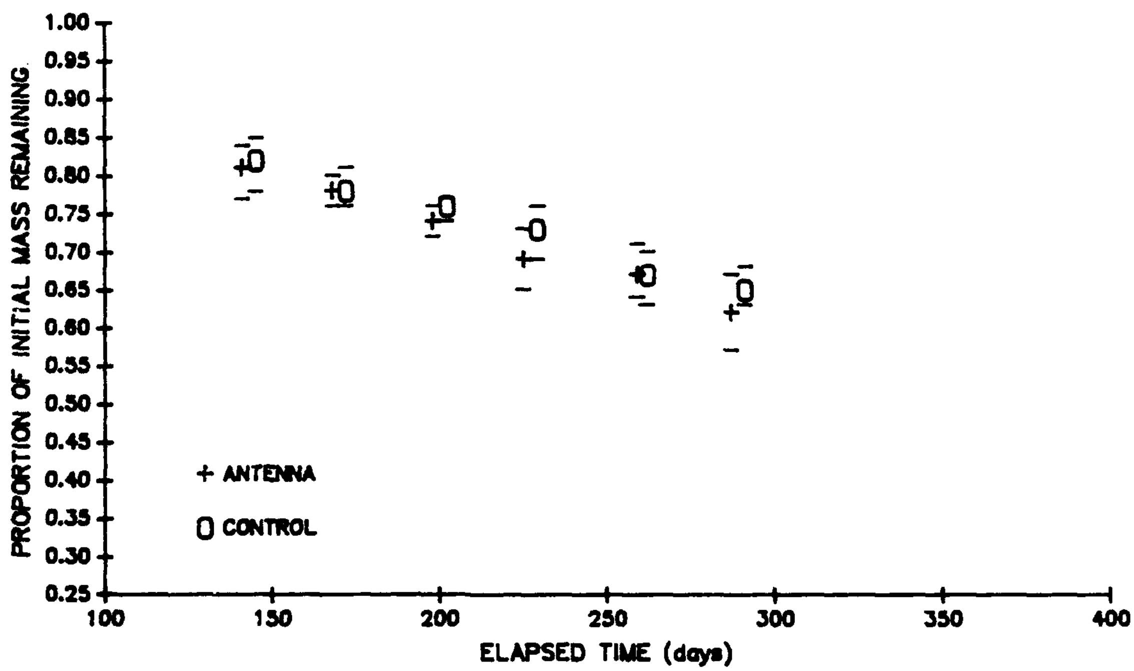

FIGURE 6. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1992–1993 experiment.

hardwood stand, respectively). As noted above, the experimental design appropriately supports data analysis by ANACOV. ANACOV is based on much larger samples than are the monthly CV values reported in Tables 6 through 10, and tend to explain much of the variability evident in the CV values. This is partly because n is larger, but also because factors used for statistical blocking and covariance analysis are included in the ANACOV models. The CV values presented in Tables 6 through 10 are therefore quite conservative compared to ANACOV results.

Precision in the data sets was slightly higher for the hardwood stands than for the plantations. The hardwood stands represent more stable environments for comparison of decomposition mass loss among years than do the rapidly developing pine plantations. This is an especially important consideration with respect to our objective of detecting possible effects of increasing ELF EM field exposures. Therefore, primary emphasis for testing ELF-related hypotheses will be placed on comparisons between the two study hardwood stands. Pine has provided the most precise mass loss data over the years, and maple the least precise.

Explanation of all differences in decomposition rate among years is an unrealistic goal, especially for the three plantations, where vegetational changes are proceeding at different rates and interacting with yearly weather differences. Also, the annual parent litter collections differ substantially in substrate quality, even though they are made at the same locations each year. To the extent that substrate quality affects decomposition rate, and that years rank differently in quality for each litter species, it should be expected that years might rank differently in rate of dry matter mass loss for the three species.

Detection limits derived from ANACOV models (containing only sets of seasonal temperature- and precipitation-related variables and a sample retrieval date correction factor as covariates) were presented in Table 11 last year. Mean X_m detection limits for years, sites, and siteyears were comparable for the hardwoods and plantations. Litter species ranked maple ≥ oak ≥ pine, in order of decreasing detection limits (increasing statistical power). Detection limits for years were ≤ 8, 4, and 3 for maple, oak, and pine, respectively. All detection limits for site changes were well below 2 %. Detection limits for siteyears were ≤ 10, 5, and 3 % for maple, oak, and pine, respectively. Overall, these low detection limits have challenged our ability to explain differences among years, sites, and siteyears.

The covariates included are conceptually and logically straightforward. Total precipitation, the number of precipitation events delivering at least 0.1 inches of rain, and soil temperature are the weather parameters included. However, to adequately address the impact of these parameters on the biological process of leaf litter decomposition, their representation within the ANACOV models appears somewhat complex. These weather parameters can have very different implications for decomposition progress depending on their temporal distributions over the course of each annual experiment. Moisture events during the spring, soon after melting of the typically large snowpack, and before the landscape has warmed sufficiently to favor rapid decomposition, contribute far less to decomposition than equivalent rainfall events during mid-summer, when the decomposer system is likely to be more limited by moisture availability than by temperature. Because of these differences, we have included each of the three weather parameters as three independent covariates representing spring levels (e.g., spring cumulative degree days), summer levels, and autumn levels. This results in the use of nine variables (three seasons times three weather parameters) in our ANACOV models (see Table 7 for specific definition of the seasons).

