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**Compilation of 1992 Annual Reports
of the Navy ELF Communications System
Ecological Monitoring Program**

Volume 1 of 3 Volumes:
Tabs A, B

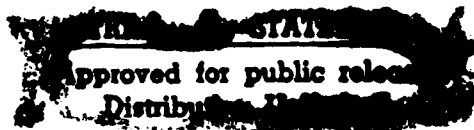
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13. ABSTRACT (Maximum 200 words) During 1992, the U.S. Navy continued to conduct a program to monitor flora, fauna, and their ecological relationships for possible effects from electromagnetic (EM) fields produced by the Navy's Extremely Low Frequency (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 1992. It is anticipated that data will continue to be collected 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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REWORD

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 1982-1992. 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.

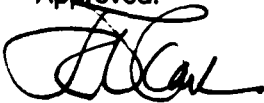
As was done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Previous compilations and other program documents are listed under Tab I.

Respectfully submitted,
IIT RESEARCH INSTITUTE


John E. Zapotosky, Ph.D.
Program Coordinator

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R. D. Carlson, Director
ELF Electromagnetic Compatibility Assurance

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**ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM**

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- B. Litter Decomposition and Microflora:
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- H. Aquatic Ecosystems:
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- I. Listing of Technical Reports

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HERBACEOUS PLANT COVER AND TREE STUDIES

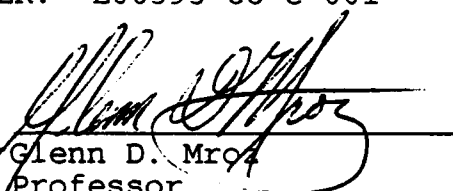
The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1992

SUBCONTRACT NUMBER: E06595-88-C-001

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ELF Environmental Monitoring Program

Upland Flora 1992 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 occurred in the 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 instrumenting 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 1991 and 1992 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. Analysis of data, however, is seldom complete in the same year as data gathering and final

synthesis of these studies will appear in the 1993 and 1994 annual reports.

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.
-

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 required buffer strips 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

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.

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

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 infer if 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 central to discussions of proposed continuation. 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 technical summary and proposal, 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, variability in plant growth, development, or phenological events within the influence of the ELF antenna system must first be related to microclimatic and other ambient variables 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:

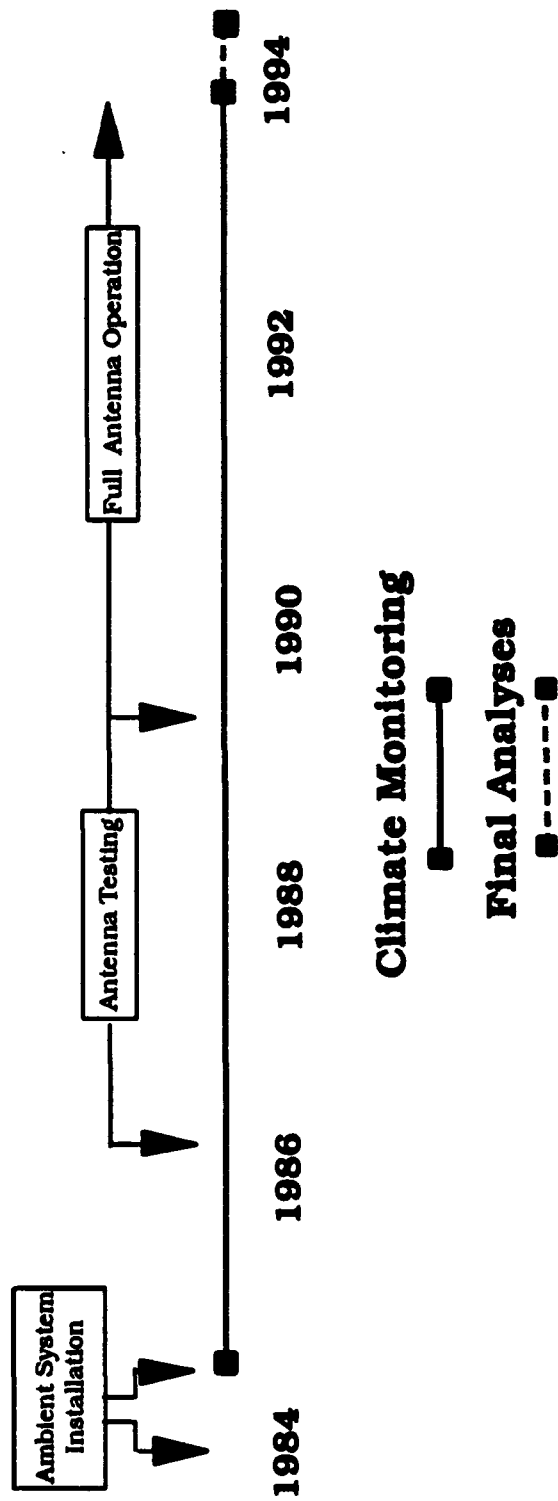
1. evaluate the natural ambient differences between the control site and the test sites.
2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.
3. select ambient variables which are independent of ELF system effects which then 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 seven years has indicated that soil chemistry is important to the project's growth modeling efforts. Thus comparisons of soil

Figure 1.1

Schedule of annual ambient monitoring objectives



chemical properties among sites and years are include in this element. The ambient monitoring element is separated into two 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 Growth and Tree Studies Project annual report.

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 board 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

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

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. Thus the 1990 measurements were only the sixth 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

Missing Data Replacement

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 seven 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 1985-90 have been presented in previous Herbaceous Plant Cover and Tree Studies annual reports. The 1991 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 1991 criteria 3 was only used to estimate 11 days of missing data at the antenna site during system startup in early April. Also during this period soil temperature at a depth of 5 cm at both the antenna and ground sites were missing. Since criteria's 1-3 could not be used, soil temperatures at this depth was estimated using soil temperature at a depth of 10cm at the ground site as the independent variable for the regression equations.

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.

Table 1.2. General analysis of variance of Element 1.

<u>Source of Variation</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F-Ratio</u>
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(MS)/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

Progress

This year concludes the eighth full year of data collection by the ambient monitoring system (1985-1992) and the fourth year of full powered operation of the ELF antenna (1989-1992). This year's report includes summaries and statistical analysis of the climatic information through 1991 and also analyses to determine if the ambient variables are related to the electromagnetic fields which have been measured at the sites during 1985-1991. 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 variables are either affected by or confounded with the 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 1985-1991 was 0.7 and 1.0 °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 0.7 °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 the ground site ($p=.004$) and control compared to the antenna site ($p<.001$).

Annual Comparisons: Air temperatures in 1987 and 1988 were warmer than in any other year of the study. 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. Ranking of the temperatures at the control and antenna sites were as follows (Table 1.3): 1988=1987>1991>1989=1986>1990>1985.

Site by Year Comparisons: ANOVA test again in 1991 indicated significant site by year interactions for the control vs. ground ($p=.022$) site comparisons but not the control vs. antenna site comparisons ($p=.367$). Figure 1.2 shows the mean air temperature at the control and antenna plantations and the differences in air temperature between these two plantations during the 1985-1991 growing seasons. Differences in air temperature between the two sites increased from a low in 1985 of 0.5 °C to a high of 1.5 °C in 1988. Starting in 1989 these differences have been decreasing and in 1991 the control plantation was only 0.6°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 during the seven year study period (Figure 1.4). However, site by stand type by year interactions have not been found to significantly differ ($p=.218$) for the control antenna comparison.

Comparisons of the average air temperature in the plantation and hardwoods at the control and antenna sites, during 1985-1991, 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) the increased

Table 1.3 Comparison of mean air temperature (°C) 2 m above ground during the 1985-91 growing seasons (April-Oct.).

Plantation					
	<u>Ground</u>	<u>Antenna</u>	<u>Control</u>	<u>Control-Ground</u>	<u>Control-Antenna</u>
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
Ave.	12.0	12.3	13.0	1.0	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
Ave.	12.1	12.8	0.7

1985-1991 MEAN DAILY AIR TEMPERATURE (°C)

Site Comparisons

Control	Ground
13.0 a	12.0 b
Control	Antenna
12.9 a	12.2 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

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

Figure 1.2

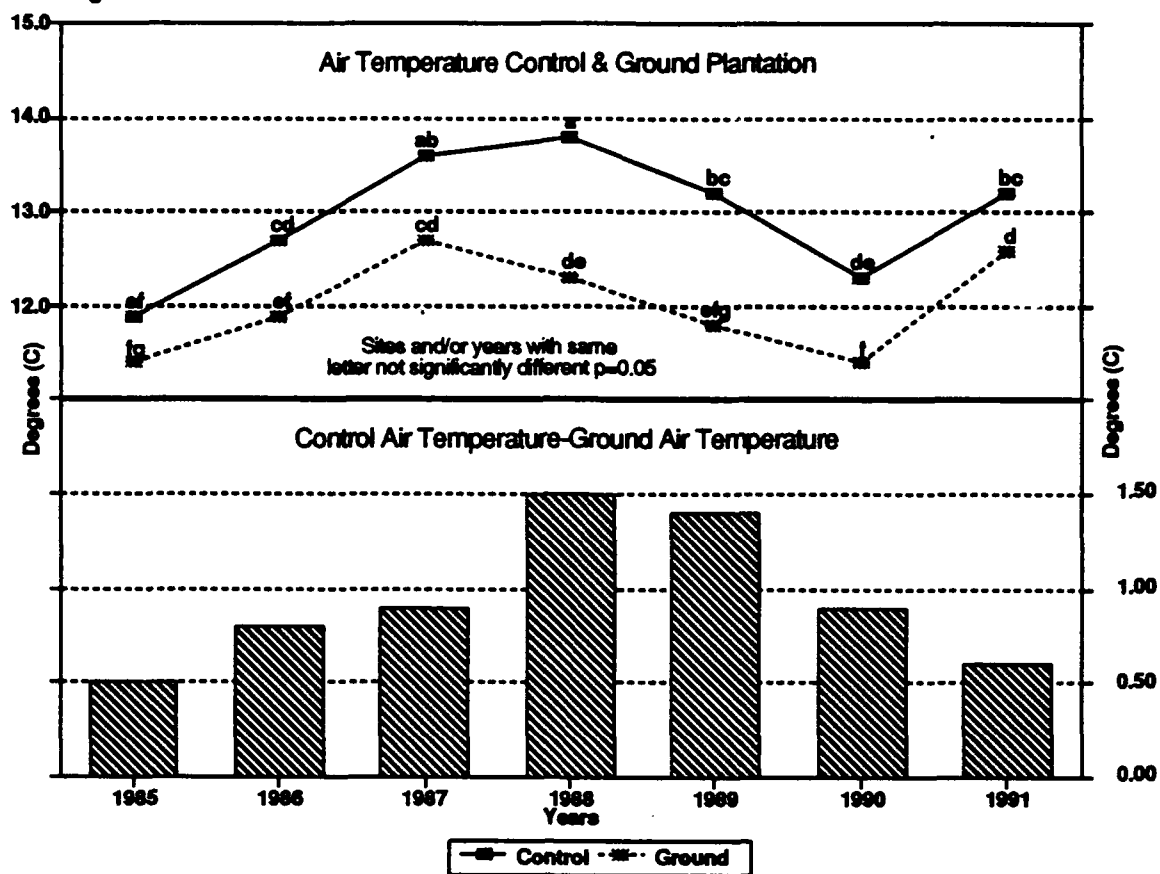


Figure 1.3

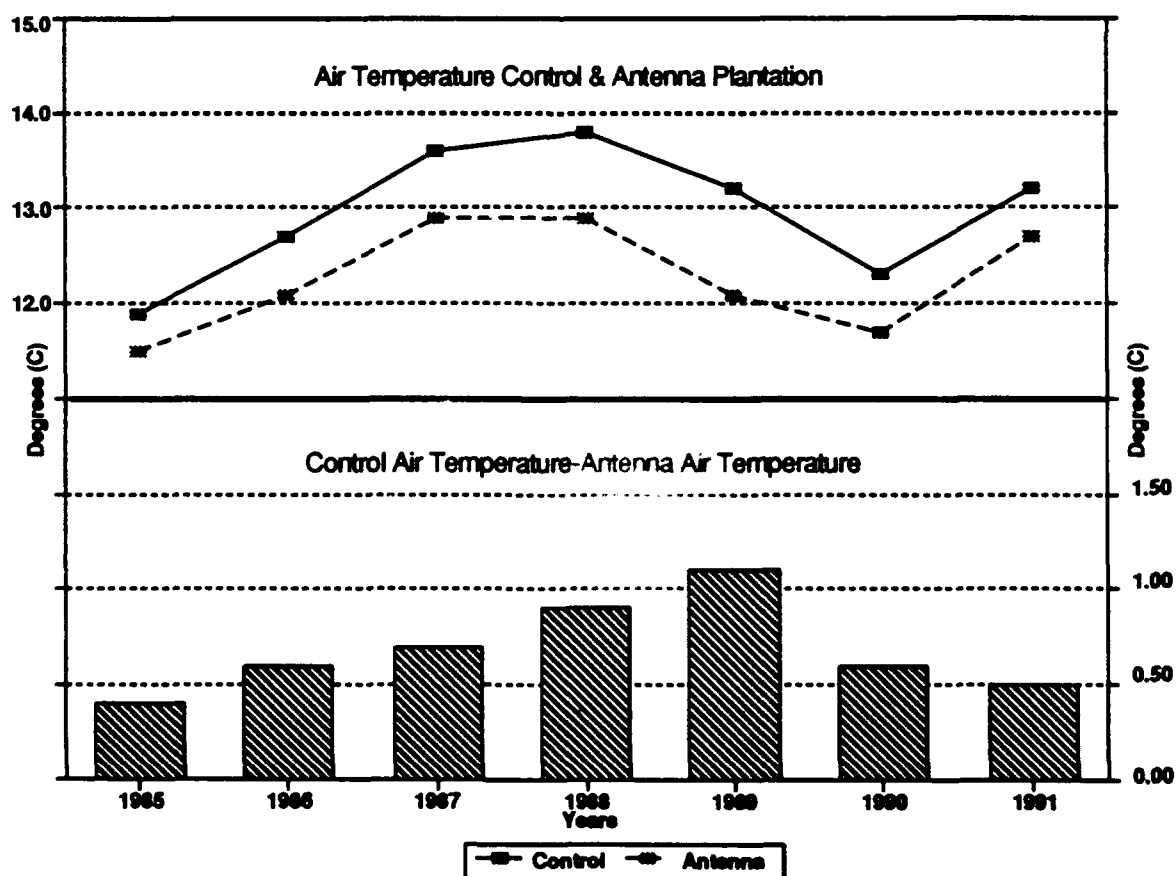


Figure 1.4

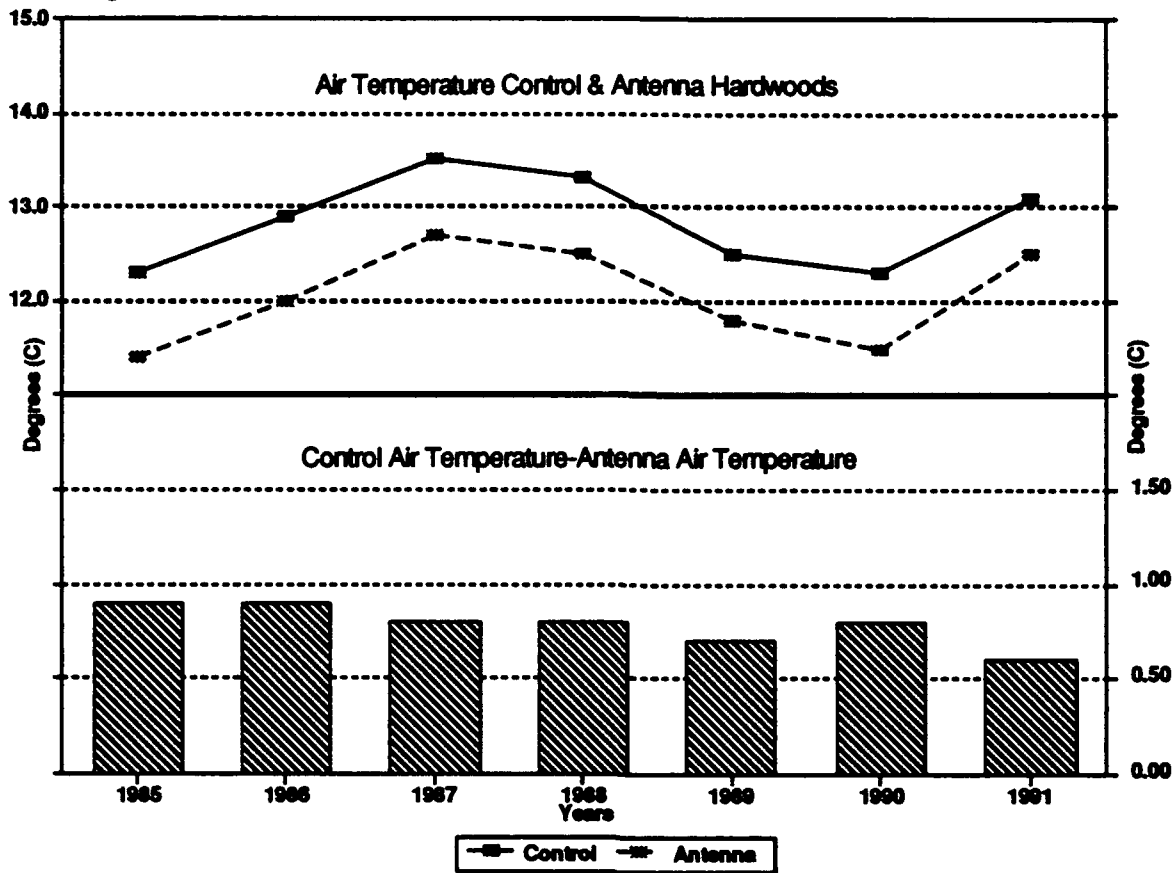
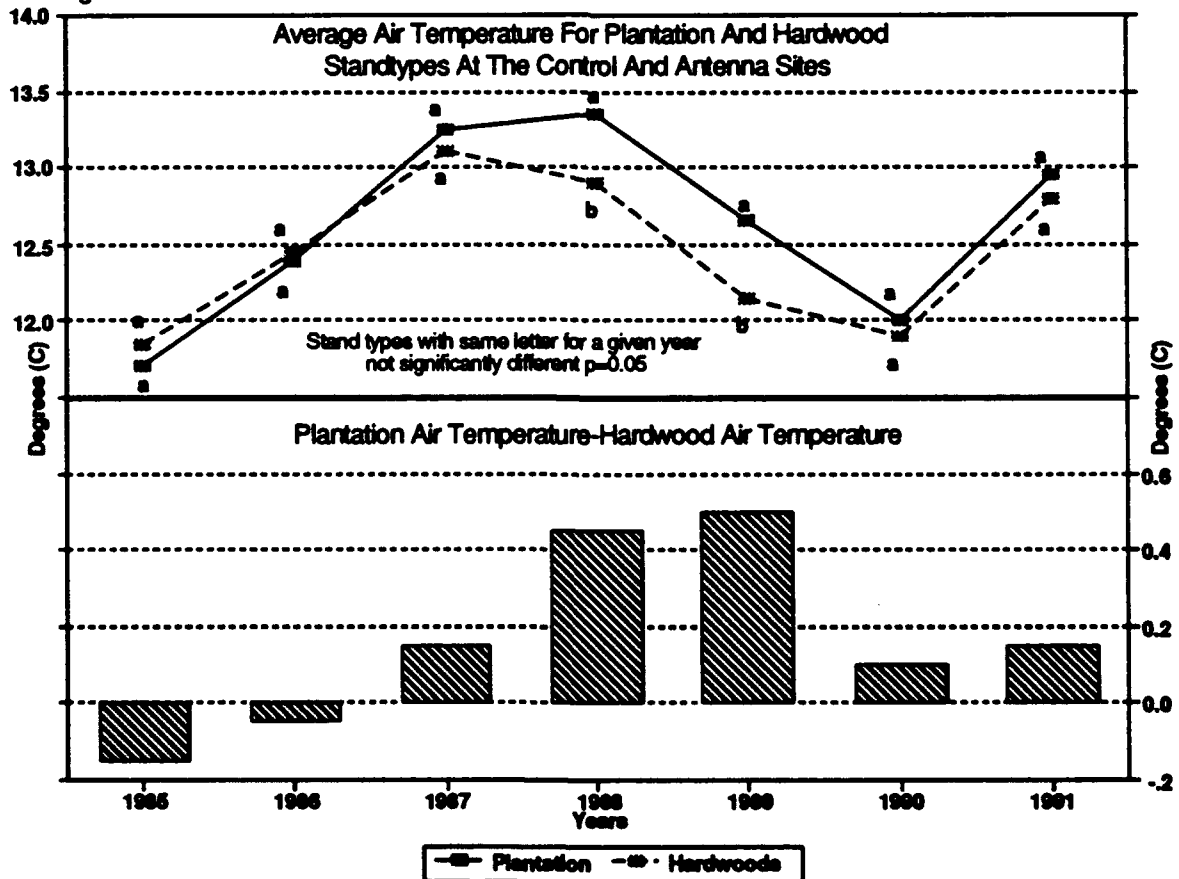


Figure 1.5



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 related to the height growth of the red pine in the plantations. As the canopy of the red pine approached the height of the air temperature sensors in the plantations, air temperature was 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 and the decreased differences in the temperatures between the control and test plantations during 1990 and 1991 suggests that either, 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 is minimal 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 although the effect of the red pine canopy on air temperature has diminished since 1989 (Figure 1.6), it is still altering the temperature at the plantation. 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). However since 1987 air temperature in the plantation has been greater or equal to the air temperatures observed in the hardwoods.

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 (DNATD) 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 DNATD 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

Figure 1.6

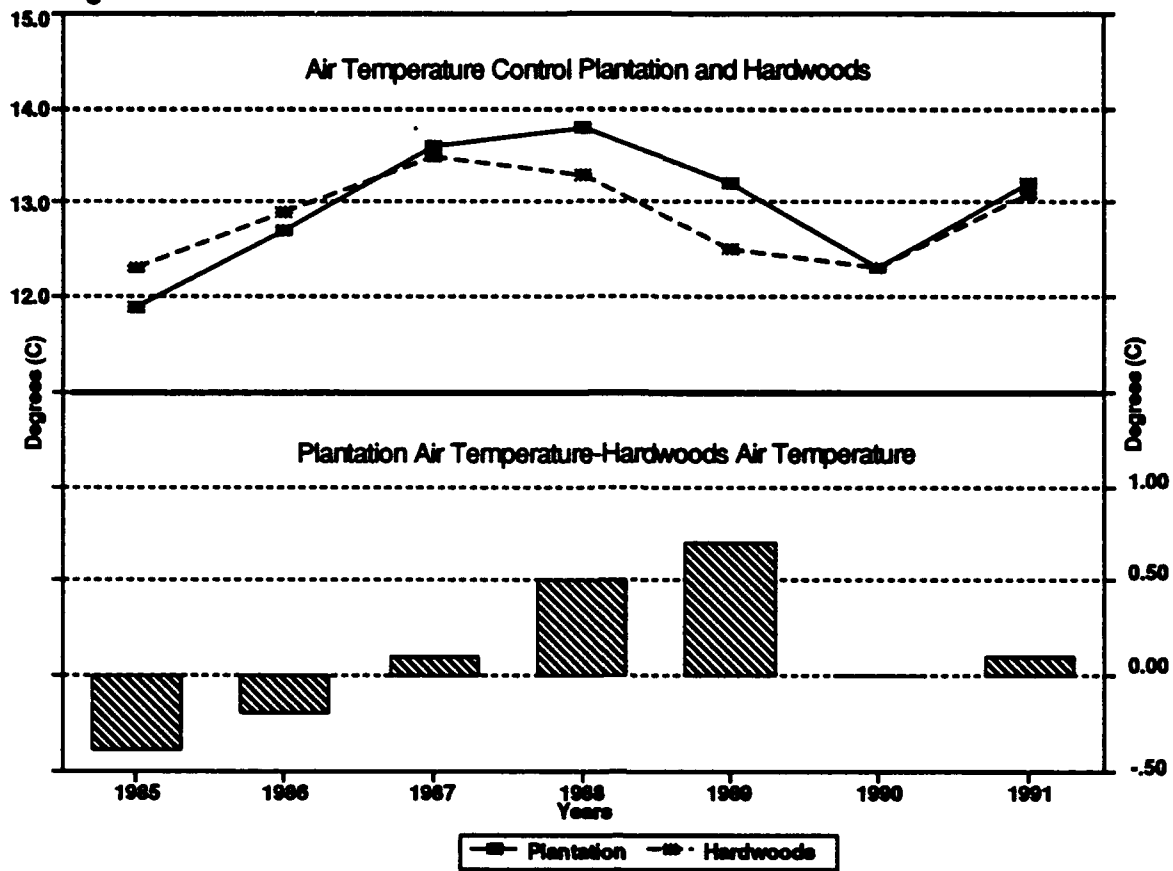
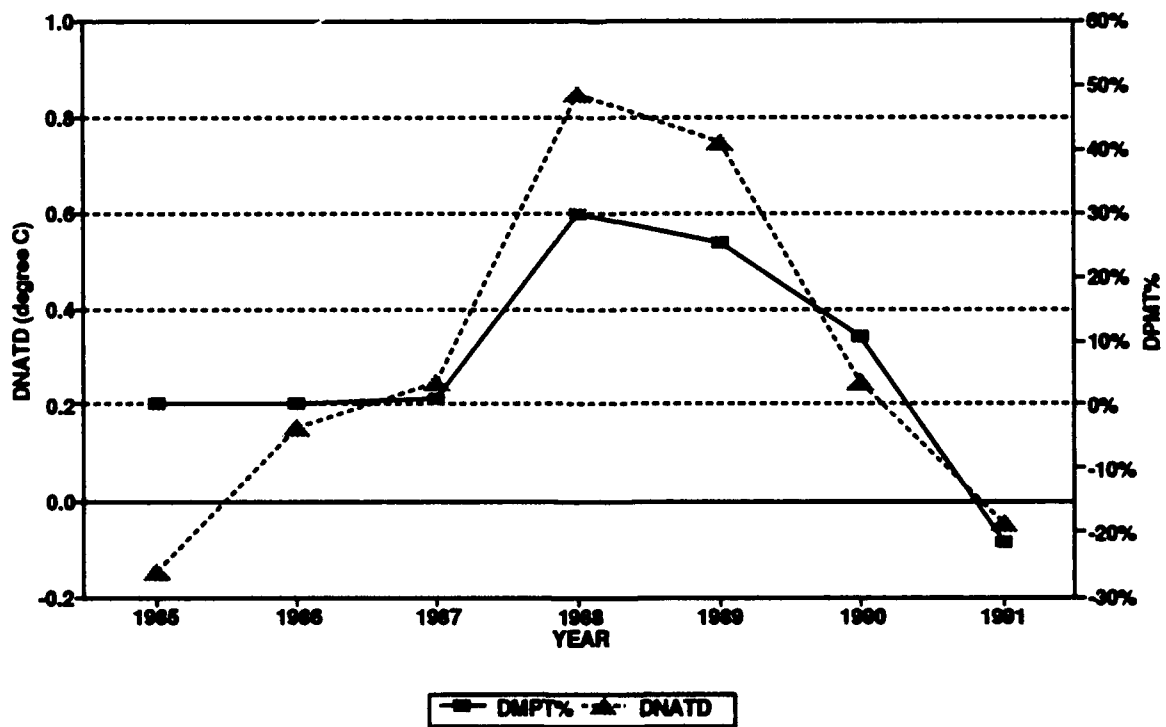


Figure 1.7

DNATD & DPMT% FOR THE CONTROL vs. GROUND PLANTATION



designated height class. In 1988 and 1989 DNATD averaged approximately 0.8 °C and the DPMT% was between 25 and 30%. The reduction in the differences in air temperature between the control and ground plantations in 1990-1991 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 the ground had a greater portion of the red pine within the specified height interval than the control and thus the differences in air temperature between sites were less than the 1985-1986 average. 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 and is continuing to alter 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. Although the effects of the canopy on air temperature is being reduced in the plantation as the canopies are over topping the sensor height, it is evident that as of 1991 the temperature of all plantations were still being altered by the red pine canopy.

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 in part due 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 seven 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 in 1990 and 1991. 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 the 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. If height growth rates have been altered by the antenna operation, air temperature would also be altered by antenna operation. There does not appear to be any direct effect of ELF on air temperature unless the ELF antenna operation has altered the height growth of the trees in the plantation. Thus any conclusions regarding the effect of ELF

on air temperature can only be considered preliminary until the effects of ELF on tree growth in the plantations have been quantified.

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 ($p=.173$) or the control and antenna sites ($p=.190$) 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 1985-1991 was 1.2 °C for the control vs. ground comparisons and 1.3 °C for the control vs. antenna comparison. Annual differences in soil temperature (5 cm) were significant ($p<.001$) for both

Table 1.4 Comparison of mean soil temperature (°C) at a depth of 5 cm during the 1985-91 growing seasons (April-Oct.).

Plantation					
	<u>Ground</u>	<u>Antenna</u>	<u>Control</u>	<u>Control-Ground</u>	<u>Control-Antenna</u>
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
Ave.	12.8	13.1	13.1	0.3	0.0

Hardwoods					
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
Ave.		10.9	11.5		0.6

1985-91 MEAN DAILY SOIL TEMPERATURE (5cm) C°

Site Comparison

Control	Ground
13.1 a ¹	12.8 a
Control	Antenna
12.3 a	12.0 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

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

comparisons. Multiple range tests showed soil temperatures (5cm) during 1986-1988 to be greater than during 1985, 1989, 1990, or 1991 for the control vs. ground comparisons. Mean annual soil temperatures (5cm) for the control vs. antenna comparison were ranked in a similar fashion (Table 1.4)

Site by Year Comparisons: Although differences between the soil temperatures at the control and test site plantations were greater in 1988 and 1989 than any other year (Table 1.4) site by year interactions were not significant for the control vs. ground ($p=.106$) or the control vs. antenna ($p=.409$) comparisons. 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 plantations were neither consistently warmer nor cooler than at the antenna plantation. None the less site by stand type interactions ($p=.069$) and site by stand type by year interactions ($p=.725$) were not found to be significant. Although the increased soil temperature at the control plantations relative to the test plantations during 1988 and 1989 were consistent with the higher air temperatures in the control plantation during this period, statistical comparisons have indicated that the increased soil temperatures during 1988 and 1989 were not greater than the temporal or spatial variation in this stand type.

Soil Temperature (depth 10 cm)

Site Comparisons: Average soil temperatures (10 cm) at the control site were within 0.9°C and 0.5°C of the 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 ($p=.471$) or the control and antenna sites ($p=.113$).

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, 1989, 1990, and 1991 temperatures (Table 1.5).

Site by Year Comparisons: Site by year interactions were not significant for either the control vs. ground ($p=.273$) or the control vs. antenna ($p=.307$) comparisons. Site by stand type interactions were not significant ($p=.126$) but site by stand type by year interactions for the first time during the study were significant ($p=.034$). Figure 1.8 is a graph of the control and antenna average growing season soil temperatures (10cm) for each stand type and each year of the study as

Table 1.5 Comparison of soil temperature (10 cm) during the 1985-91 growing seasons (April-Oct.).

Plantation					
	<u>Ground</u>	<u>Antenna</u>	<u>Control</u>	<u>Control-Ground</u>	<u>Control-Antenna</u>
1985	12.2	12.6	12.4	0.2	-0.2
1986	13.0	13.	13.3	0.3	-0.1
1987	13.2	13.1	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
Ave.	12.5	12.9	12.7	0.2	-0.2

Hardwoods			
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
Ave.	10.7	11.2	0.5

1985-91 MEAN DAILY SOIL TEMPERATURE (10CM) C⁰

Site Comparison

Control	Ground
12.7 a	12.5 a
Control	Antenna
12.0 a	11.8 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

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

well as results from a multiple range test used to perform mean separation. 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 during 1991 soil temperature in the control hardwoods was significantly higher than in the antenna hardwoods. Also 1991 was the first year that soil temperatures at this depth was not significantly greater ($p=.05$) in the plantations than both hardwood stands.

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 1.9). Prior to 1990 increased or decreased air temperatures at the hardwoods resulted in similar increases or decreases in soil temperatures. In 1990 air temperature decreases resulted in little change in soil temperatures. This lack in reduction of 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. 1991), which 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 1.9) 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 temperature (10cm) at the antenna were 0.4 °C less than the increases at the control hardwoods. Comparisons of litter weight (Mroz et al. 1991) and soil moisture content (10cm) during 1990 and 1991 do not show any relationship to the increased differences in soil temperature (10cm) between the sites. An increased difference in soil temperature (5cm) between the control and antenna hardwoods was also observed during 1991. However the difference was less than observed at a depth of 10cm and was not significant ($p=0.05$).

Differences in soil temperature (10cm) among the plantations and hardwoods were less in 1991 than in any other year of the study (Figure 1.8). Like the hardwoods, annual variation in soil temperature (10cm) in the plantations is strongly related to annual variation in air temperature prior to 1990 (Figure 1.10). However an increase in air temperature of 0.9 to 1.0 °C resulted in a maximum of only 0.1 °C increase in soil temperature from 1990 to 1991. The decreased differences in soil temperatures between stand types appears to be primarily due to a decrease of soil temperatures in the plantations. Soil temperatures (10cm) in the plantations prior to 1988 at the control and prior to 1991 at the antenna were higher than the air temperature in the plantations. Currently average growing season soil temperatures (10cm) are 0.4 to 1.2 °C less than air temperature in the plantations. The reductions in soil temperature in the plantations reflects the decreased insolation resulting from the increased foliar area of the red pine canopies and also the formation of a relatively homogenous litter layer on the mineral soil

Figure 1.8

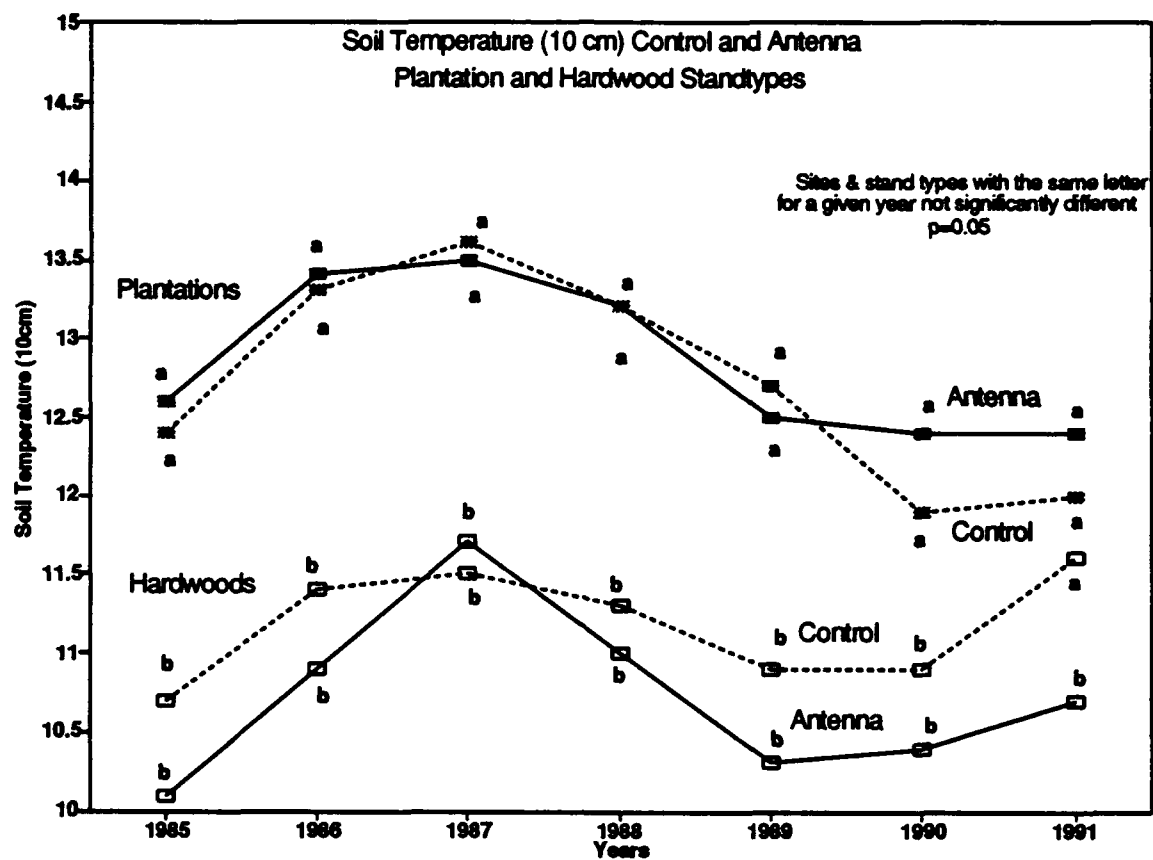


Figure 1.9

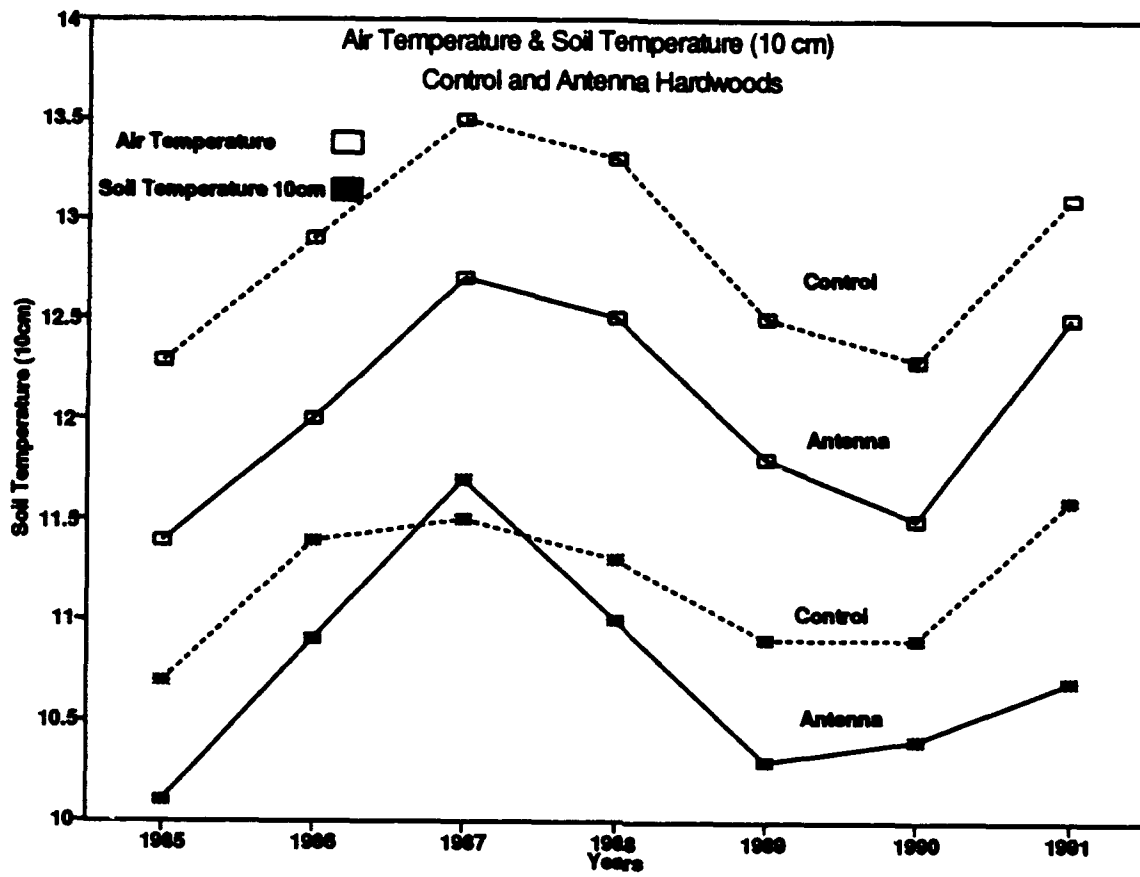
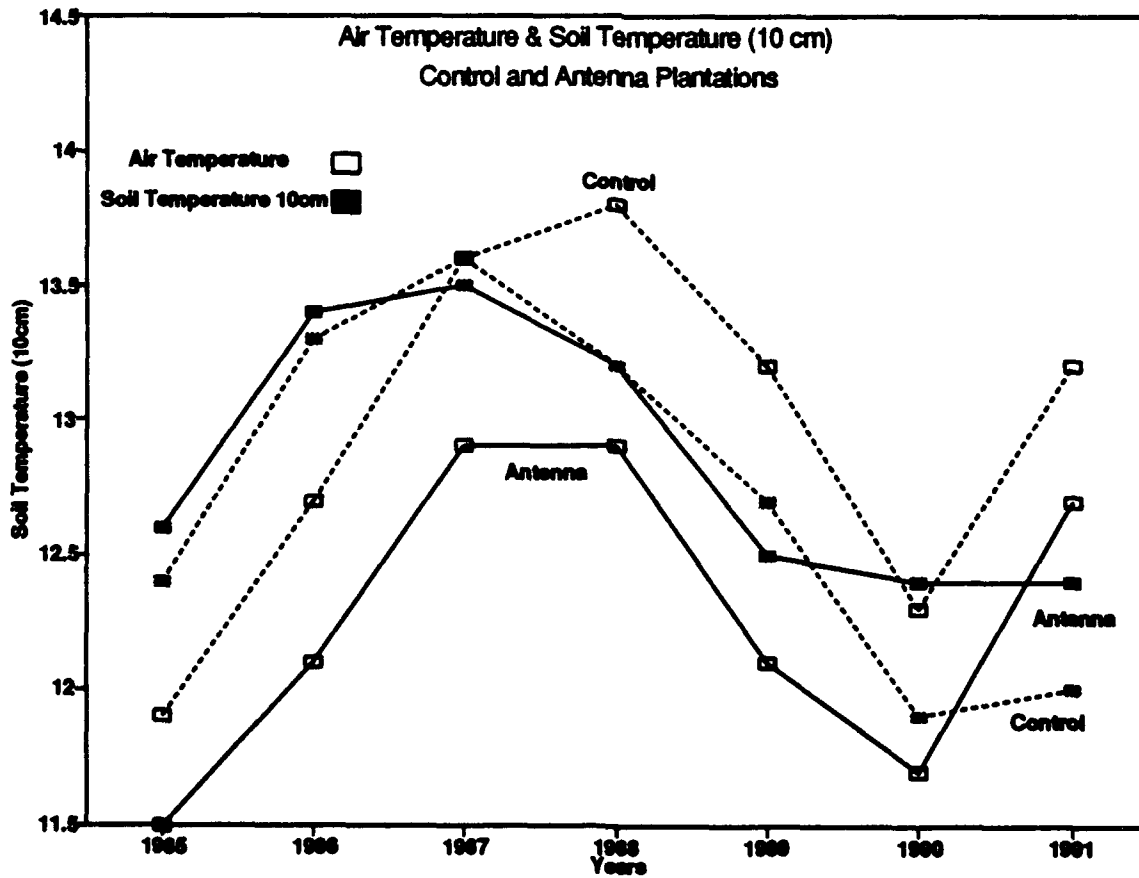


Figure 1.10



surface. The differing rates of soil temperature reductions, as indicated by Figure 1.10, most likely reflect the differing rates of crown growth and tree survival at the control and antenna plantations.