The only other covariate included in our ANACOV models deals with the procedural fact that monthly litter bag samples could not always be retrieved from the field on the same day of each month during each year. The covariate value used to correct for differing sample retrieval dates is the number of days, plus or minus, between the target date and the actual sample retrieval date. Decomposition rates vary greatly over the year, with very slow weight loss in the spring and progressing to rates several times faster by the last sampling date in the autumn. Therefore, this covariate is also represented within the ANACOV models with a "seasonal" adjustment. However, the large differences in decomposition rates which can occur even between successive months require that each month (rather than each season) should be represented independently within the model. Thus, separate sample date collection deviation covariates are included independently for each month.

A summary of the statistical analyses presented in the 1992 Annual Report with corresponding preliminary results is again presented here, as Table 6. All covariate names are defined in Table 7. The models referenced in Table 6 include data from the 1984/85 through 1991/92 experiments, and include only the set of seasonal weather-related variables and the sample retrieval date correction term as covariates.

Analysis of the siteyear patterns in the hardwood stands (for all three litter species) suggested that ELF EM fields may slightly accelerate the rate of litter decomposition. Means Model ANACOV results were presented last year in Tables 14-15, Tables 16-17, and Tables 18-19, for maple, oak, and pine (respectively) in the hardwood stands. Throughout the eight year study, the patterns of annual change in overall X_m have tended to be similar for both study hardwood stands. Nevertheless, ANACOV indicated a tendency for decomposition to progress more quickly at the control site than at the overhead antenna site through 1987, but more quickly at the antenna site than at the control site from 1988 through 1992 (Figures 7-9). This tendency was not statistically significant for all years, and was most pronounced for oak litter (Figure 8). The largest difference observed between the hardwood

Table 6. Summary of statistical analyses and results for measured variables, Element 1.

Variable	Model	Test Procedure[a]	Covariates[b]	Treatments	Findings Through 1992[c]
X_m (proportion of initial dry matter mass remaining)					
	Maple, Hardwood Stands				
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR01s	Year, Site Siteyear Month	**Possible ELF Effect**
	Maple, Plantations				
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR01s	Year, Site Siteyear Month	No Detectable Effect
	Oak, Hardwood Stands				
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR10s	Year, Site Siteyear Month	**Possible ELF Effect**
	Oak, Plantations				
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR01s	Year, Site Siteyear Month	No Detectable Effect
	Pine, Hardwood Stands				
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR10s	Year, Site Siteyear Month	**Possible ELF Effect**
	Pine, Plantations				
		ANACOV	DEV*MONTH ST5DDs, PRCs, PR01s	Year, Site Siteyear Month	No Detectable Effect

a/ ANACOV = Analysis of Covariance (Proc GLM, SAS)
b/ Covariate names are defined in Table 13. The suffix "s" in a covariate name specifies the set of 3 seasonal covariates (e.g., ST5DDs = ST5DDSPR, ST5DDSUM, and ST5DDFAL).
c/ All statistical tests are at $\alpha = 0.05$.

Table 7. Definitions for names of variables used in ANACOV models presented in this report.

ATDDRT	-the running total of air temperature degree days (30 cm above ground, 4.4°C basis); available 1985-1992.
ATDDs	-the set of seasonal covariates ATDDSPR (air temperature degree days, April through early July), ATDDSUM (early July through early September), and ATDDFAL (early September through early November); available 1985-1992.
ST5DDRT	-the running total of soil temperature degree days (5 cm below ground, 4.4°C basis); available 1985-1992.
ST5DDs	-the set of seasonal covariates ST5DDSPR, ST5DDSUM, and ST5DDFAL (see ATDDs); available 1985-1992.
PR01RT	-the running total of days with rainfall totaling 0.01 inch or more; available 1985-1992.
PR01s	-the set of seasonal covariates PR01SPR, PR01SUM, PR01FAL (see ATDDs); available 1985-1992.
PR10RT	-the running total of days with rainfall totaling 0.1 inch or more; available 1985-1992.
PR10s	-the set of seasonal covariates PR10SPR, PR10SUM, and PR10FAL (see ATDDs); available 1985-1992.
PRCRT	-the running total of precipitation; available 1985-1992.
PRCs	-the set of seasonal total precipitation covariates PRCSPR, PRCSUM, and PRCFAL (see ATDDs); available 1985-1992.
DELAY	-elapsed time in days between excavation of red pine seedlings and delivery of mycorrhizae to the lab for streptomycete studies; available 1986-1991.
PH	-mean pH of rhizosphere soil associated with red pine mycorrhizae sampled for streptomycete studies; available 1986-1990.

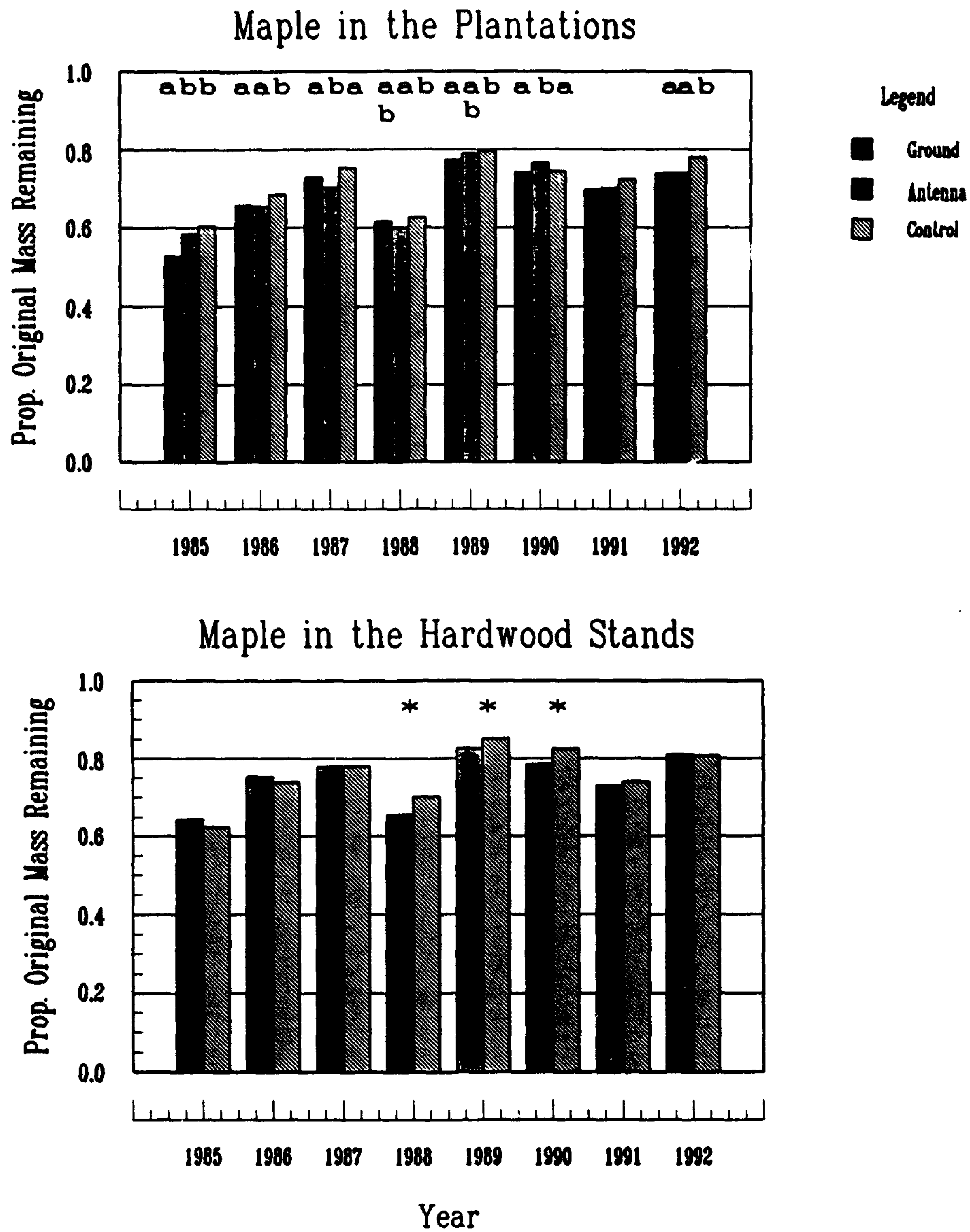

Figure 7. Site comparisons, from Means Model ANACOVs for maple litter in the plantations (top) and hardwood stands (below). Data were back-transformed from LSMeans ($\sin^{-1}$ square-root of X_m) for presentation. For each year, plantations with different letters and hardwood stands with asterisks are significantly different.