Summary: Again this year ANOVA tests with soil temperature (5cm) showed no significant differences ($p \leq .05$) among sites or significant ($p \leq .05$) site by year, site by stand type, or site by stand type by year interactions. Results were similar for soil temperature (10cm) except site by stand type by year interactions were significant ($p = .034$). Average growing season soil temperatures (10cm) were found to have decreased in the plantations, relative to the hardwoods, during the past two to three years at the control and antenna sites. During 1991 soil temperature in the antenna hardwoods has decreased in comparison to the control hardwoods. The reduction in temperature in the plantations is a result of the decreased solar insolation with the increased leaf area and canopies of the red pine plantations. However, no specific information is available to explain the increased differences in soil temperature between the control and antenna hardwood stands. Since the soil temperature sensor location is altered slightly each year in order to recalibrate the soil moisture portion of the sensor, the change in temperatures may be a result of spatial variability. Continued observation of soil temperatures in 1992 and 1993 should be able to evaluate whether the changes in temperature in the hardwoods is a result of spatial variability or changes in biotic factors.

At this time 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 increased differences in soil temperature (10cm) among the hardwood stands in 1991 are still unexplained. Furthermore, the increased effect of the red pine plantation canopy on soil temperature will magnify any changes in soil temperature induced by the potential alteration of the red pine by the ELF fields at the antenna and ground sites.

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 was greater than at the antenna for all years of the study but was only greater than the ground site during 1986, 1988, 1989, and 1990. ANOVA tests indicated significant higher soil moisture content (5cm) at the control than at the antenna site ($p=.003$) but not the ground ($p=.135$). Average soil moisture content (5 cm) during 1986-1991 was 1.2% and 2.7% greater at the control than at the ground and antenna sites respectively (Table 1.6). Differences in moisture content of the control and antenna sites is related to the differences in the water holding capacity of these two sites (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 considerably 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 ($p=.093$).

Differences in soil water potential between the sites were not found to be significant ($p=.832$) for the control vs. ground comparison but were significant for the control vs. antenna comparison ($p=.012$). 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 ($p<.001$) among years for both the control vs. ground and control vs. antenna comparisons ($p=.003$). Soil moisture content (5 cm) and soil water potential (5 cm) were

Table 1.6 Comparison of soil moisture content (%) and soil water potential(-Mpa) at a depth of 5 cm during the 1986-91 growing seasons (April-Oct.).

Plantation										
	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa
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
Ave.	13.9	.018	11.7	.013	15.1	.015	1.2	-.003	3.4	.002
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	.020			2.7	.006
Ave.			10.7	.019	12.9	.027			2.0	.008
Site Comparison										
	Control		Ground							
Moisture Content	15.1	a ¹			13.9	a				
Soil Water Pot.	.015	a ²			.018	a				
	Control		Antenna							
Moisture Content	14.0	a			11.2	b				
Soil Water Pot.	.020	b			.016	a				
Annual Comparison										
	Control & Ground		Control & Antenna							
	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa
1986	14.6	bc	.018	b	12.4	c	.020	c		
1987	13.6	c	.020	b	11.6	cd	.030	d		
1988	12.3	d	.027	b	11.1	d	.026	d		
1989	13.6	c	.018	b	11.4	cd	.023	c		
1990	17.8	a	.012	a	15.4	a	.010	a		
1991	15.1	b	.012	a	13.5	b	.014	b		

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

²ANOVA 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—————	
	<u>Plantation</u>	<u>Hardwood</u>
Ground	240.9	
Antenna	125.9	188.3
Control	239.2	257.5

significantly higher ($p \leq .05$) in 1990 and 1991 than in any other year of the study. The higher moisture contents and water potentials in 1990 and 1991 can be attributed to relatively high 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 ($p = .120$). The site by stand type by year interaction was also significant ($p = .006$) 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 1.11). However, multiple range tests showed significant differences between the control and antenna plantation during 1987 and 1989 as well as in 1986 and 1990 (Figure 1.12).

Differences in soil moisture content (5cm) between the control and antenna hardwoods were significant during 1986, 1989, and 1991. Differences in moisture content in the hardwoods at the two sites has increased during the last four years. This increase may 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,

Figure 1.11

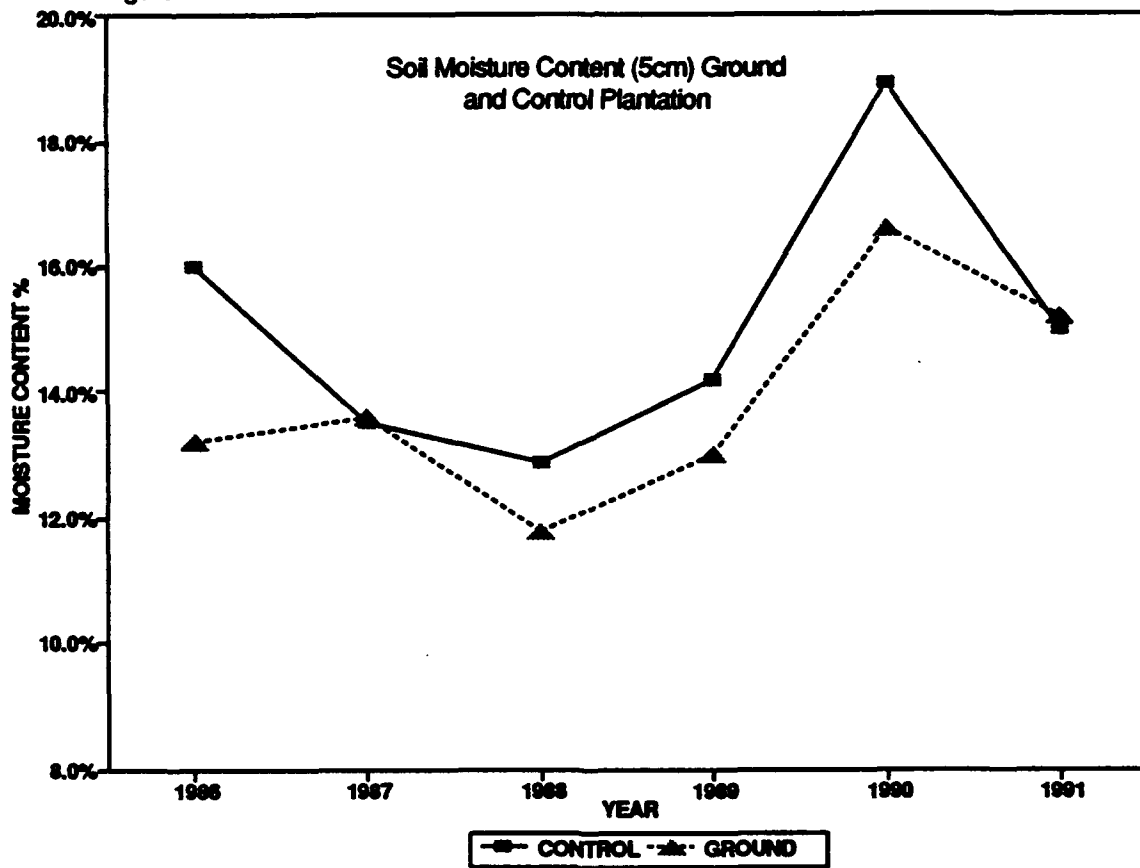


Figure 1.12

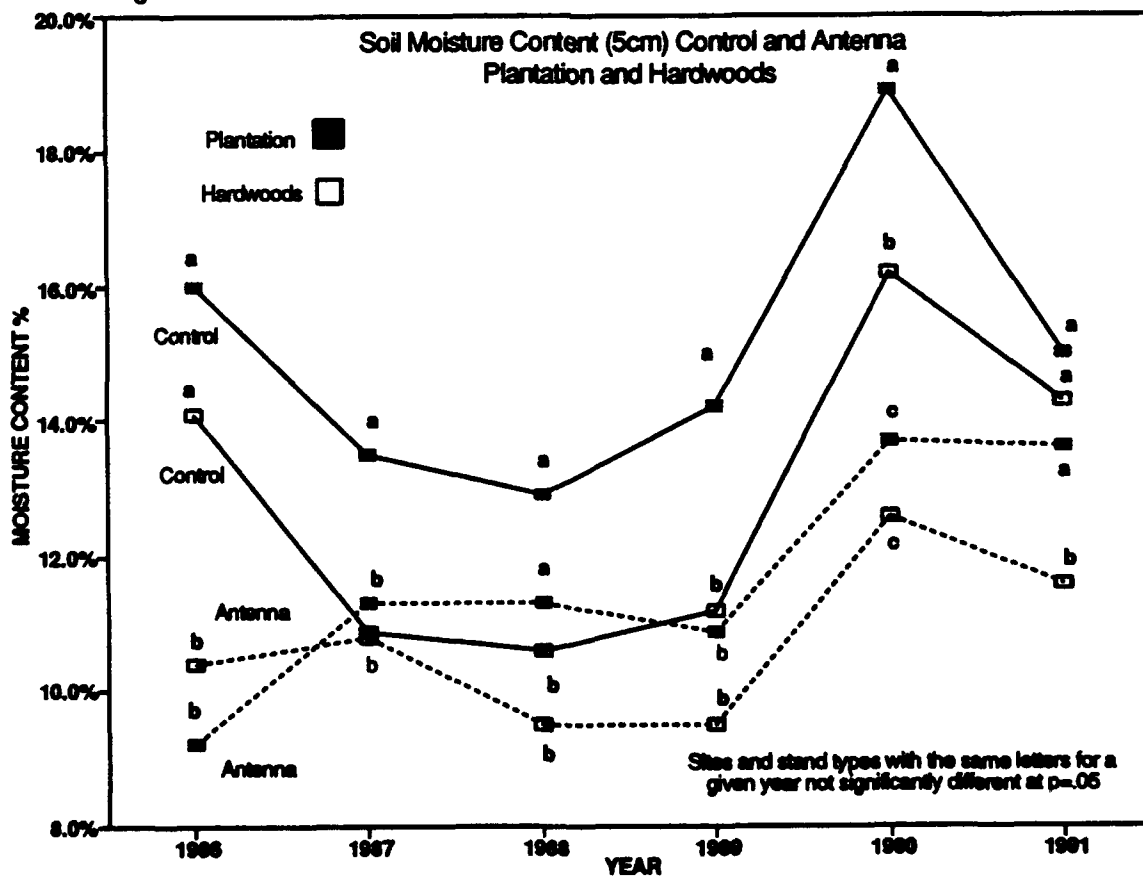


Table 1.8 Average soil moisture content 5cm for differing soil water potentials at control and antenna hardwoods.

	Antenna		Control	
	<u>-MPA</u> ¹	% ²	<u>-MPA</u>	%
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

¹ Soil Water Potential

² Soil Moisture Content

differences in moisture content between sites were the greatest.

During periods of high water stress, leaf stomata close thereby reducing evapotranspiration and loss of water from the soil. This limits the rate of soil moisture removal from the soil and to a large degree reduces the minimal moisture content of the soil. Since the moisture contents at low soil water potentials are more similar between the antenna and control sites than moisture contents at high soil water potentials (Table 1.8), differences in moisture content between sites are minimal during years of high water stress and low soil water potentials. The increased site differences in soil moisture content (5cm) is more evident in the hardwoods due to the limited variation in leaf area and canopy biomass during the study. In the aggrading plantations, annual increases in leaf area and thus evapotranspiration obscures this relationship.

As a result of the higher detection limits associated with soil water potential (5cm) and the varying relationships between soil moisture content and soil water potential among sites, site by year interactions were only significant for the control and antenna comparison ($p=.002$). Neither the site by year interaction for the control vs. ground comparison ($p=.711$) nor the site by stand type by year interaction for the control vs. antenna comparison ($p=.759$) 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 ($p=.082$) but was significantly higher than the antenna site ($p=.008$). However differences in soil water potential were not significant for either control vs. ground ($p=.776$) nor the control vs. antenna ($p=.242$) 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 ($p=.061$). 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 comparison (Table 1.9). Moisture content (10 cm) for the control vs. ground comparison was also significantly higher in 1990 than in any study year except 1986. Both soil moisture content and water potential (10cm) was at the lowest levels in 1988. Like soil moisture content (5cm), annual fluctuations in soil moisture content (10cm) generally follow climatic trends in precipitation and air temperature.

Site by Year Comparisons: ANOVA tests of soil moisture content (10cm) showed significant site by year interactions for the control vs. ground comparison ($p=.002$) but not the control vs. antenna comparison ($p=.057$). The significant interaction for the control and ground comparison appears to be related to the moisture contents at the two sites during 1990 (Figure 1.13). Average moisture content in both the control and antenna sites were higher in 1990 than in 1989 (Table 1.9, Figure 1.14). However, average moisture content during 1990 at the ground site was lower than in 1989. As shown in Table 1.6, average moisture content at a depth of 5cm at the control and antenna was higher in 1990 than in 1989. However, average moisture content (10cm) during 1990 at the ground site was lower than in 1989 or 1991. Comparisons of soil moisture content at both depths suggest that soil moisture content (10cm) has a lower annual variation than

Table 1.9 Comparison of soil moisture content (%) and soil water potential(-Mpa) at a depth of 10 cm during the 1986-91 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
Ave.	13.9	.017	10.7	.014	15.3	.015	1.4	-.002	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
Ave.			10.9	.017	13.0	.020			2.1	.003
Site Comparison										
			Control		Ground					
Moisture Content			15.3 a ¹		13.9 a					
Soil Water Pot.			.015 a ²		.017 a					
			Control		Antenna					
Moisture Content			14.1 a		10.6 b					
Soil Water Pot.			.017 a		.015 a					
Annual Comparison										
	Control & Ground				Control & Antenna					
	%		-Mpa		%		-Mpa			
1986	14.9	ab	.017 bc		11.6	c	.020 c			
1987	14.7	bc	.015 ab		12.2	bc	.017 c			
1988	13.6	bc	.021 c		12.0	bc	.019 c			
1989	14.2	bc	.018 bc		11.5	c	.020 c			
1990	15.9	a	.012 a		14.6	a	.010 a			
1991	14.4	bc	.014 ab		12.6	b	.014 b			

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

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

Figure 1.13

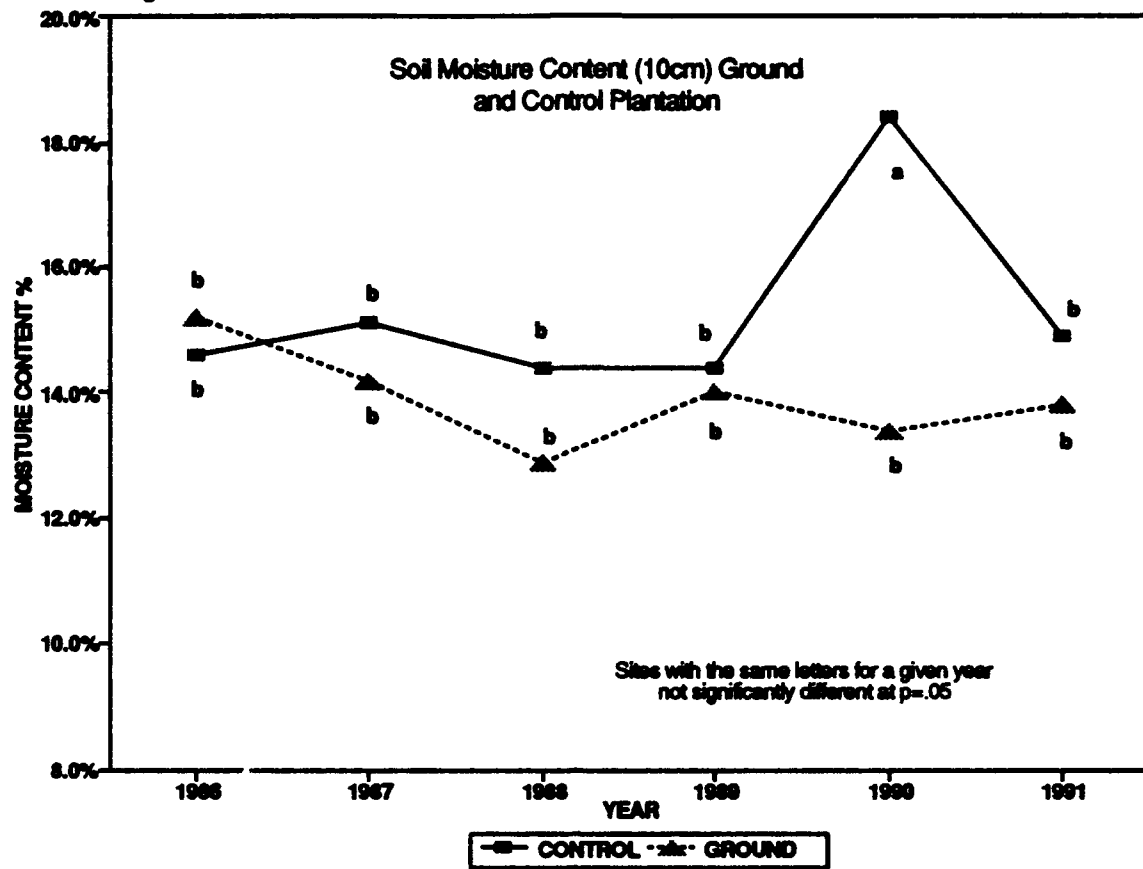
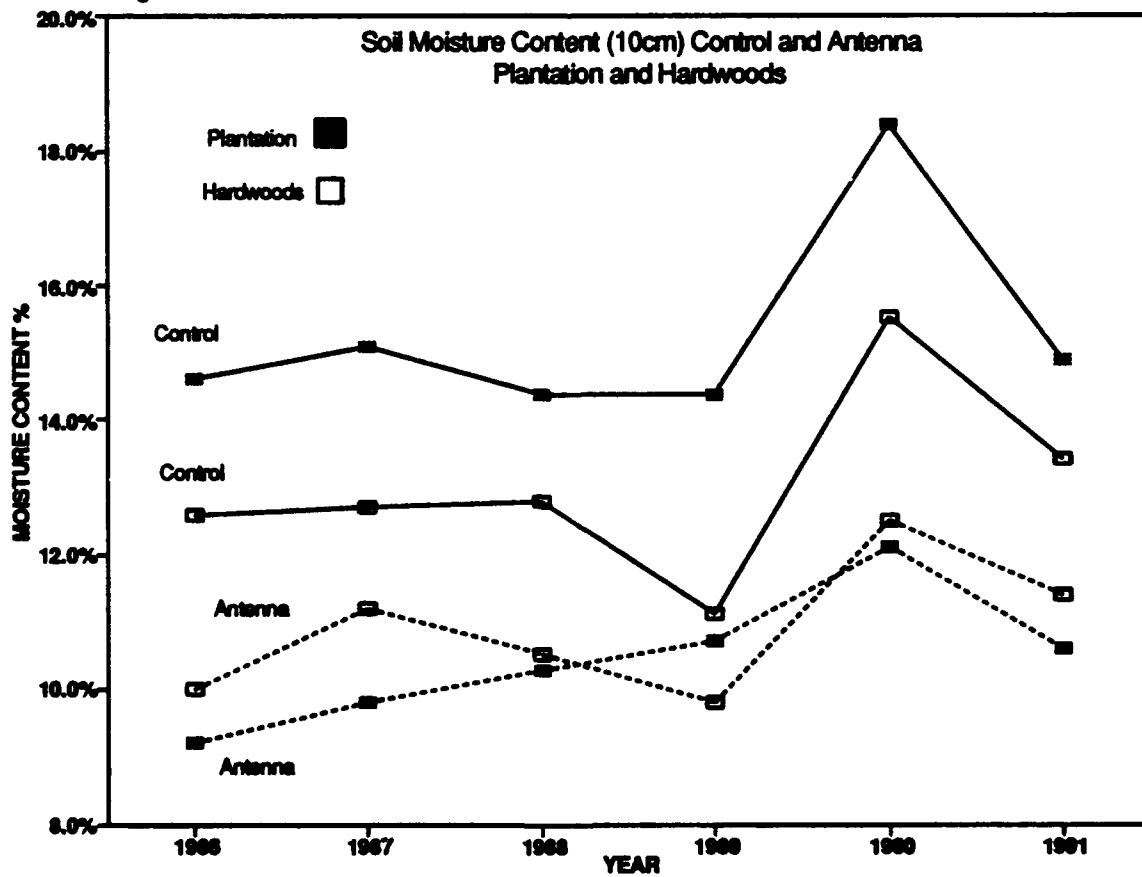


Figure 1.14



content at 5 cm. This may be due to changes in soil texture or structure, lower amounts of roots, or lower evaporation at this depth. Thus the decreased soil moisture contents in 1990 at the ground site appear to be an anomaly which is related to the inherent precision of the soil moisture sensors and/or a general natural buffering of moisture changes at this depth.

Site by stand type by year interactions were not significant for either soil moisture content ($p=.636$) or soil water potential ($p=.751$) 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. Differences in the moisture content of the stand types at the two sites, as noted by the significant site by stand type interactions, has not fluctuated during the six year measurement period. 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 the control vs. ground comparison 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. Additional monitoring in the next two years should confirm or refute this conclusion. 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 precipitation and air temperature rather than changes in vegetation structure or dynamics.

Precipitation

The amount of precipitation and the distribution of precipitation over time are two primary factors controlling

Figure 1.15

RUNNING TOTAL PRECIPITATION 1985-1991

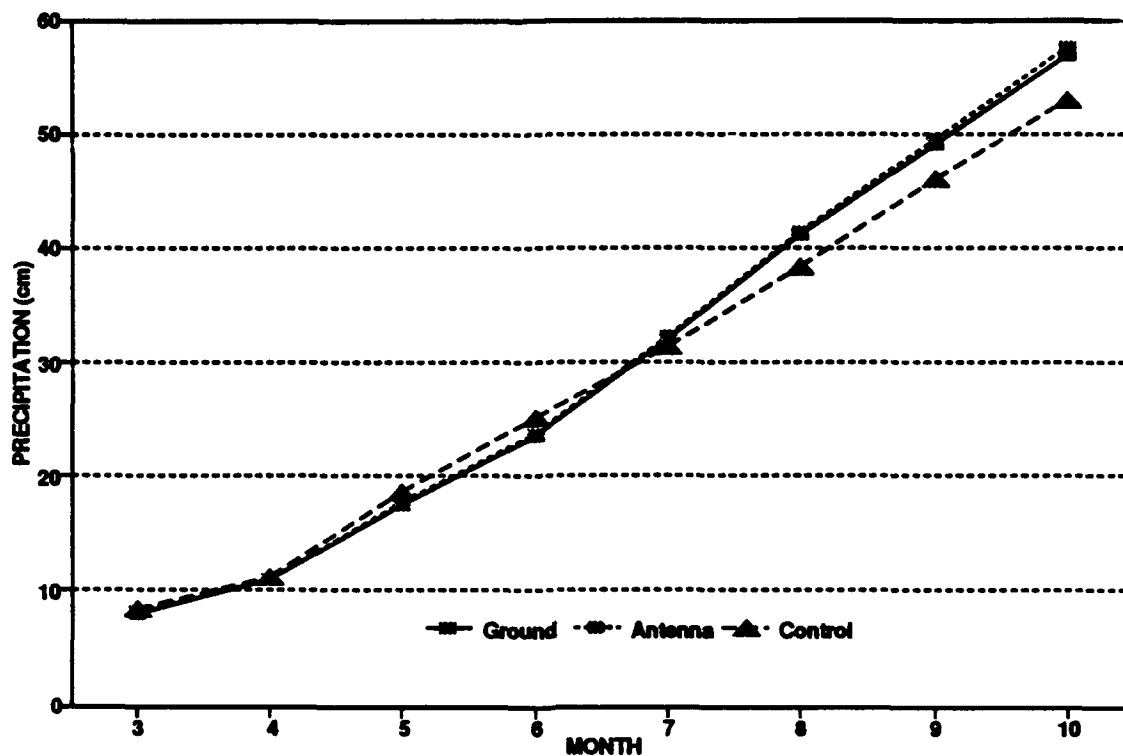
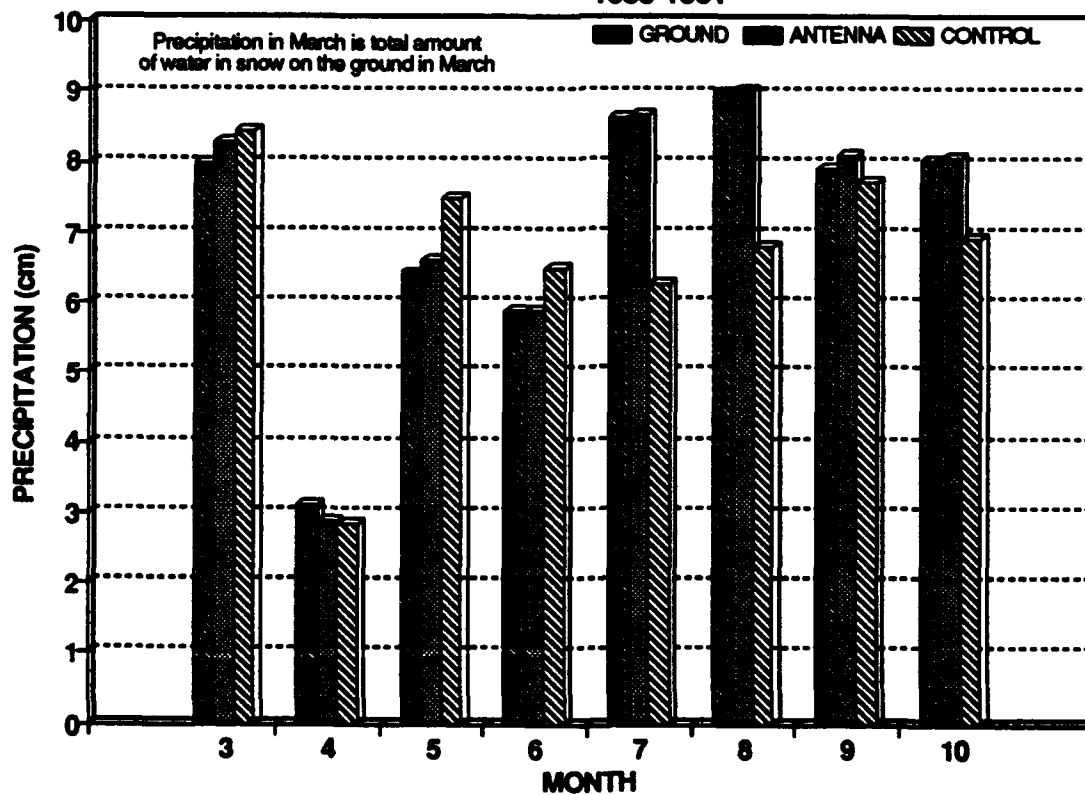


Figure 1.16

AVERAGE MONTHLY PRECIPITATION 1985-1991



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 1985-1991 study period (Figure 1.15). During this period the ground and antenna sites respectively received 4.01 cm and 4.53 cm more precipitation during the growing season than did the control site. The majority of this difference occurs during July and August (Figure 1.16). During these two months the ground and antenna site on the average have received 4.60 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 ($p=.545$) or the control vs. antenna comparison ($p=.519$).

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. However, ANOVA test showed significant differences in the average weekly precipitation amounts for the control vs. antenna comparison ($p=.094$) or the control vs. ground comparisons ($p=.135$).

Site by Year Comparisons: Site by year interactions were neither significant for the control vs. ground comparison ($p=.991$) nor the control vs. antenna comparison ($p=.981$). 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.

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

Table 1.10 Comparison average weekly precipitation amounts (cm) during the 1985-91 growing seasons (April-Oct.).

	<u>Ground</u>	<u>Antenna</u>	<u>Control</u>	<u>Control-Ground</u>	<u>Control-Antenna</u>
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
Ave.	1.77	1.78	1.62	-0.15	-0.16

Site Comparison

Control	Ground
1.62 a ¹	1.77 a
Control	Antenna
1.62 a	1.78 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

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

the sensor was being calibrated 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 363.5 Langleys/day (Table 1.11). Differences in average daily global solar radiation among

years were not significant ($p=.923$). Figure 1.17 shows that variation of global radiation within years are much greater than the variation among years.

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.

Table 1.11 Average global solar radiation during the 1985-1991 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	
383.2 a	363.5 a	373.9 a	

¹Averages 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.

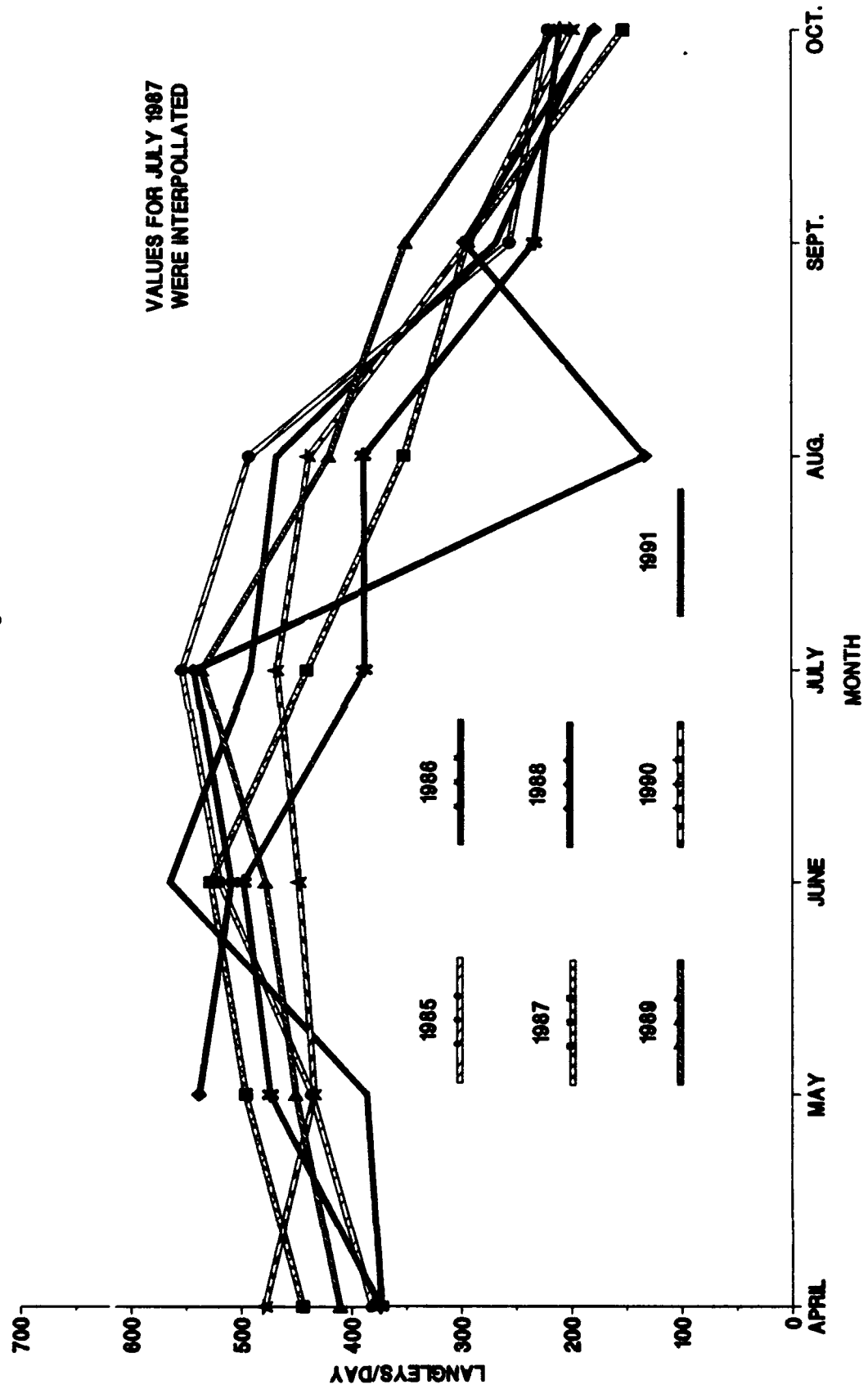
²Years with the same letter not significantly different at $p=0.05$

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.

Figure 1.17

Global Solar Radiation Ground Site
(1985-1991 Growing Season)



As a result of sensor repairs and system failures 1991 was the fifth 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 (1987-1991) and the control vs. ground ($p = .002$) comparisons (1987-1989, 1991). Average relative humidity was 13.1% greater at the antenna than control site during 1987-1991 while relative humidity at the ground was 7.9% higher than at the control site during 1987-1989, 1991.

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>1988>1989 for the control vs. antenna comparisons and 1987=1991>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 (Figure 1.18 & 1.19). 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. Decreases in the differences in relative humidity may be related to the increase height of the trees in the plantations in much the same manner that air temperature has been altered. 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 1992-1993 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

Figure 1.18

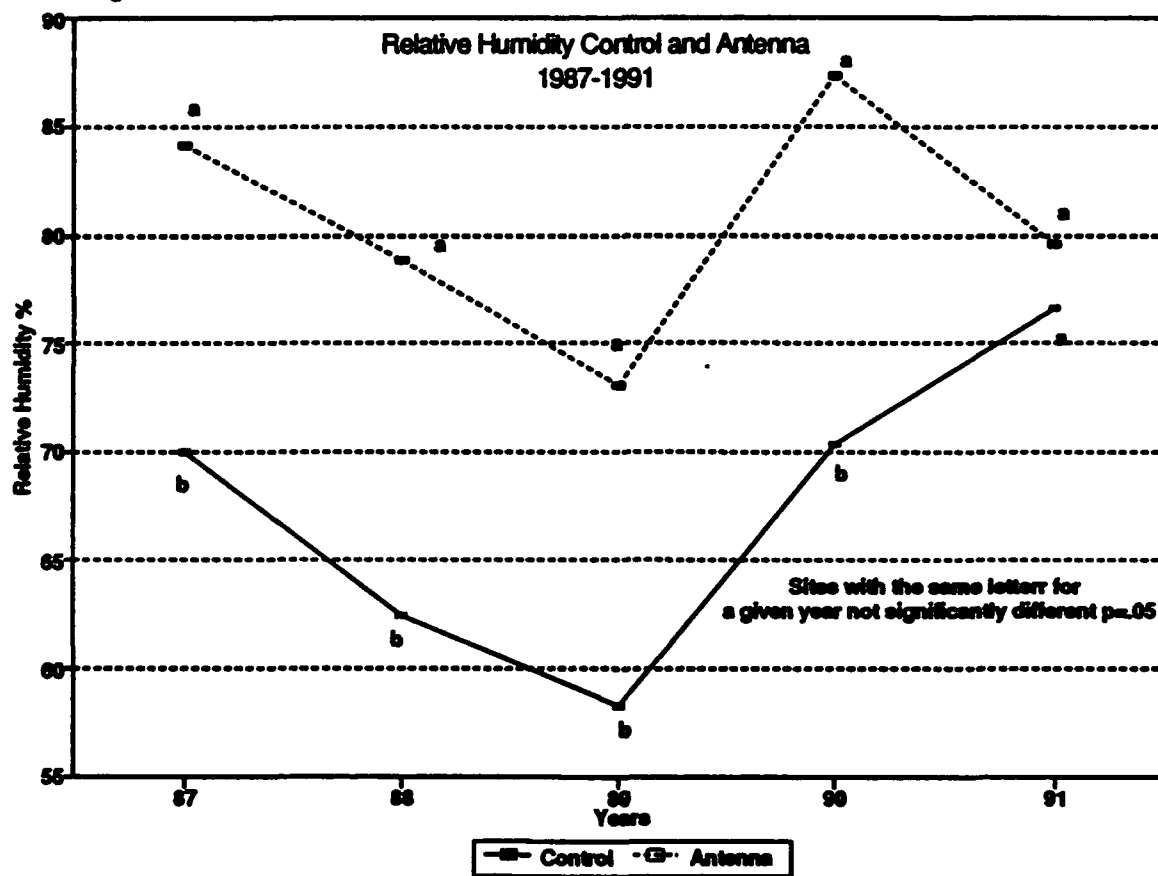


Figure 1.19

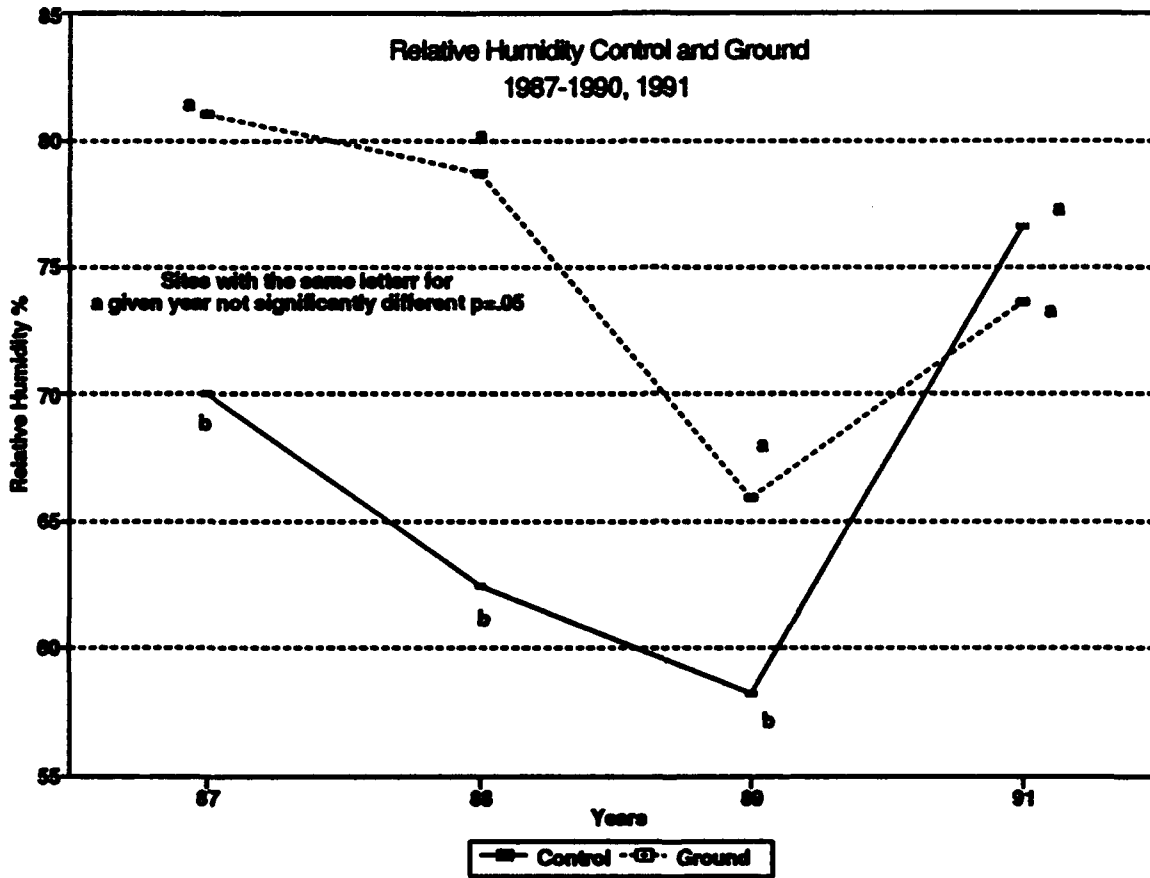


Table 1.12 Comparison of relative humidity during the 1987- and 1991 (May-Oct.).

Relative Humidity %					
	<u>Ground</u>	<u>Antenna</u>	<u>Control</u>	<u>Control- Ground</u>	<u>Control- Antenna</u>
1987	81.0	84.1	70.0	-11.0	-14.1
1988	78.7	78.8	62.5	-16.2	-16.3
1989	65.9	73.1	58.3	-7.6	-14.8
1990		87.3	70.3		-17.0
1991	73.6	79.6	76.6	3.0	-3.0
Mean					
(87-91)		80.6	67.5		-13.1
(87-89,91)	74.8		66.9	-7.9	

**Relative Humidity
%**

<u>Control</u> 67.5 b	<u>Ground</u> 74.8 a
<u>Control</u> 66.9 b	<u>Antenna</u> 80.6 a

	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>
Control vs. Ground	75.5 a	71.2 b	62.1 c		75.1 a
Control vs. Antenna	77.1 a	71.2 b	65.7 c	78.8 a	78.1 a

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

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 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 1986-1991 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 1986-1991 due to the downtime of the platforms. PAR is dramatically reduced during May and 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 1.11 Einsteins/day higher at the antenna site than at the control site during 1986-1991 (Table 1.13). However, differences in PAR among sites were not significant ($p=.617$) 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 ($p=.387$). Site by year interactions were also not significantly different ($p=.061$). However, the probability value associated with this interaction was the lowest to date.

Table 1.13. Comparison of photosynthetically active radiation during 1986 -1991 (May-July).

	Average Daily PAR (Einsteins/Day)						
	<u>1986</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>86-91</u>
Control	4.77	5.06	4.53	3.27	6.42	5.24	4.88 a ¹
Antenna	6.33	5.83	6.10	5.56	6.69	5.44	5.99 a
Control- Antenna	-1.56	-0.77	-1.57	-2.29	-0.25	-0.22	-1.11
Average	5.55 a	5.45 a	5.31 a	4.42 a	6.55 a	5.34 a	5.44

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

Summary: Detection limits for PAR are quite high because there is only one sensor at each site and the variability in PAR from year to year and from month to month is high. Thus it is not surprising that site, year, and/or site by year comparisons were not significant. Differences in PAR between the sites during the six years of measurement do not appear show any trends which are related to the ELF antenna operation. It should be noted however that differences in PAR between the two sites are at there lowest levels in the past six years.

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 1988-1991 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 °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 °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 ($p=.008$).

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 not significantly different among years ($p=.155$) and site by year interactions were not significant ($p=.963$) for this years analysis.

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 variable considered, there is no indication that ELF antenna

operation has modified the air temperatures of this stand type.

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, and 1991 (May-October)

Average Daily Air Temperature 30 cm (°C)							
	1985	1986	1988	1989	1990	1991	$\bar{x}$
Control	13.3	13.6	14.8	13.9	13.2	14.1	13.8 a ¹
Antenna	12.6	12.8	13.6	12.9	11.9	13.3	12.8 b
Control- Antenna	0.8	0.8	1.2	1.0	1.3	0.8	1.0
$\bar{x}$	12.9 a	13.2 a	14.2 a	13.4 a	12.6 a	13.7 a	13.3

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

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 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 16% of the mean for soil moisture content in both comparisons and soil water potential in the control vs. antenna comparison. DTL for site by year, site by

Table 1.15 Detection limits (DTL) and detection limits as a percent of overall mean (DTL%) for control vs. ground site comparisons (1985-1991).

Variable	Site		Year		Site by Year	
	DTL ¹	DTL%	DTL	DTL%	DTL	DTL%
Air Temperature 2m (°C)	0.5	3.8	0.3	2.4	0.4	3.3
Soil Temp. 5cm (°C)	0.5	3.1	0.3	2.5	0.5	3.6
Soil Temp. 10cm (°C)	0.6	4.9	0.3	2.7	0.4	3.8
Soil Moist. 5cm (°C)	1.3	8.7	1.1	7.6	1.6	10.7
Soil Wat. Pot. 5cm (°C)	.67	36.8	0.35	19.4	0.50	27.5
Soil Moist. 10cm (°C)	1.5	10.5	1.0	6.8	1.4	9.6
Soil Wat. Pot. 10cm (°C)	0.83	44.8	0.36	19.2	0.50	27.2
Sol. Rad. (L d ⁻¹)			86.9	56.0		
Rel. Humidity (%)	3.8	5.0	3.9	6.4	7.9	10.9
Precip. (cm)	0.62	38.0	0.80	49.3	1.11	68.8

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 (1985-1990).