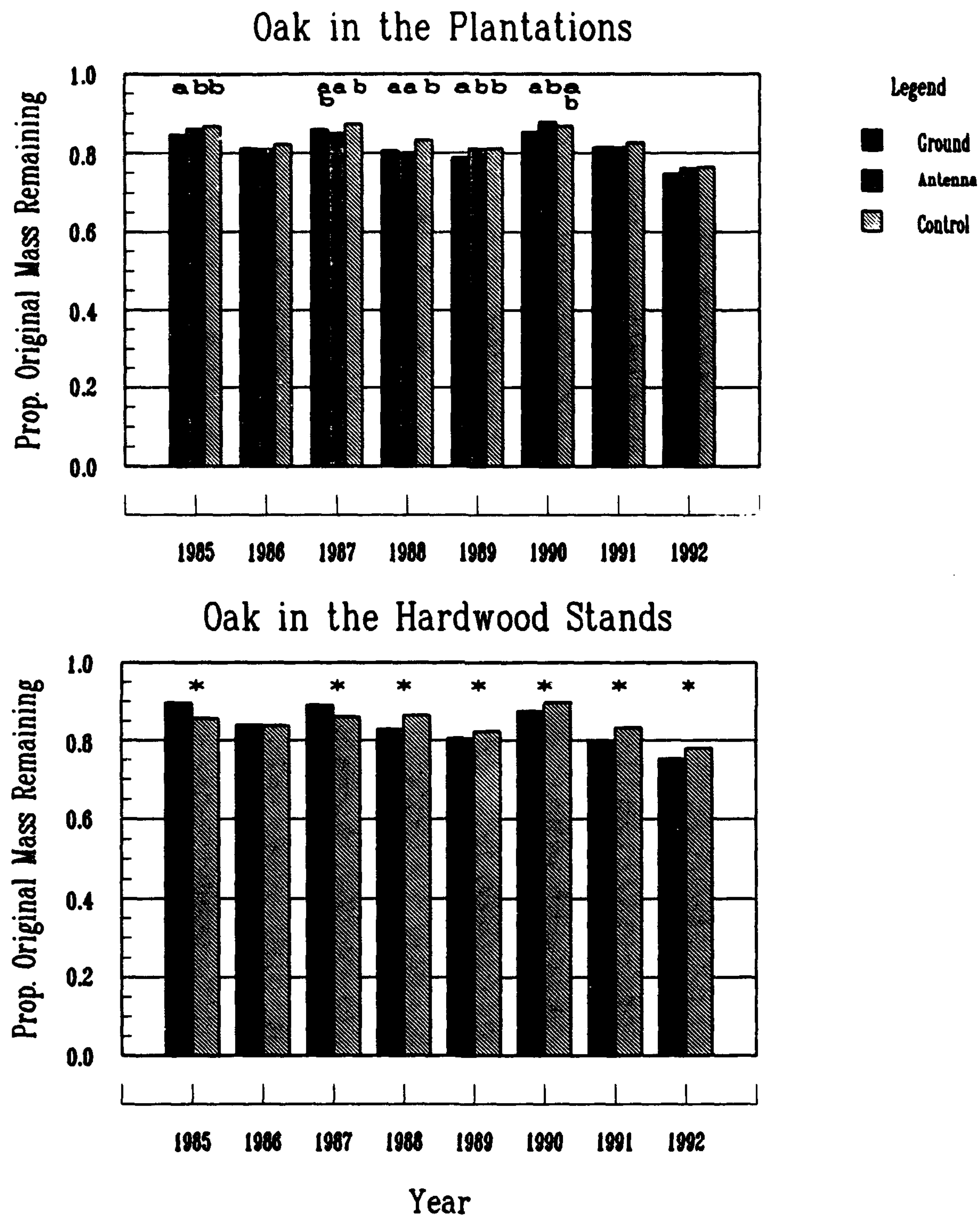

Figure 8. Site comparisons, from Means Model ANACOVs for oak litter in the plantations (top) and hardwood stands (below). Data were back-transformed from LSMeans ($\sin^{-1}$ square-root of X_m) for presentation. For each year, plantations with different letters and hardwood stands with asterisks are significantly different.

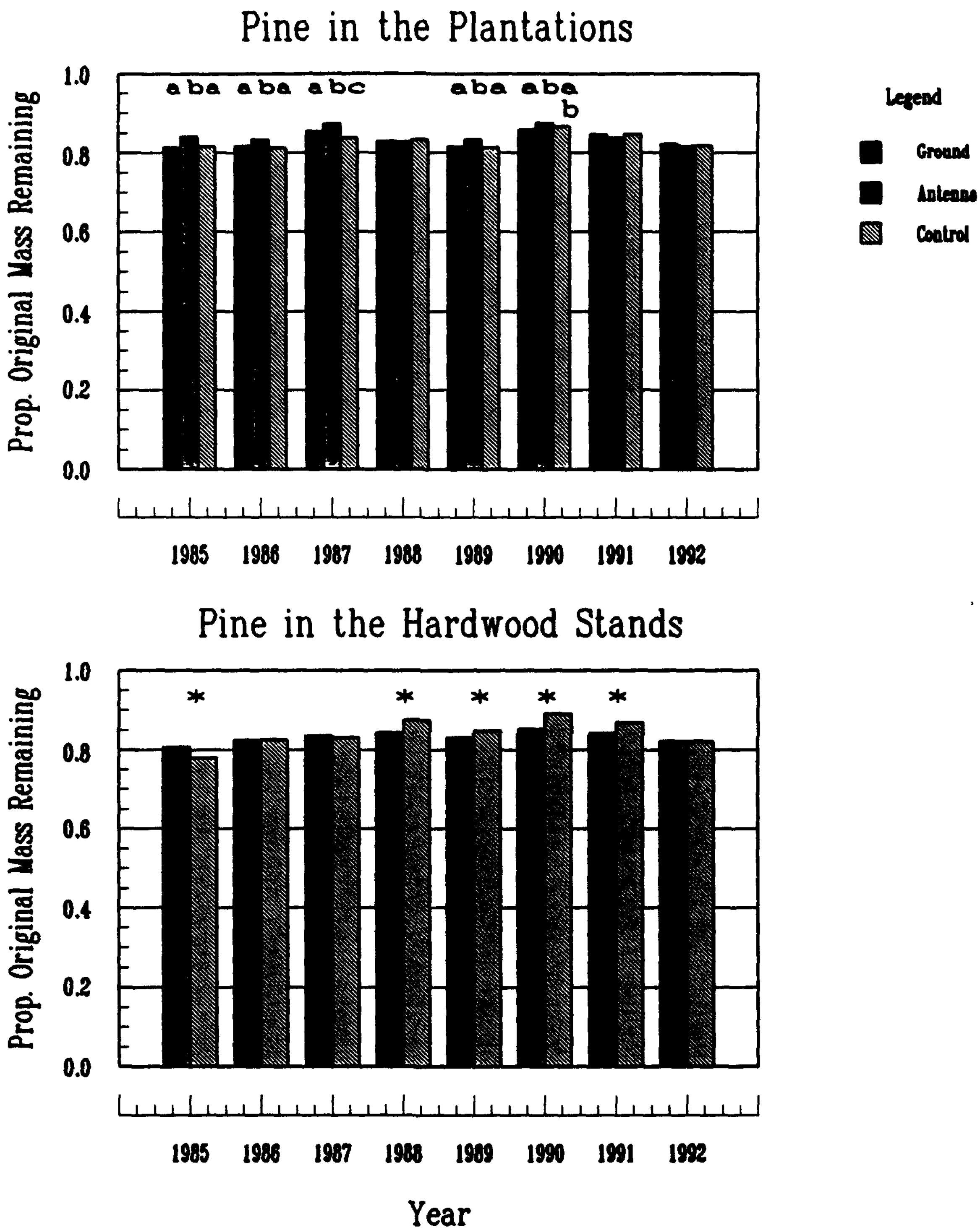

Figure 9. Site comparisons, from Means Model ANACOVs for pine litter in the plantations (top) and hardwood stands (below). Data were back-transformed from LSMeans ($\sin^{-1}$ square-root of X_m) for presentation. For each year, plantations with different letters and hardwood stands with asterisks are significantly different.

stands in a given year was approximately 5 percent of X_m, for maple in 1988. However, the difference in X_m between the hardwood stands in 1992 was not statistically significant for either maple or pine. Results of the 1992/93 experiment are of great interest. Issues to be considered include 1) whether or not a true change in decomposition rate has actually developed at the antenna site relative to the control site (and, if so, whether or not the pattern of the change is consistent with ELF EM exposure), 2) the actual magnitude of any rate changes, and 3) the biological significance and potential ramifications of such changes.

Element 2: RED PINE SEEDLING RHIZOPLANE STREPTOMYCETES

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectomycorrhizae, and can influence mycorrhizosphere microbial population composition through production and excretion of compounds such as antibiotics, vitamins, amino acids, and hormones (Marx 1982, Keast and Tonkin 1983, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk et al. 1987, Richter et al. 1989). Streptomycetes have also been found to degrade calcium oxalate, cellulose, and lignin/lignocellulose, in both coniferous and deciduous litter systems (Graustein et al. 1977, Crawford 1978, Knutson et al. 1980, Antai and Crawford 1981, McCarthy and Broda 1984). As part of the indigenous soil and root-related microflora, populations of streptomycetes are not considered to undergo great population changes in stable ecosystems (Orchard 1984). For these reasons, streptomycete populations associated with the mycorrhizae of the planted red pine seedlings were selected for inclusion in these long-term studies.

Field work for these studies was completed in 1991. A final report for these studies was included in our 1992 Annual Report. No indication was found of any ELF EM field effect on mycorrhizoplane streptomycete populations.

Element 3. Armillaria Root Disease Epidemiology

Introduction

The ongoing Armillaria root disease epidemics in the three red pine study plantations have been documented since the onset of mortality in 1986. Armillaria root disease is of interest to the Ecological Monitoring Program because 1) it is the only lethal contagious disease of red pine occurring in the study plantations, 2) it is often stress-induced, and 3) it is caused by large, long-lived and genetically stable pathogenic fungus individuals referred to as "genets" (Smith et al. 1990, 1992). Armillaria species colonize woody debris, stumps, and moribund root systems, causing white-rot type wood decay. These foodbases are colonized by means of airborne spores and/or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize subsequent foodbases. Red pines may become infected by rhizomorphs or by root growth into contact with decaying foodbases. The Armillaria root disease work element involves evaluation of potentially subtle ELF EM field effects on the activities of communities of Armillaria genets. While we do not have the means to test for an effect of ELF EM fields on genet establishment, we can test for an effect of ELF EM fields on the rates of disease progress associated with existing genets.

It is important to realize that funding was not originally proposed for study of Armillaria root disease epidemiology because the disease could not be shown to be present at the outset of the Ecological Monitoring Program. Indeed, the host populations (the red pine plantations) were created after the Program was established! The Armillaria root disease work element has been adopted by the Litter Decomposition and Microflora project as of FY92 (from the Upland Flora project), as we discontinued the mycorrhizoplane streptomycete studies and scaled back the litter decomposition work element. Resources in past years have permitted documentation of the epidemics and gradual preparation of the database needed for statistically sound investigation of the epidemic in each study plantation. The decision to continue data collection and complete the statistical analysis for the Armillaria root disease work element was based on the following considerations:

1. Armillaria root disease, the only lethal disease of red pine in the study plantations, has killed between 2 and 41 percent of the seedling populations in plantation quarter-plots.

2. There was good reason to expect that mortality due to this disease would continue, because: a) adequate woody foodbases occur on the sites, b) clones of the virulent A. ostoyae have been identified, c) and documented epidemics in the Lake States have peaked after 10 years of activity.

3. There is a strong association between Armillaria root disease severity and host (i.e., red pine) health. In other words, various stresses (possibly including ELF EM fields) predispose host plants to successful infection by Armillaria spp.

4. Because Armillaria root disease is readily diagnosed, it is possible to accurately map and statistically model disease progress.

5. Having mapped the spatially heterogeneous plantation seedling populations, we were in good position to model disease progress if we could ascertain the positions of pathogenic Armillaria genets.

6. Our picture of the spatial distributions of Armillaria genets in all three red pine plantations was completed in 1993.