Variable	Site		Year		Site by Year		Site by Stand		Site by Year		Site by Stand	
	DTL ¹	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%
Air Temp. (°C)	0.2	1.6	0.2	1.4	0.2	2.0	0.5	4.0	0.3	2.3	0.3	2.3
Soil Temp. 5cm (°C)	0.5	4.0	0.1	.88	0.3	2.3	0.4	3.7	0.7	5.7		
Soil Temp. 10cm (°C)	0.2	1.7	0.2	1.8	0.3	2.5	0.6	5.5	0.5	4.0		
Soil Moist. 5cm (%)	1.2	9.6	0.8	6.4	1.1	9.0	1.5	11.8	1.4	11.0		
Soil Wat. Pot. 5cm (-Mpa)	0.20	11.3	0.20	11.8	0.28	16.0	0.53	31.0	0.40	23.1		
Soil Moist. 10cm (%)	1.3	9.6	0.7	5.3	0.4	3.1	2.1	16.9	1.5	12.2		
Soil Wat. Pot. 10cm (-Mpa)	0.30	16.0	0.16	8.6	0.22	12.1	0.40	21.2	0.40	22.1		
PAR 30cm (E/day)	4.04	84.1	1.1	41.6	2.7	58.6						
Relative Humidity	2.8	3.8	3.6	4.9	5.2	7.0						
Precip. (cm)	0.62	38.4	0.69	42.0	1.00	61.0						
Air Temp. 30cm (°C)	.28	2.0	1.1	8.8	1.5	12.4						

¹ DTL calculated at p=0.05

stand type, and site by stand type by year interactions were also less than 15% for soil moisture content but not soil water potential. Soil water potential and moisture content DTL at both depths for the site factor in the control vs. ground comparisons increased two to three fold over DTL calculated in 1990. The increase in the detection limits were traced to missing values for a lower order error term in the analysis. This term was removed from the analysis and the current DTL calculated from the appropriate error terms.

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 correspond to 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 over the duration of the project are made. Changes in the relationships of the climate between the control and test sites would indicate possible ELF field effects on the ecology of the test sites. These changes are expressed in our statistical design through

Table 1.17 Significant differences for control vs. ground site comparisons (1985-1991)

<u>Variable</u>	<u>FACTOR</u>		
	<u>Site</u>	<u>Year</u>	<u>Site by Year</u>
Air Temp. (2m)	*1	*	*
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 - $p > .05$

significant site by year or site by stand type by year interactions. As of the 1991 measurements air temperature (2m), 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 1985-1991 site by stand by year interactions for both soil temperature 10cm and soil moisture content 5cm were significant (Table 1.18).

Significant site by year air temperature (2 m) interactions have been shown to be related to the productivity of the red pine at the control and test sites. Thus at least for this climatic variable potential effects of ELF electromagnetic fields on air temperature cannot be addressed until the effects of these fields on the productivity of red pine have been quantified. To some degree the significant site by stand type by year interactions for soil temperature 10cm is also related to the red pine productivity and its effects on insolation at the control and antenna plantations. However, soil temperature 10cm in the

antenna hardwoods appears to have increased relative to the soil temperature observed in the control hardwoods during 1991. This alteration of temperature cannot currently 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 ELF antenna operation, 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 next two years of the study. As of the 1991 the significant interactions for soil moisture (5cm & 10cm), soil water potential (5cm), and relative humidity have not appeared to be related to ELF antenna operation or changes in vegetation productivity among the sites. However, other approaches were utilized to further evaluate the accurateness of these conclusions.

Table 1.18 Significant differences for the control vs. antenna comparisons (1985-1991)

FACTORS					
<u>Variable</u>	<u>Site</u>	<u>Year</u>	<u>Site by Year</u>	<u>Site by Stand Type</u>	<u>Site by Stand Type by Year</u>
Air Temp. (2m)	* ¹	*	-	-	-
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 * $p \leq .05$

Factors denoted by - $p > .05$

One such 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 would suggest that either ELF antenna operation has affected a given ambient variable or that an 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, minimums, maximums, and/or totals for each year during 1985-1991. The mean maximum magnetic and longitudinal electric field strengths (76hz) are presented in Table 1, Appendix A.

Table 1.19. Correlation coefficients and significance levels associated with annual ambient variables and plot averages of maximum longitudinal (L) and magnetic (M) 76hz field strengths (1985-1991).

	Plantation		Hardwoods	
	<u>L</u>	<u>M</u>	<u>L</u>	<u>M</u>
Air Temp. 2m	-.347**1	-.323*	-.380*	-.422**
Soil Temp. 5cm	-.483**	-.462**	-.385*	-.392*
Soil Moist. 5cm	.082	-.052	-.248	-.256
Soil Temp. 10cm	-.390**	-.381**	-.414**	-.449**
Soil Moist. 10cm	-.101	-.309*	-.317	-.320
Average Weekly Precipitation	.009	.022		
Global Solar Radiation	.142	.085		
Relative Humidity	.109	.310		
Solar Radiation Par			.389	.378
Air Temperature 30 cm			-.468	-.484

1 ‡ .05 < p ≤ .10
 * .05 ≥ p > .01
 ** .01 ≥ p

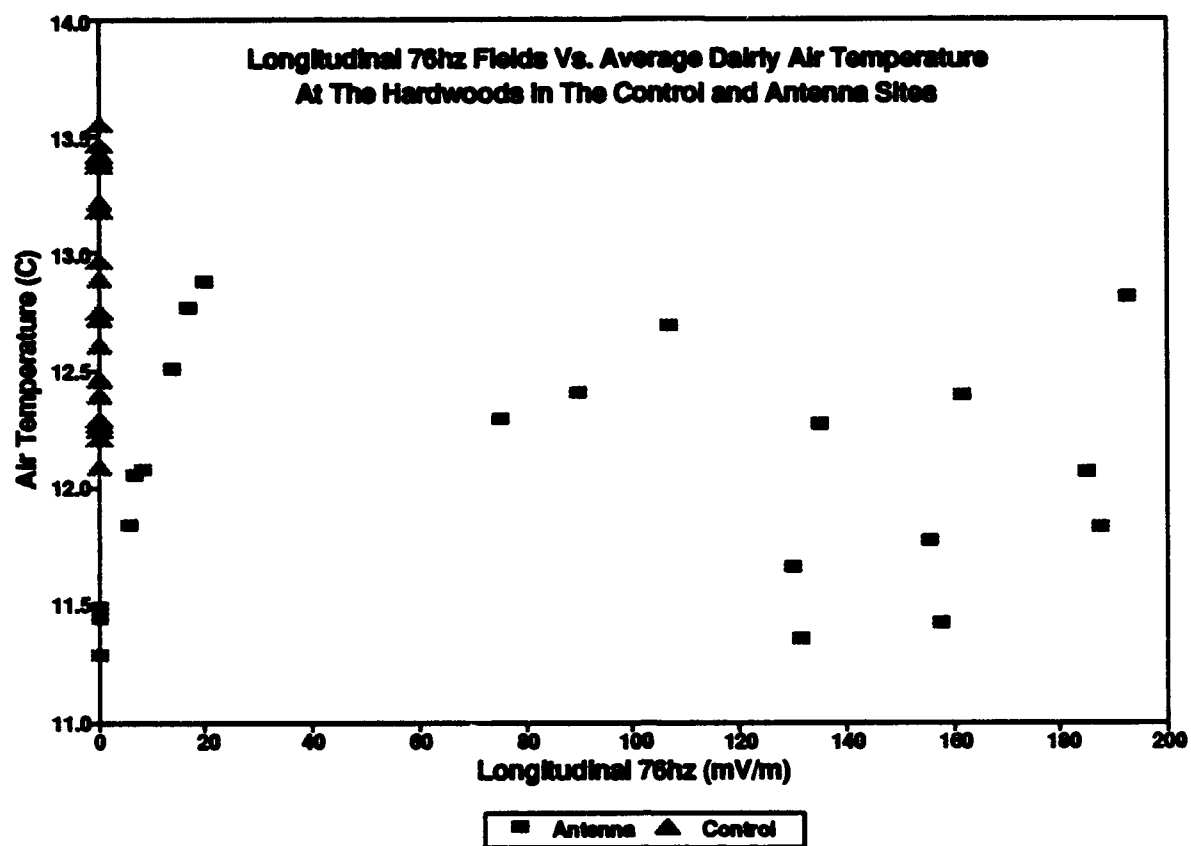
Table 1.19 indicates that air and soil temperatures are significantly ($p \leq 0.05$) correlated with both longitudinal and magnetic ELF fields. However, these correlations may be misleading. For example air temperature appears to be strongly correlated to both longitudinal and magnetic fields in the hardwoods (Table 1.19), but when air temperature is plotted with longitudinal field strengths from both sites (Figure 1.20) or each site separately (Figures 1.21 and 1.22), it is obvious that the correlations are related to the differences in air temperatures among the 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 when field strengths were at their maximum (Figures 1.21 and 1.22). The poor relationship among field strengths and climatic variables is more clearly evident when correlation coefficients are determined for each site separately (Table 1.20). Soil and air temperature variables which appear to be strongly correlated to field strengths in the hardwood stands (Table 1.19) are not significantly correlated to either magnetic flux densities or longitudinal fields when the control and antenna sites are considered individually. With the exception of soil temperature 5cm, none of the climatic variables measured in the hardwoods are significantly correlated with either of the field strength measurements.

Table 1.20. Correlation coefficients and significance levels associated with annual ambient variables and plot averages of maximum longitudinal (L) and magnetic (M) 76hz field strengths (1985-1991).

	-----PLANTATION-----					
	Ground		Antenna		Control	
	<u>L</u>	<u>M</u>	<u>L</u>	<u>M</u>	<u>L</u>	<u>M</u>
Air Temp. 2m	-.203	-.167	.078	.022	.007	-.082
Soil Temp. 5cm	-.641** ¹	-.649**	-.521*	-.564**	-.313	-.458*
Soil Moist. 5cm	.411†	.392†	.678**	.670**	.399†	.461*
Soil Temp. 10cm	-.480*	-.560**	-.590**	-.622**	-.618**	-.703**
Soil Moist. 10cm	-.040	-.357	.816**	.805**	.328	.371
	-----HARDWOODS-----					
Air Temp. 2m			.050	-.054	-.272	-.367†
Soil Temp. 5cm			-.208	-.224	-.378	-.434*
Soil Moist. 5cm			.300	.264	.452†	.428†
Soil Temp. 10cm			-.288	-.353	-.155	-.150
Soil Moist. 10cm			.254	.229	.273	.135

¹ † .05 < p ≤ .10
 * .01 < p ≤ .05
 ** .01 ≥ p

Figure 1.20



**Longitudinal 76hz Fields Vs. Average Daily Air Temperature
At The Hardwoods In The Control Site**

Longitudinal 76hz (mV/m)	Air Temperature (C)	Sample Number
0.000	12.20	87
0.000	12.25	88
0.000	12.30	89
0.000	12.35	90
0.000	12.90	87
0.000	13.00	87
0.000	13.05	87
0.000	13.10	87
0.000	13.15	87
0.010	13.40	88
0.010	13.45	88
0.012	13.20	88
0.012	13.25	88
0.015	13.40	88
0.015	13.45	88
0.040	12.38	90
0.040	12.40	90
0.040	12.60	89
0.040	12.62	89
0.040	13.18	91
0.040	13.20	91
0.050	12.28	90
0.050	12.30	90
0.050	12.75	91
0.050	12.78	91
0.058	12.45	90
0.058	12.48	90
0.058	12.72	89
0.058	12.75	89
0.058	13.38	91
0.058	13.40	91

**Longitudinal 76hz Fields Vs. Average Dairy Air Temperature
At The Hardwoods In The Antenna Site**

Year	Longitudinal 76hz (mV/m)	Air Temperature (C)
85	2	11.3
85	2	11.4
85	2	11.5
85	5	11.8
86	5	12.05
86	5	12.1
86	5	12.1
86	5	12.1
87	15	12.5
87	15	12.9
87	15	12.95
88	75	12.3
88	105	12.7
88	105	12.75
88	105	12.75
89	90	12.4
89	130	11.6
89	130	11.7
89	130	11.7
89	160	11.6
89	160	11.7
89	160	11.7
89	185	12.1
89	185	12.1
89	185	12.1
90	130	11.4
90	155	11.45
90	155	11.5
90	155	11.5
90	185	11.85
90	185	11.9
90	185	11.9
91	135	12.28
91	160	12.4
91	185	12.85
91	185	12.9
91	185	12.9

In the plantations a number of variables are strongly correlated with the magnetic and longitudinal fields. Soil temperature 5cm and 10cm are significantly ($p \leq 0.05$) correlated with field strengths at all three sites. Soil temperatures 5cm and 10cm showed decreasing trends with increasing field strengths. Since these trends were not significant in the hardwoods and soil temperatures were negatively correlated to field strengths at both control and test sites (Figures 1.23 and 1.24), these trends most likely reflect the increasing canopy and the decreasing insolation in the aggrading plantations during the study, rather than alteration of soil temperature by ELF antenna operation or annual changes in air temperature.

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 (Figure 1.25 and 1.26) rather than decrease from 1986 to 1991 and soil moisture contents were not consistently or strongly correlated to fields in the control or ground plantations. It is possible that changes in soil moisture content during the study is related to either decreases in temperature or increases in precipitation, but these variables were not found to be significantly ($p \leq 0.05$) correlated with field strengths (Tables 1.19 and 1.20). Site by year and site by year by stand type 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, at this time there is no clear evidence to support an ELF induced change in soil moisture in the antenna plantation without similar effects in the hardwoods or at the ground plantation. Other climatic variables which also had significant site by year or site by stand type by year interactions (air temperature (2m), air temperature (30cm), soil temperature 10cm, and relative humidity) showed no significant correlations with ELF fields that could not be explained by normal or expected growth of the red pine in the plantations during the study.

Figure 1.23

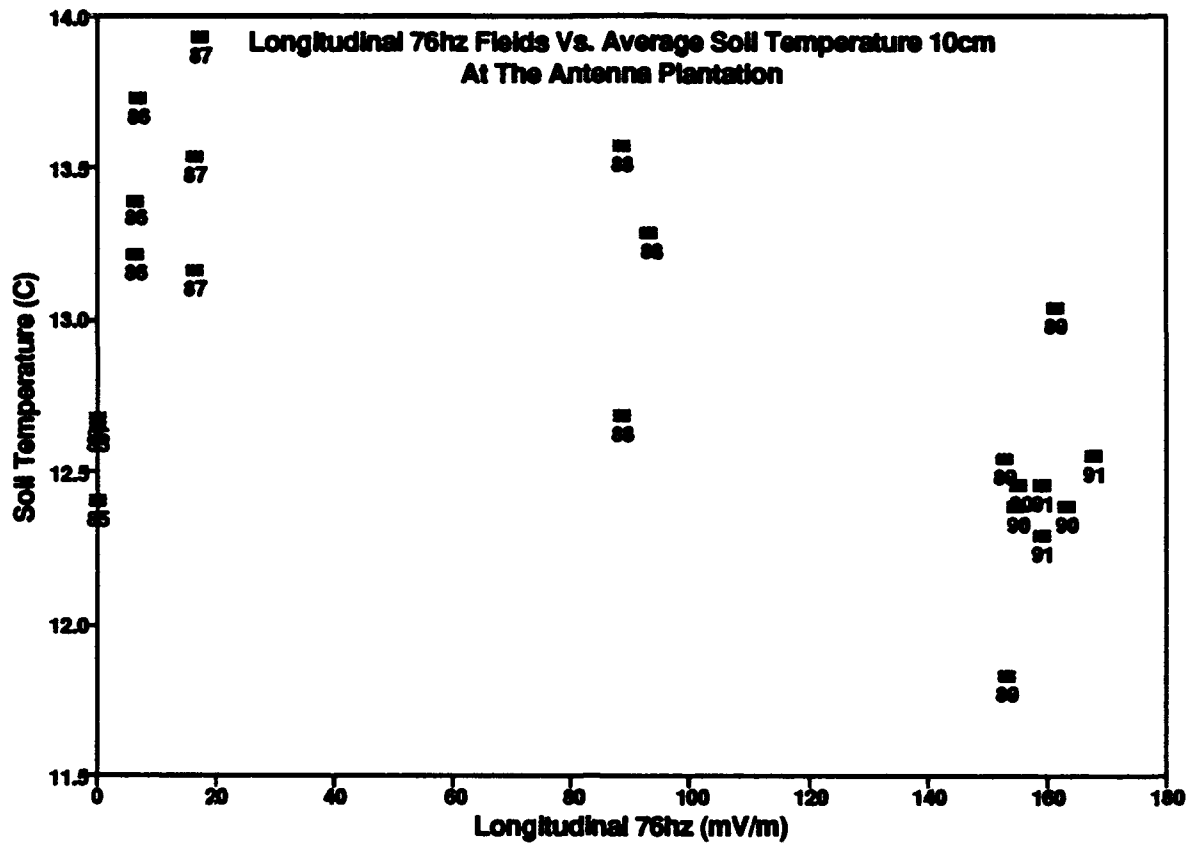


Figure 1.24

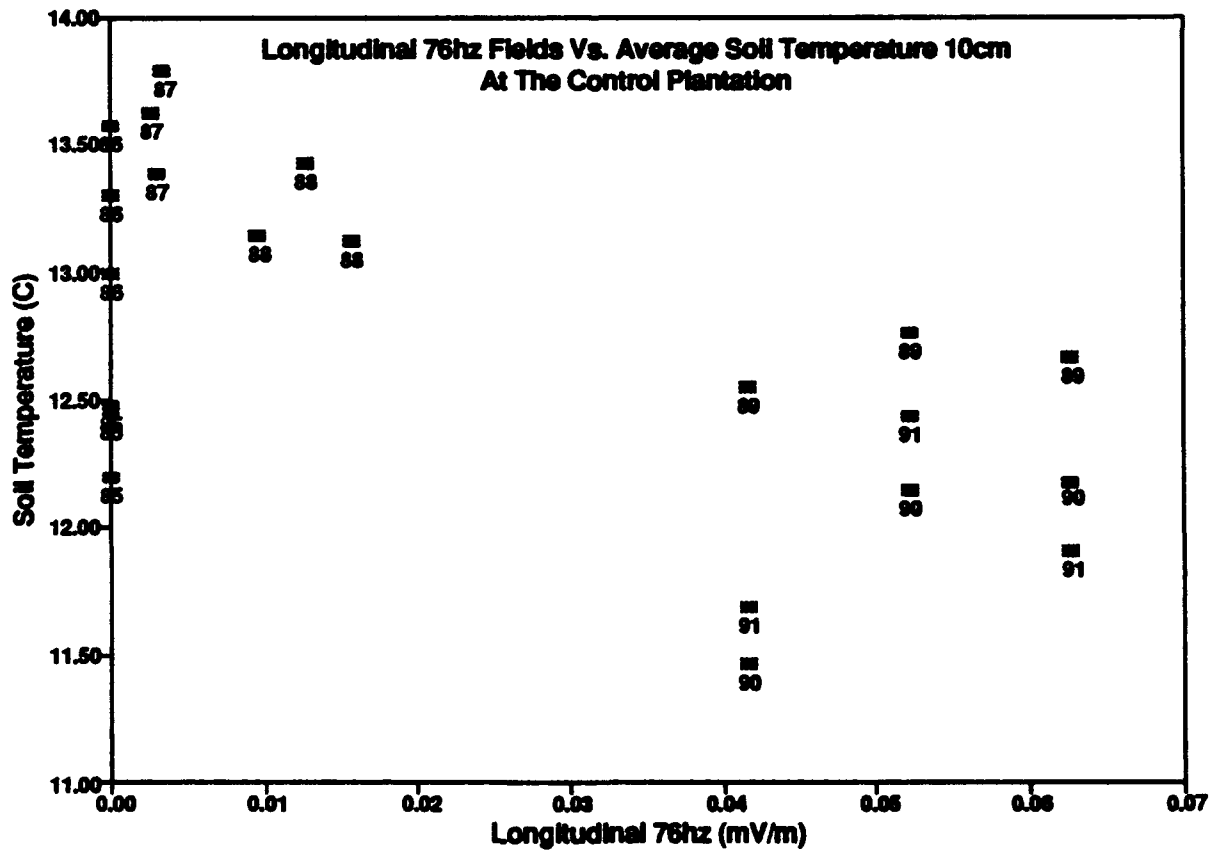


Figure 1.25

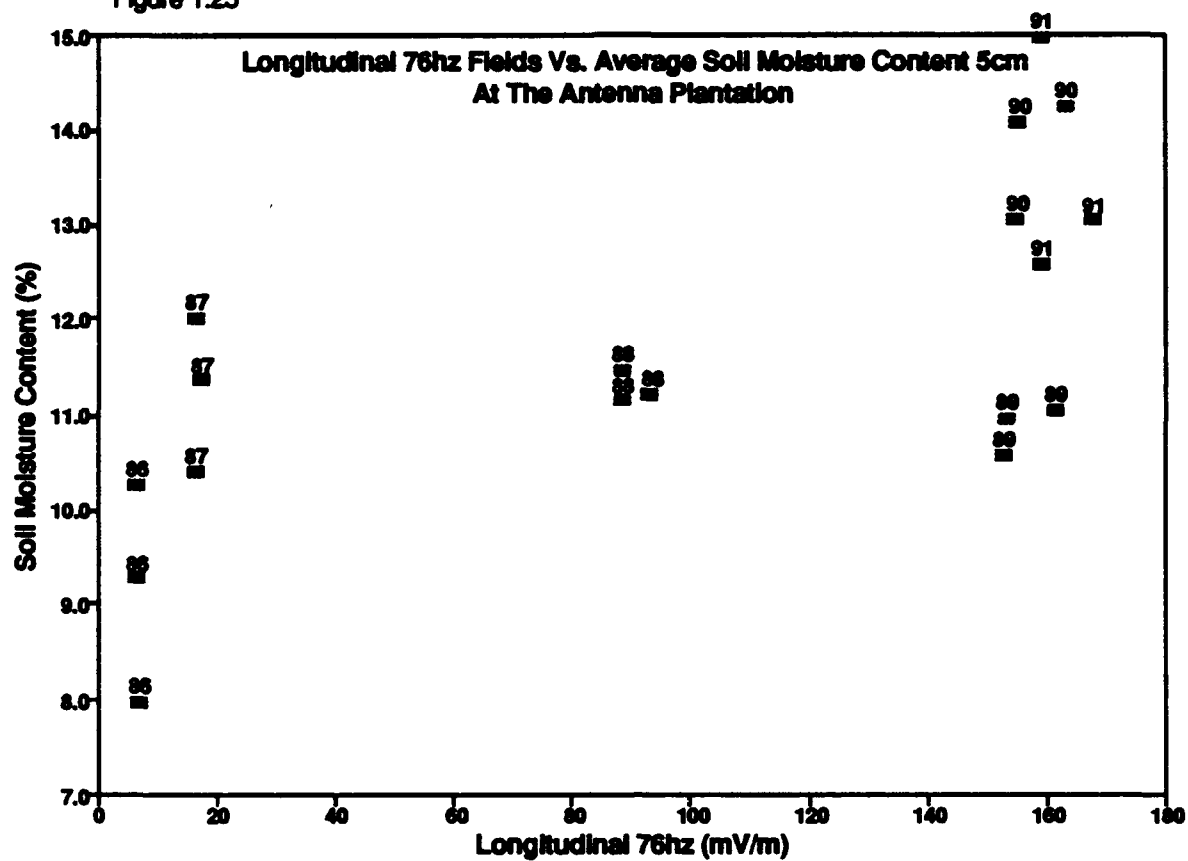
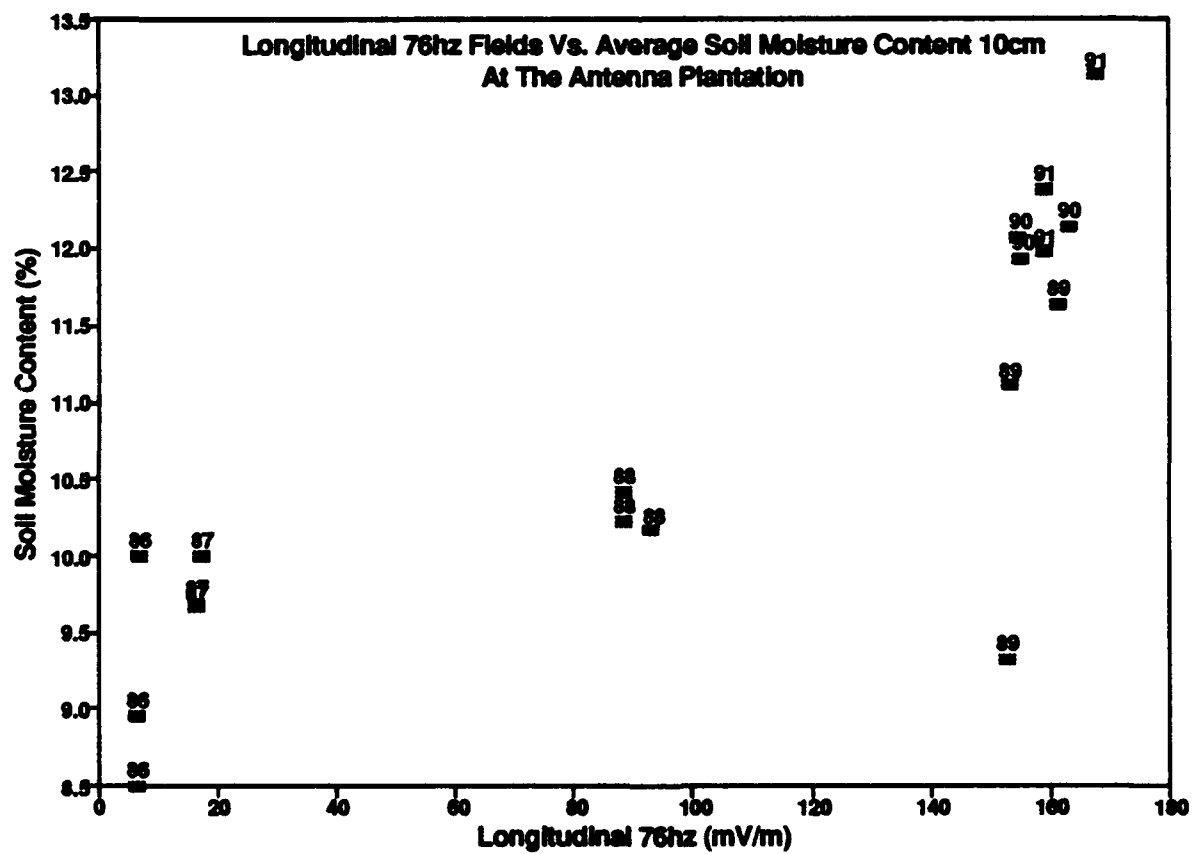


Figure 1.26



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. Last year's (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. It was concluded that considering the detection limits associated with site and year factors and the stable relationship of elemental contents among sites over the study period, it appeared that the variability in nutrient values for a given year were due to spatial variability within the study sites whereas the differences of elemental contents among years were related to laboratory soil analytical quality control.

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 in 1991 to only sample in these months. 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 this past year 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. Correlations with ambient variables 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 except Mg 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 N and K in the hardwood stands. Significant site by year interactions remained for Ca and Mg in the plantations and K in the hardwood stands. Multiple range tests showed K differences occurred in only in 1985 and 1991 in the hardwoods (Figure 1.27) while there were more widespread differences for Ca (Figure 1.28) and Mg (Figure 1.29).

Although soil and air temperature and soil moisture were significantly correlated with nutrient content in this preliminary analysis, these may not be the best covariates available for explaining year and site by year differences. For example, soil nutrients are highest on the control site and lowest on the antenna site across the years and are generally positively related to moisture content and negatively related to temperature variables. While these are valuable in predicting growth, soil nutrient contents are more influenced over short time periods by fluctuations in soil factors such as organic matter content for total N and P and changes that organic matter fluctuations would have on cation exchange capacity for cations. A decrease in the surface soil organic matter content over time from soil mixing and litter fragmentation due to other study activities might explain the general downward trend in soil nutrient levels over the length of the study. For this reason we will continue our soil monitoring efforts in the coming year and will include loss on ignition in our analyses.

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

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

	Year						
	85	86	87	88	89	90	91
	-----Kg/Ha-----						
Ground							
N	1981	1092	1241	1114	1018	1206	1248
P	510	569	529	450	463	603	505
K	78	55	57	64	65	73	43
Ca	835	455	460	477	430	505	456
Mg	74	41	46	39	65	72	46
Antenna							
N	1659	1033	1056	1003	1017	1026	1057
P	466	671	612	681	555	738	632
K	68	55	48	52	54	58	35
Ca	530	456	371	351	390	330	305
Mg	55	42	33	27	52	49	36
Control							
N	1714	1104	1235	1175	1120	1230	1153
P	784	725	829	816	765	855	762
K	79	62	68	61	50	67	45
Ca	823	554	752	583	760	529	378
Mg	61	46	56	42	73	65	40

Table 1.23. Significance levels from the analysis of variance of soil nutrient content 1985-1991.

Plantations					
	N	P	K	Ca	Mg
Site	.864	.051	.870	.160	.522
Year	.044	.004	.000	.007	.000
Year x Site	.585	.413	.239	.002	.019
Hardwoods					
Site	.349	.027	.012	.033	.019
Year	.000	.000	.000	.001	.000
Year x Site	.089	.149	.004	.182	.124

Table 1.24 Significance levels from the covariate analysis of soil nutrient content, 1985-1991.

Plantations					
	N	P	K	Ca	Mg
Site	.535	.229	.814	.827	.372
Year	.061	.015	.000	.010	.000
Year x Site	.587	.390	.464	.006	.021
Hardwoods					
Site	.818	.286	.196	.131	.032
Year	.004	.149	.003	.180	.006
Year x Site	.104	.177	.007	.191	.105

Figure 1.27

SOIL POTASSIUM (Kg/Ha) Hardwood Plots

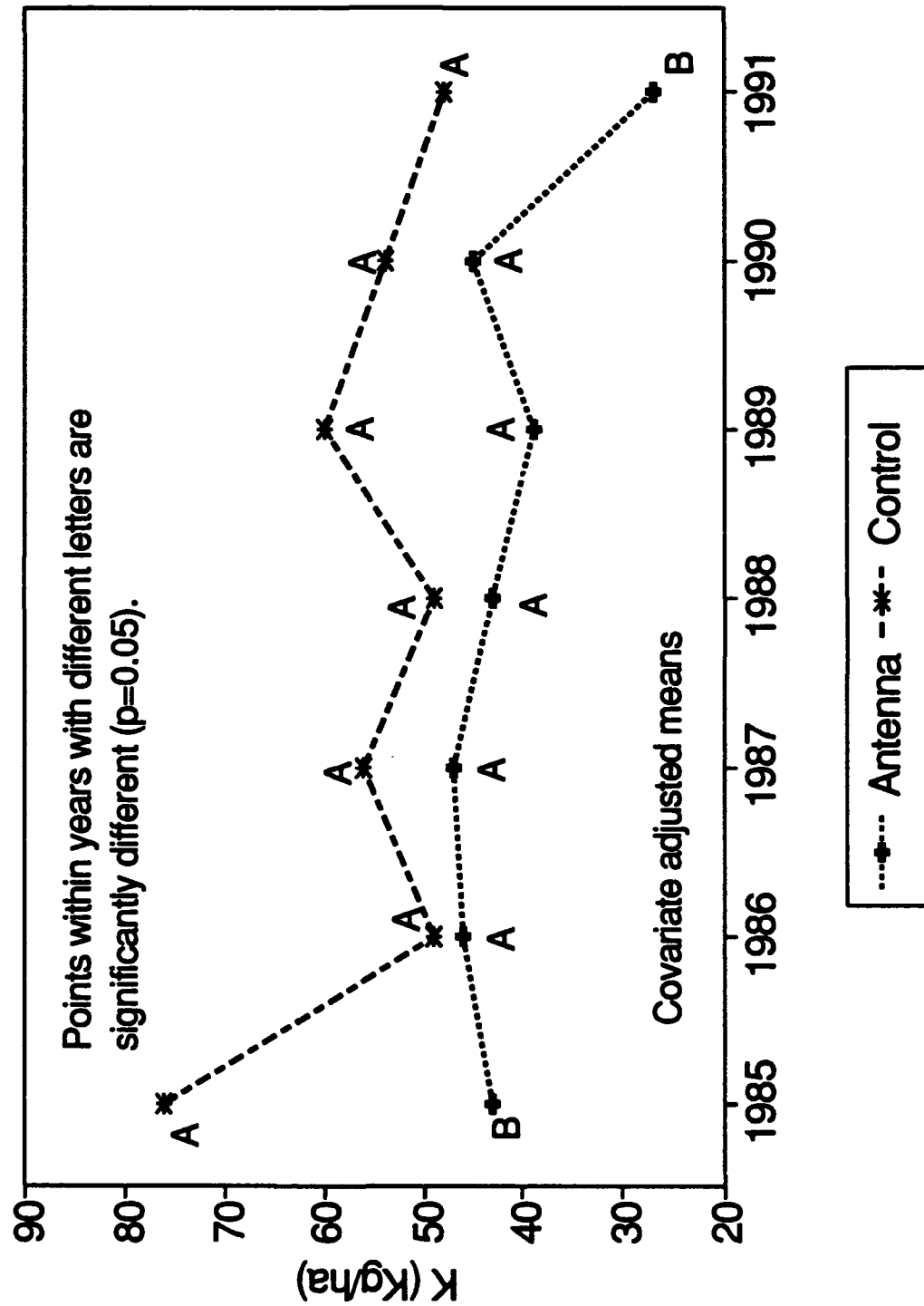


Figure 1.28

SOIL CALCIUM (Kg/Ha) Red Pine Plantations

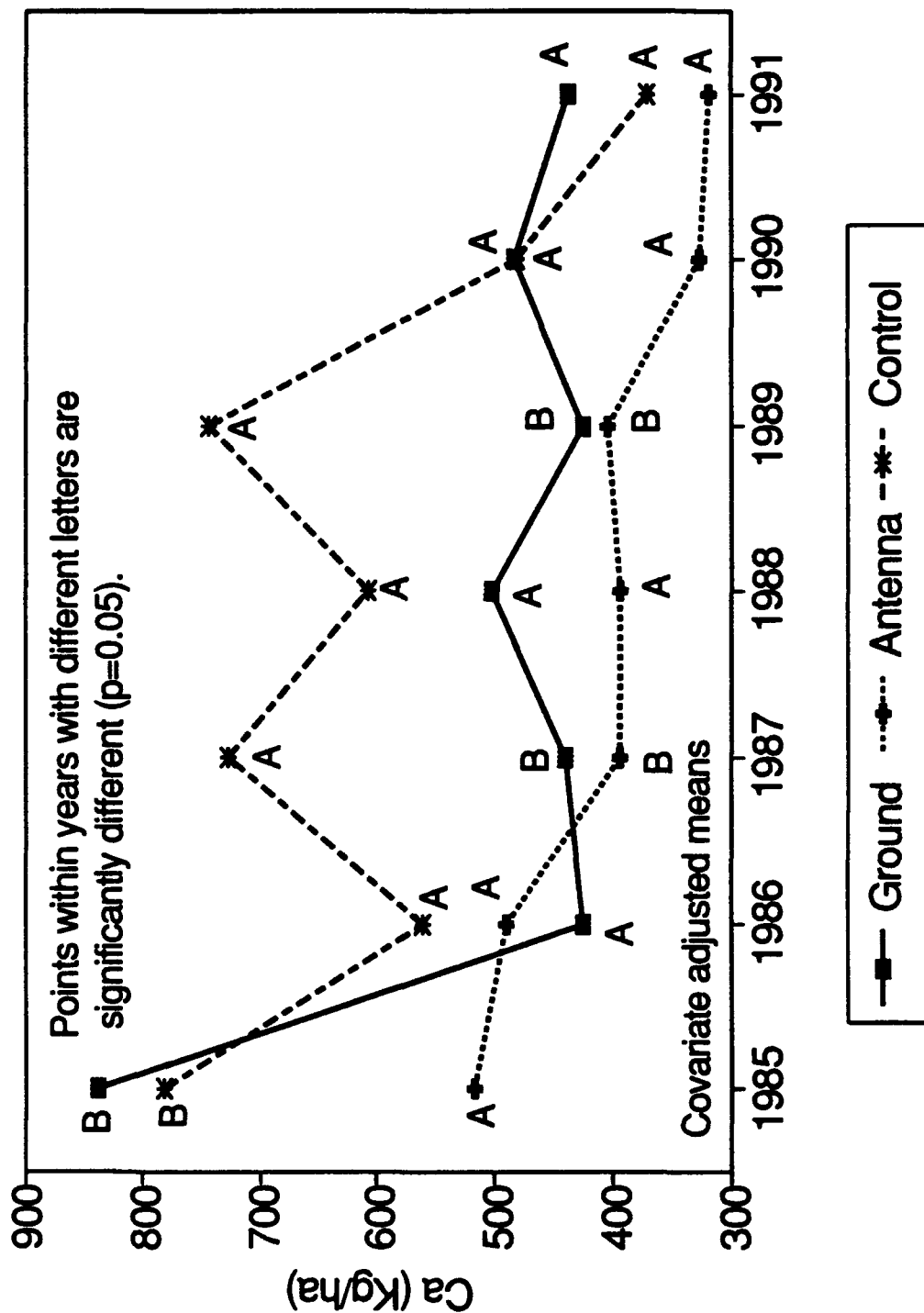
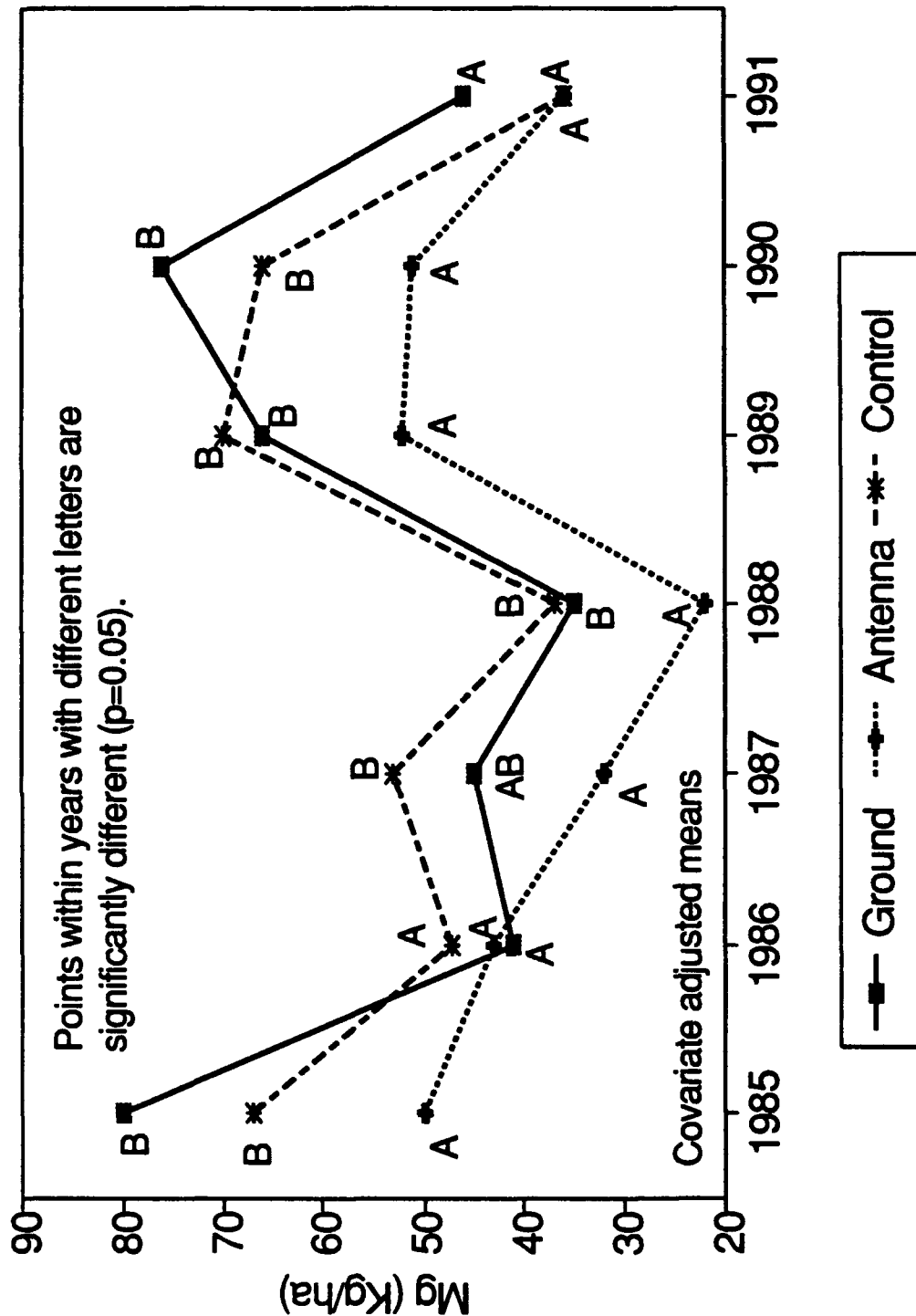


Figure 1.29

SOIL MAGNESIUM (Kg/Ha) Red Pine Plantations



Nitrogen Mineralization

Tree productivity analysis completed during the past years have indicated 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 be tested to show independence of ELF effects.

During this past year, efforts have focused on gathering field data and analyzing for site, stand and temporal effects. The comparisons in this report constitute major progress in this stage of study. Once completed, the data will be included in growth modeling efforts. If mineralization proves to be a valuable addition to these models, work will proceed 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 $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ 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 $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ 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 $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$. 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 on April 30, 1990 and ended October 14, 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 _{YMTTP(S)}
YR * MO * ST * Plot(site)	22	SS _{YMTTP(S)}	MS _{YMTTP(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

This year report includes the second year of N mineralization data collected in both antenna and control sites. In last year's report the rates of ammonification and nitrification were compared between sites, stand type, and among months. In this year's report the year comparisons are also included to determine if the ammonification and nitrification rates are related to annual climate and soil factor changes.

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. Comparison average ammonification and nitrification (kg N/ha) in 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
Site Comparison				
	Antenna		Control	
	4.41a		6.80b	
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
Site Comparison				
	Antenna		Control	
	1.86a		2.07a	

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

Annual comparisons: 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 1.30). In the antenna plantation, rates were higher in July and August than in September and June. In May and October the ammonification rates decreased to a minimum. At the control site, ammonification rates were the highest during July and lowest in October. Similar trends were found in the hardwood stands. 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 $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ to be immobilized by microorganisms.

Site by year comparisons: Forest floor ammonification site

Figure 1.30 Average ammonification in forest floor

(May 1990 - Oct 1991)

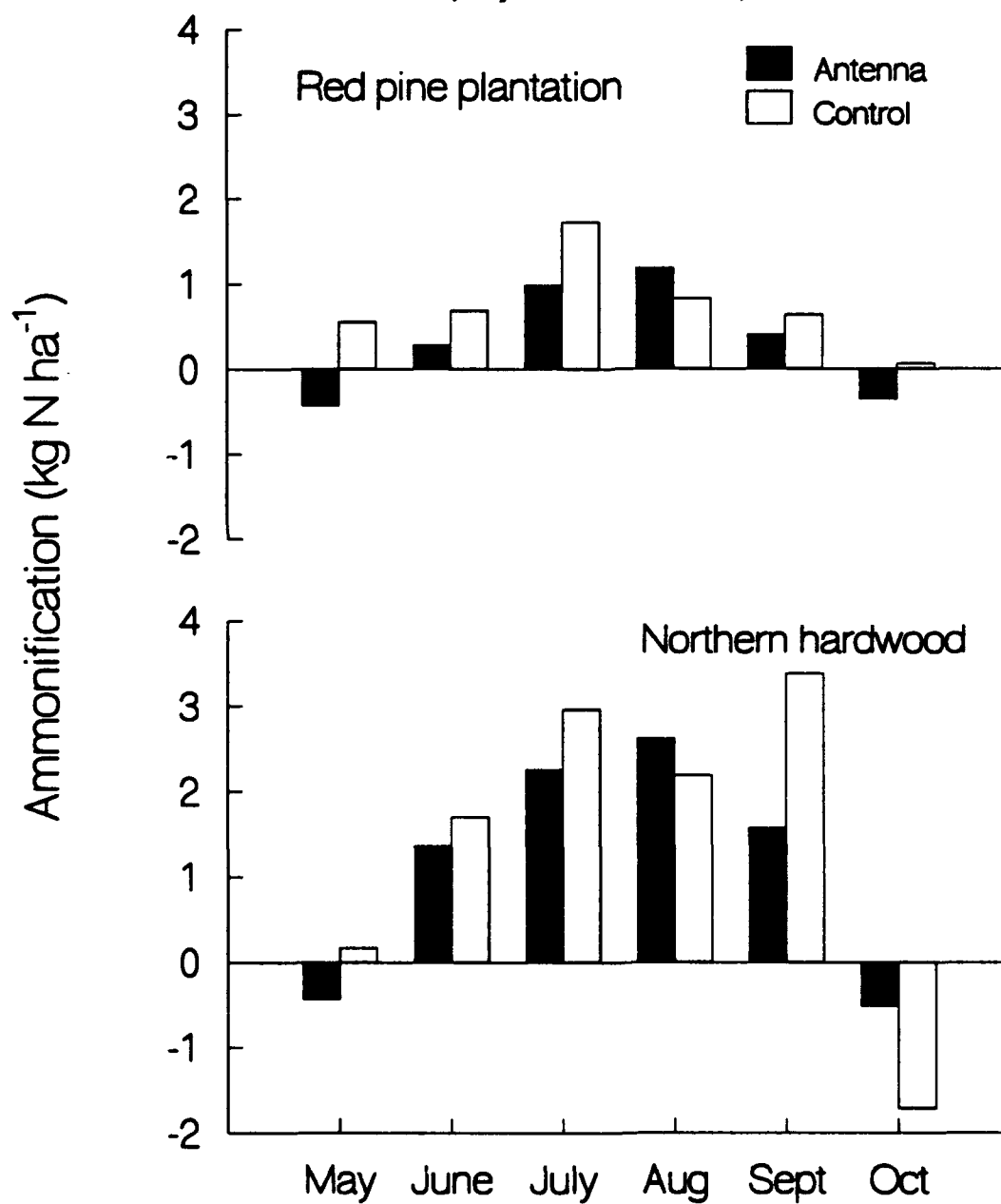


Table 1.27 Significant levels from the analysis of variance for ammonification and nitrification in forest floor and detection limits of site, stand type, and site by stand type interaction

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 *	0.464	0.381
Site		
Detection Limits		
Site	0.322	0.101
stand type	0.544	0.101
Site * stand type	0.554	0.104
Site * stand type *	0.402	0.084
year		
% Mean		
Site	36.2	32.3
Stand type	61.1	32.5
Site * stand type	62.2	33.4
Site * Stand type *	45.1	27.0
year		

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). Lab analysis of such factors as organic carbon and total N are not complete and could not be included in the correlation analyses. Therefore, their relationships with ammonification can not be presented until next

year's report.

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 ($p=0.351$). 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.

Annual comparisons: 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 1.31). Multiple range tests showed that the nitrification rates in the red pine plantation were lowest in May and the highest in July and August. Rates of nitrification in the hardwood stand had a similar seasonal trend at the antenna and control sites, but the highest rates occurs in August and September (Figure 1.31).

Site by year interaction: 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)

Site comparisons: Annual ammonification rates in mineral soil (0-10 cm) were not significantly different ($p=0.417$) between antenna and control sites (Table 1.28 and 5). 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 1.31 Average nitrification in forest floor
(May 1990 - Oct 1991)

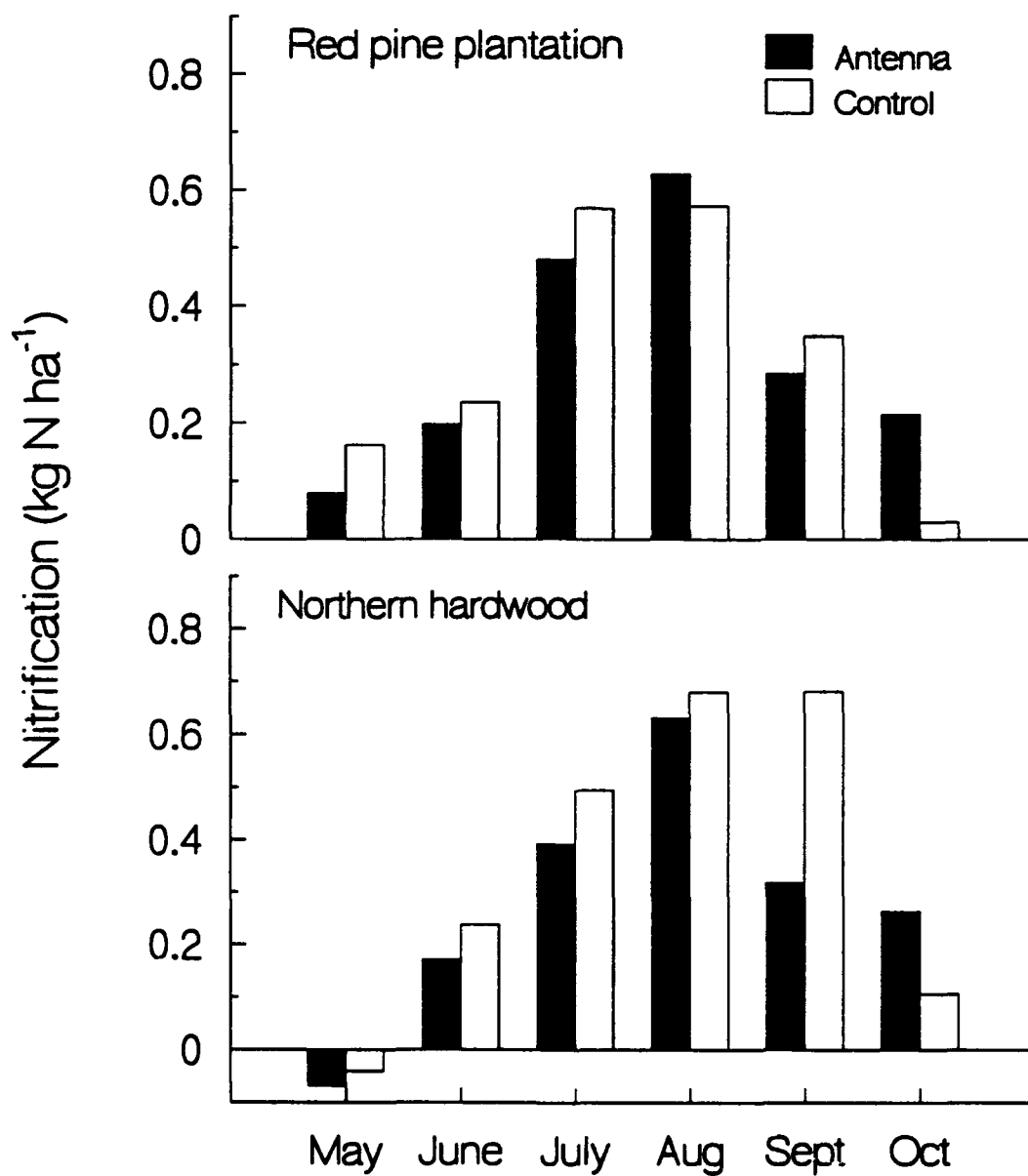


Table 1.28 Comparison average ammonification and nitrification (kg N/ha) in mineral soil (0-10 cm) during 1990-1991 growing seasons (May-Oct)

	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

Site Comparison	
Antenna	Control
43.81a	44.47a

	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

Site Comparison	
Antenna	Control
10.42a	10.56a

than the hardwoods at both sites (Table 1.29).

Annual comparisons: 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 1.32). The ammonification rates were at a minimum in May at the antenna site plantation and in October at the control site hardwood stand. From May to July, ammonification rates in the plantations at the both sites increased and reached a seasonal peak in July. Similar seasonal trends were observed in the hardwood stands (Figure 1.32).

Site by year interaction: 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 1.32 Average ammonification in mineral soils (0-10 cm)
(May 1990 - Oct 1991)

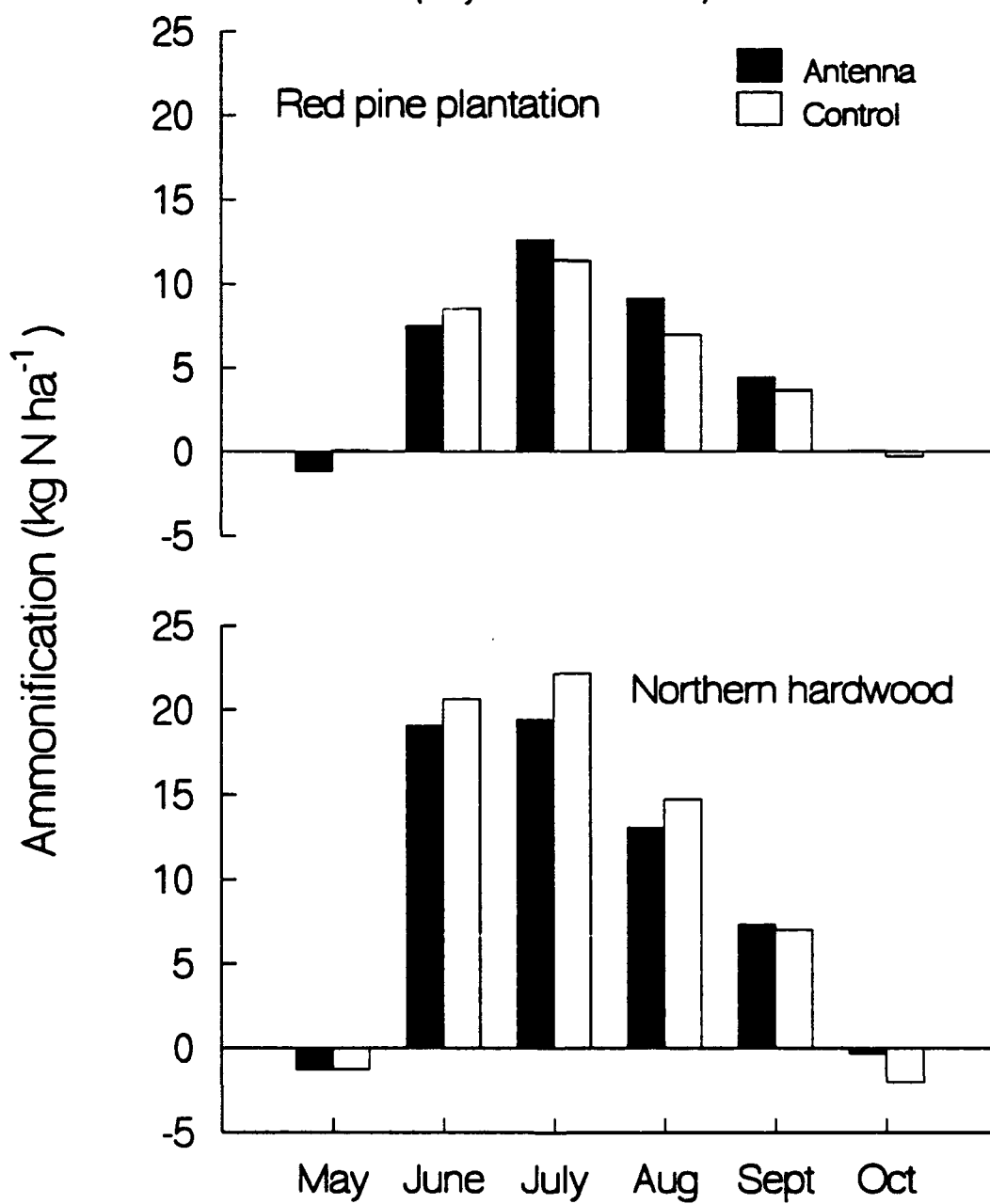


Table 1.29. Significant levels from the analysis of variance for ammonification and nitrification in mineral soils (0-10 cm) and detection limits of site, stand type, and site by stand type interaction

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 *	0.166	0.814
Site		

Detection Limits

Site	0.543	0.149
Stand type	0.883	0.260
Site * stand type	0.924	0.273
Site * Stand type *	1.086	0.301
year		

% Mean

Site	7.09	8.35
Stand type	11.53	14.59
Site * stand type	12.06	15.31
Site * stand type *	14.18	16.88
year		

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).

Nitrification in Mineral Soils (0-10 cm)

Site comparisons: 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 comparisons: 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. Nitrification rates were minimal in May for both plantation and hardwood stands and reached a seasonal peak in July or August (Figure 1.33).

Site by year interaction: 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 of total N mineralized in forest floor averaged 2.64 kg N/ha in red pine plantation. This is below the range of 4.3 kg N/ha observed in a white pine stand (Boone 1992), but above the value of -0.4 kg N/ha (Table 1.31) in an old-growth mixed-conifer forest (Hart and Firestone 1992). Amounts of total N mineralized in mineral soil (0-10 cm) in growing seasons were 40.7 kg N/ha/yr in plantation and 68.5 kg N/ha/yr in the hardwoods. This compares well with 32 kg N/ha/yr observed in red pine stands and the 62 kg N/ha/yr observed in mixed sugar maple stands in the Great Lakes region by Nadelhoffer et al. (1982), but below the range of 62 to 102 kg/ha/yr of N reported by (Zak and Pregitzer 1990) and (Mladenoff 1987; Table 1.31).

Summary

Our two year's 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

Figure 1.33 Average nitrification in mineral soils (0-10 cm)
(May 1990 - Oct 1991)

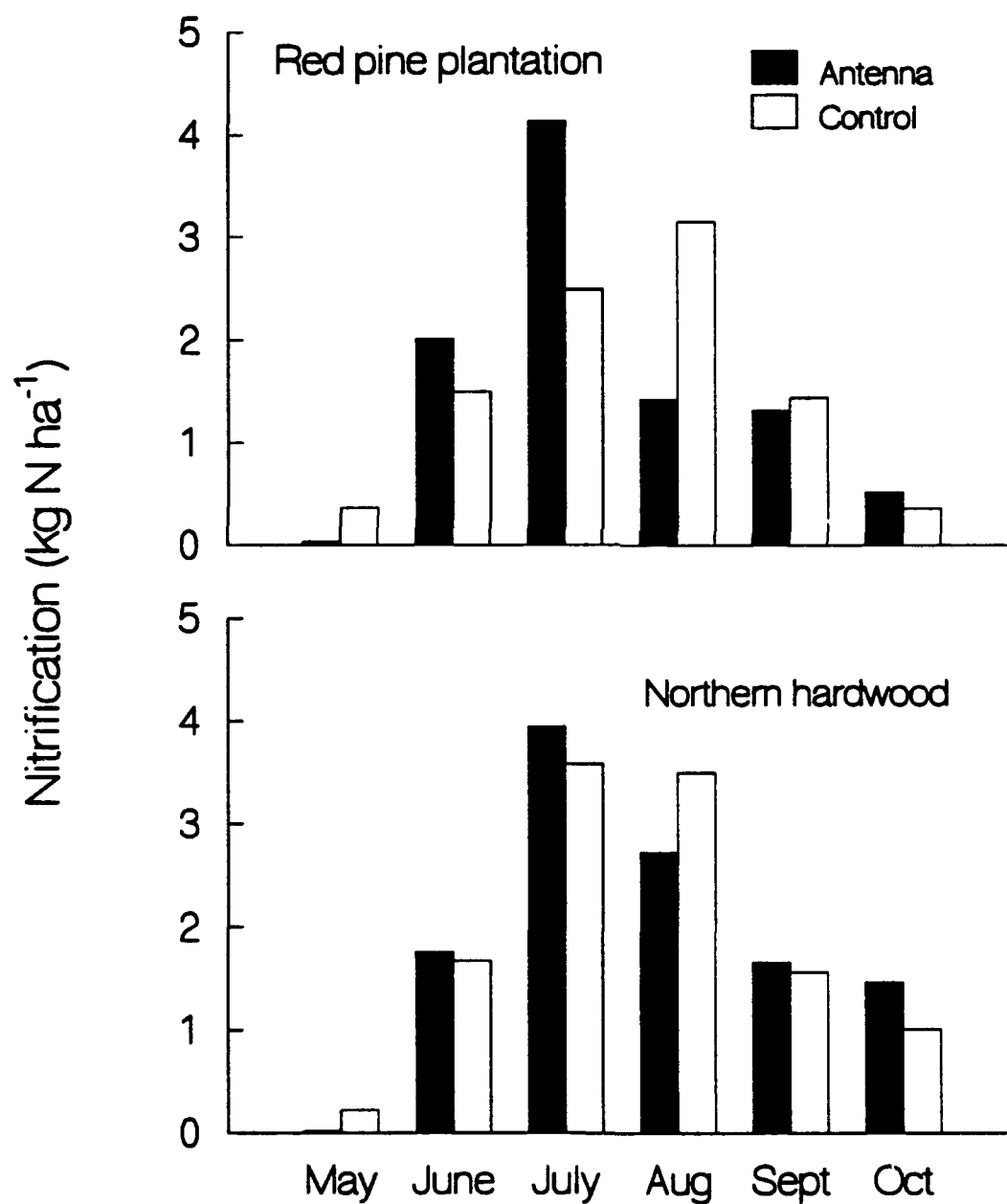


Table 1.30. Correlation coefficients of forest floor (FAMM) and mineral soil (SAMM) ammonification and forest floor (FNITR) and mineral soil (SNITR) nitrification with major soil factors (n=288; '*' p<0.05; '**' p<0.001).

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 pine	74-114 20-29	0-8 cm 0-8 cm	two years	Hill and Shackleton (1989)
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.	Mladenoff (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.

Further work will focus on determining what factors (mineral soil nutrient content, climatic variables, litter fluxes etc.) control the rate of these processes at the study sites. Using the model developed from this information and our measurement of these factors prior to antenna operation, we can then evaluate whether rates of these process were similar at the two sites prior to antenna operation. After evaluating the rates of these process prior to antenna operation, we should be able to 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 (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 site 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 analysis 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.

Each analysis will eventually test the overall null hypothesis:

H_0 : There is no difference in the magnitude or the pattern of seasonal diameter increment before and 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 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 1989-1992 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 split plot analysis of covariance. The analysis of covariance table used in this study is found in Table 2.3. Since monthly soil nutrient concentrations are a critical covariate, the analysis of covariance reported here is performed on data collected through 1991. An analysis including the 1992 data will be performed following completion of laboratory analysis of the soil samples.

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 Index	Site Index	Age (yrs)
Antenna								
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								
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										
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										
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 analysis of 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 change from year to year, such as annual rainfall.

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 in 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 at the antenna site. 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.) on the study plots. This outbreak occurred across northern Michigan and southern Canada (Heyd, Personal Communication) and appears to have been related to climatic conditions in the preceeding years (Mroz et al. 1991, Jones et al. 1993, Appendix D). There were four additional northern red oaks and four quaking aspens 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 site. 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 aspens, 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 will be monitored in 1993 and, if growth appears to be abnormally low, they will be removed from the 1992 and later 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 at both study sites beginning on April 22 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until October 7 when growth had slowed considerably and over 50 percent of leaf fall had taken place. This provided a total of 25 measurements in 1992.

Progress

Growth Analysis

Magnitudes and rates of diameter increment were examined for each species. Analysis of tree diameter is approached in two ways. The split plot 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 were developed in past years (Mroz et al. 1988, Appendix C) 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 split plot 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 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 is 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 are not completely available for 1984. For these reasons, the 1984 diameter growth measurements are not included in the analysis of covariance. Monthly soil nutrient concentration proved to be an important covariate for explaining both site and year differences in diameter growth. These data are not yet available for the 1992 growing season; the tree growth information from 1992 will not be incorporated into these analyses until a complete set of covariates is available. Table 2.4 presents the total annual diameter growth by species for each of the nine growing seasons, even though data from 1984 and 1992 are not included in the following 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 significant differences

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

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

Species	Source of Variation		
	Site	Year	Site * Year Interaction
Analysis of Variance (No Covariates)			
Northern Red Oak	0.112	0.000	0.754
Paper Birch	0.039	0.000	0.364
Aspen	0.002	0.000	0.002
Red Maple	0.012	0.000	0.055
Analysis of Covariance			
Northern Red Oak ^{b/}	0.673	0.000	0.452
Paper Birch	0.099	0.000	0.532
Aspen	0.485	0.000	0.001
Red Maple	0.800	0.004	0.230

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.

($p < 0.05$) between the study sites for all species except northern red oak. For aspen, there was a significant ($p < 0.05$) site by 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 there were no differences ($p = 0.05$) in individual tree diameter growth rates between sites for any of the four species. There were differences ($p < 0.05$) among years for all four species and there was a significant ($p < 0.05$) site by year interaction for aspen.

These results indicate that there were no differences between the individual tree diameter growth rates on the two sites for any of the four study species. There were significant differences among the study years which were not accounted for by the covariates. The significant interaction between site and year for aspen indicates that aspen is the only species for which the relationship between individual tree diameter growth rates on the two sites changed over time.

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 for each species 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:

1986^a 1988^b 1990^c 1991^c 1987^c 1989^c 1985^d

For northern red oak, there were differences among years as noted previously but the years following antenna operation at full strength (1989-1991) were grouped among the pre-operational years, implying no ELF effect on individual tree annual diameter growth.

Paper Birch:

1985^a 1986^b 1988^b 1987^b 1989^c 1990^c 1991^c

For paper birch, the differences among years were arranged chronologically, with the three years following full power antenna operation having the lowest growth and being similar to each other. The possible effects of ELF exposure on these results are discussed further using the diameter growth model comparisons, but there were no differences between the antenna and control sites in these comparisons based on the analysis of covariance.

Aspen (Control Site)

1986^a 1991^b 1988^b 1987^b 1985^b 1989^b 1990^b

Interpretation of the results for aspen are complicated by the site by year interaction in the analysis of covariance. The 1986 growth from the control site was lower than the other years at the control site but similar to the growth in 1990, 1987, and 1988 at the antenna site. For the control site the other years were similar and there is no pattern over time.

Aspen (Antenna Site)

1991^a 1989^{ab} 1985^{ab} 1986^{ab} 1988^{bc} 1987^{bc} 1990^c

At the antenna site, there was a greater degree of difference in diameter growth among the years but the years of full power antenna operation (1989-1991) were not grouped together which indicates no consistent growth response to the EM fields. Based on these results, there is no clear indication of an effect of ELF antenna operation on individual tree diameter growth based on the analysis of covariance.

Red Maple:

1989^a 1990^b 1986^c 1987^{cd} 1991^{de} 1985^{ef} 1988^f

For red maple, there were no differences between the antenna and control sites in the analysis of covariance. The differences among years indicate that 1989 and 1990 both had lower adjusted individual tree diameter growth than the other years while adjusted diameter growth in 1991 was similar to that in 1987. There are, therefore, no clear indications of an ELF effect on individual tree diameter growth in the results of the analysis of covariance. The fact that adjusted individual tree diameter growth in 1989 and 1990 were lower than the other years is being examined further in the diameter growth model analyses discussed below.

One of the critical assumptions of an 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 effect 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 no ELF effect on individual tree diameter growth. To test this assumption, the correlation between the average plot EM field exposure level and the covariates were calculated. Significant ($p < 0.05$) correlations were found between the July soil potassium concentration and the magnetic field strength ($r = -.50$) and between air temperature degree days through May and magnetic field strength ($r = -0.30$). The analyses in Element 1 show that differences in air temperature in the hardwoods at the two sites have remained stable over the life of the study. The

correlations here are due to the fact that successive years were warmer while, at the same time, the EM field levels also increased. The addition of 1992, which was a cool year, may alleviate these correlations.

The fact that two variables are correlated does not imply a cause and effect relationship and there is no reason to believe that there is a causal relationship between magnetic field strength and July soil potassium concentration or air temperature degree days through May. In any case, the covariates are significantly correlated with EM field exposure levels and the analysis of covariance of individual tree diameter growth rates should not be considered sufficient to determine whether or not there is an effect of EM field exposure level on individual tree diameter growth rate. The analyses do not suggest a significant effect due to EM fields but there could still be an effect which is masked by the correlations between the EM field exposure levels and the covariates.

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 cannot be adequately 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. 1992, 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 season, these observed growth 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:

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

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:

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

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 for 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 1991 growing seasons.

The possible effects of ELF fields on total annual 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 correlations 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

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

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
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

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

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
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

Table 2.9. Performance of the combined diameter growth model by site and year for aspen.

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
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	-0.0048, 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

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

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
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

and the measured diameter growth. The average residual will differ from zero if the factors in the diameter growth model fail to account for the variability in growth.

The differences in the numbers of observations from year to year indicated in Tables 2.6-2.9 are due to mortality within the stands, the banding of small trees and, from 1989 to 1990, to the inclusion of the mapped trees in the 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 the previous year plus 26 additional plot trees in 1990 due to the mapping of the buffer zone. This means that more than one-half of the observations used to calculate the residuals in 1990 and 1991 were not included in the analyses in previous years. These additional trees contribute to smaller standard errors in 1990 and 1991, increasing the precision of the measures of average residual and providing greater sensitivity in the evaluation of changes from trends predicted by the models.

For northern red oak, the 95 percent studentized confidence interval for the average residual overlaps zero in 1986-1989 with the exception of 1986 at the antenna site. In both 1990 and 1991, the studentized 95 percent confidence intervals did not overlap zero at either site and, in fact, indicate that the trees on both sites grew more than expected as a result of a condition or conditions which did not exist during the baseline period. The confidence interval from the control site overlapped the interval from the antenna site, indicating no significant difference in the average residual between the two sites. The degree of overlap was much less in 1991 than it had been in 1990. These results indicate that the trees grew differently in 1990 and 1991 than in previous years but, since the results were similar on the antenna and control sites, there is no evidence that the ELF fields have impacted total annual northern red oak diameter growth on the study sites. These results are consistent with those from the analysis of covariance discussed previously; there is no indication of an effect of ELF fields on the annual individual tree diameter growth rate for northern red oak.

For paper birch, the 95 percent studentized confidence interval for the average residual on both the antenna and control site overlapped zero, indicating no deviation from expected growth trends. This is in contrast with previous years where the average residuals indicated less than expected growth. There are no differences in the average residuals from the two sites in any year of the study, indicating that the trees on both sites are responding similarly to growing conditions. These results indicate that, even though there was significant mortality in the paper birch at the control site in 1991, the surviving trees on both sites appear to have recovered from the growth declines seen in previous years which appear to have been due to climatic conditions (Jones et al. 1993). There is no indication of divergent behavior between the antenna and the control sites and, therefore, no indication of an effect of ELF fields on annual individual tree diameter growth of paper birch. These results are consistent with those from the analysis of covariance

discussed previously; the declining growth over time appears to be due to climatic conditions affecting each site similarly and not to an ELF effect on paper birch annual individual tree diameter growth.

Through 1988, aspen annual diameter growth residuals had been increasing at the antenna site while those at the control site were consistent and not different from zero (Mroz et al. 1989). In 1989 and 1990, years of full power (150 amp) antenna operation, aspen annual diameter growth model residuals were not different from zero and they were not different from the residuals at the control site in 1990. The EW leg of the antenna was not operating from 8 May through 12 July 1991 (when 65 to 85 percent of aspen diameter growth occurred) and the trees were exposed to magnetic fields roughly in between the exposure levels of 1987 and 1988 (Appendix A). In 1991, the average annual diameter growth model residual on the antenna site returned to, and even exceeded, the levels seen in 1987 and 1988 on the antenna site, prior to full power operation of the antenna (Figure 2.1). The control also exhibited greater than expected diameter growth in 1991 though at a much lower level than the antenna site. These results are consistent with a stimulation of aspen growth and development by ELF fields in the range of exposures (1 - 4 mG) received on the the plots in 1987, 1988, and during the early to mid-growing season of 1991. Further evaluation of this possibility is discussed below in the evaluation of the relationships between the ELF magnetic flux exposure levels and the growth model residuals.

In 1991, like the results in 1988 but contrary to the results in 1989 and 1990, the diameter growth model residuals for red maple indicate less than expected growth at both the control and the antenna sites (Table 2.9). The studentized 95 percent confidence intervals did not include zero at either site but the confidence interval of the control site was entirely within the range of the confidence interval for the antenna site. For red maple, therefore, growth has differed from the expected levels for the past four years but there were no differences in the average diameter growth model residuals from the two sites in any year. This indicates that there are either some factor or factors which are not accounted for by the growth model or that the climatic conditions in the past few years are beyond the range of conditions present in the years used to parameterize the model. In any case, there is no difference in the growth patterns between the antenna and the control sites and there is no evidence of an effect of ELF antenna operation on red maple annual individual tree diameter growth.

As in past years (Mroz et al. 1991), further evaluation of the effects of ELF fields on individual tree total annual diameter growth was conducted by examining the expected level of exposure to the magnetic flux generated by the antenna for all banded trees using the interpolation equations given in Appendix A. As reported in the past, the correlation between the magnetic flux at the antenna site and the northern red oak diameter growth model residuals was significant for both the flux levels in the current year ($r=0.14$) and the flux levels of the previous year

Aspen Diameter Growth Model Residuals 1986 - 1991

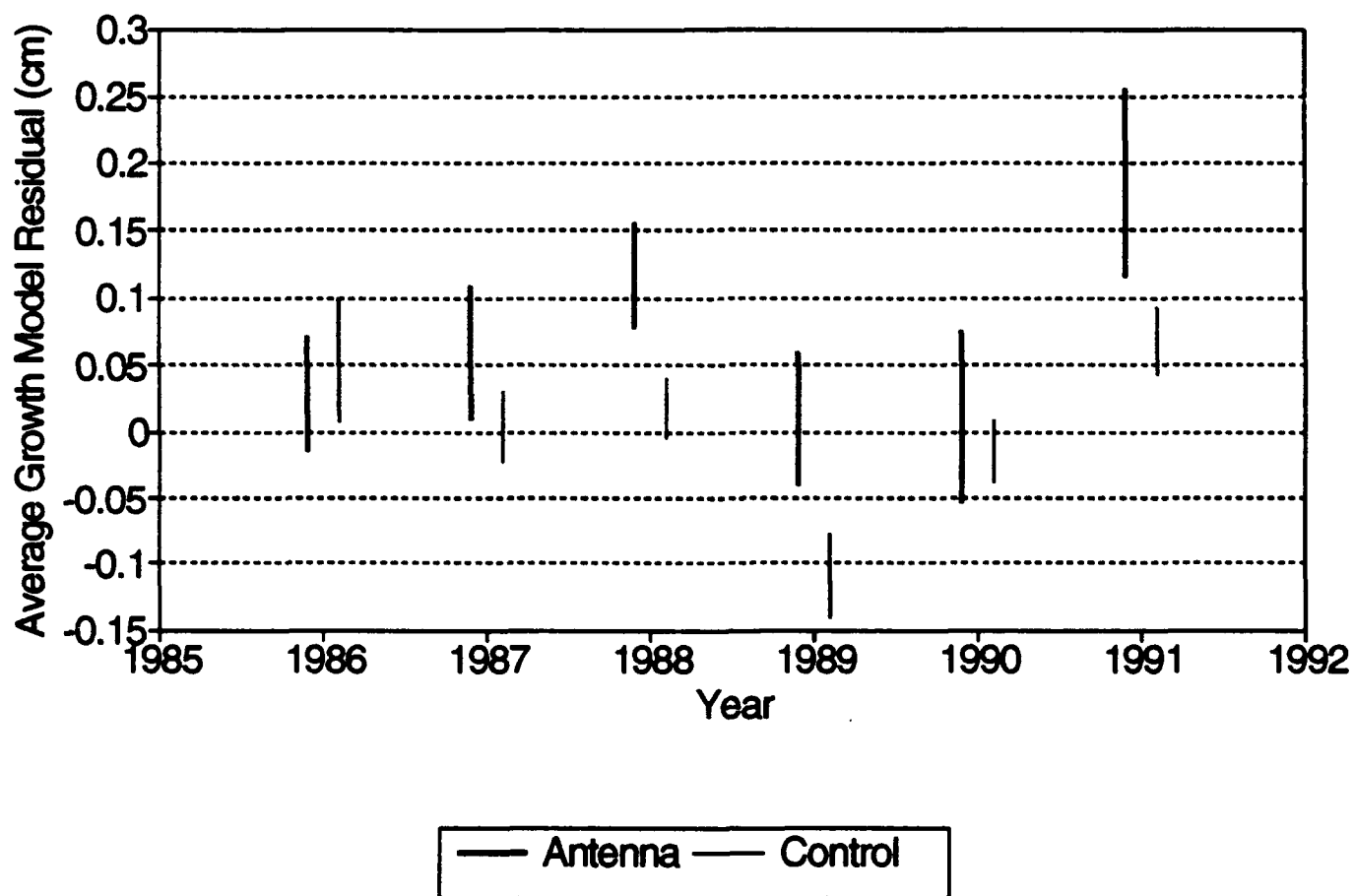


Figure 2.1. Average aspen diameter growth model residuals and 95 % studentized confidence intervals for both the antenna and control sites, 1986-1991.

Aspen Growth and Magnetic Flux 1986-1991

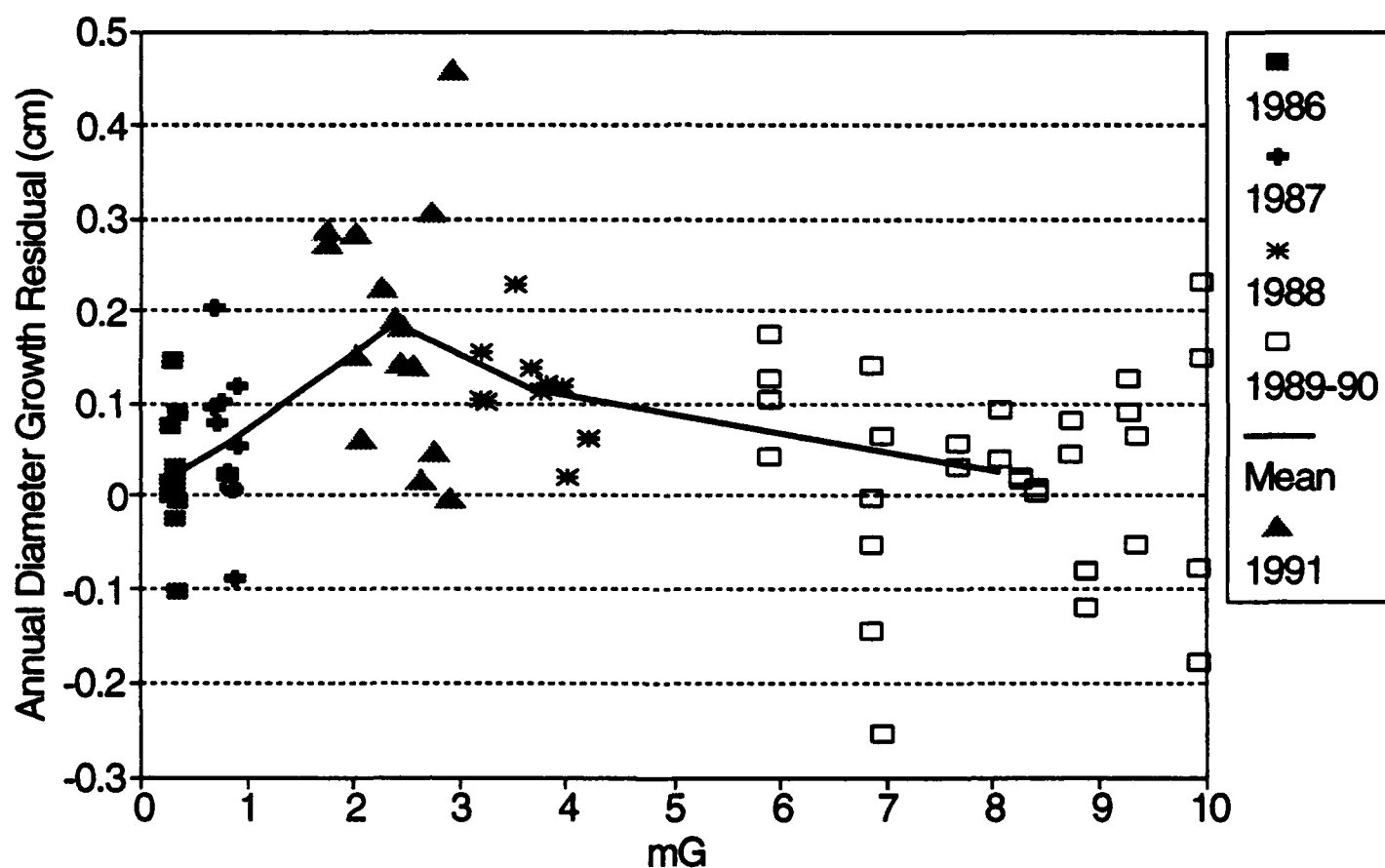


Figure 2.2. Aspen diameter growth model residuals for the antenna site, 1986-1991. The magnetic flux values are estimated using the interpolation equations in Appendix A. Values from 1991 are from the early growing season when the EW antenna leg was not in operation.

($r=0.21$). The same was true for red maple at the antenna site; the correlation between the diameter growth model residual and current year magnetic flux level was 0.31 and the correlation with the previous years magnetic flux level was 0.17. There were no significant correlations between the magnetic flux levels for either the current or previous years for paper birch or aspen. At first glance this appears to be in conflict with the results reported above and in Figure 2.1 for aspen. Upon further investigation of the relationship between magnetic flux level and diameter growth model residual for aspen (Figure 2.2), one can clearly see the preponderance of positive growth model residuals between 1 and 4 mG with residuals near zero at lower and higher exposure levels. This is not a linear trend which is why the linear correlation between the magnetic flux levels and diameter growth model residuals was not significantly different from zero. Analyses of 1992 growth model residuals are being given top priority; if relationships in 1992 return to the levels seen in 1989 and 1990, this will be strong empirical evidence of a stimulation effect of ELF fields from 1 to 4 mG on annual aspen diameter growth. Similar evaluations will be made for the other three species and the results will be included in future reports.

When examining diameter growth model residuals from individual trees for several years, it is possible that the results in one year could affect the results for following years. All the analyses conducted above implicitly assume an independence in the values of the diameter growth model residuals from different years. 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 in 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, 1988 and 1989, and so on). A two-year lag indicates correlations between residuals two years apart (1986 and 1988, 1987 and 1989, 1988 and 1990, and 1989 and 1991), a three-year lag indicates correlations between residuals three years apart (1986 and 1989, 1987 and 1990, 1988 and 1991), a four-year lag indicates correlations between residuals four years apart (1986 and 1990, and 1987 and 1991), and a five-year lag indicates correlations between residuals five years apart (1986 and 1991). The lack of a significant correlation implies that the assumption of a time independence made during the above analyses is valid and that

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

Site	Species	Time Lag				
		1 Year	2 Years	3 Years	4 Years	5 Years
Antenna	Northern Red Oak	-0.083	-0.309	-0.006	0.025	-0.126
	Paper Birch	0.142	-0.052	-0.120	-0.342	-0.129
	Aspen	-0.294	-0.281	0.241	-0.045	-0.121
	Red Maple	-0.216	-0.268*	0.061	-0.075	-0.002
Control	Northern Red Oak	0.006	-0.137	-0.162	-0.097	-0.110
	Paper Birch	-0.146	-0.255	0.021	-0.130	0.010
	Aspen	-0.014	-0.473*	0.031	0.017	-0.061
	Red Maple	-0.173	-0.307	0.144	-0.043	-0.121

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

there is no need to consider a time dependent structure to the residuals through the 1991 growing season. Two of the correlations given in Table 2.10 are significantly different from zero: the two-year lag for red maple at the antenna site and the two-year lag for aspen at the control site. Both of these increased a large amount over the results of the previous year (Mroz et al. 1992). The two-year lag for red maple at the antenna site was -0.27 this year and -0.10 last year; the two-year lag for aspen at the control site was -0.47 this year and -0.33 last year. Procedures to account for this apparent time dependency have not been undertaken this year due to the discrepancy in the results from the 1990 to the 1991 growing season. This analysis will be repeated in 1992 and, if the time dependency is still apparent in the data, appropriate procedures will be undertaken to account for this structure in the growth model analyses.

Seasonal Growth Pattern

Possible ELF field effects on seasonal diameter growth pattern are examined by using the Kolmogorov-Smirnov procedure to compare the distribution of seasonal diameter growth predicted by the growth model (Mroz et al. 1988, Reed et al. 1992, 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, or 1990 (Mroz et al. 1991). 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 for paper birch at both sites through there had been more differences at the control site than the antenna site (Mroz et al. 1991). In 1991, there were no significant 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. 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 significant differences between the observed and predicted seasonal diameter growth patterns in 1988, 1989, and 1990 (Mroz et al. 1991). In 1991, 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 the antenna operation.

There were significant ($p < 0.05$) differences 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 a different plot at the antenna site in 1988 (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, or 1991. There is, therefore, no evidence of an effect of ELF fields on the seasonal diameter growth pattern of red maple.

Summary

1. The analyses of covariance indicated no differences ($p = 0.05$) between the antenna and control sites in total annual diameter growth for any of the four species. The covariates are correlated ($p < 0.05$) with ELF field exposure levels which confuses the interpretation of these results. These associations between the covariates and the ELF fields could mask true differences in total annual diameter growth between the two sites.

2. To provide a more robust analyses, 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, the results are consistent with a stimulation of diameter growth at magnetic flux levels of 1 to 4 mG though this conclusion will be tested using the 1992 diameter growth, which occurred at higher exposure levels, as soon as possible. There are no clear indications of an ELF effect on total annual diameter growth for any of the other three species though more indepth analyses similar to those for aspen will be conducted as soon as possible.

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 mycorrhizal studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Thus, construction of the antenna ground through a red pine plantation 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 2.11.

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_0 : 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_0 : 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 analyzed through the 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 ELF system has operated at low levels throughout the 1987

Table 2.11. 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	192.75
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.

(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 (1989-1992). 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) 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 the 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. Only a few seedlings died during the course of the last six growing seasons (Table 2.11).