Methods

The pathogen was isolated into pure culture from nearly all seedlings killed by Armillaria root disease. Isolates were also obtained each autumn from Armillaria mushrooms collected from stumps in the plantations. Isolates were grown in confrontation with each other in Petri dish culture for assignment to vegetatively compatible groups of isolates. Vegetatively compatible isolates have been shown to belong to the same fungus individual or "genet" (Smith et al. 1990, 1992).

Construction of historical (1986 to present) maps of the spatial distribution of Armillaria genets is up-to-date. We have attributed spatial boundaries to each genet according to a rule set (Table 8), and have determined the included host populations. This permits statistical analysis of the rate of disease progress on an individual genet basis, rather than on the arbitrary quarterplot basis reported in the 1992 Annual Report. Analyses based on the areas occupied by genets are attractive, because 1) they take into account the genetic identity of each pathogenic genet, and 2) they restrict calculations of disease progress to the portion of the host population accessible by each pathogen genet. Disease progress rates were calculated for each genet which killed at least 10 seedlings.

The appropriate measure of disease progress is the decimal proportion (Y_i) of the initial host seedling population which has been killed by Armillaria root disease at any specified point in time. For these calculations, the initial host seedling population was defined as the number of living seedlings at the beginning of the 1986 field season, minus those which were destructively sampled during the study period for experimental purposes. This provided an initial living population which was not diminished except by Armillaria root disease mortality over the duration of the study. The year 1986 was selected as starting point, because 1) the first Armillaria root disease

Table 8. Rule set for mapping *Armillaria* genets.

1. A genet boundary consists of the smallest possible number of straight line segments (each $\leq$ 20 m long) which connect or enclose the largest possible number of points where the genet has been isolated. Each line segment must begin and end at a point where the genet has been isolated.

2. Genet maps may consist of any combination of points, lines, and/or polygons.

3. Sets of map points separated from the rest of their genet by more than 20 m are designated sub-genets of that genet.

mortality in the study plantations occurred in 1986, and 2) at two years of age in 1986 the plantations were beyond the point of experiencing mortality due to planting stress. Analyses of Armillaria root disease progress were simplified by the absence of other lethal infectious diseases in the study plantations.

Because the distributions of host plants vary greatly within and among plantations (largely due to initial planting failures), it was essential to map the plantation seedling populations in order to determine initial host counts for calculation of Y_i within genet boundaries. Therefore, the live seedling populations in all three study plantations were mapped and tagged. Unlike the other studies at these sites, the Armillaria root disease studies are based on repeated census of each plantation. As a result, the adequacy of root disease documentation for the three epidemics is not an issue.

A variety of mathematical models have been used to describe and compare disease progress among plant disease epidemics (Campbell and Madden 1990, Madden and Campbell 1990). Our preliminary analysis of the epidemics in the three study plantations has considered the monomolecular, Gompertz, and logistic models. The linearized forms of these models are:

monomolecular: $\ln(K/(K-y)) = -\ln(B)+rt$

Gompertz: $-\ln(-\ln(y/K) = -\ln(B)+rt$

logistic: $\ln(y/(K-y)) = \ln(y_0/(K-y_0))+rt$

In the above equations, y is the level of disease at time t, K is the maximum level of disease attainable (y_{max}, presently presumed K=1.00), B is a constant of integration, y_0 is the initial level of disease ($y_0 = 0.00$), e is the base of natural logarithms, r is a rate parameter with units of $time^{-1}$, and exp represents e raised to some specified power.

Rate constants for disease progress were estimated using each of the models listed above, for each of the 18 pathogenic Armillaria genets encountered: 3, 6, and 9 genets in the ground antenna, overhead antenna, and control plantations, respectively. For each model, the appropriately transformed y_i was regressed versus air temperature degree days accumulated since plantation establishment in the spring of 1984 (CUATDD). CUATDD was selected as a surrogate for elapsed time, because of the temperature dependency of biological activity and the long winters in the study area. The most appropriate disease progress model for each genet was identified by comparing the values of R^2, the mean square error, and the standard error of the rate estimate, and by comparing the plots of the standardized residuals versus predicted values (Campbell and Madden 1990). Because the data from all 18 genets were best fit by the monomolecular model, monomolecular rate parameter estimates were compared directly, using ANOVA (Madden 1986). Because the rate parameter or regression coefficient is an estimate of the slope of the linearized disease progress model, the Tukey-Kramer method was used to perform an unplanned test of all 18 regression coefficients (Sokal and Rohlf 1981, Rohlf and Sokal 1981).

All regressions and ANOVAs have been conducted on the mainframe computer using PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985). For ANOVA, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$; for the Tukey-Kramer unplanned comparison test, an experiment-wise $\alpha=.01$ was used.

Correlation analysis was used to explore the relationship among genets between monomolecular disease progress rate and seedling height at the end of 1992. Seedling height was selected for its value as an indicator of host (target) size and condition. The area occupied by each study genet is being determined. Once this is accomplished, correlation analysis will be used to evaluate the relationships between hardwood stump foodbase characteristics (numbers and basal areas per hectare by tree species) and disease progress rate.

In addition to comparing the three plantations using rate constants based on all years, we will consider comparisons of rate constants derived from "roughly" pre- and post-operational years' data for each of the three plantations.

Description of Progress and Summary of Results

Our preliminary maps of Armillaria genets indicate that genets of the same Armillaria species overlap little, whereas genets of different Armillaria species overlap freely. It has therefore been possible to analyze rates of disease progress within the boundaries of individual A. ostoyae genets. This approach addresses our concern regarding the variation among quarter-replicates in the proportion of their land area occupied by A. ostoyae.