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 1992 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 possible use in explaining results of the growth analyses. 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 to fields. In order to account for evident competition between seedlings for available resources, additional measurements were made on neighboring seedlings in 1990, 1991, and 1992. 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 1991. 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 analyses 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 an 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 or diameter increment among the three sites as well as from year to year. At this point there are eight years of growth measurements available (1985 through 1992). Previous analyses have indicated the importance of soil nutrient concentrations as covariates to explain both site and yearly differences that occur in the height and diameter growth (Mroz et al. 1986). These values are unavailable for the 1992 growing season at this time. Therefore, until 1992 soil nutrient analyses are completed, all growth analyses discussed include data from 1985 through 1991 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 2.12. Covariates for analyses on both height and diameter growth were selected based on an intensive variable screening procedure used in previous work (Mroz et al. 1988). No modification of covariates has been

Table 2.12. Average seasonal diameter growth (cm) and height growth (cm) for each site from 1985 to 1991.^{a/}

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

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

Earlier 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 1991 coupled with 1985 to 1990 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.

One assumption in the analysis of covariance is that the covariates are independent of the levels of ELF magnetic fields (mG); in this case, each covariate selected should not be linearly correlated with the EM field exposure levels to avoid confounding any possible effects of the fields on tree growth. Correlations were calculated between the average plot values for the selected covariates and the average plot magnetic flux (mG) during the growing seasons. Due to the high impact of the previous season's soil physical and chemical properties as well as climate, correlations between EM fields in the previous growing season as well as the current growing season were examined. A significant linear correlation ($p=0.05$) was found between the magnetic flux (mG) and total Kjeldahl nitrogen in the soil during July of both the previous and current years where $r=-.30$ and $r=-.40$, respectively and water holding capacity from 10 to 30 cm for the previous and the current year where $r=.30$ and $r=.32$, respectively. Total Kjeldahl nitrogen has steadily decreased from 1985 to 1989, possibly due to leaching, and water holding capacity is constant across time. Both of these facts imply that a cause and effect relationship of these covariates with the EM field is not likely, but will continue to be monitored.

Prior to the analyses 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 2.13). With the addition of the three above-mentioned covariates, existing site and 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. The test showed, with few exceptions, that 1) all three sites are significantly different ($p = 0.05$) from one another each year, and 2) for each site, average height growth is significantly different ($p = 0.05$) each year (Table 2.14).

The significant time factor is not surprising when considering the young age of the seedlings. Early growth is generally sigmoidal in shape until the seedlings are older and growth slows down and becomes more linear. This nonlinearity is why the analysis of covariance is not able to explain the yearly differences; the nonlinear growth model addresses the time factor more adequately.

Figure 2.3 illustrates that although the three study sites are significantly different from one another each year, the pattern of differences is consistent across time both during the pre-operational years as well as during the post-operational years. First, the ground site always has the lowest average annual height growth followed by the antenna site, and then the control site. Secondly, when the amount of height growth increases from 1986 to 1989 and then decreases in 1990 before increasing again in 1991, this pattern holds true for all three sites. This consistency, as well as the fact that height growth is expected to increase over time due to the young age of the trees, seems to imply that the covariates in the analysis of covariance are not adequately explaining existing physical and chemical site differences as well as climatic differences rather than suggesting that EM fields are causing the height growth differences which are found among the study sites.

At this point time, significant differences ($p = 0.05$) do exist among the three sites and among all growing seasons, however, the amount which can be attributed to ELF fields and the amount which is due to the biological growth trends of young seedlings is not distinguishable at this time.

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 the information from the

Table 2.13 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	0.0000 ^{a/}	0.0004
Year	0.0000	0.0000
Site x Year	0.0000	0.0000
Diameter Growth (cm)		
Site	0.0000	0.0296
Year	0.0000	0.0000
Site x Year	0.0000	0.0000

^{a/} A significance level smaller than 0.05 would indicate significance ($p=0.05$).

Table 2.14. Significant relationships in the analysis of covariances on both sites and years for mean seasonal height growths (cm) which have been adjusted by the covariates and arranged in order of magnitude from lowest to highest.^{a/}

Pre-Operational
(1986 - 1988)

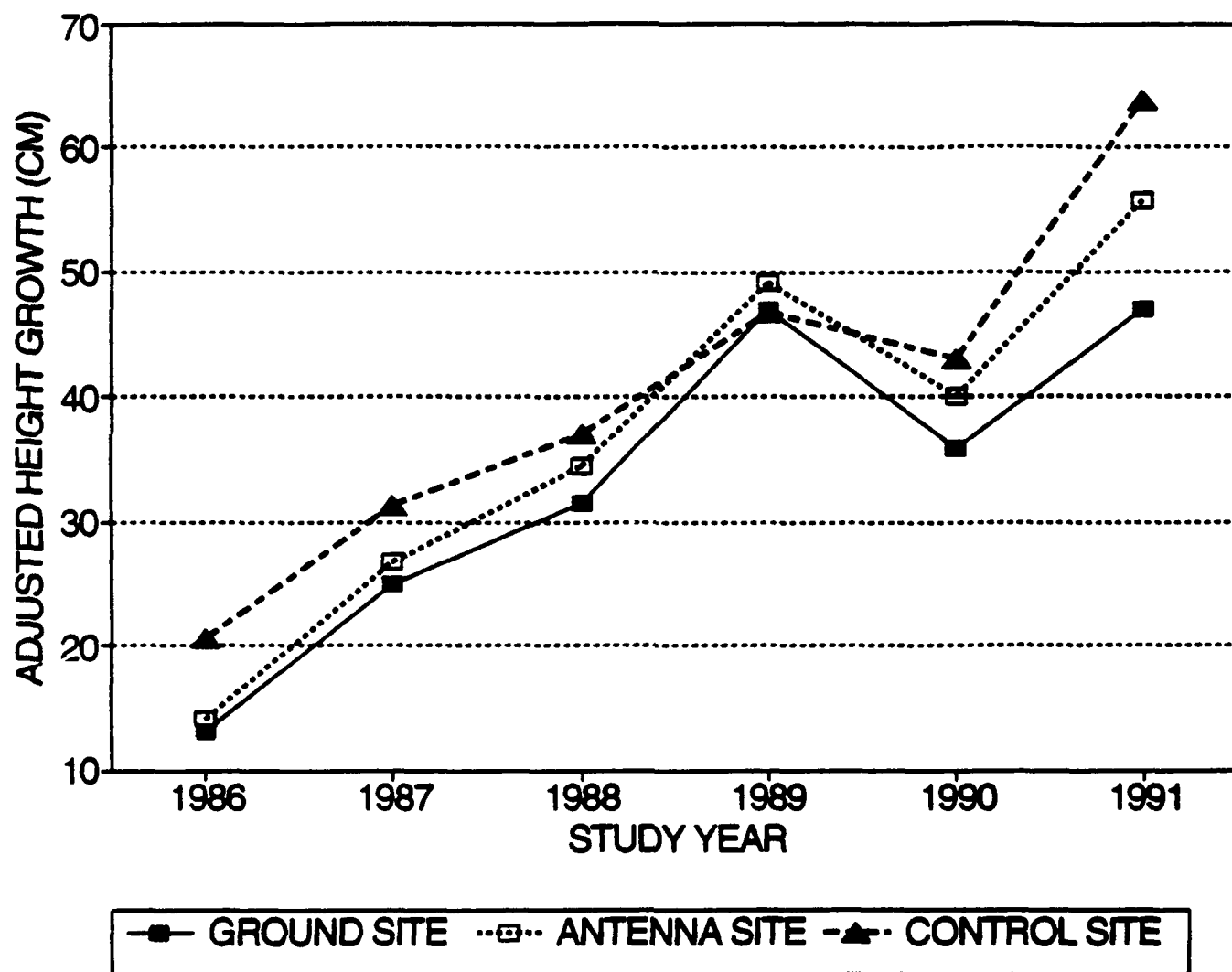
G86^a A86^a C86^b G87^c A87^d C87^e G88^e A88^f C88^g

Post-Operational
(1989 - 1991)

G90^f A90^h C90ⁱ C89^j G91^j G89^j A89^k A91^l C91^m

^{a/} Different letters of the alphabet indicate significant differences in adjusted height growths at the $\alpha=.05$ level. The letter G signifies the ground site, A signifies the antenna site, and C signifies the control site.

Figure 2.3. Adjusted height growth (cm) for the three study sites from 1986 to 1991.



previous season. This is consistent with the physiological nature of the seedlings. Thus, in the diameter growth analyses, average annual growth from 1985 through 1990 were used in the analyses.

Due to multicollinearity, 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 for this analysis of covariance were: air temperature degree days through August (on a 4.4° 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 2.13).

With the addition of these covariates, neither site differences ($p = .0296$) nor yearly differences ($p < 0.001$) were completely explained and a site-year interaction ($p < .001$) still remained (Table 2.13). 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 2.15 depicts the significant differences ($p = 0.05$) among the sites and among the study years.

Figure 2.4 illustrates the same consistent pattern in average annual diameter growths on each site from 1985 to 1991 as was found with average annual height growths. First, in 1985 and 1986 there were no significant differences among the three sites ($p = 0.05$), but from 1987 (a pre-operational year) through 1991 (a post-operational year), the antenna site has maintained a significantly higher ($p = 0.05$) average annual diameter growth than either of the other two sites. Second, the ranking of the other two sites has also not changed from 1987 through 1991; the ground site has the lowest average annual diameter growth followed by the control site. Thirdly, average annual diameter growth has increased from 1985 to 1987, decreased in 1988, then increased from 1989 to 1991. This trend has held true for all three sites regardless of whether the antenna was on or not. These patterns, together with Zhang's work (1991), who found site differences in redpine biomass were due to differences in site characteristics, suggest that at this time, existing differences in average annual diameter growths are the result of site

Table 2.15. Significant relationships in the analysis of covariances on both sites and years for mean seasonal diameter growths (cm) which have been adjusted by the covariates and arranged in order of magnitude from lowest to highest.^{a/}

Pre-Operational
(1985 - 1988)

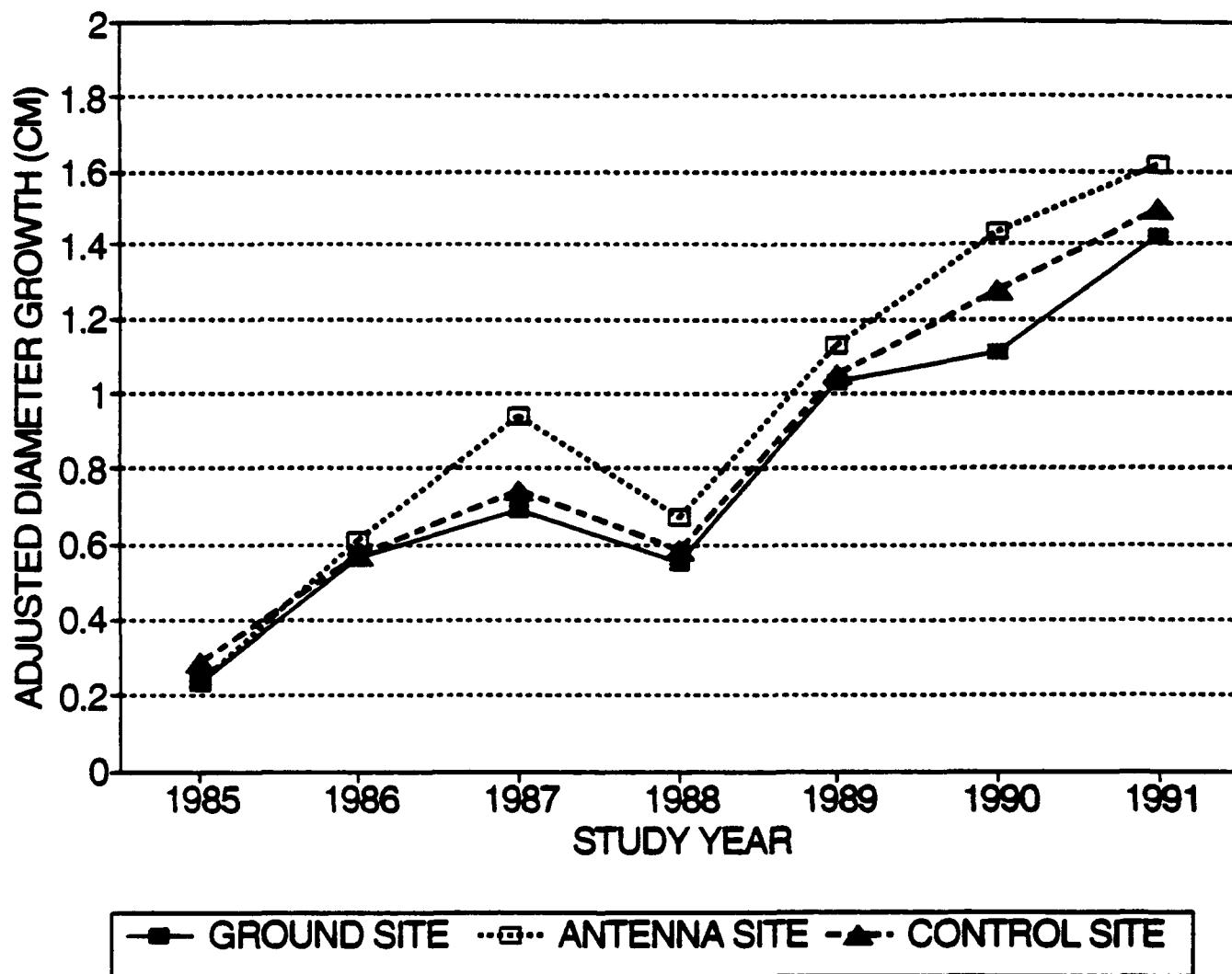
G85 ^a	A85 ^a	C85 ^a	G88 ^b	G86 ^b	C86 ^b	C88 ^b
	A86 ^{bc}	A88 ^{cd}	G87 ^{de}	C87 ^e	A87 ^f	

Post-Operational
(1989 - 1991)

G89 ^g	C89 ^g	G90 ^h	A89 ^h	C90 ⁱ	G91 ^j	A90 ^j	C91 ^k	A91 ^l

^{a/} Different letters of the alphabet indicate significant differences in adjusted diameter growths at the $\alpha=0.05$ level. The letter G signifies the ground site, A signifies the antenna site, and C signifies the control site.

Figure 2.4. Adjusted diameter growth (cm) for the three study sites from 1985 to 1991.



characteristics not accounted for through the covariates rather than ELF fields.

Seasonal Pattern of Height Growth

Height growth models based on incremental seasonal growth of the leading shoot were developed (Jones et al. 1991). 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 each 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 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 model form is as follows:

$$g_t = \left[(1 - e^{-\left(\frac{1.7595 \cdot \text{TGRO} \cdot e^{-.4024 \cdot \text{ATDD}_2}}{1.7595 \cdot \text{TGRO} - .4024 \cdot \text{ATDD}_1} \right)}) - (1 - e^{-\left(\frac{1.7595 \cdot \text{TGRO} \cdot e^{-.4024 \cdot \text{ATDD}_1}}{1.7595 \cdot \text{TGRO} - .4024 \cdot \text{ATDD}_2} \right)}) \right] \cdot (-1.7601 \cdot (\text{MT} - .101)) \cdot (\text{TGRO}) \cdot (e^{-\left(\frac{1.7595 \cdot \text{TGRO} \cdot e^{-.4024 \cdot \text{ATDD}_2}}{1.7595 \cdot \text{TGRO} - .4024 \cdot \text{ATDD}_1} \right)})$$

where

- g_t = amount of shoot growth (0.1 cm) occurring in week t
- TGRO = expected total shoot growth (0.1 cm) in the growing season
- ATDD_1 = air temperature degree days (4.4° C) to the beginning of week t

ATDD₂ = air temperature degree days (4.4° C) to the end of week t
 MT = average soil water tension for week t (if actual soil water tension is less than .101 -MPa, mt was set to .101 -MPa for model development)

The exponent

$$1.7595 * TGRO^{.4024}$$

is based on the concept that the duration of shoot growth varies with the amount of total seasonal growth (Perala 1985); as total shoot growth increases, the duration of growth increases as well. Tests show this to be highly significant and applicable to the study sites.

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. 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. Examination of the residuals from 1986 through 1991 found no significant differences ($p=0.05$) between the observed proportions and the predicted proportion of seasonal height growth (Table 2.16). The yearly differences in average annual height which were found in the analysis of covariance may be addressed here. As discussed, one would expect a difference in average annual height during the early stages of development. The nonlinear model is able to show that the observed yearly differences are not different from what we expected (or predicted) and therefore suggests that, to this point in time, the ELF system is not responsible for the yearly differences in average annual height growth which have been observed.

As discussed earlier with the hardwood diameter growth residual analysis, the independence of the red pine height growth residuals with respect to time needs to be examined. The correlations between seedling height growth residuals were calculated and averaged by site (Table 2.17). A one year lag compared the correlations between successive years (1986 and 1987, 1987 and 1988, 1988 and 1989, 1989 and 1990, and 1990 and 1991). 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. No correlations for any of the time lags at any of the three sites were significantly different from zero ($p=0.05$). The lack of significant correlations implies

Table 2.16. Residual analysis from the height growth model for the ground, antenna, and control sites in 1986 through 1991.

	Average Weekly Residual (cm)	Studentized 95% Confidence Interval
Ground		
1986	-0.0568	(-0.2019, 0.0883)
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)
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)
Control		
1986	-0.0687	(-0.2600, 0.1226)
1987	-0.0562	(-0.2723, 0.1597)
1988	-0.0600	(-0.3238, 0.2038)
1939	-0.1091	(-0.3555, 0.1373)
1990	-0.1348	(-0.7494, 0.4797)
1991	-0.0967	(-0.5892, 0.3958)

Table 2.17. Autocorrelations for one, two, three, and four year lags at the ground, antenna, and control sites in 1985 through 1991.

	Ground	Antenna	Control
One Year Lag	0.0203	-0.0176	0.0243
Two Year Lag	-0.1602	-0.2306	-0.1256
Three Year Lag	-0.1217	-0.1698	-0.1990
Four Year Lag	-0.1772	-0.0568	-0.1180
Five Year Lag	-0.0612	-0.0253	-0.0814

that the assumption of a time independence holds for the above analyses and thus, there is no need to consider a time dependent structure for these residuals through the 1991 growing season.

Possible changes in individual height growth patterns may also be evaluated through correlation analysis with EM field exposures. Each seedling's position was mapped and the expected level of exposure to the magnetic flux generated each year by the antenna for all seedlings was calculated using the interpolation equations given in Appendix A. As found in the past, there was a significant correlation between red pine growth model residual and the magnetic flux levels at the ground site during the current year ($r=-.12$) and at the antenna site both during the current year ($r=-.29$) and the previous year ($r=-.22$). When correlations were examined for the 1991 year alone, no significant correlations were found ($r=.10$ at the ground site and $r=-.13$ at the antenna site) which has also been true for all previous analyses.

The Kolmogorov-Smirnov procedure was employed to examine if ELF 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 through the 1991 growing seasons. If an environmental 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 2.5, 2.6, and 2.7 illustrate the observed and predicted cumulative growth percentages at each site for the 1991 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 1991). This suggests that ELF fields have had no significant impact on the pattern or distribution of seasonal height growth through the 1991 growing season.

Summary

1. At this point, diameter and height growth differences do exist. Although, these differences can not be assumed to be independent of the ELF fields, consistent trends in annual diameter and height growth both among the test sites and across the pre-operational and post-operational years of the study suggest that the differences are due to site characteristics not accounted for by the covariates rather than ELF fields.

Figure 2.5. 1991 OBSERVED vs PREDICTED
RED PINE HEIGHT GROWTH

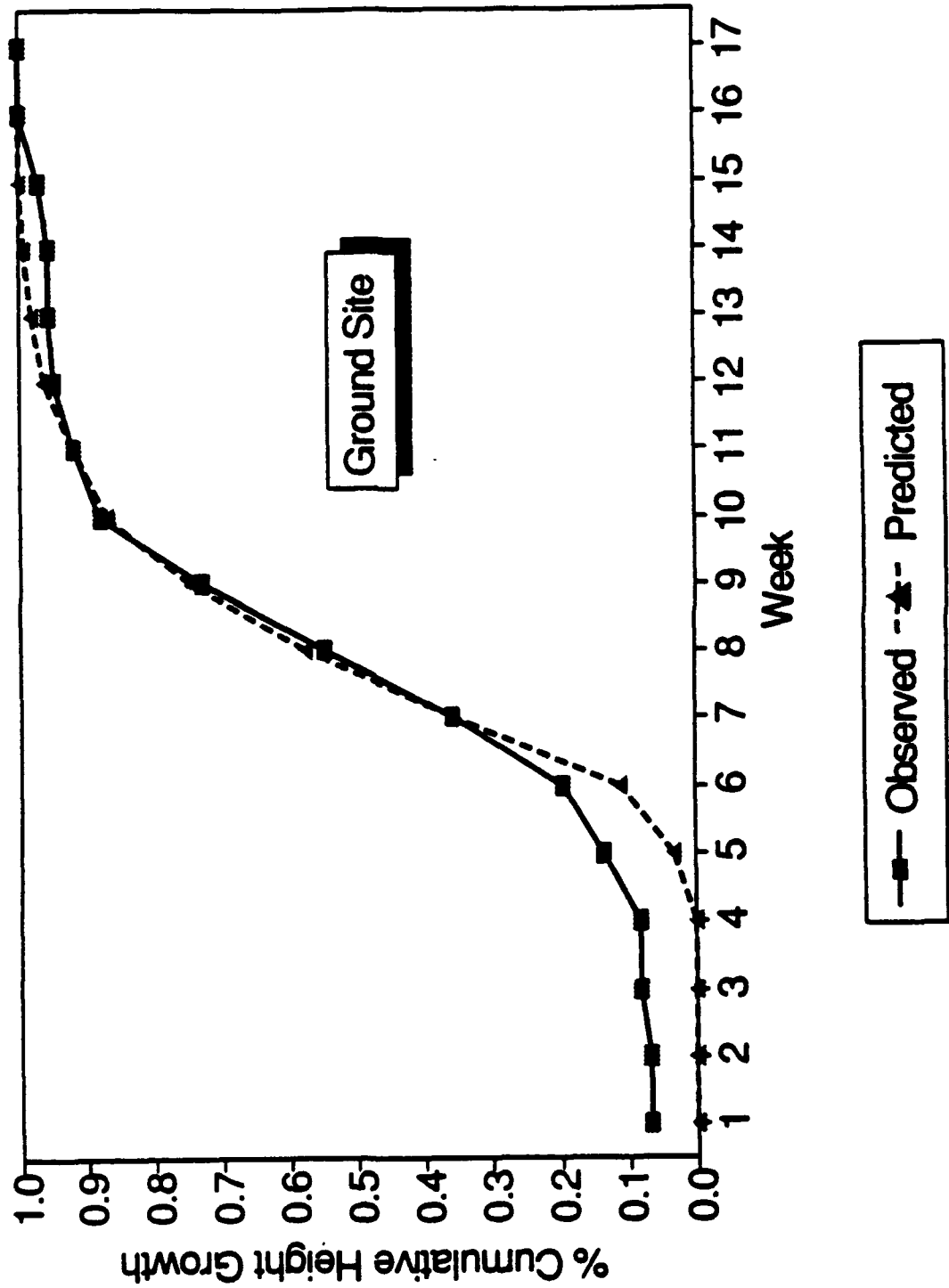


Figure 2.6. 1991 OBSERVED vs PREDICTED
RED PINE HEIGHT GROWTH

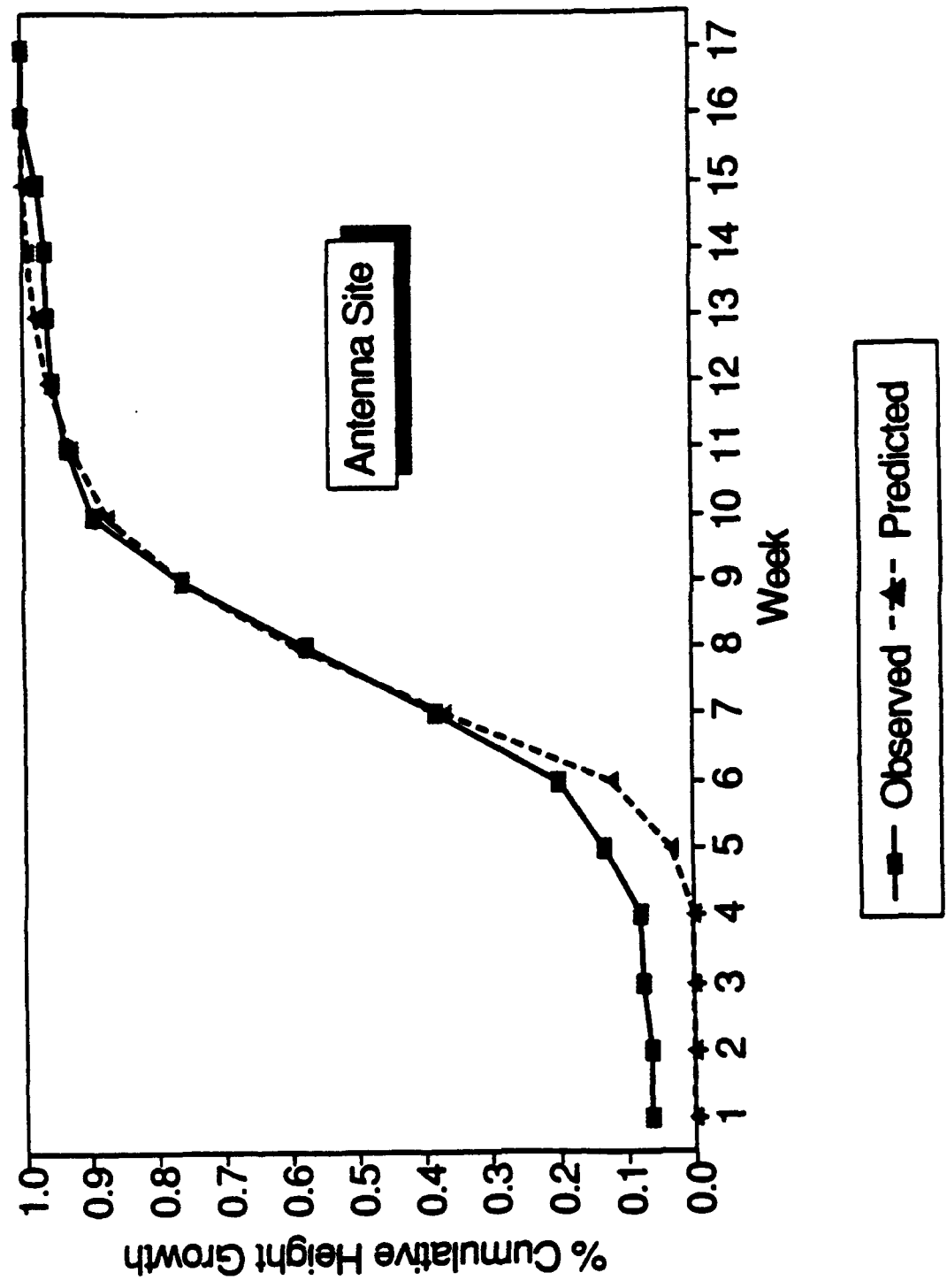
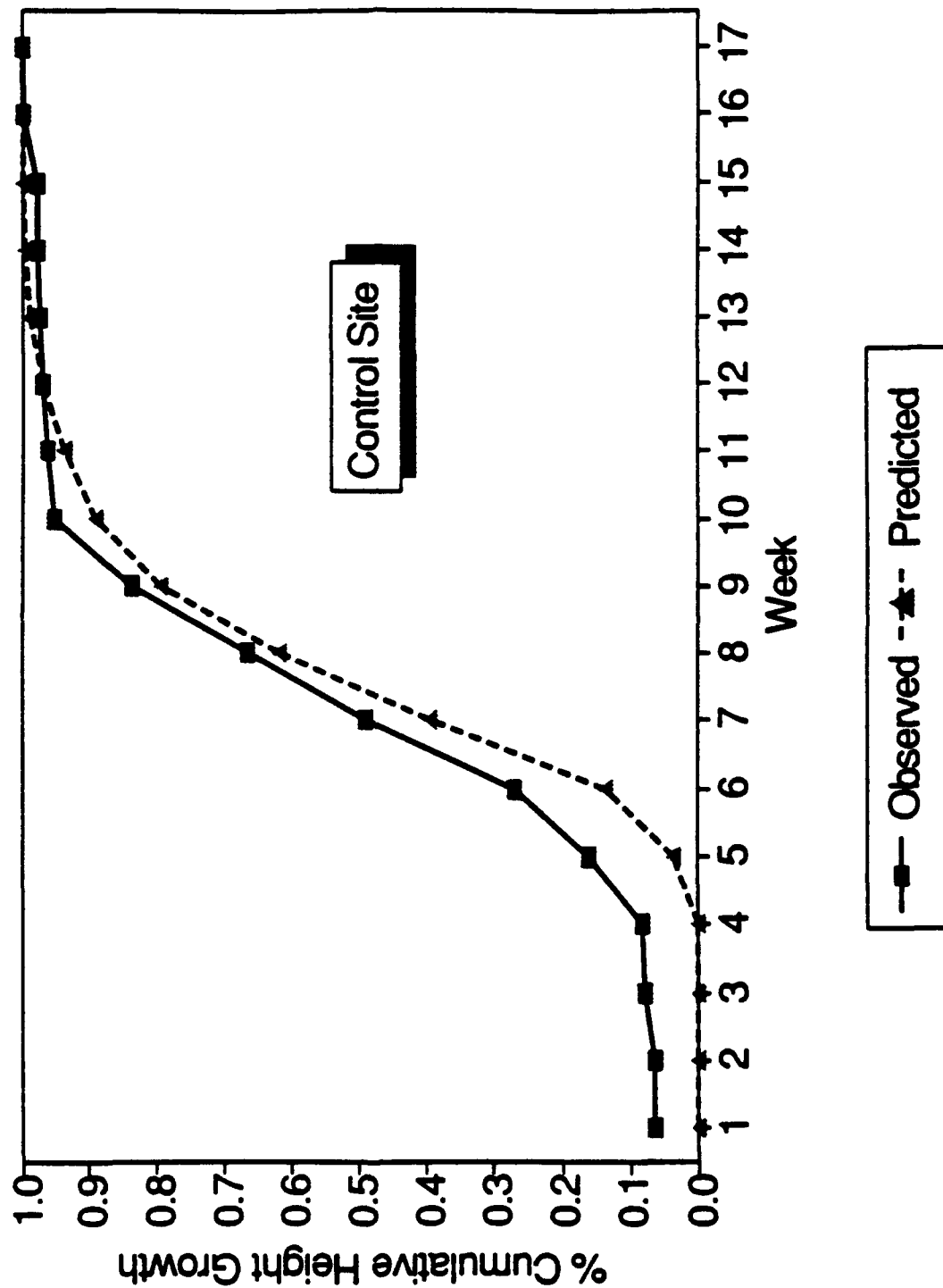


Figure 2.7. 1991 OBSERVED vs PREDICTED
RED PINE HEIGHT GROWTH



2. The individual height growth model was developed to supplement the analysis of covariance. Effects due to ELF fields were examined through a comparison of growth model residuals across time and among sites. A lack of significant differences ($p=0.05$) in these residuals both across time and among sites suggests that the ELF fields have no affect on the height growth of the individual red pine seedlings.

3. Results from the Kolmogorov-Smirnov test indicate that there is no difference between the observed and predicted seasonal height growth patterns through the 1991 growing season.

Leaf Water Potential

Leaf water potential (LWP) is a measure of the internal moisture status of plants and can be a useful measure of overall physiological condition. The overall objective of the red pine LWP study is to quantify the LWP/growth relationship prior to and after activation of the ELF antenna and evaluate the usefulness of LWP as a covariate in the growth analysis of red pine.

Optimum tree growth is dependent on many factors such as healthy root systems which allow adequate uptake of water and nutrients. Similarly, the aboveground biomass must function properly to translocate water and nutrients from the roots to provide photosynthate for growth. A physiological change that would affect the function of the root system and aboveground biomass may also affect the growth of the plant. Such changes may affect the internal moisture status. Thus, changes in LWP may indicate changes in physiological processes that affect plant growth.

Leaf water potential can also be used to help explain growth differences between sites. Site characteristics such as soil physical and chemical properties, microsite, water holding capacity, and climate have an effect on the growth of red pine. Because red pine exhibits relatively little genetic diversity, seedling growth expresses the potential of a site to provide optimal conditions for growth. The quality of the site is thus reflected in the growth of the seedling. If site quality is not optimum, physiological growth is also not at an optimum level and this may be reflected by LWP.

Finally, LWP values can be used to indicate moisture stress during periods of drought. Extended drought can reduce water uptake and reduce growth and survival of red pine seedlings. The LWP values may help explain differences in year to year growth that are due to drought conditions.

Therefore, LWP reflects the integrated effects of physiological processes and environmental conditions on seedling growth and will be evaluated as a potential covariate in the red pine growth studies.

Sampling and Data Collection

LWP sampling began in 1984 and continued on a yearly basis until 1992 which was the last measurement year for LWP in this study. The red pine seedlings were planted in June 1984 and became established during that growing season and in 1985. LWP values (MPa) were more negative in 1984 than in subsequent years due to planting shock and do not accurately reflect LWP of established seedlings. Furthermore, ambient monitoring data were not yet collected in 1984 for use in covariate analysis. In 1985, LWP measurements in May and September were conducted under very cold conditions resulting in frozen xylem water and artificially low LWP values. In addition, LWP measurements were collected monthly in 1985 rather than

biweekly as in 1986 - 1992. The 1985 data could not be easily compared to subsequent years when measurements were made biweekly. Therefore, the analysis of LWP presented here will include years 1986-1992.

Sampling in 1992 was conducted biweekly beginning on May 28 and continuing until September 1 at the Ground, Antenna, and Control sites. Sampling was not conducted after this time due to cold temperatures at the scheduled time of sampling and the potential for frozen xylem water; this results in low LWP values that are not an accurate reflection of seedling moisture status. On each sampling date, fifteen actively growing red pines were randomly selected from each site. A one year old needle was cut from each red pine in the pre-dawn hours and immediately placed in a pressure chamber to determine LWP (Richie and Hinckley, 1975). During the daylight hours prior to LWP determination, basal diameter, shoot elongation, total height, and current year needle elongation were measured. The aboveground portion of one randomly selected sample tree per plot removed from the site the afternoon following LWP determination to obtain aboveground biomass estimates. On a monthly basis, the root systems of each sample tree were excavated and root samples collected for mycorrhizae counts. See Element 4: *Mycorrhizae Characterization and Root Growth* for additional details on mycorrhizae sampling and analysis.

Topographic maps of each plot were developed in 1989 to further describe microsite variation. Computer interpolation of the elevation data then provided a method to assign an elevation to each sample tree provided its location on the plot was known. Because tree location for the sample trees is not available prior to 1988, elevation data are available only for years 1988-1992.

Progress

Average leaf water potential values varied between $-.09$ and $-.60$ MPa for all measurement dates in 1992 (Figure 2.8 and Table 2.18). Becker et al. (1987) reported that LWP values

Figure 2.8

LEAF WATER POTENTIAL (-Mpa)

1992

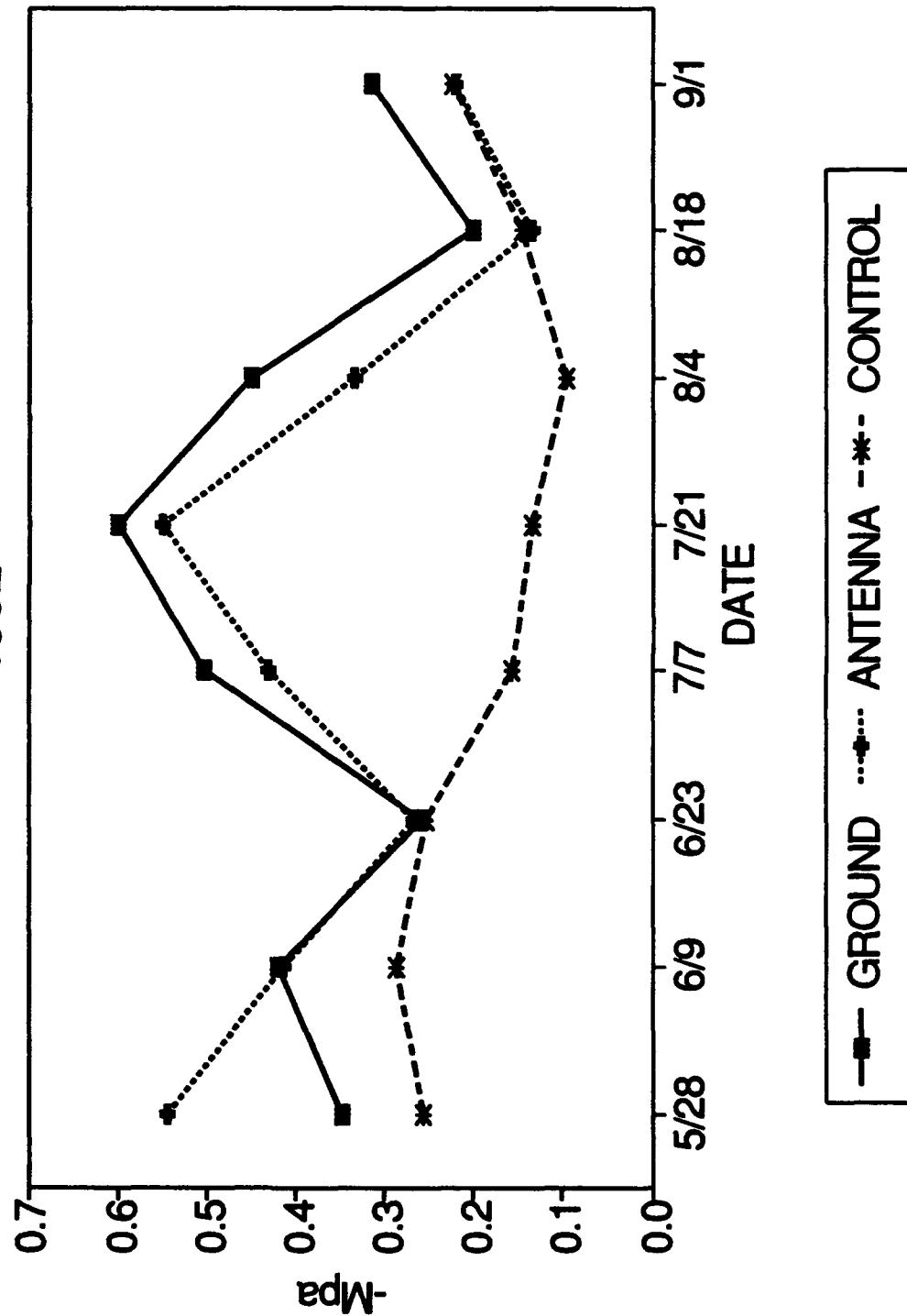


**Table 2.18. Average leaf water potential, 1992 (-Mpa)
N=15.**

<u>Date</u>	<u>Ground</u>		<u>Antenna</u>		<u>Control</u>		<u>Overall</u>
		Std.		Std.		Std.	
	<u>Mean</u>	<u>Dev.</u>	<u>Mean</u>	<u>Dev.</u>	<u>Mean</u>	<u>Dev.</u>	
	----- -MPa -----						
5/28	.35	.22	.54	.24	.25	.10	.38 ^{cd}
6/9	.42	.18	.41	.15	.28	.17	.37 ^{bcd}
6/23	.26	.17	.27	.16	.25	.13	.26 ^{abc}
7/7	.50	.23	.43	.17	.15	.07	.36 ^{abd}
7/21	.60	.21	.55	.19	.13	.05	.43 ^{bcd}
8/4	.45	.20	.33	.22	.09	.03	.29 ^{bc}
8/18	.20	.12	.13	.06	.14	.06	.16 ^a
9/1	.31	.12	.22	.15	.22	.09	.25 ^{ab}
Overall	.39 ^x		.36 ^x		.19 ^y		

Values followed by the same letter are not significantly different (p=0.05).

ranging from -.80 to -1.1 MPa did not produce measurable reductions in red pine seedling growth. LWP means for all measurement dates were relatively high (low stress) and were within or above this range. The pattern of LWP during 1992 at the Ground and Antenna Sites was similar but was generally lower and less variable at the Control site (Fig 2.8).

Analysis of variance was conducted in order to test differences in LWP and between measurement dates and sites in 1992. Significant differences (p=0.05) were found between sites, measurement dates, and in the site/date interaction. LWP was significantly higher (less stress) at the Control site than at the Ground and Antenna sites. These differences (where the Control differed from the Ground and Antenna sites) were also reported in 1986 and 1990. Significant differences between measurement dates were reported for all years while significant site/date interactions were found in all years except 1986 and 1987. (See reports by Mroz et. al., 1986-1992).

The combined data for years 1986-1992 were then examined through analysis of variance to evaluate LWP differences between sites and years. The design and ANOVA table for this analysis are presented in Table 2.19.

**Table 2.19 Anova table for the analysis of 1986 - 1992
leaf water potential data.**

<u>Source of Variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F-Ratio</u>
Year	6	SS(Y)	MS(Y)	MS(Y)/MS(E1)
Date w Year (E1)	46	SS(E1)	MS(E1)	MS(E1)/MS(WR)
Site	2	SS(S)	MS(S)	MS(S)/MS(E2)
Site by Year	12	SS(SY)	MS(SY)	MS(SY)/MS(E2)
Date w Year by Site (E2)	91	SS(E2)	MS(E2)	MS(E2)/MS(WR)

w = within

In the initial analysis of variance without covariates, significant differences in LWP were found between years, and in the site/year interaction but differences between sites were not significant (Table 2.21). Analysis of covariance (ANCOVA) was then used to determine if climatic and microsite characteristics could be used to explain the differences between years and in the site/year interaction. In 1989 and prior to ANCOVA, regression analysis was conducted to select variables that explained significant variation in LWP. Climatic variables selected by the regression analysis were average daily air temperature, total precipitation between measurement dates, and average daily minimum relative humidity. These variables were then used as covariates in ANCOVA for all subsequent years. Linear correlation coefficients between each of these variables and LWP are found in Table 2.20.

**Table 2.20. Correlations between LWP and ambient variables
selected by regression analysis. 1986-1992**

<u>Variable</u>	<u>Correlation</u>
Precipitation between measurement dates	.12*
Average daily air temperature (°C)	.14*
Average daily minimum relative humidity	.11*

* Significant at p=0.05

LWP was weakly but significantly correlated to each ambient variable. With the inclusion of the 1992 LWP data in the

analysis, no significant differences were found among sites. However, significant differences were found among years and in the site/year interaction (Table 2.22). Differences among years were first reported for the 1991 analysis while the 1992 analysis was the first time that significant differences in the site/year interaction were found.

Table 2.21. Significance levels from analysis of covariance for LWP, 1986 - 1992.

<u>Factor</u>	<u>No Covariates</u>	<u>With Covariates</u>
	----- P-value -----	
Site	.107	.895
Year	.000	.000
Site by Year	.035	.031

The covariates that explained year and site/year differences in past years did not explain these differences when the 1992 data was included in the analysis. The reason that ambient variables did not explain these differences is unclear. The literature indicates that a strong relationship exists between LWP and soil moisture and temperature (Nambiar et. al. 1979, Hinckley et. al. 1978, Fahey and Young 1984, and Teskey et. al. 1984). However, from year to year, we consistently find LWP only weakly but significantly correlated with average daily air temperature and not significantly correlated to soil moisture at 10 cm depth. It appears that the level of soil moisture was such that over the duration of the study (or at least on LWP measurement dates) changes in soil moisture did not produce pronounced changes in LWP. Average soil moisture of the LWP measurement dates was at least 10 percent. Sucoff (1972) showed that for red pine in Minnesota, soil moisture fell below 10 percent before large decreases occurred in LWP (more stress). Thus, it appears that the yearly differences found in LWP are not directly related to drought.

In a review of water relations in tree species (Abrams 1988), several studies showed seasonal osmotic pressure, which is related to LWP, varied significantly in non-droughted plants. In addition, phenological events such as bud swelling, shoot elongation, and bud initialization and other environmental factors not related to drought also had a pronounced effect on osmotic pressure (Columbo 1987, Abrams, 1988). It seems likely that some of these factors may also be affecting LWP among sites and years. In such situations, climatic variables may operate in combination with physiological processes and other environmental factors to initiate a response in LWP. Identifying potential relationships of LWP with phenological stage may be helpful in explaining yearly differences.

Multiple range tests were performed to identify where significant differences in LWP occurred among sites and within years over the length of the study (Fig. 2.9). The relationship between sites changes several times between 1986 and 1992. Since the time the ELF system became operational, significant differences in LWP were found between the Ground and Control sites in 1990 and also in 1992. However, LWP in 1990 at the Ground site was greater (less stress) than at the Control site but was lower (more stress) than the Control site in 1992. Significant differences between the Control site and the Ground site were also found in the pre-operational years of 1986 and 1988. In these years also, the relationship of LWP between these sites was reversed with LWP greater at the Ground site in 1986 but greater at the Control site in 1988.

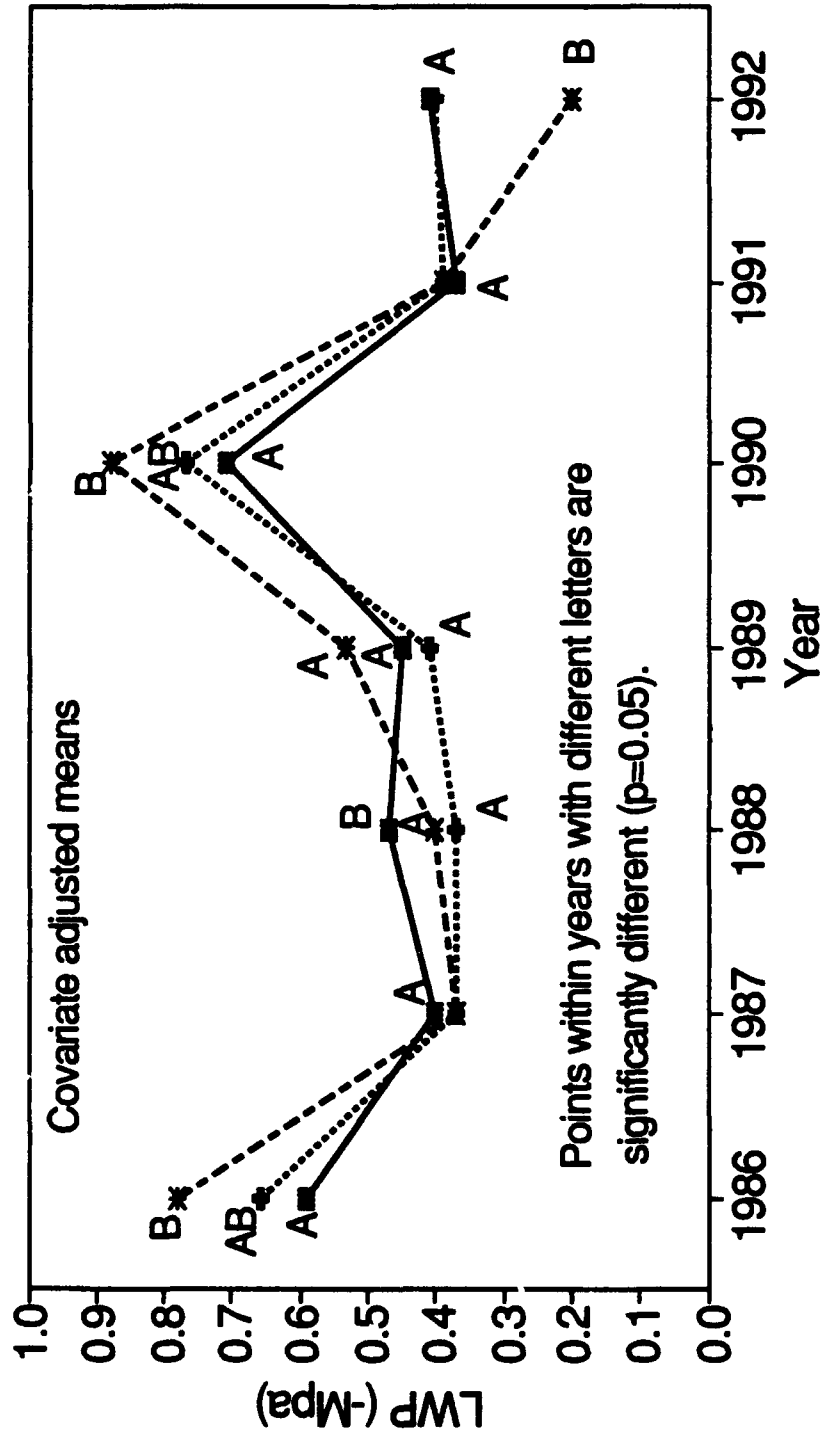
LWP was significantly higher at the Control site in 1992 than at the Ground and Antenna sites (Fig. 2.9). The level of LWP at the Ground and Antenna sites in 1992 was not significantly different than LWP at those sites in pre-operational years 1987, 1988, and 1989. However, a possible ELF effect might exist in 1992 if ELF electromagnetic fields affected LWP in such a way at the Ground and Antenna sites as to prevent LWP from increasing to the same levels as at the Control site. Additional years of LWP measurement would be desirable in order to determine if this situation exists and would continue. However, 1992 was the last scheduled year for LWP measurement. Therefore, at this point in time, we cannot ascertain whether the significant differences in LWP between sites in 1992 were due to ELF electromagnetic fields.

Future efforts in analyzing the LWP data will include investigating relationships from measured ELF fields. This will include EM field data from the permanently measured points which were then extrapolated to provide field intensity estimates for all locations within the study sites. Work will also continue to identify non-drought related factors which might be causing changes in LWP.

Figure 2.9

LEAF WATER POTENTIAL (-Mpa)

1986-1992



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) relative 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.

H₀: 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

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 there after 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 these 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.

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 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 (R. 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 potential covariates for the analysis includes factors measured two and one years prior to sampling as well as the year during sampling. Work this year has included soil, tree and climate

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

characteristics from the year prior to sampling, in some specific instances two years prior to sampling, and the year of sampling as potential covariates (Table 2.23).

Table 2.23. Potential covariates considered in analysis

<u>Covariate</u>	<u>Growing Season Average</u>	<u>Monthly Average</u>	<u>Current Year</u>	<u>Year of Expansion</u>	<u>Year of Bud Set</u>
<u>Climate</u>					
Air Temp.	✓	✓	✓	✓	
Soil Temp.					
5 & 10 cm	✓	✓	✓	✓	
Soil Moisture%					
5 & 10 cm	✓	✓	✓	✓	
Soil Water Pot.					
5 & 10 cm	✓	✓	✓	✓	
Air Temp. Cum.					
Growing Deg. Days ¹	✓		✓	✓	✓
<u>Tree Dimensions</u>²					
Total Height			✓		
Basal Diameter			✓		
Current Ht. Growth			✓		
Top Weight			✓		
Ht. Probability ³			✓		
Ht. Growth Probability			✓		
Diam. Probability			✓		
Mycorrhizal Roots			✓		
<u>Soil Nutrient Conc. &⁴ Content</u>					
Nitrogen	✓		✓	✓	
Phosphorus	✓		✓	✓	
Potassium	✓		✓	✓	
Calcium	✓		✓	✓	
Magnesium	✓		✓	✓	

¹ Cumulative degrees for different phenological phases (7/15-9/30 & 4/15-8/31)

² Tree measurement at the time of sampling

³ Cumulative normal probability density (for a given tree dimension) $-\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mu - x)^2}{2\sigma^2}}$ where μ & σ are estimated for each site and year from all permanently marked trees in October

⁴ Concentrations and contents are an average from soil sampled in June and July

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 with the 1986-1989 developmental data (Herbaceous Plant & Tree Study 1990).

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 ANOCOVA 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.

After covariate selection, analysis of variance and covariance were performed using six years of information (1986-1991) to determine differences in foliar concentration among sites and years. The coefficients of the selected covariates for the ANOCOVA tests were not constrained to pre-antenna operational values and were refitted using the additional two years of data. Multiple range tests (SNK) were used to determine differences among sites, years, or site year groups after significant ANOVA or ANOCOVA tests.

Progress

Nutrient concentrations and standard deviation for each site and year from 1986-1991 are presented in Table 2.24. 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 and 1991 nutrient concentrations increased above 1.0%. Nutrient concentrations are ranked in the order: N > K > Ca > P > Mg for all years sampled.

Table 2.24. Mean and standard deviation of foliage nutrient concentrations for red pine seedlings at ELF study sites (1986-1991)

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)	0.34(.07)	0.21(.02)	0.09(.01)
Antenna	1.10(.16)	0.12(.02)	0.33(.04)	0.24(.07)	0.09(.01)
Control	1.04(.15)	0.12(.01)	0.36(.06)	0.23(.03)	0.09(.01)
1988					
Ground	1.16(.14)	0.14(.02)	0.58(.06)	0.25(.05)	0.11(.01)
Antenna	1.27(.15)	0.15(.02)	0.56(.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)	0.38(.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)

Standard deviations of individual nutrient concentrations are generally within 10 to 20% of the mean for all sites and years (Table 2.24). 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 variation during 1986-1991 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 2.25 along with the p-value and detection limits for the ANOVA and ANOCOVA tests using the covariate developmental data. Use of soil nitrogen concentrations during leaf expansion as a covariate greatly reduced the variation

Table 2.25. 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).

	-----P Value-----				
	N	P	K	Ca	Mg
Without Covariates					
Site	.042	.060	.178	.139	.016
Year	.000	.000	.000	.000	.000
Year x Site	.249	.451	.007	.410	.008
	-----%				
Without Covariates					
Site	8.7	5.4	8.1	9.5	3.4
Year	5.0	5.6	6.3	10.4	4.8
Year x Site	8.6	9.8	10.9	18.0	8.4
	-----P Value-----				
	N ¹	p ²	K ³	Ca ⁴	Mg ⁵
With Covariates					
Site	.316	.272	.214	.413	.029
Year	.001	.176	.000	.614	.000
Year x Site	.166	.241	.003	.327	.008
	-----%				
With Covariates					
Site	10.0	6.0	9.0	7.7	2.7
Year	4.8	5.1	5.4	9.5	4.8
Year x Site	8.2	8.8	9.4	16.4	8.4

¹Covariate=Natural log soil nitrogen concentration during leaf expansion

²Covariate=Mean soil water potential 5cm (September) current year

³Covariate=Soil water potential 5cm (May-September) previous year. (Only 1987-1989 data was used in this analysis due to the lack of soil moisture data in 1985)

⁴Covariate=Height probability & soil temperature 10 (May) current year

⁵Covariate=Current year height growth probability

associated with the year factor in the analysis of foliar nitrogen. Comparison of soil and foliar nitrogen showed that soil total nitrogen concentrations were extremely high in 1985 while foliar concentrations of one year old fascicles were likewise high in 1986 (Figure 2.10). The increased amounts of nitrogen in the soil in 1985 after harvesting and during the year of leaf expansion of the 1986 foliar samples appears to be responsible for a large portion in the increase in foliar nitrogen levels observed in 1986.

Individual sample tree measurements were also significant covariates for foliar magnesium and calcium concentrations. Concentrations of these cations generally increased with the relative size of tree for a given site and year. These covariates tended to decrease detection limits associated with the site factors as well as year and site by year interactions.

Detection limits were also reduced by the covariates used in the phosphorus and potassium analyses. Reductions were greatest for the year and site by year components. The covariates associated with the phosphorus analysis and the calcium analysis explained a large proportion of the annual variation for these elements.

Site & Year Comparisons: ANOVA tests indicated significant ($p \leq 0.05$) differences among years for all nutrients and among sites for magnesium (Table 2.26). The antenna site had significantly lower concentrations of magnesium (0.090%) compared to the control (0.096%) or the ground site (0.097%). Concentrations of calcium and magnesium increased while concentrations of nitrogen decreased during the 1986-1989 at all sites (Figures 2.10, 2.16, and 2.18). 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 and 1991, concentrations of these elements have appeared to stabilize and differences between years have been minimized.

Year by site interactions were only significant ($p \leq 0.05$) for nitrogen and potassium (Table 2.26). Figures 2.10 and 2.11 show that these significant interactions were not related to any increase or decrease in differences in foliar concentrations among sites over time or after ELF antenna operation. For each nutrient Rather, differences in foliar concentrations of nitrogen and potassium among sites were only significant ($p \leq 0.05$) during 1986 and 1988 respectively.

Detection limits associated with the analysis of variance (without covariates) were generally below 10% (Table 2.26). Detection limits were also for the most part lower for site and year factors than year by site interactions. The low detection limits of these analyses supports the acceptability of nutrient concentrations as an indicator of plant responses to ELF electromagnetic radiation.

Inclusion of the selected covariates (Table 2.25) had little effect on either p-values or detection limits associated with the analyses (Table 2.26). Concentration differences among years or site by years were still significant for the ANOCOVA tests

Table 2.26. Results of red pine foliage nutrient analyses of variance (p value) and computed detection limits (%) with and without covariates (1986-1991).

	-----P Value-----				
	N	P	K	Ca	Mg
Without Covariates					
Site	.088	.146	.412	.192	.010
Year	.000	.004	.000	.000	.000
Year x Site	.002	.281	.003	.621	.055
	-----%				
Without Covariates					
Site	6.5	8.7	6.1	8.2	5.2
Year	4.6	9.6	5.7	9.8	5.7
Year x Site	8.1	16.7	9.9	17.0	10.0
	-----P Value-----				
	N	P	K	Ca	Mg
With Covariates					
Site	.287	.335	.574	.383	.099
Year	.000	.514	.000	.001	.000
Year x Site	.003	.263	.001	.680	.075
	-----%				
With Covariates					
Site	6.9	8.7	6.5	7.3	3.8
Year	4.7	9.6	5.4	9.5	5.9
Year x Site	8.1	16.7	9.3	16.5	10.2

associated with N, K, Ca, and Mg. In many instances the p-value was increased for these factors as a result of a decrease in the degree of freedom associated with the error term rather than a reduction in the sum of squares. Detection limits for year and site by year analytical components increased or remained the same for N, P, and Mg. However, detection limits for these factors were reduced for Ca and K. Although all covariates explained significant proportions of the variation in nutrient concentrations for the developmental data, only the covariate used in the potassium comparison was significant ($p=.045$) when all available years of data were analyzed. The poor performance

Figure 2.10

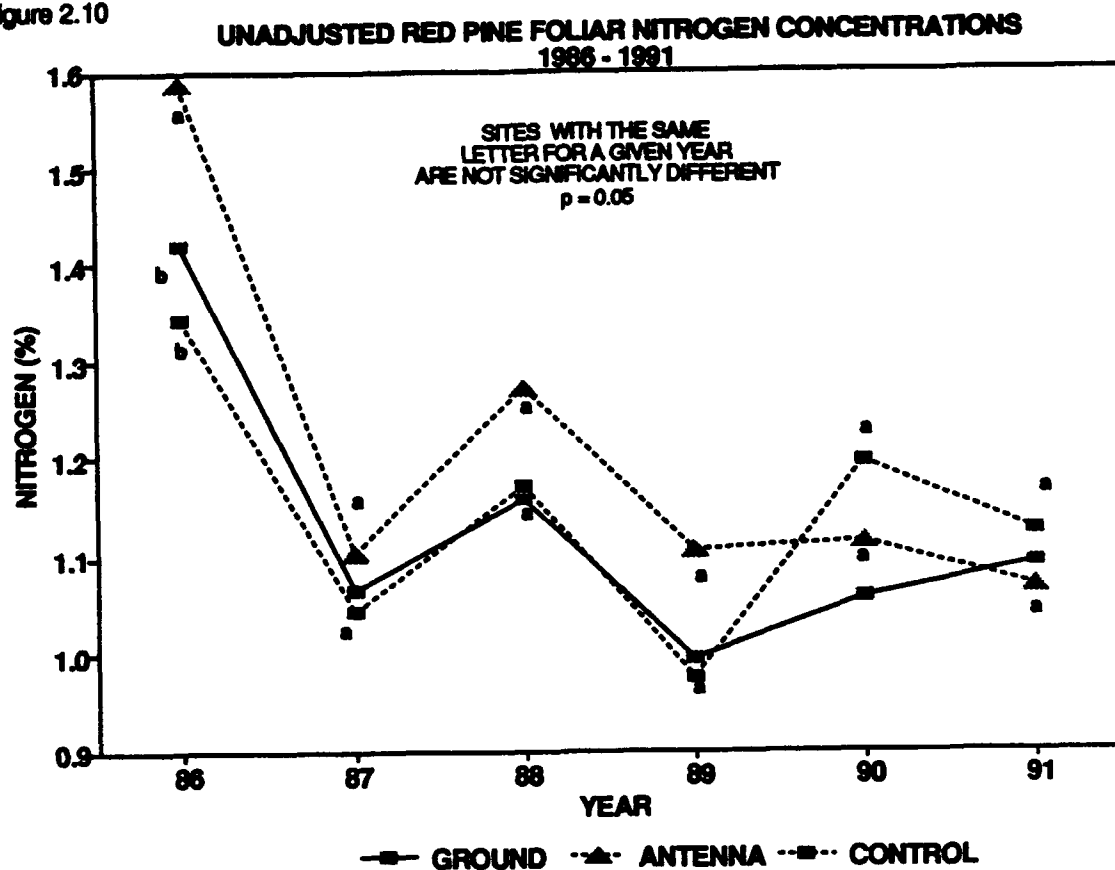


Figure 2.11

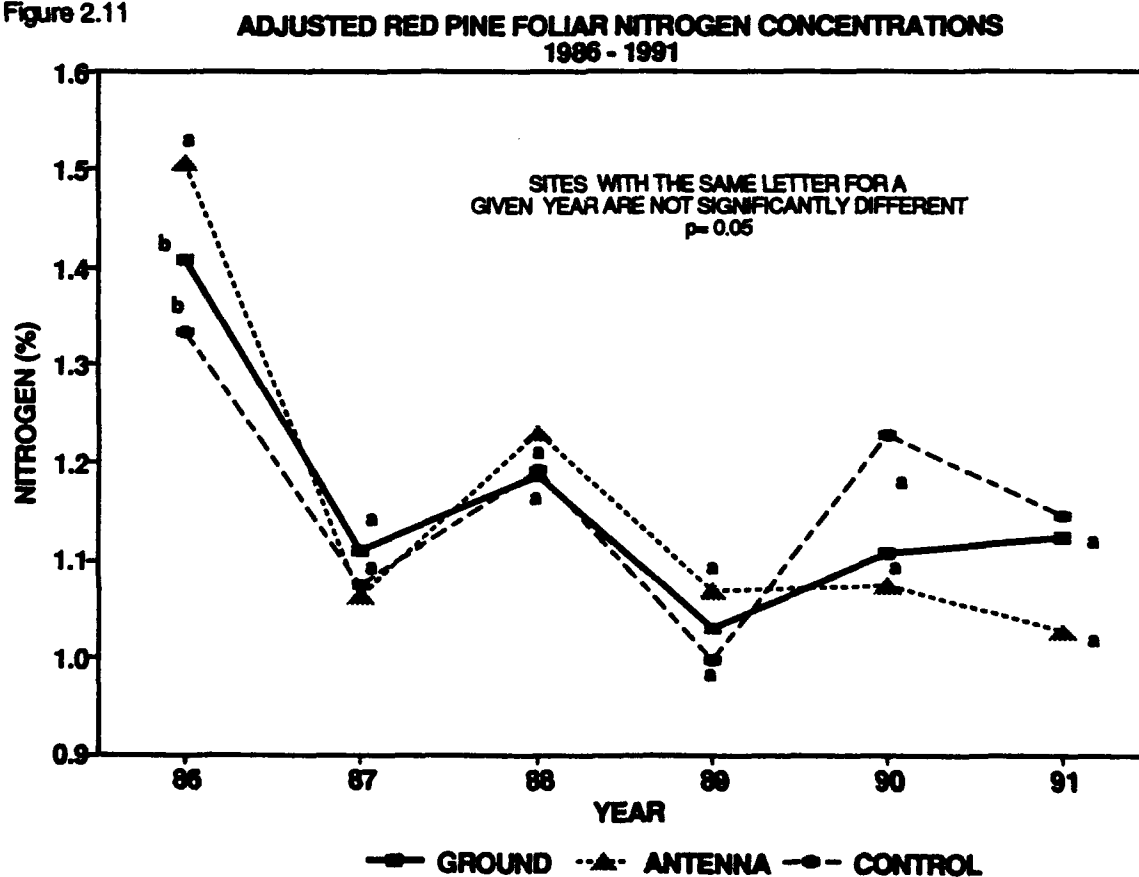


Figure 2.12

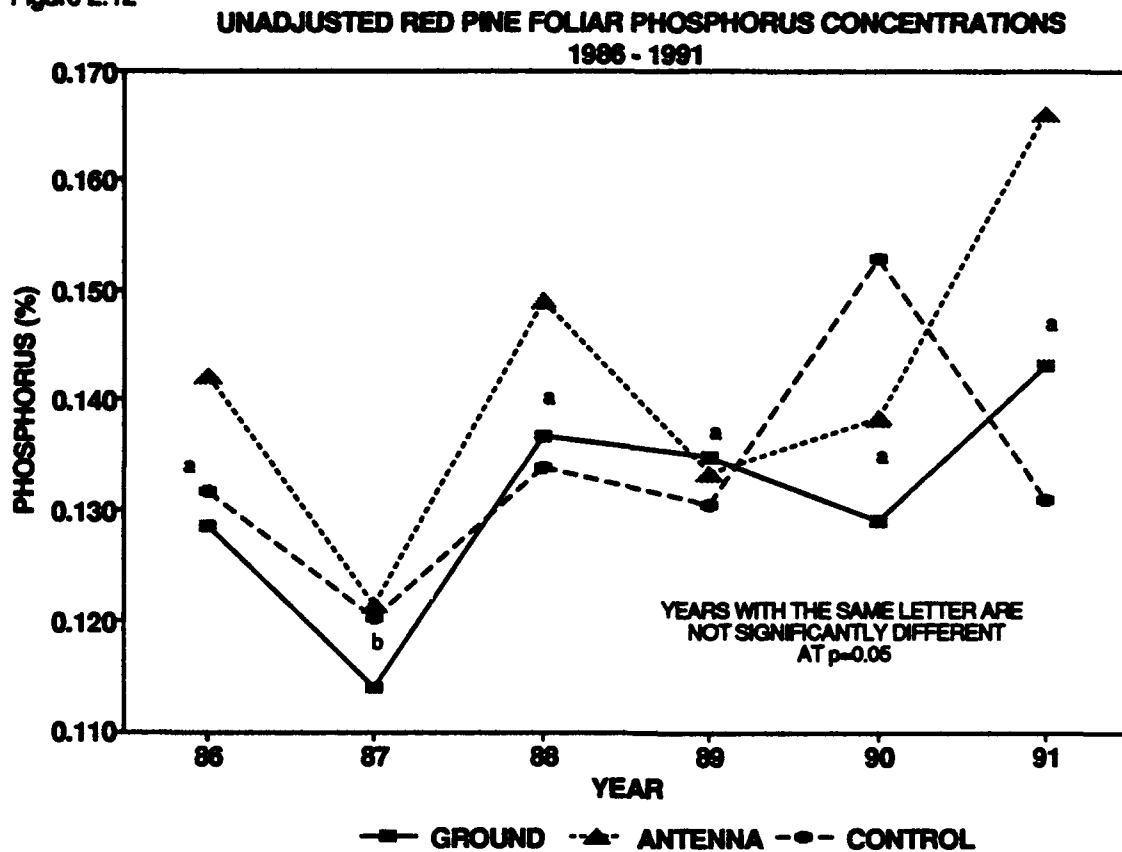


Figure 2.13

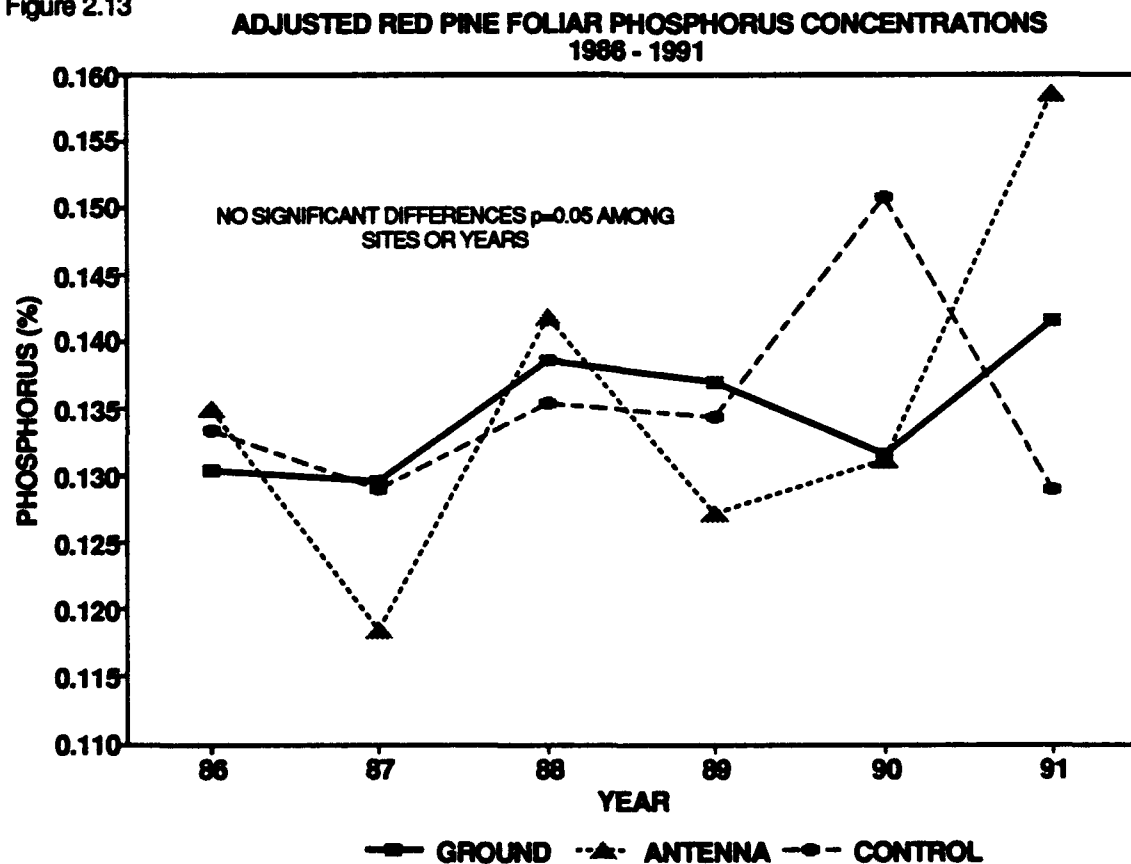


FIGURE 2.14

UNADJUSTED RED PINE FOLIAR POTASSIUM CONCENTRATIONS
1987 - 1991

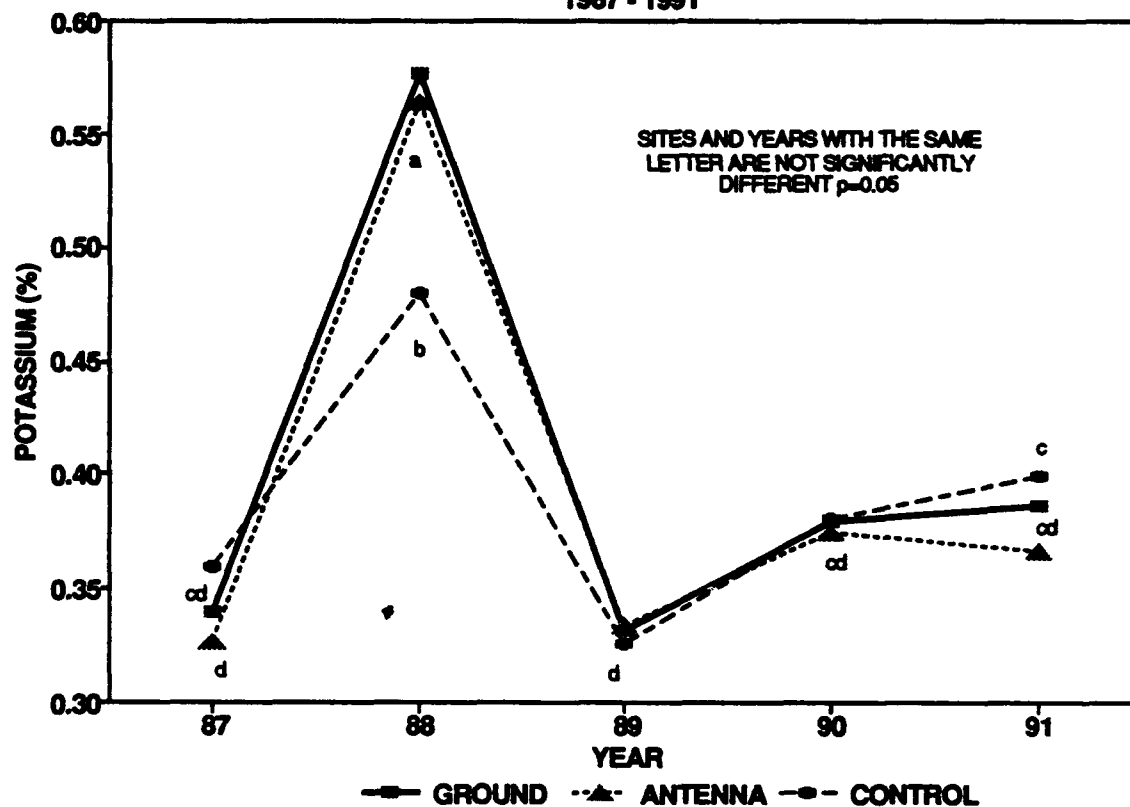


FIGURE 2.15

ADJUSTED RED PINE FOLIAR POTASSIUM CONCENTRATIONS
1987 - 1991

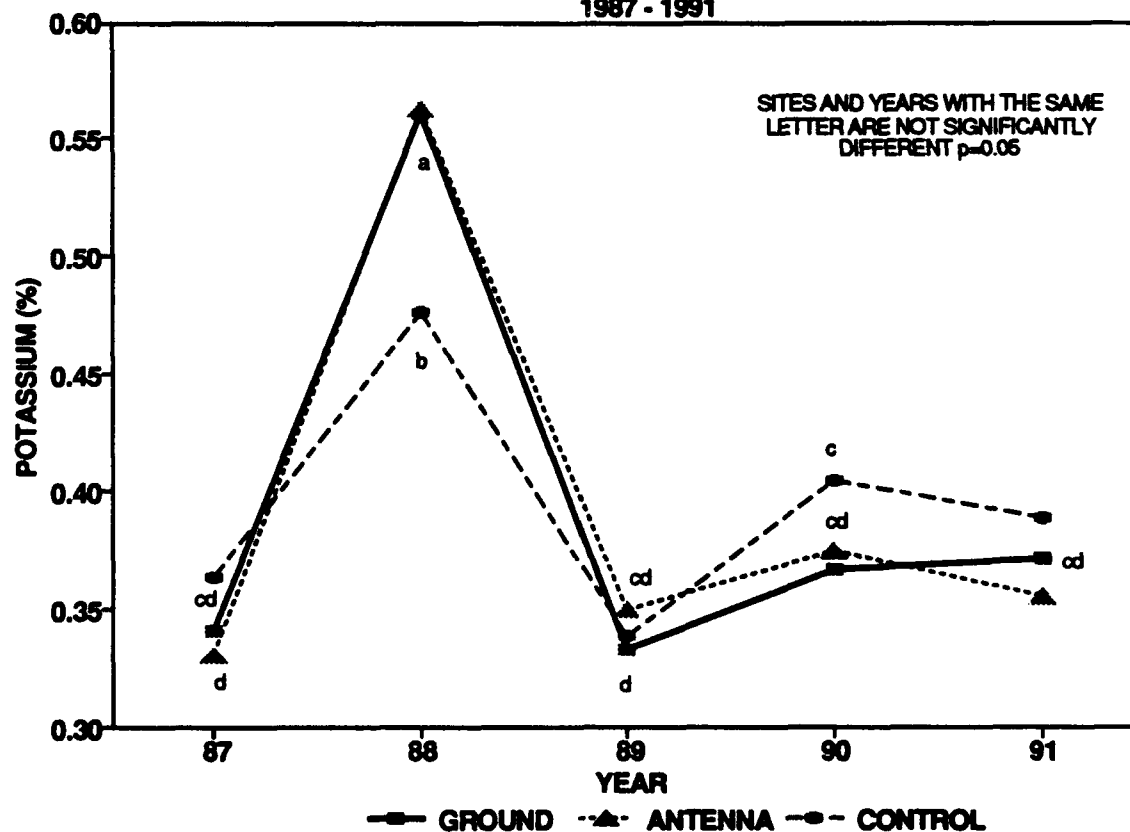


FIGURE 2.16

UNADJUSTED RED PINE FOLIAR CALCIUM CONCENTRATIONS
1986 - 1991

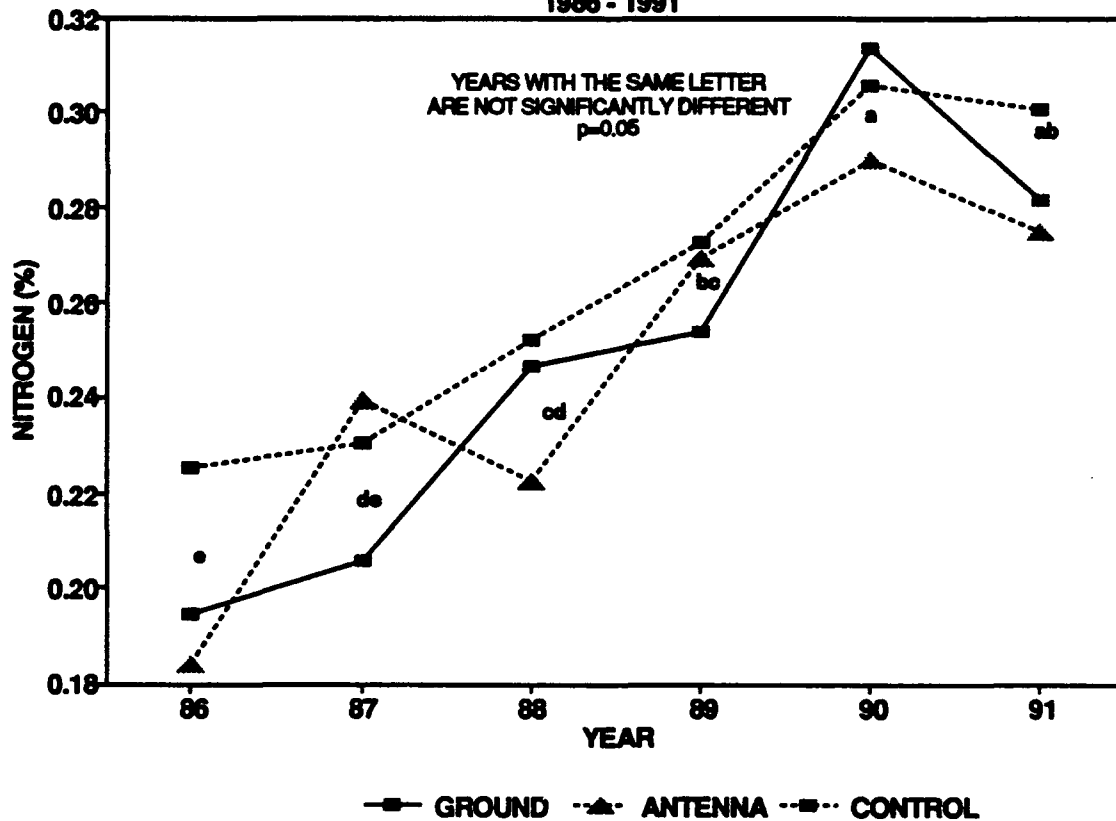


FIGURE 2.17

ADJUSTED RED PINE FOLIAR CALCIUM CONCENTRATIONS
1986 - 1991

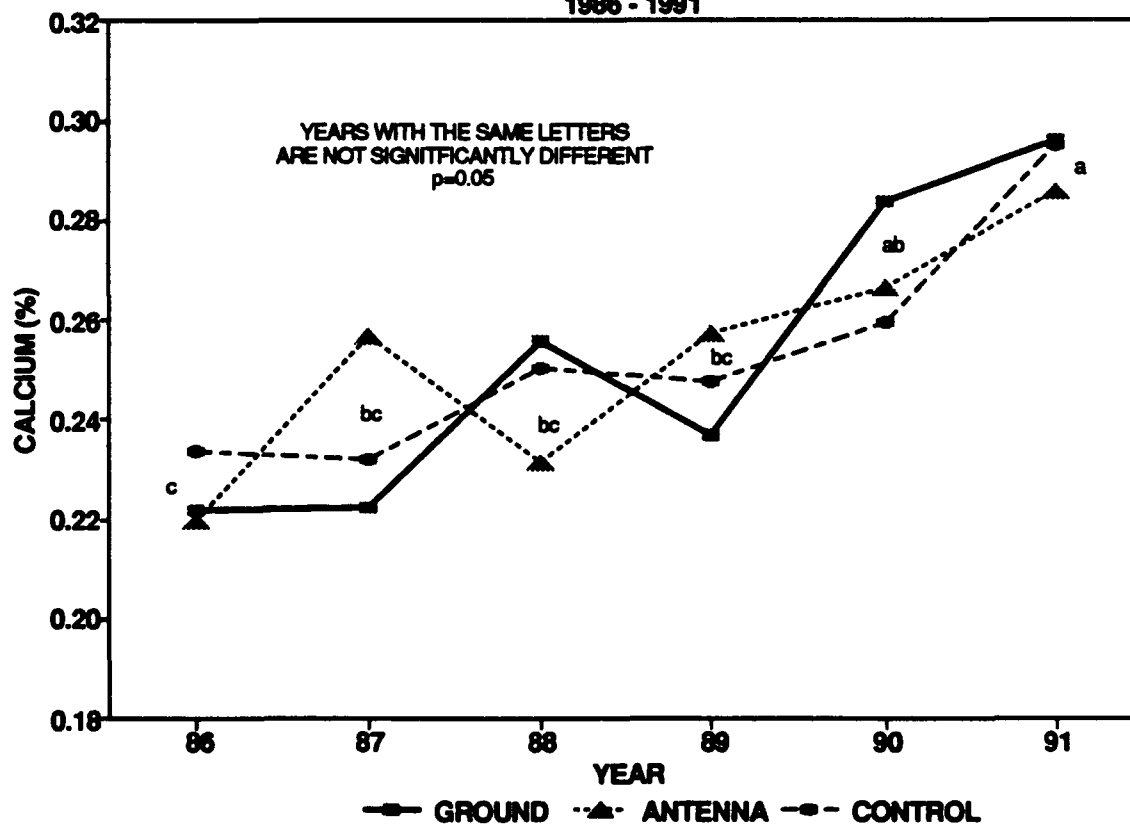


FIGURE 2.18

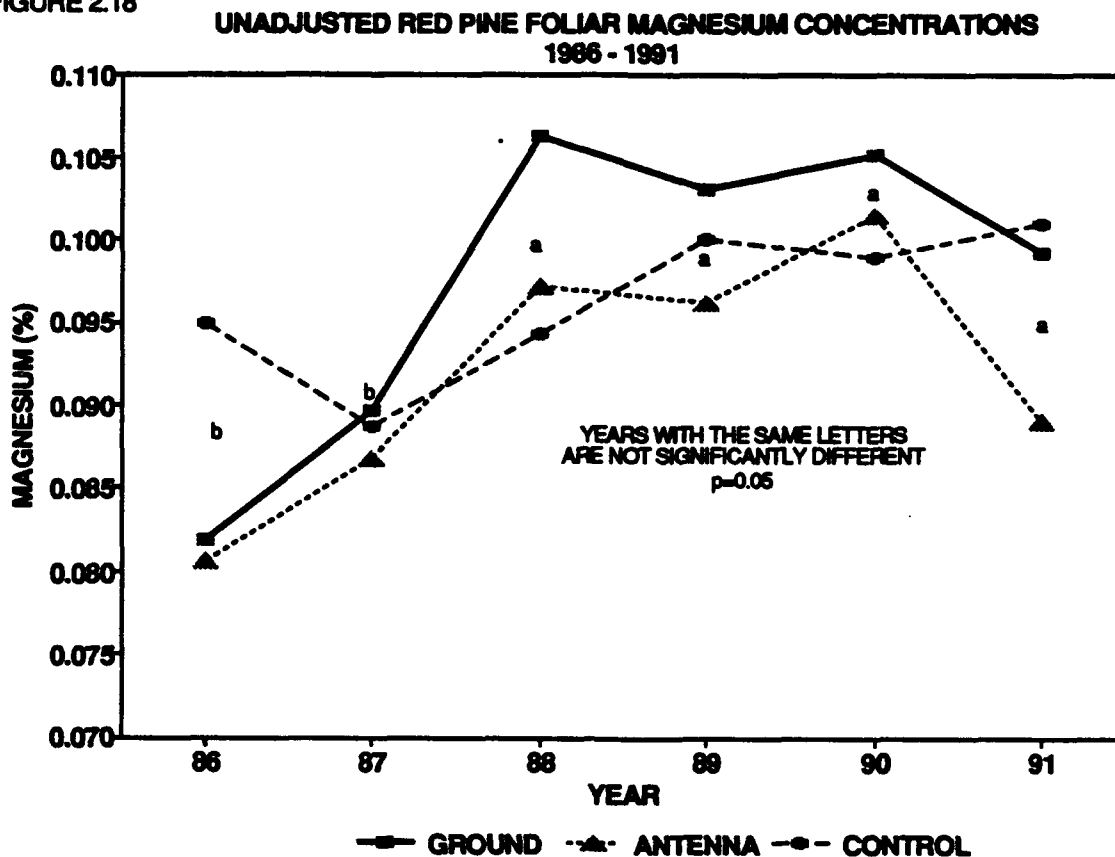
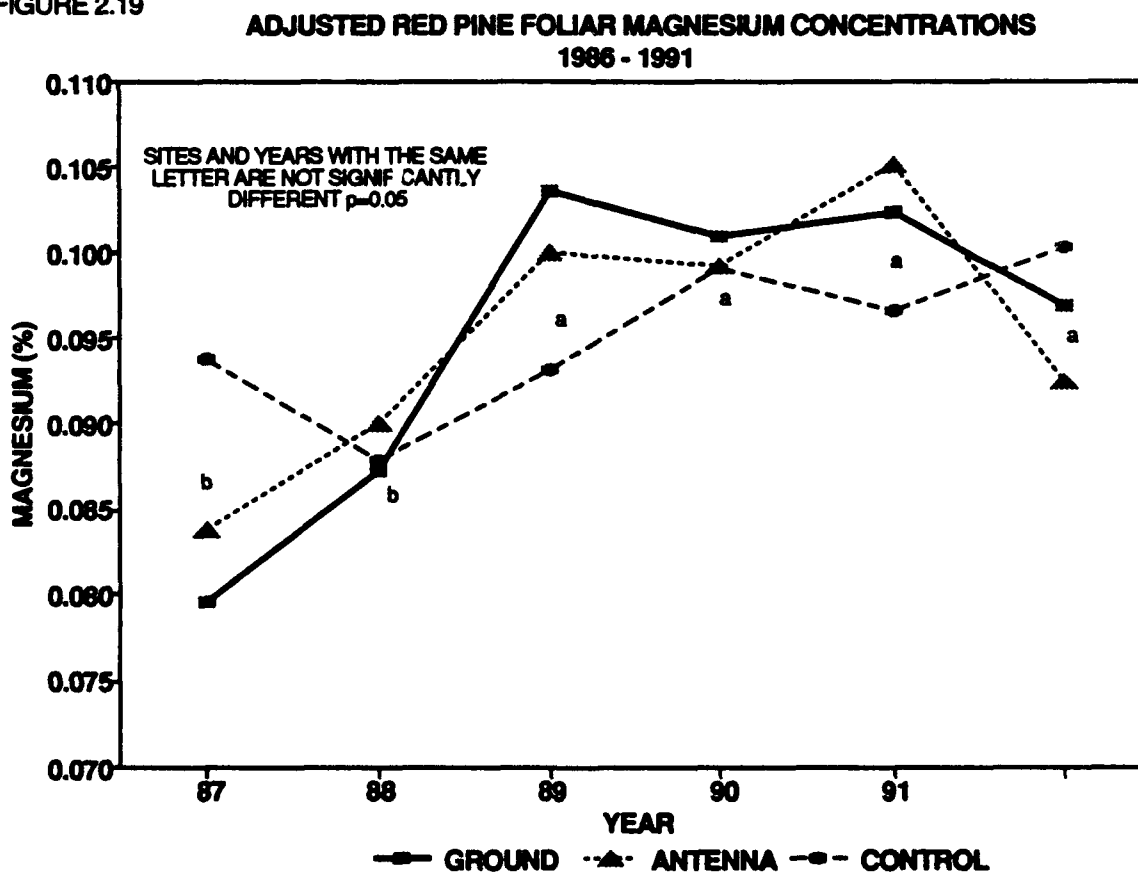


FIGURE 2.19



of these covariates suggests that either these variables are not strongly related to concentration levels, the relationship of concentration to these covariates have changed during the study, a longer time period of data is needed to adequately fit the covariates, and/or the relationship among covariates and foliar concentrations are not linear.