Annual disease progress (percent mortality) since plantation establishment is presented in Table 9. Monomolecular rate parameter values for disease progress in each of the 18 genets are presented in Table 10, along with results of the Tukey-Kramer

Table 9. Cumulative disease progress (percent seedling mortality) caused by the pathogenic *Armillaria* genets occurring in the 3 study plantations.

		Year							
Plantation	Genet	1986	1987	1988	1989	1990	1991	1992	1993
Ground	1	1.9	5.8	12.6	18.4	24.3	25.2	25.2	26.2
	2	1.6	6.4	14.1	19.0	21.8	22.6	22.6	22.6
	3	0.0	1.4	1.4	4.3	6.4	6.4	7.9	7.9
Antenna	1	0.7	7.1	21.6	31.4	37.5	38.5	39.5	39.9
	2	0.0	1.3	8.7	20.8	24.8	26.2	27.5	27.5
	3	0.0	2.0	8.2	18.4	22.4	22.4	28.6	28.6
	4	3.4	5.1	13.6	18.6	22.0	23.7	23.7	25.4
	5	2.9	5.8	15.1	18.0	19.8	19.8	19.8	19.8
	6	3.1	6.2	10.3	11.3	12.4	12.4	13.4	13.4
Control	1	2.7	21.6	29.7	40.5	40.5	40.5	43.2	43.2
	2	1.2	10.8	24.1	31.3	33.7	33.7	33.7	34.9
	3	0.5	6.7	16.4	21.5	26.7	27.2	30.8	31.3
	4	2.2	8.7	15.2	19.6	21.7	21.7	23.9	23.9
	5	0.4	6.1	9.6	14.6	18.6	18.6	19.3	19.3
	6	1.3	9.4	15.4	16.8	17.4	17.4	19.5	19.5
	7	1.1	5.7	8.5	13.3	15.9	16.5	16.9	16.9
	8	0.0	2.4	6.3	9.6	10.8	11.4	12.6	12.6
	9	0.1	2.1	5.3	7.6	9.4	10.0	10.9	11.1

Table 10. Monomolecular rates (r_M) of disease (mortality) progress[2] for individual *Armillaria* genets, with associated r^2 and standard errors of the estimates (s_r), and average height (cm) of surviving seedlings[3].

Site	Genet	r_M		r^2	s_r	Height
1	1	0.2802	abc	0.96	0.025425	269
1	2	0.2415	-bcde	0.93	0.028961	264
1	3	0.0797	-------h	0.94	0.009178	276
2	1	0.4932	a	0.96	0.047833	297
2	2	0.3361	abc	0.94	0.037802	281
2	3	0.3152	abc	0.96	0.029289	280
2	4	0.2417	-bcd	0.96	0.023451	304
2	5	0.1881	-bcdefgh	0.88	0.031713	308
2	6	0.0969	-----fgh	0.90	0.014536	272
3	1	0.4119	abcd	0.88	0.069519	300
3	2	0.3548	abcde	0.87	0.057632	298
3	3	0.3102	ab	0.98	0.020293	310
3	4	0.2081	-bcdef	0.94	0.023868	320
3	5	0.1851	--cdef	0.95	0.018667	312
3	6	0.1505	--cdefgh	0.83	0.030440	305
3	7	0.1476	---defg	0.96	0.013550	331
3	8	0.1173	----efgh	0.96	0.010016	334
3	9	0.0962	------gh	0.98	0.005473	315

[1] Values are for disease progress through 1993.

[2] The monomolecular model has the following linearized form: $\ln[1/(1-y)] = -\ln(B)+rt$, where y is the proportion of the initial host population killed, y_0 is the initial amount of disease (0.0, in our case), r is the rate of disease increase, and t is a function of elapsed time (air temperature degree days, in our case). Values of r_M were compared using the Tukey-Kramer method with α=.01, k=90, ν=18 (Sokal and Rohlf 1981, Rohlf and Sokal 1981). Values of r_M with a letter in common are not significantly different.

[3] Total height was measured following growth cessation in 1992.

unplanned comparison tests. It is readily apparent that *rate of* disease progress varies greatly among genets, and that each plantation is represented by genets demonstrating statistically similar ranges of rates. Unfortunately, only 3 pathogenic genets large enough to warrant disease progress analysis occur in the ground antenna plantation, and these 3 genets occupy only slightly more than 25 percent of the plantation area. The variability in rate values within each plantation, coupled with the modest number of available genets for analysis result in little power to detect differences among the plantations. The results of ANOVA for detection of differences in disease progress rate among the three plantations are presented in Table 11. No significant differences among plantations were detected by ANOVA ($p = 0.5690$), no doubt for the reasons described above.