Regardless of whether the adjusted or unadjusted covariate means are compared (Figures 2.10-Figure 2.16) there appears to be no evidence that ELF antenna operation has affected the nutrient concentrations of the red pine foliage. Differences in P, Ca, or Mg among sites were not found to be significant ($p=.05$) for any year during the six year study period irrespective whether unadjusted or adjusted means were considered (Figures 2.12-2.13, Figures 2.16-2.19). Although differences in foliar K among sites were significant during 1988, no significant differences were evident for any other year of the study. Foliar nitrogen concentrations were significantly higher at the antenna site than the other two sites only during 1986. Average foliar nitrogen concentrations were consistently greater at the antenna than the control during 1986-1989, but during 1990-1991 average concentrations at the control were .07% greater than at the antenna site. However, the changes in foliar nitrogen concentrations at the three sites during 1990-1991 were not significant ($p \leq 0.05$).

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 changes in foliar concentrations were evident at the test sites after antenna operation. Due to the poor performance of the covariates, future work will continue on the selection of covariates to improve the analyses. First coefficients of the selected covariates (Table 2.25) will be compared from years before and during full antenna operation to determine if relationships between covariates and foliar concentrations have been altered by antenna operation. Covariates will also be selected and fitted using the entire data set. Coefficients determined from this data set will be compared as previously stated to determine possible alteration by antenna operation. Covariates selected using the entire data set which are correlated to field strengths or with coefficients which significantly differ between preoperational and operational phases will be removed. Covariates selected from entire data set and those from the preoperational data set will then be compared to determine the covariates to be used in the analysis.

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 m² 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 3.4OO 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 indicating that the ELF fields present during the 1992 growing season had no distinguishable effect on the timing of starflower's phenological events.

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 proportion of plants flowering was significantly lower on the antenna site in 1988. Reasons for this are unknown. Significant differences in the number of plants flowering were not detected in 1990, 1991, and 1992.

Observed changes may be due to handling, climate, or to interactions among these factors. 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 m²) 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 measurement 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

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).

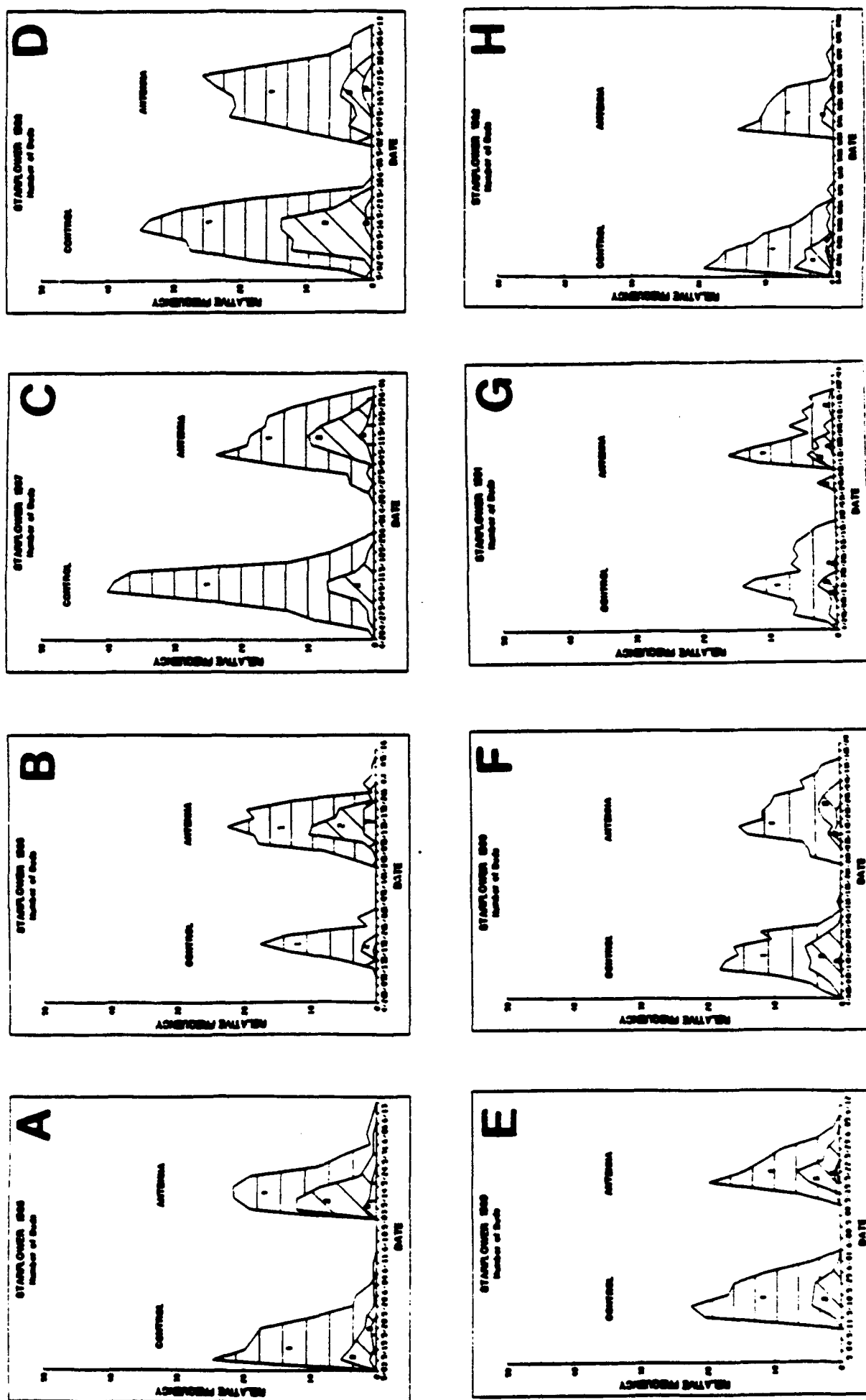


Figure 3.2: Relative frequency for number of plants with one or more flowers by sampling date on the antenna site and the control site for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), 1990 (F), 1991 (G), 1992 (H).

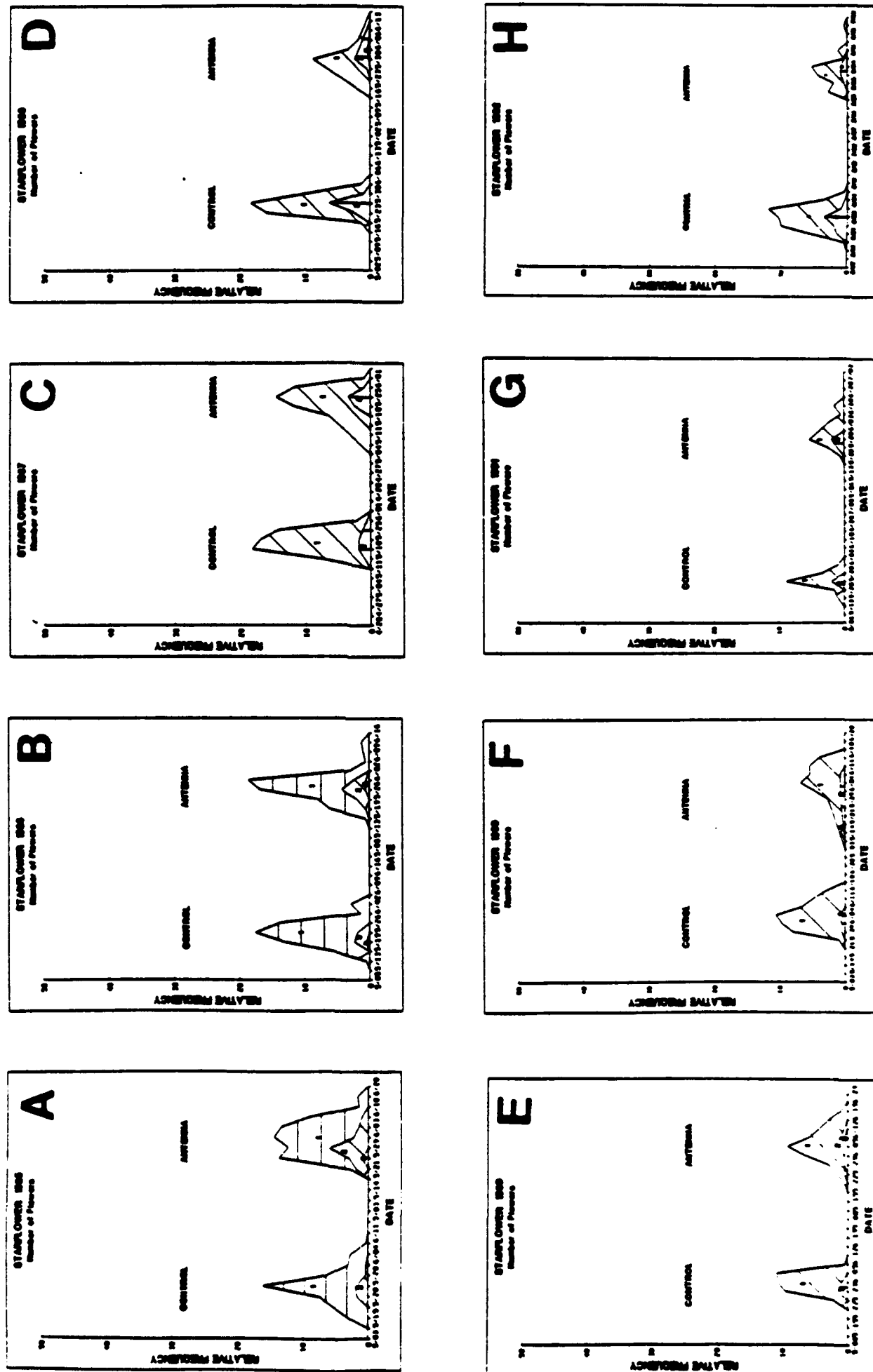
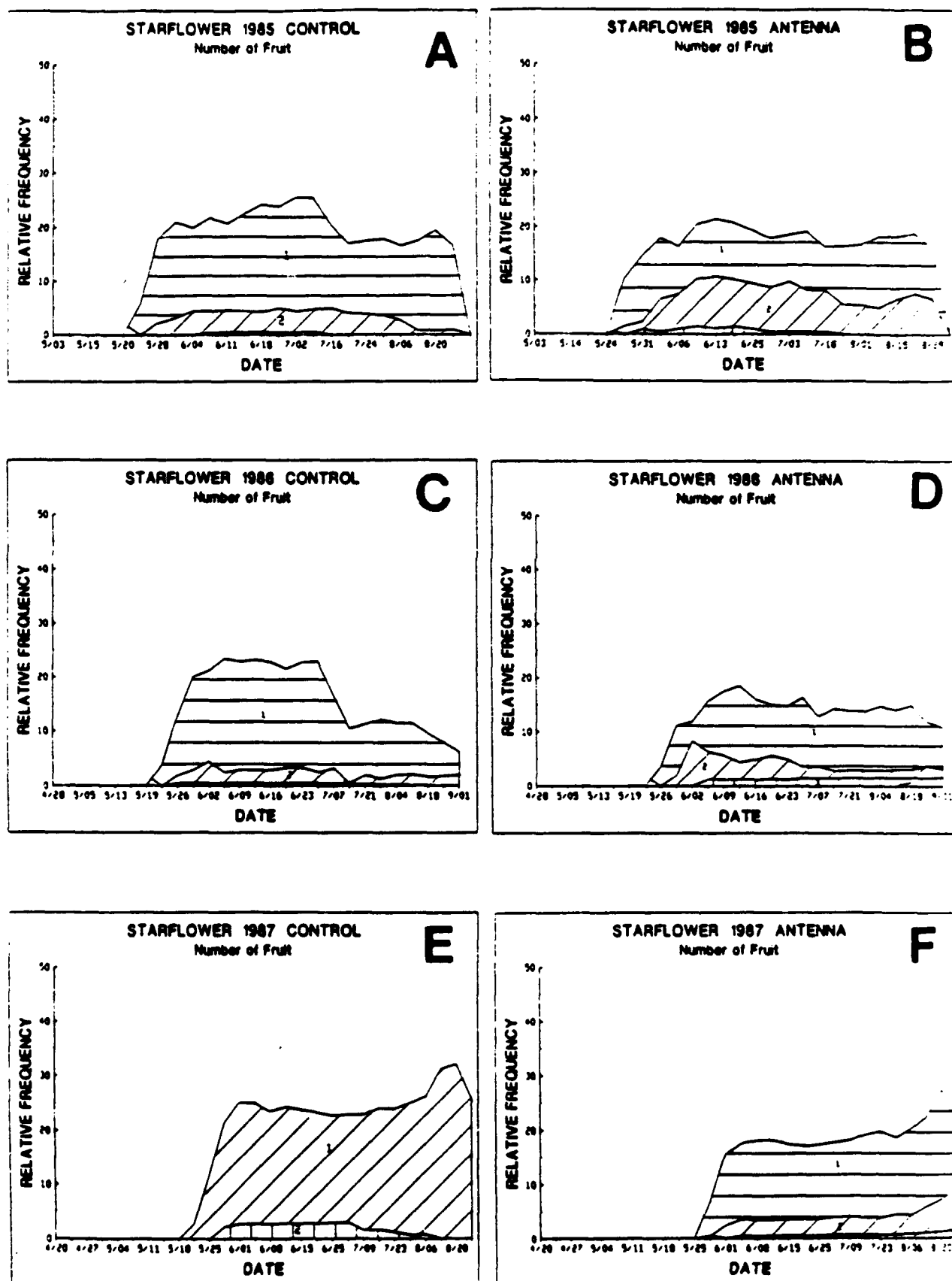
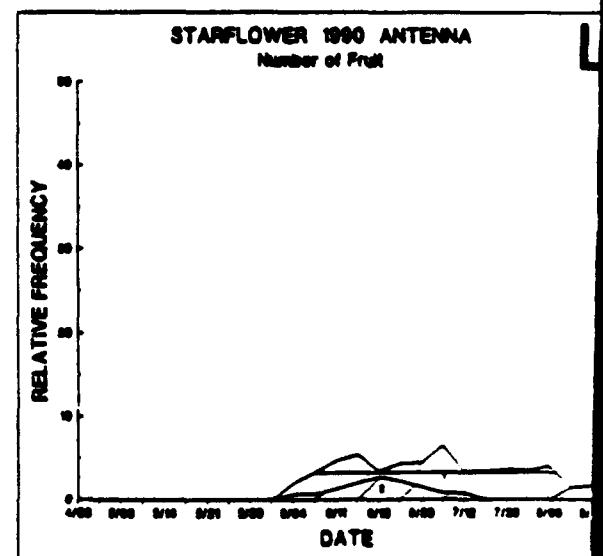
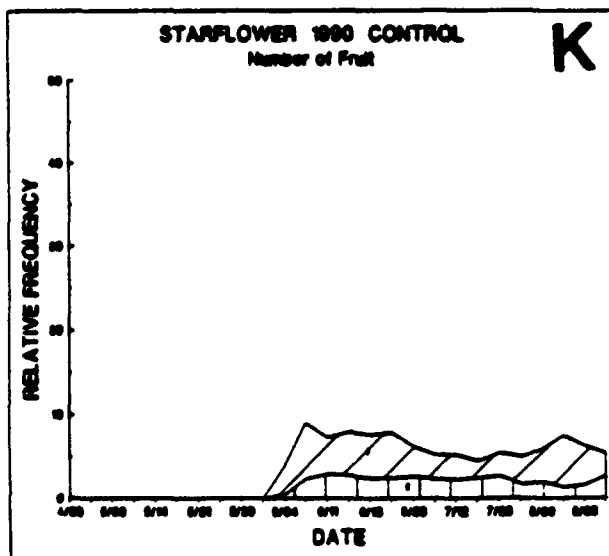
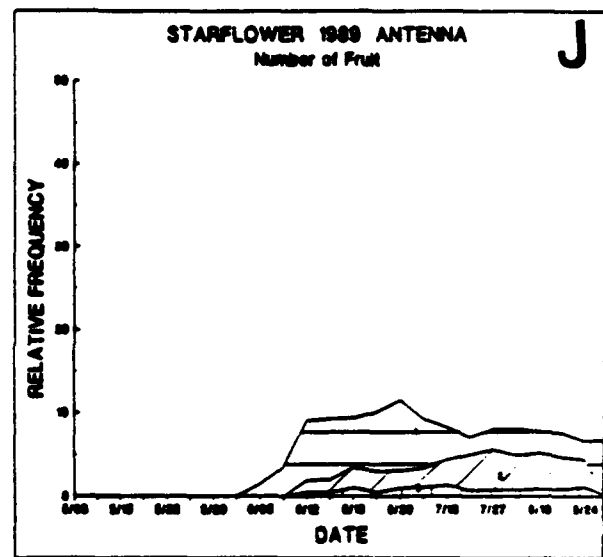
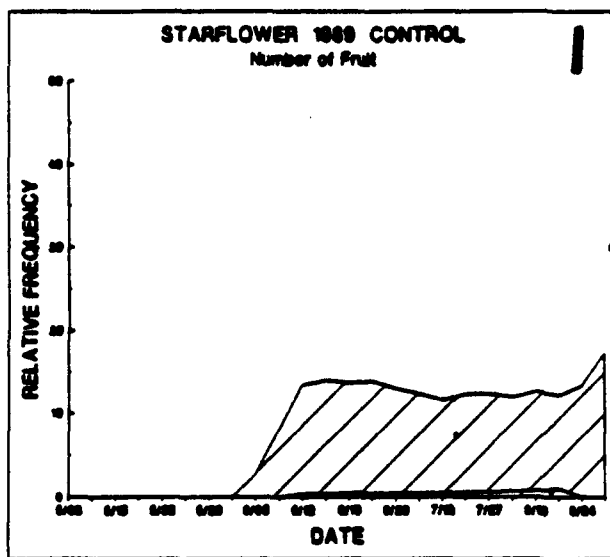
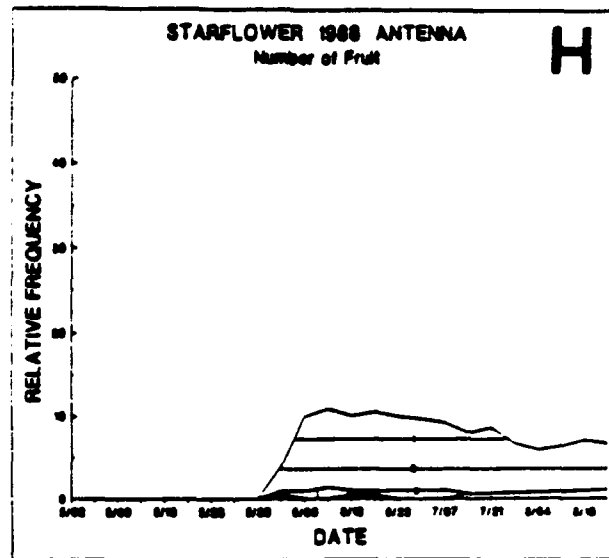
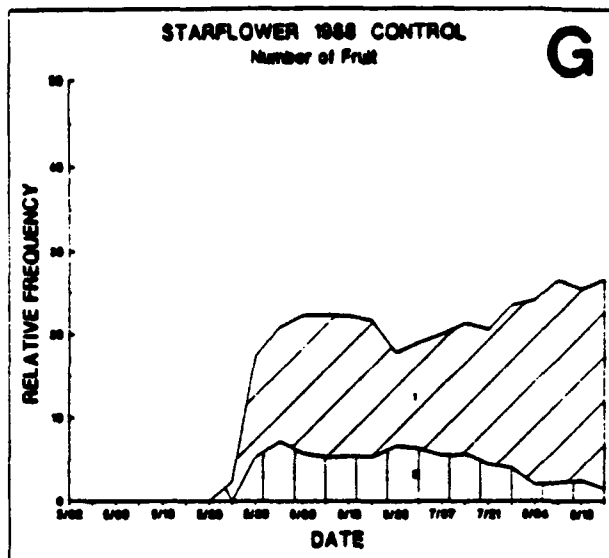


Figure 3.3: Relative frequency for number of plants with one or more fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N), and 1992 (P).





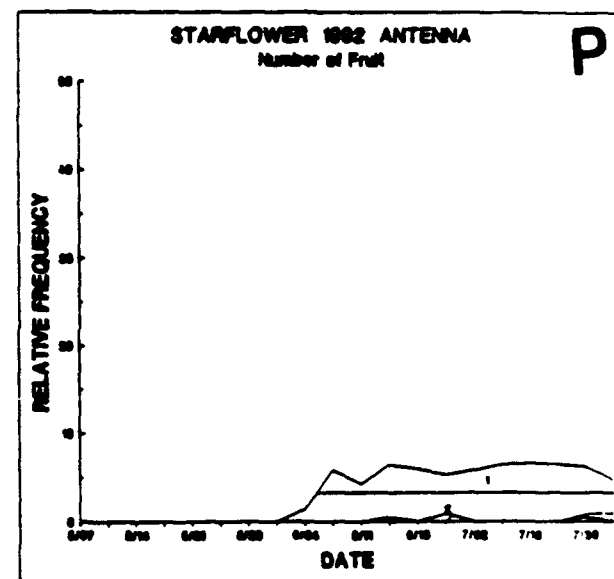
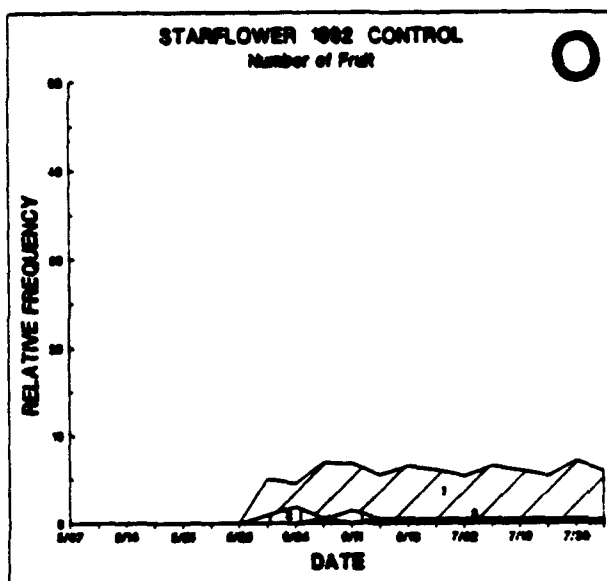
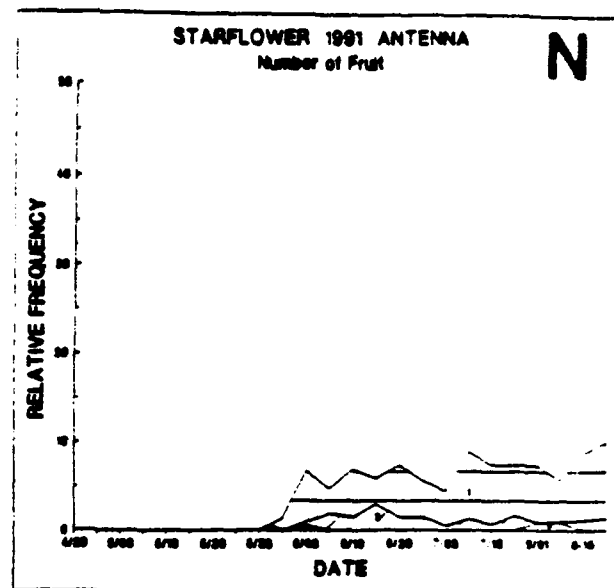
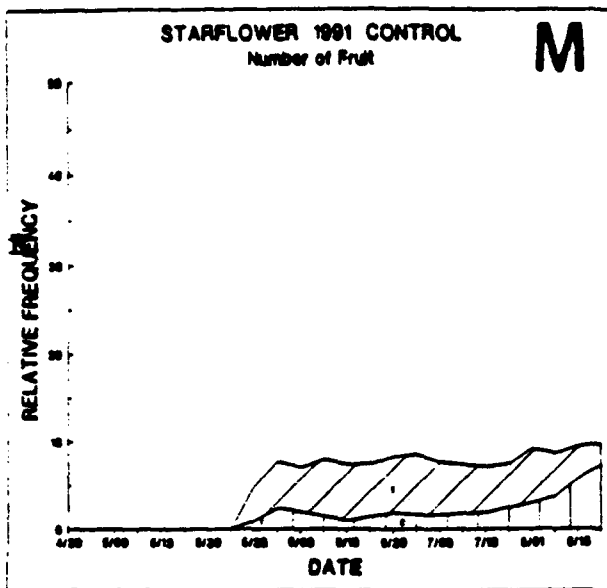
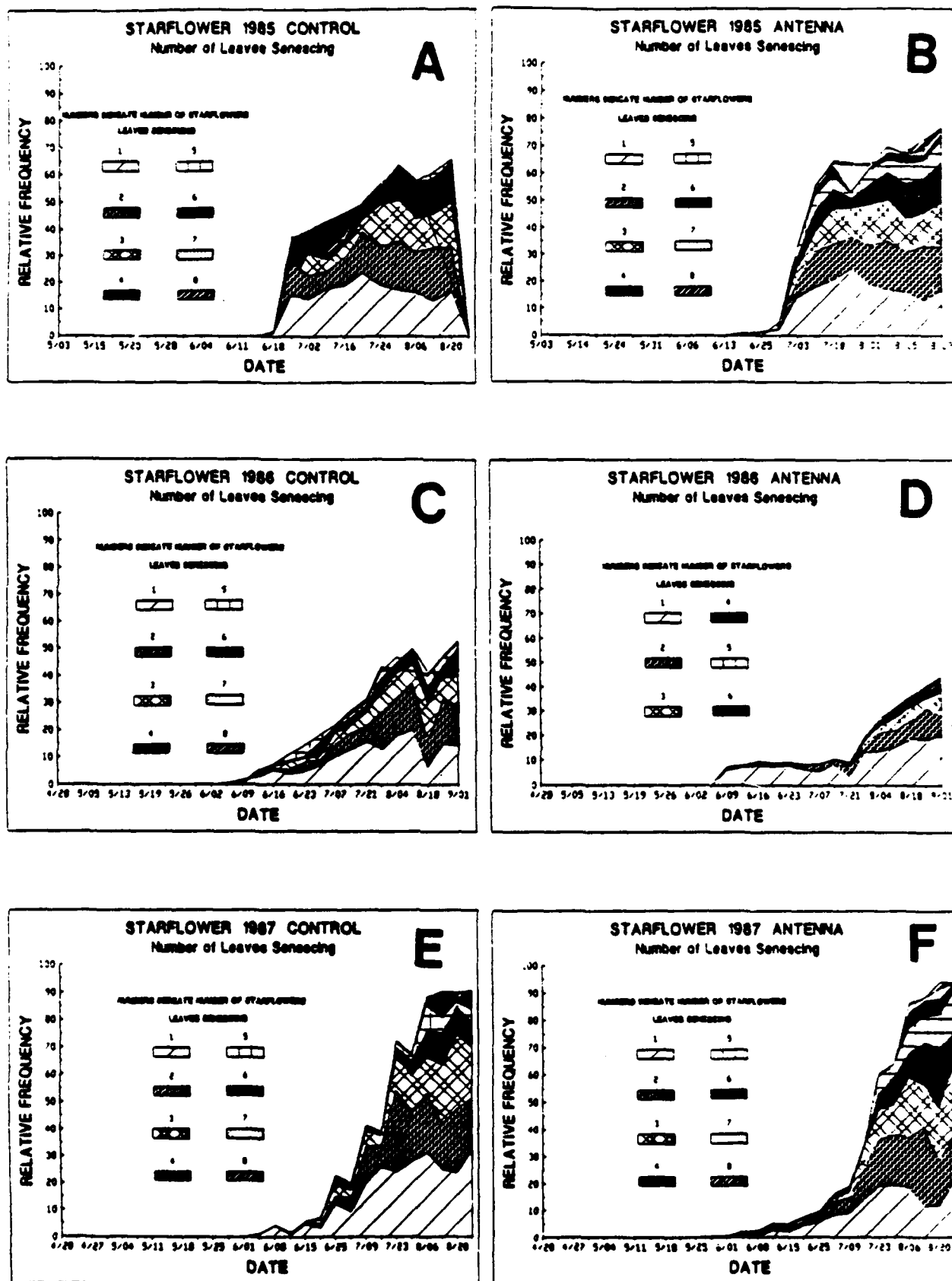
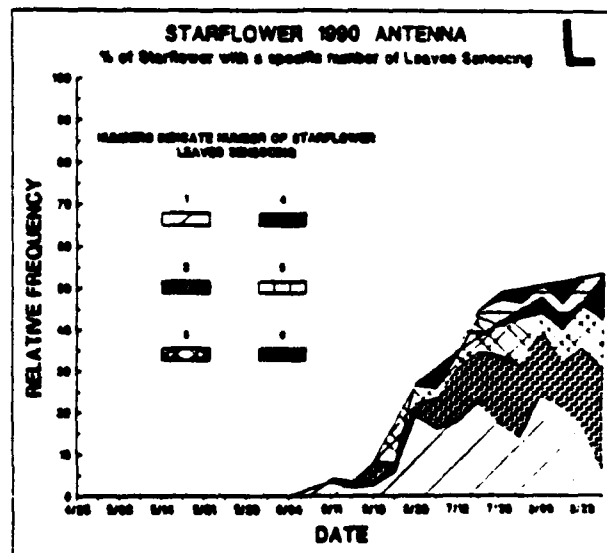
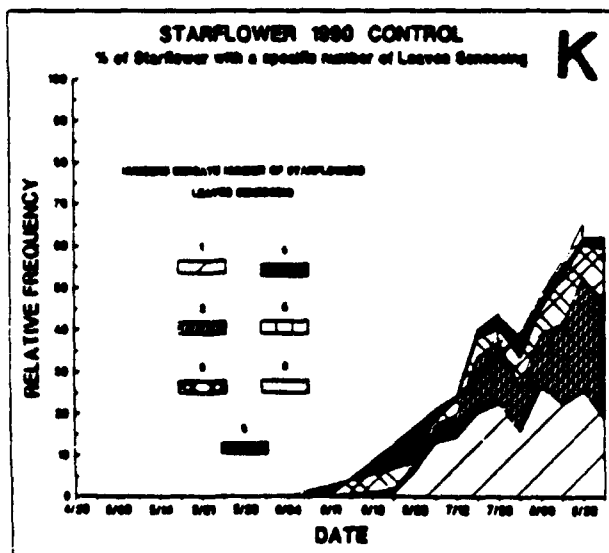
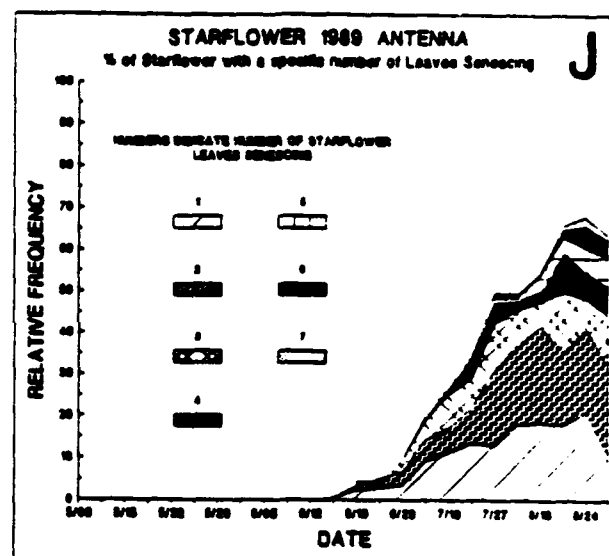
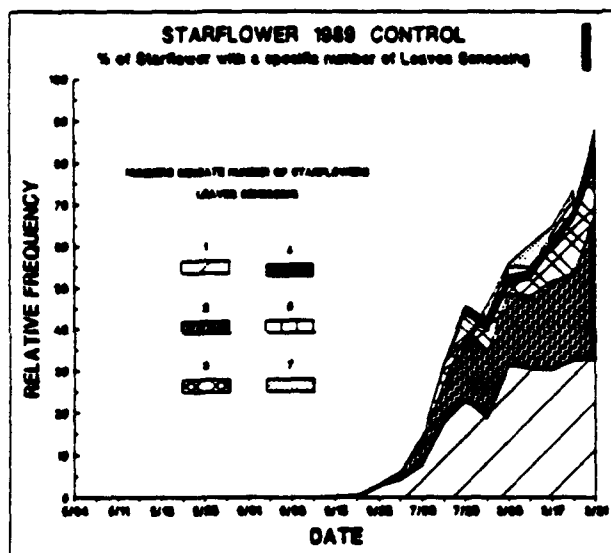
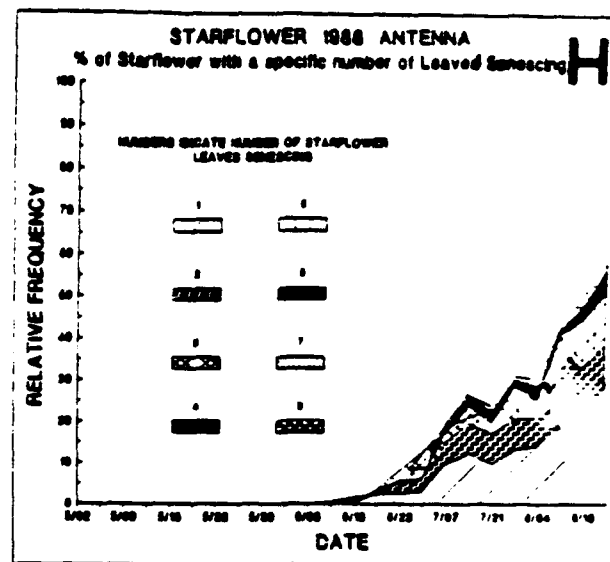
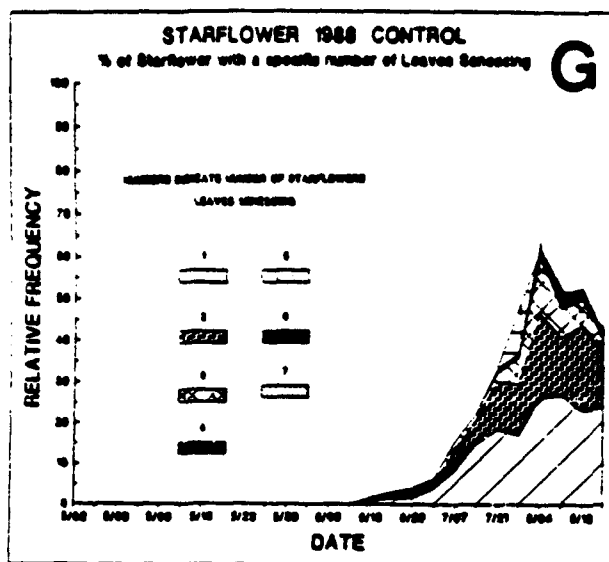


Figure 3.4: Relative frequency for number of plants with one or more leaves senescing by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N),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