The ranges of disease progress rates demonstrated by the *Armillaria* genets at each site suggest genetic differences in virulence. However, possibilities remain that these rate differences might result at least partly from differences among genets in the health of potential hosts or in the distribution of stump foodbases. Average seedling height at the end of the 1992 field season within the area occupied by each *Armillaria* genet is presented in Table 10. Results of correlation analysis of the relationship between disease progress rate and seedling height are presented in Table 12. A significant negative correlation ($r = -0.6871$, $p = 0.0409$) exists between disease progress rate and final seedling height for the 9 genets at the control plantation. A negative correlation might be interpreted to reflect reduced seedling vulnerability to lethal infection by pathogenic *Armillaria* genets with increasing plant size. For healthy plants, we expect that root infection and colonization attempts would be met with increasing levels of active resistance in increasingly large plants. Alternatively, larger plants are also larger targets, and may demonstrate increased vulnerability if they are stressed for any reason (*e.g.*, by deformed or damaged root systems, drought, etc.), and especially if local *Armillaria*

Table 11. ANOVA table for detection of differences among the 3 study plantations in the monomolecular rates of disease (mortality) increase associated with pathogenic *Armillaria* genets.

Source of Variation	df	SS	F	Signif. of F	r^2	CV
Model	2	0.01689	0.59	0.5690	0.07	51
Error	15	0.21633				
Corrected Total	17	0.23322				

Table 12. Pearson correlation coefficients for the relationship between monomolecular rate of mortality increase and seedling height at the end of 1992, for the pathogenic *Armillaria* genets in the three study plantations.

Plantation	Number of Genets	r	P
Ground Antenna	3	-0.9833	0.1165
Overhead Antenna	6	0.3168	0.5407
Control	9	-0.6871	0.0409
Combined	18	-0.1172	0.6433

inoculum is abundant. However, disease progress rate and final seedling height were not significantly correlated at either the ground or overhead antenna plantations. This result could be brought about by a balance between the factors which would cause correlation of oppposite sign.

Stump population data for the area occupied by each Armillaria study genet are presented in Table 13. Numbers and basal areas of stumps (potential Armillaria foodbases) will be tested for correlation with genet disease progress rates as soon as they can be expressed on an area basis, perhaps in time to be included in the project's final report.

Nevertheless, our results currently suggest 1) significant and similar variation in virulence among the pathogenic Armillaria genets occurring in the three study plantations, and 2) no detectable effect of ELF EM field exposures on rate of Armillaria root disease progress.

Table 13. Stump numbers and basal area (m^2) by species associated with pathogenic *Armillaria* genets.

		Aspen		Birch		Maple		Oak		Pine		Total	
Site	Genet	N	BA	N	BA	N	BA	N	BA	N	BA	N	BA
Ground	1	11	0.6	-	-	14	1.2	5	1.4	-	-	30	3.3
	2	65	2.7	9	0.3	27	2.0	8	1.1	-	-	109	6.1
	3	15	0.8	8	0.6	8	0.9	4	1.2	-	-	35	3.5
Overh'd	1	37	2.0	2	0.1	32	3.0	4	0.5	-	-	75	5.6
	2	11	0.7	8	1.5	17	1.4	-	-	1	0.2	37	3.7
	3	12	0.6	1	0.3	6	0.1	1	0.0	-	-	20	1.0
	4	16	0.8	4	0.7	13	0.3	1	0.0	-	-	34	1.7
	5	31	1.6	7	0.6	28	1.4	2	0.6	4	0.7	72	4.9
	6	10	0.4	12	1.4	14	0.5	2	0.0	1	0.0	39	2.4
Control	1	1	0.0	1	0.1	2	0.0	-	-	-	-	4	0.2
	2	2	0.1	6	0.5	1	0.0	7	1.1	-	-	16	1.7
	3	7	0.6	12	0.6	12	0.3	18	1.3	1	0.2	50	3.0
	4	6	0.1	3	0.4	4	0.1	4	0.3	-	-	17	0.9
	5	13	0.4	30	2.2	14	0.4	18	1.3	-	-	75	4.4
	6	6	0.2	15	1.2	10	0.6	8	0.6	-	-	39	2.6
	7	11	0.5	40	3.8	27	0.4	59	4.3	-	-	137	9.0
	8	10	0.4	26	2.1	17	0.3	27	2.0	-	-	80	4.8
	9	32	1.3	70	5.4	42	1.6	50	3.8	-	-	194	12.0

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GLOSSARY

Actinomycete	A large group of true bacteria, characterized by a mycelial vegetative structure.
Basal Area	The cross-sectional area of a tree at DBH, or of a stump.
Biomass	The amount of living matter in a unit area.
DBH	Diameter at breast height. Average stem diameter, outside bark, measured 4.5 feet above the ground.
Ectomycorrhizae	The type of mycorrhizae in which the fungus component grows only intercellularly within its host root, and produces an external mantle.
Foodbase	Any piece of woody debris suitable for colonization by *Armillaria* species.
Genet	An individual organism, genetically identical throughout.
Habitat Type	Land areas potentially capable of producing similar plant communities at maturity.
Litter	Dead, largely unincorporated leaves and other plant parts on the forest floor.
Mycorrhizae	A mutually beneficial association between plant roots and certain highly specialized parasitic fungi.

Mycorrhizoplane	The actual surface of mycorrhizal plant roots, together with any closely adhering particles of soil or debris.
Mycorrhizosphere	The narrow zone of surrounding soil subject to the influence of living mycorrhizal roots.
NESS	National Earth Satellite Service.
NOAA	National Oceanographic and Atmospheric Administration.
Rhizomorph	The exploratory, infective cord-like organs produced by Armillaria species, composed of differentiated hyphal aggregates, for growth through the soil and colonization of new foodbases.
Streptomycete	Members of the genus Streptomyces, a group of actinomycetes which reproduce by forming spores.