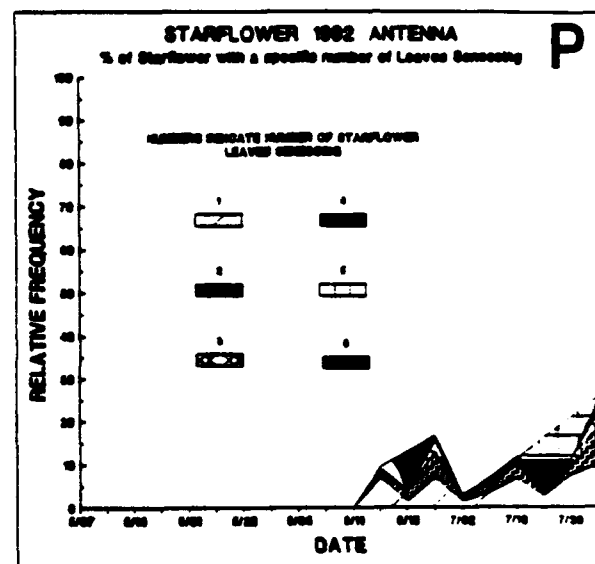
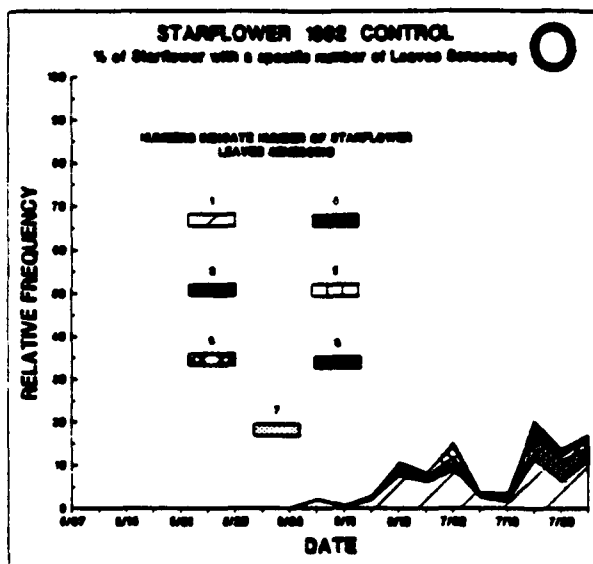
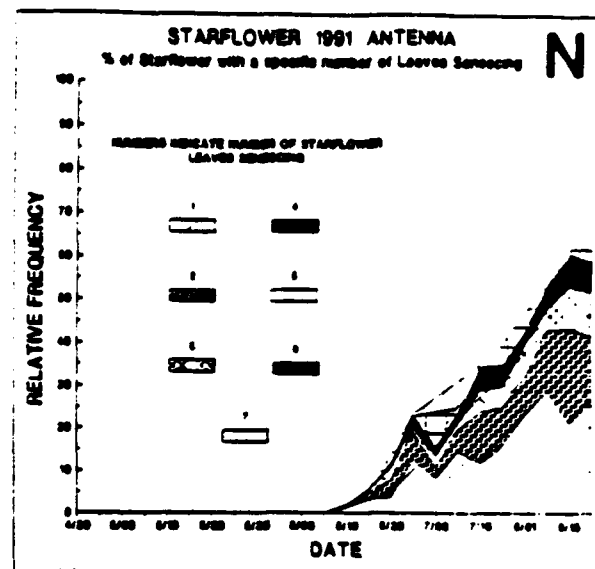
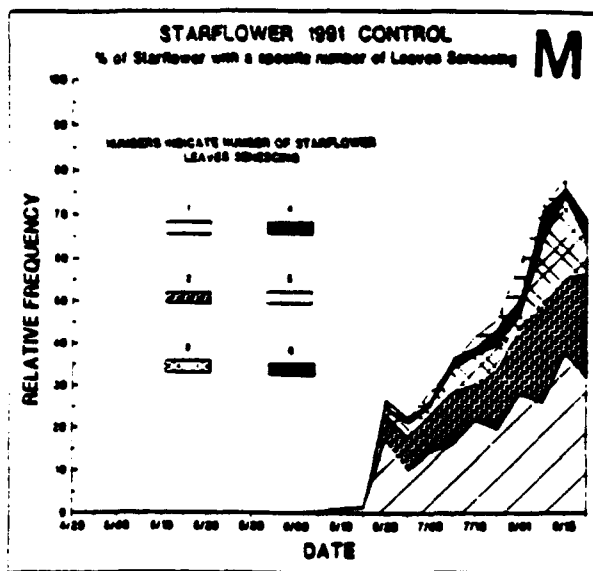
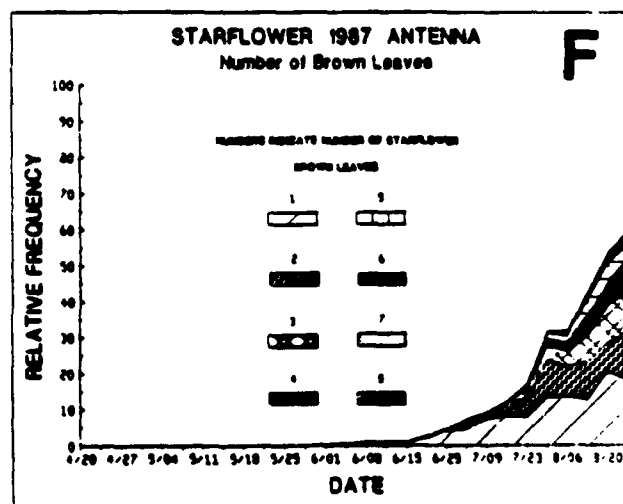
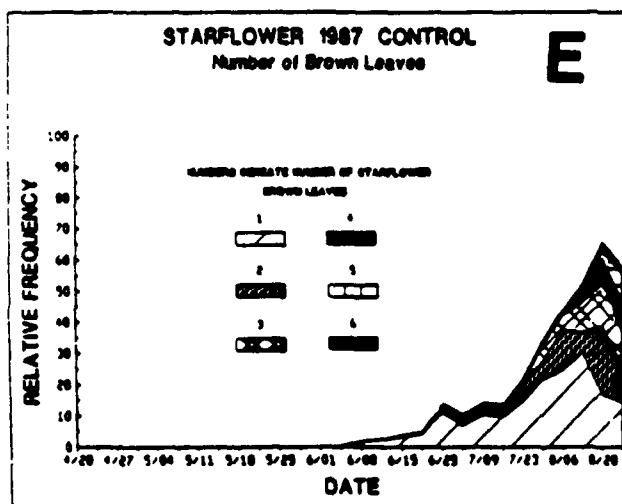
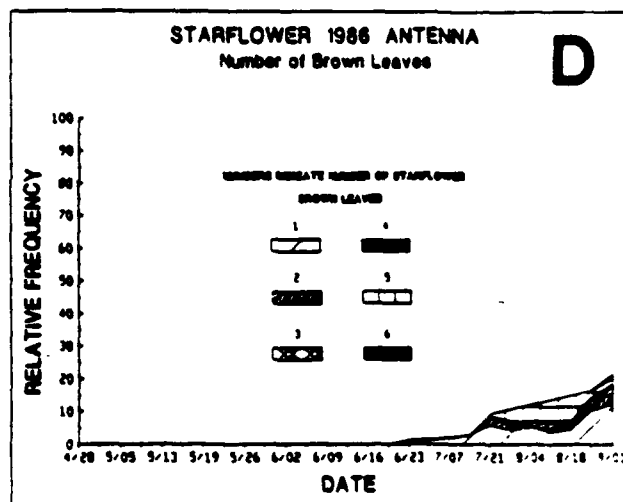
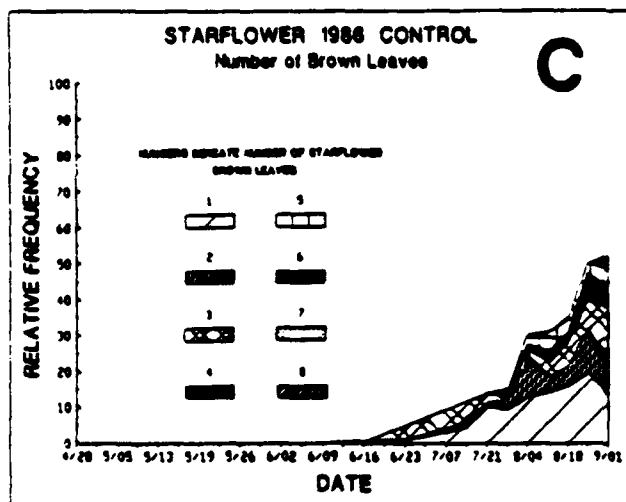
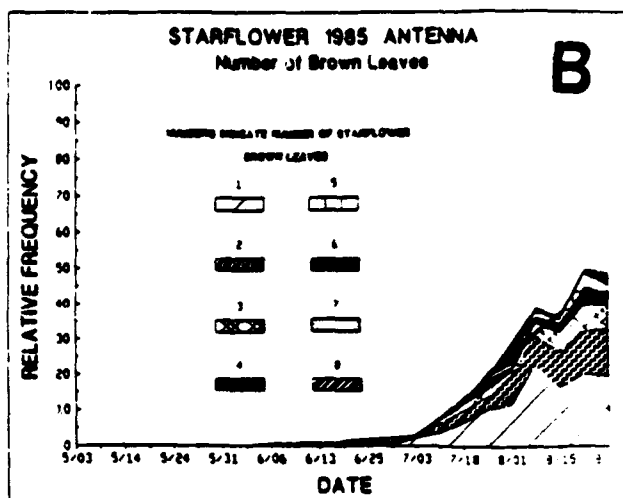
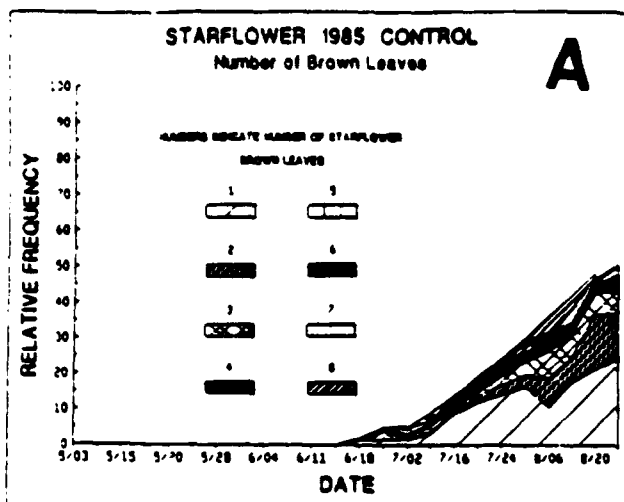
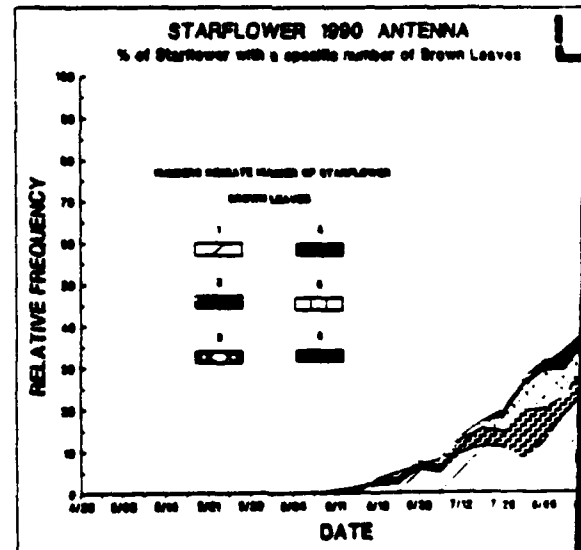
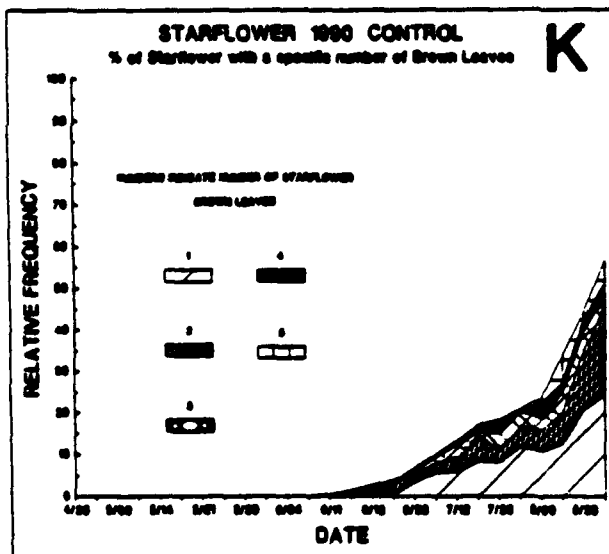
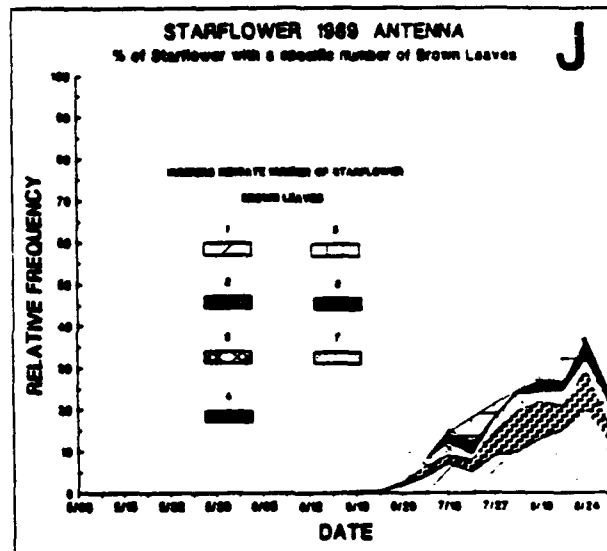
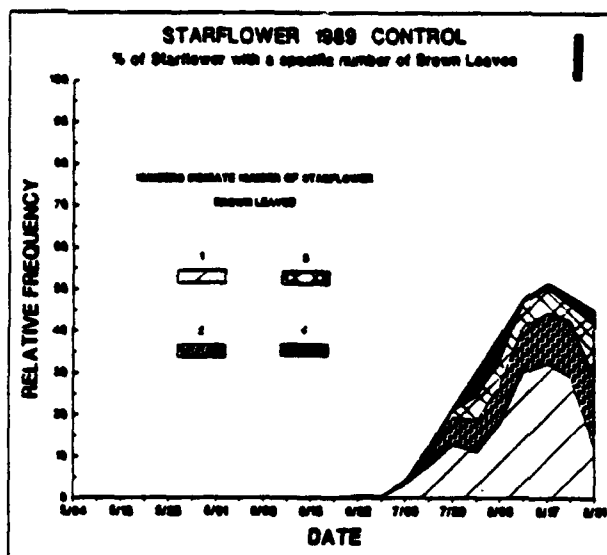
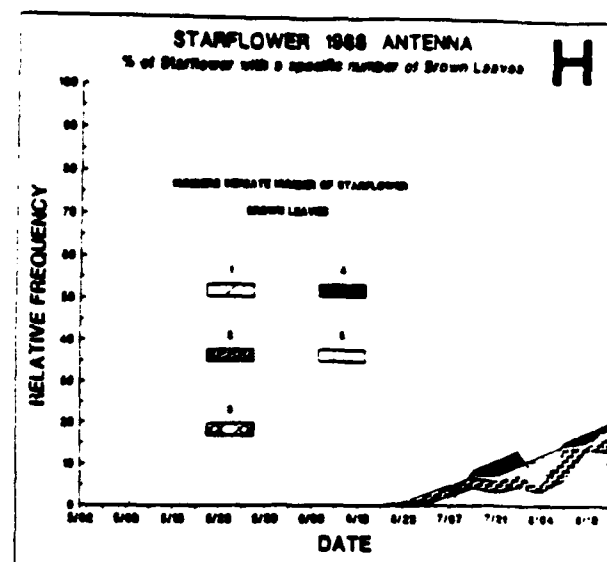
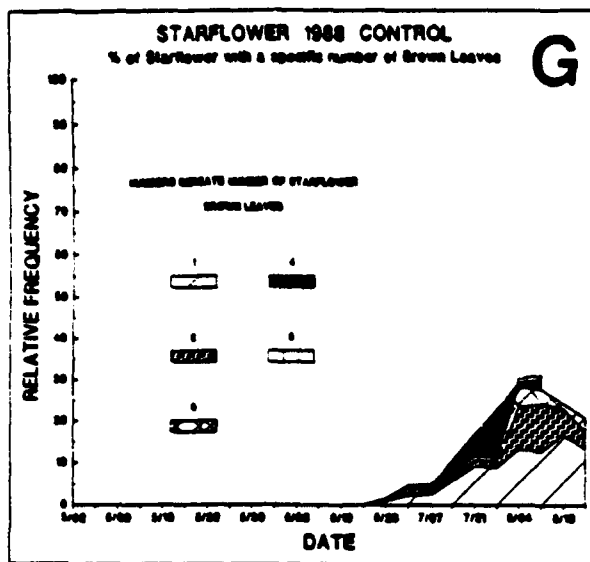


Figure 3.5: Relative frequency for number of plants with one or more brown leaves by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), 1991 (N), and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





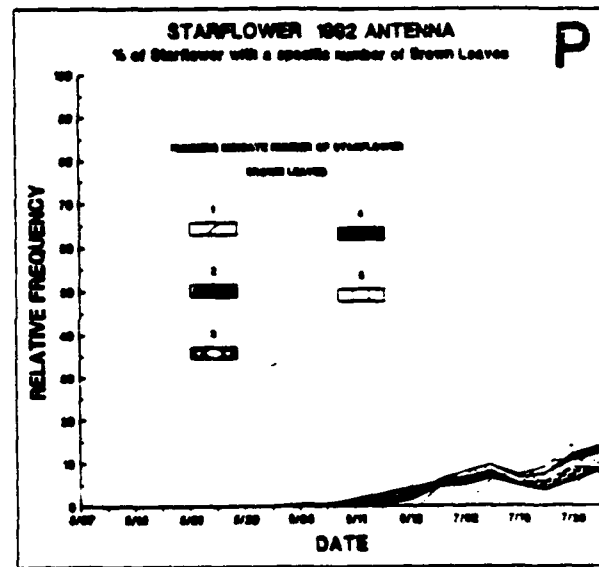
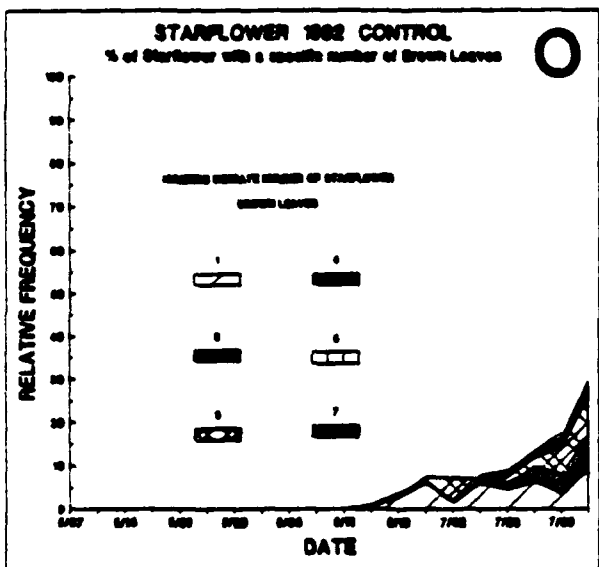
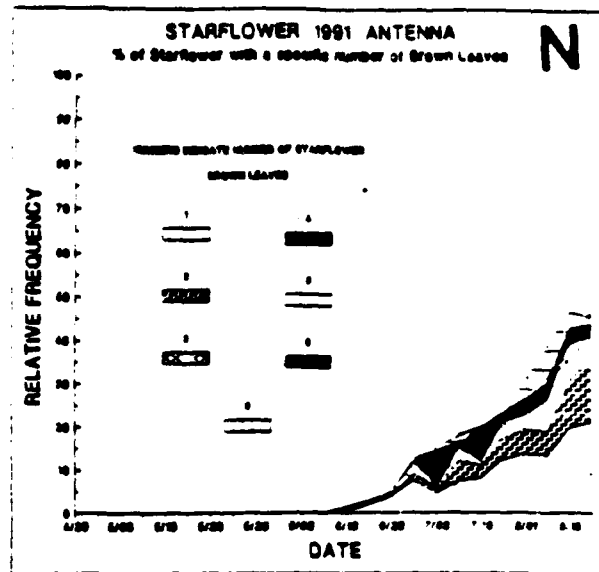
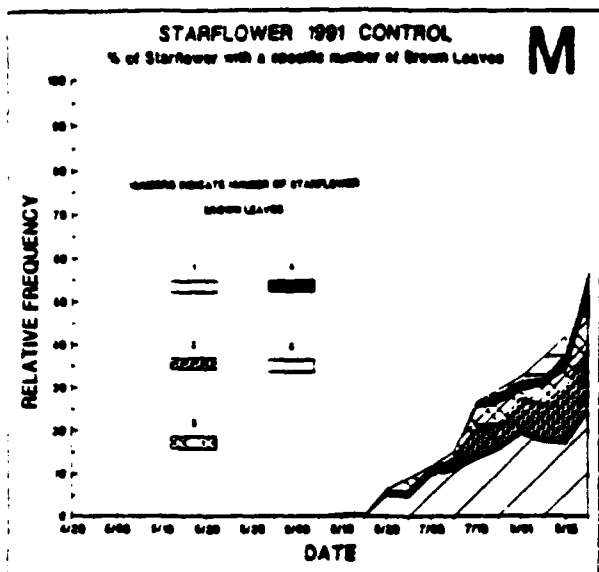
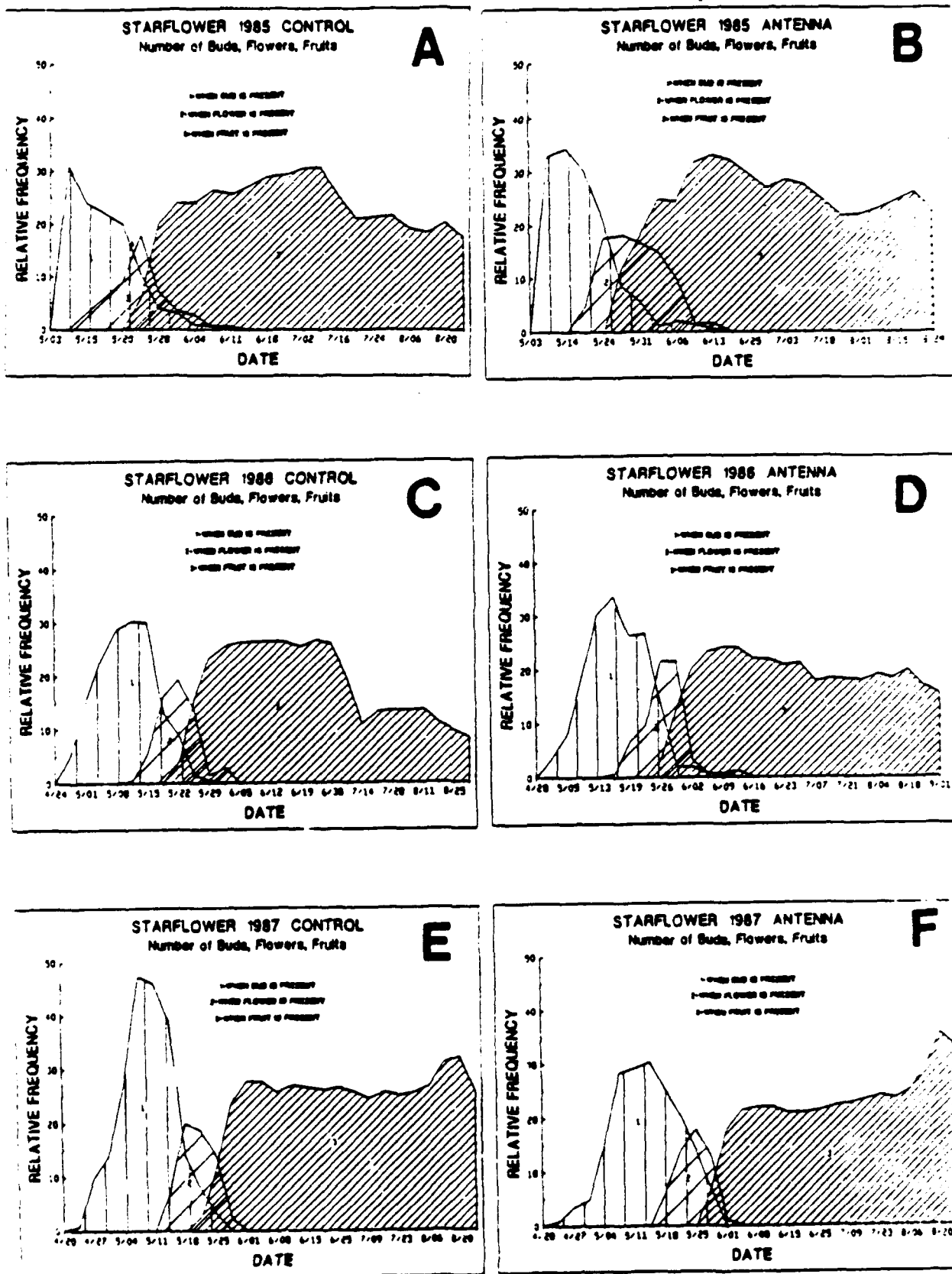
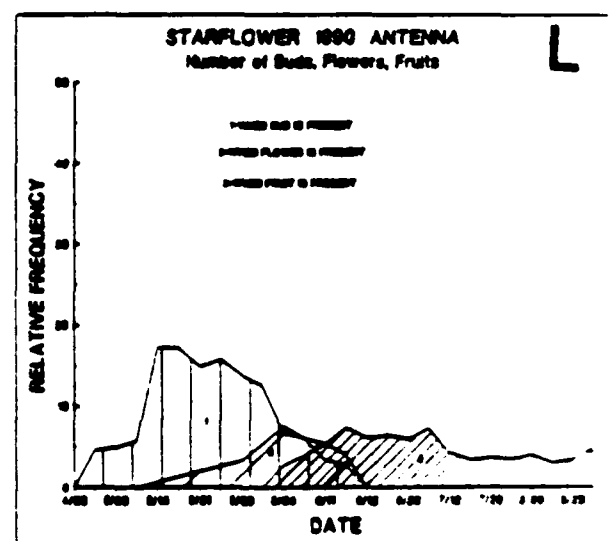
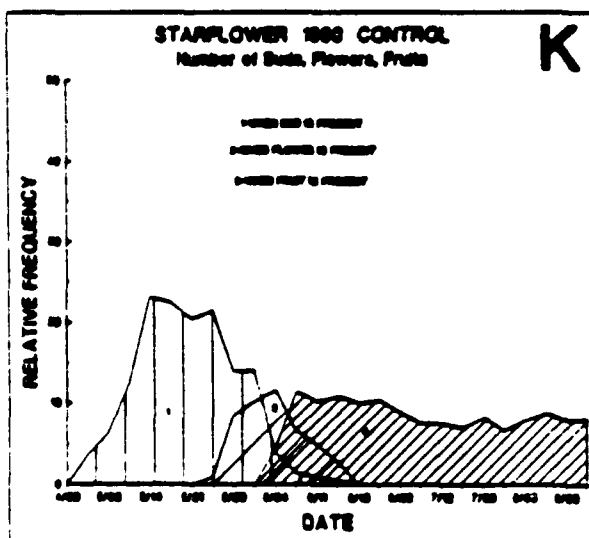
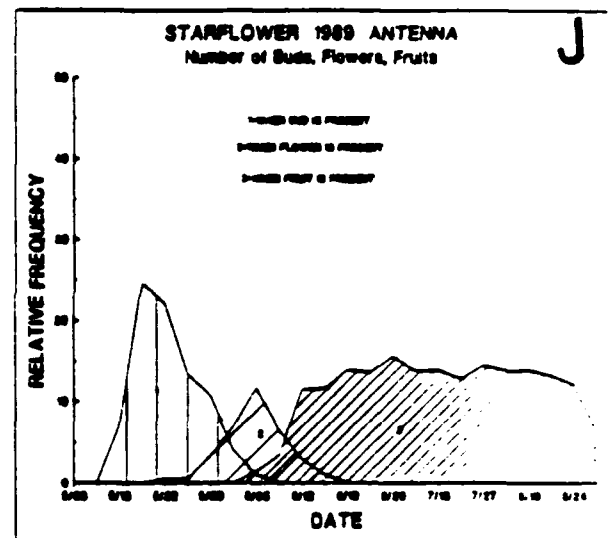
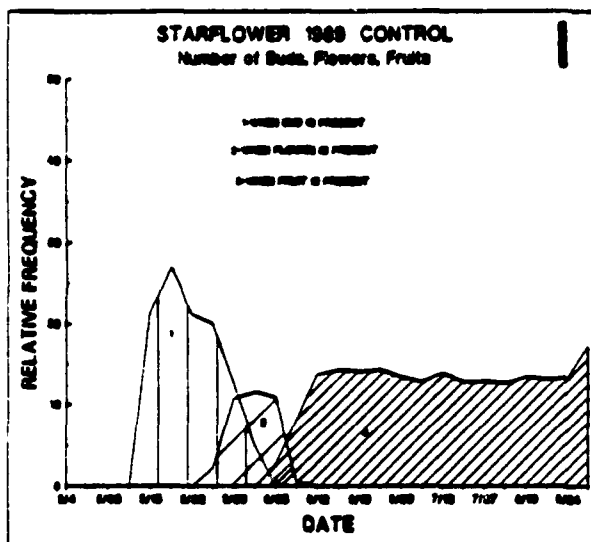
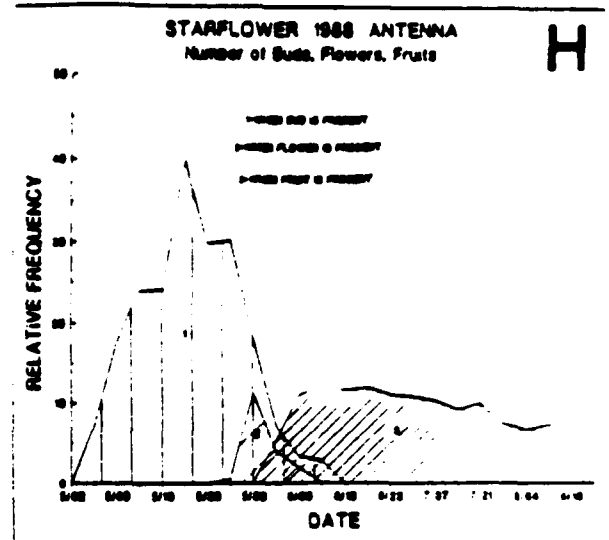
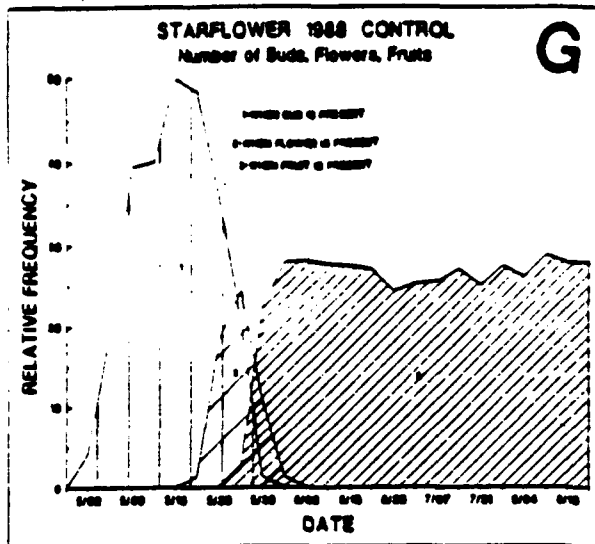
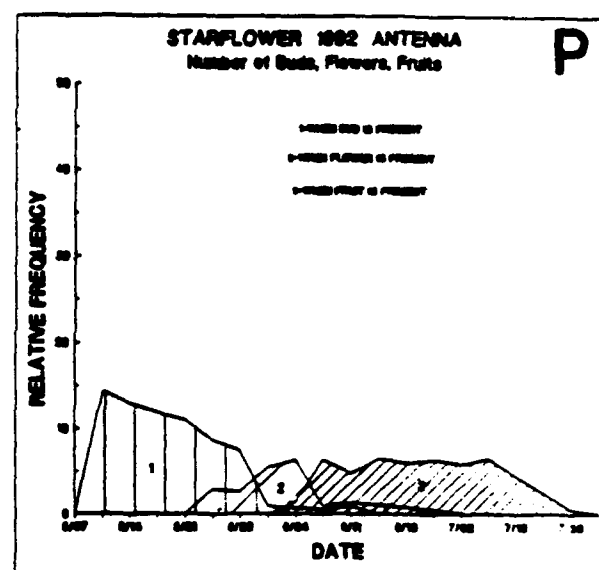
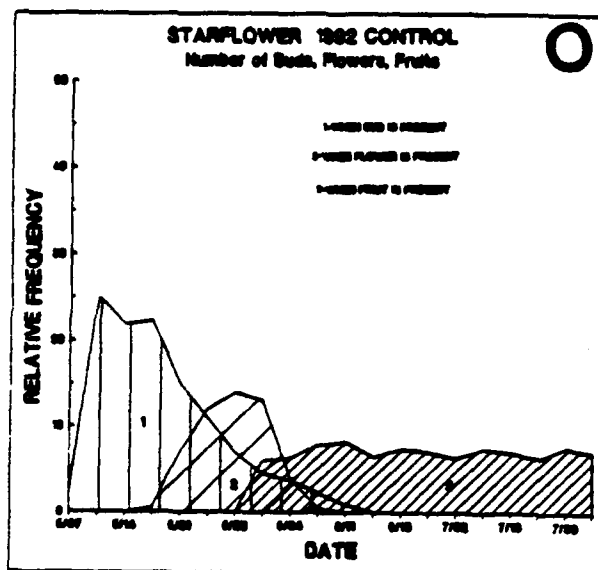
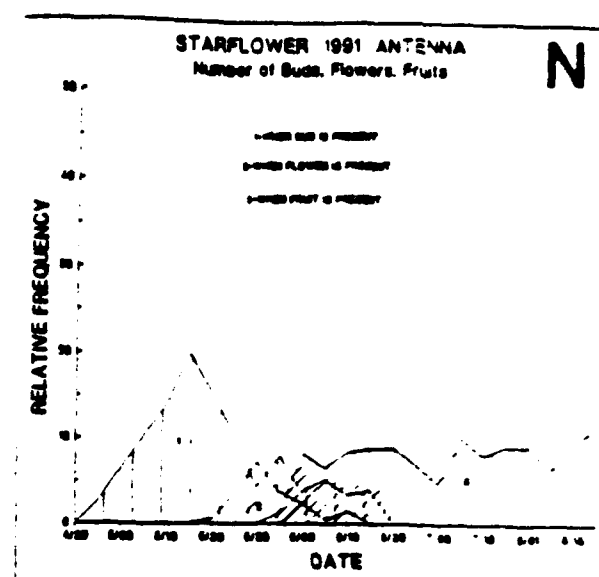
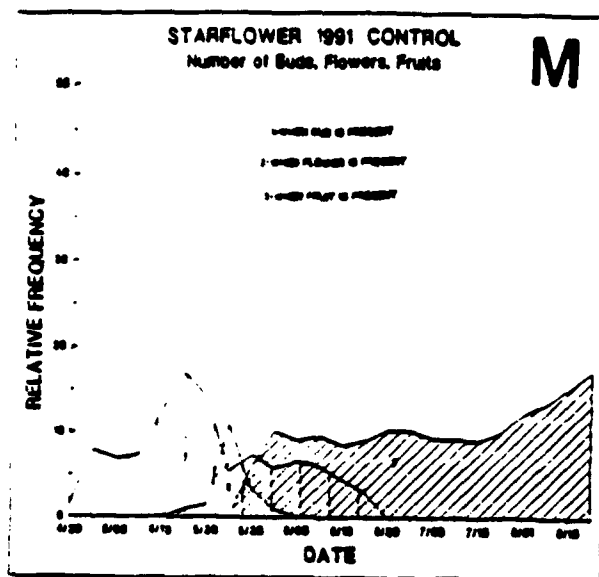


Figure 3.6: Comparison of the relative frequency and proportion of plants with one or more buds, flowers, and fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), 1991 (M), and 1992 (O); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H),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







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 (cm²/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.

<u>Source of Variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
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				
<u>Source of Variation</u>	<u>STEM</u>	<u>LGTH</u>	<u>LWTH</u>	<u>LAREA</u>
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.

<u>Source of Variation</u>	<u>STEM</u>	<u>LGTH</u>	<u>LWTH</u>	<u>LAREA</u>
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 3.30 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 3.40 and 3.4P). Reasons for this are unknown except that the climate from May to August was cold and rainy with intermittent 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 3.50 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

At this time, differences in the relationships of phenological events between the antenna and control sites cannot be discerned except in the proportion of plants flowering and the time at which flowering and fruiting begins relative to the time of peak numbers of plants with buds and flowers in 1990 and 1992. These differences were not evident in 1991. 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 are not significantly influencing starflower on the antenna site. A final report with interaction plots will be submitted in September, 1993.

To complete the analysis of the effect of extremely low frequency fields on starflower phenology and morphological characteristics, the following analyses will be included in the final report:

- A.) Quantitative analysis of number of buds, flowers, fruits, and leaves by year and site.

B.) Quantitative analysis of timing of bud, flowering, fruiting, and leaf expansion, senescing and brown leaves by site and year.

One of the things we have noticed over the length of this study is a possible decrease in the number of starflower plants on each subplot. Therefore, analysis of the change in number of plants on both sites and over the eight years of this study will also be analyzed.

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, Mejsstrik 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 μ m diameter, bearing clamps, setae scattered, often clustered in bunches of 4-8, mostly 50-80 μ m long; mantle 10-20 μ m 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 roots 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

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

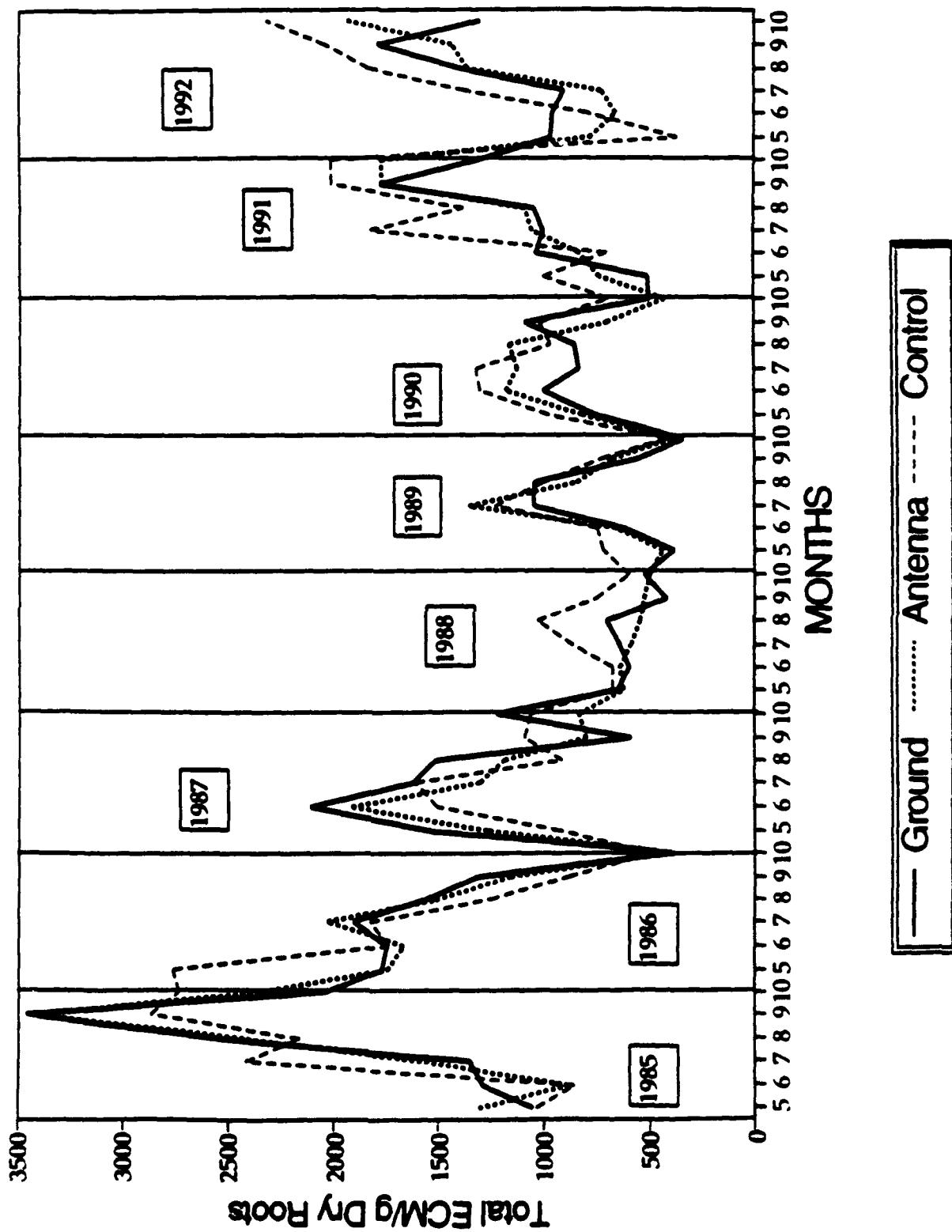
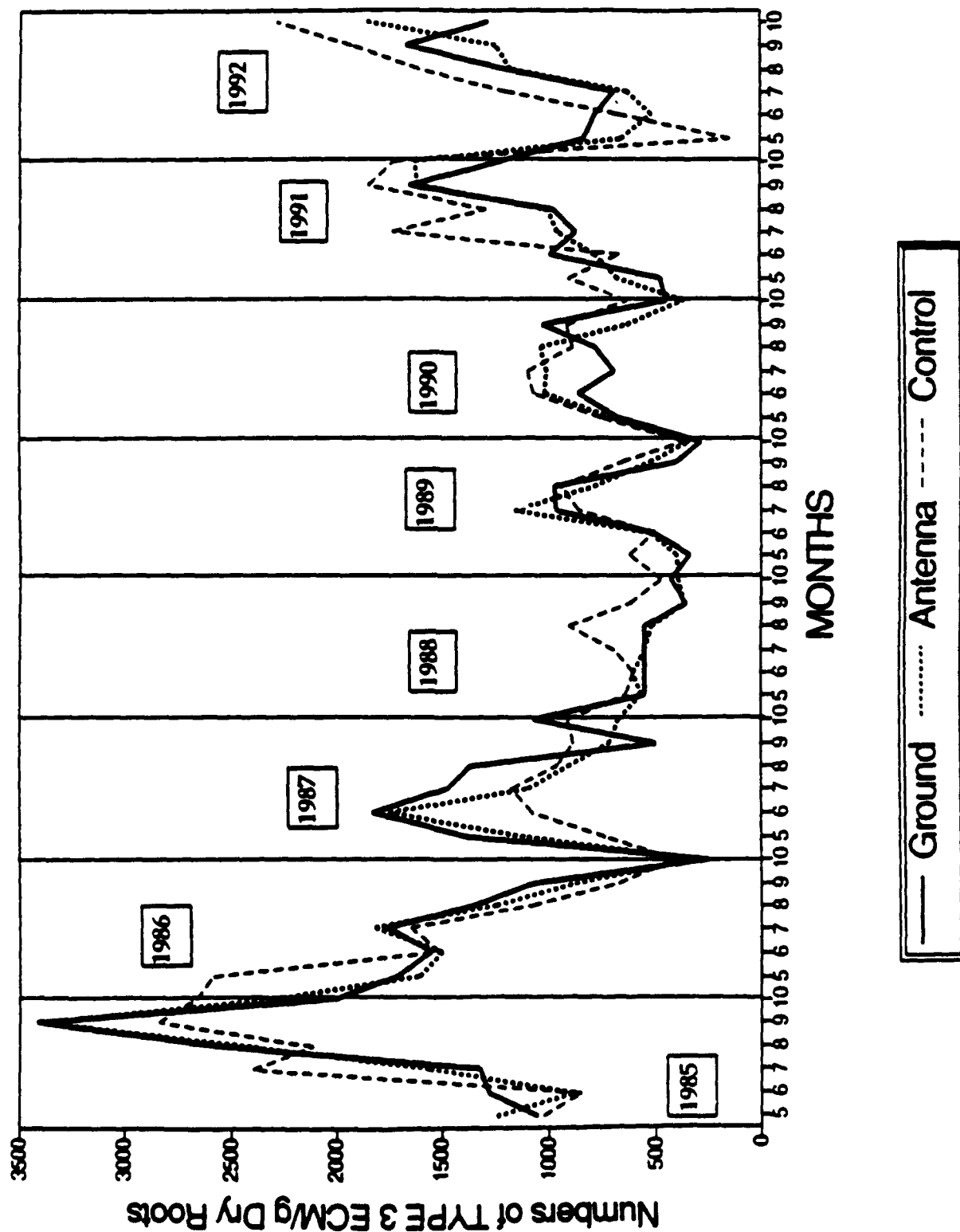


Figure 4.2: Yearly and monthly comparisons of the number of Type 3 mycorrhizal root tips (ECM) per gram of dry root.



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

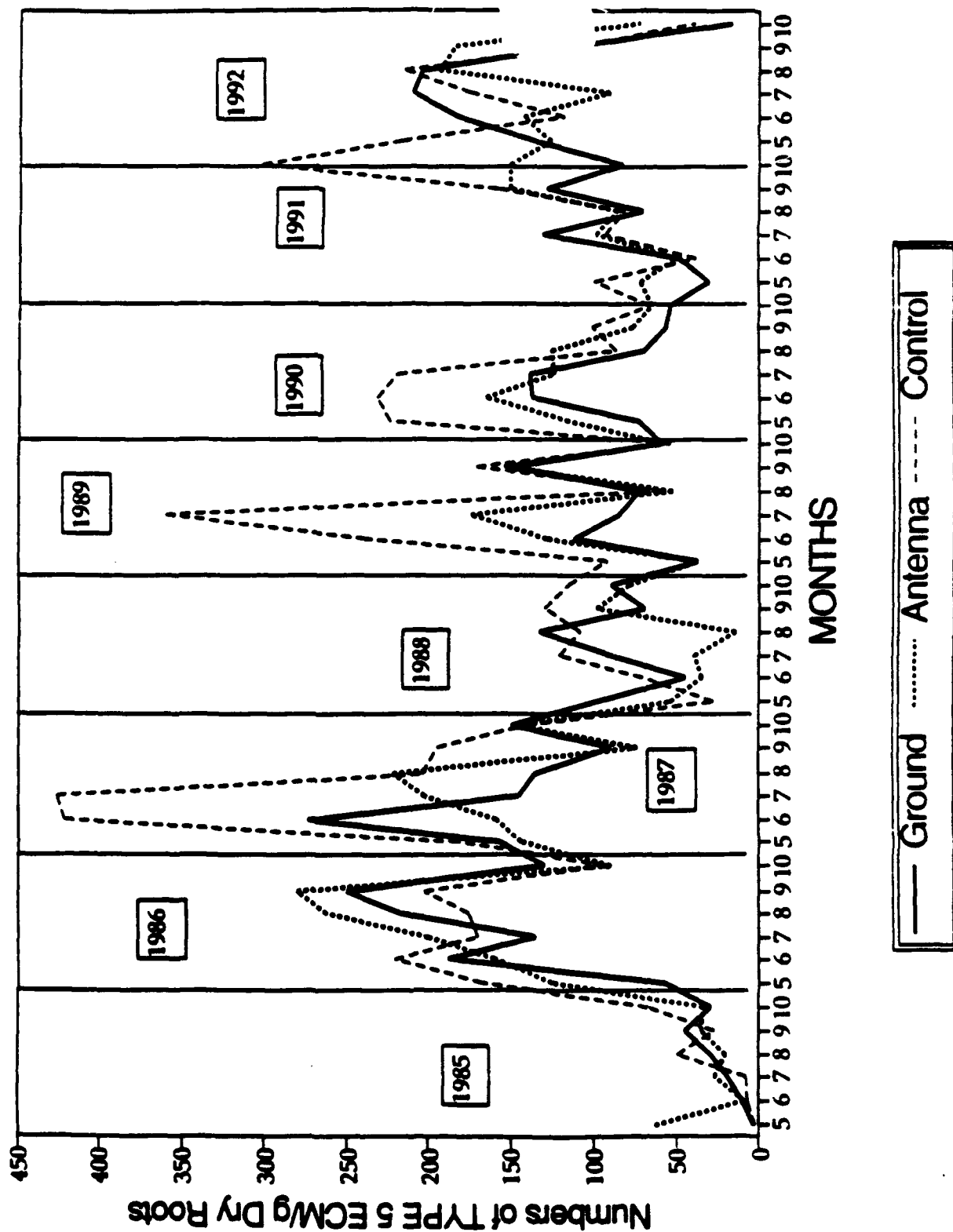
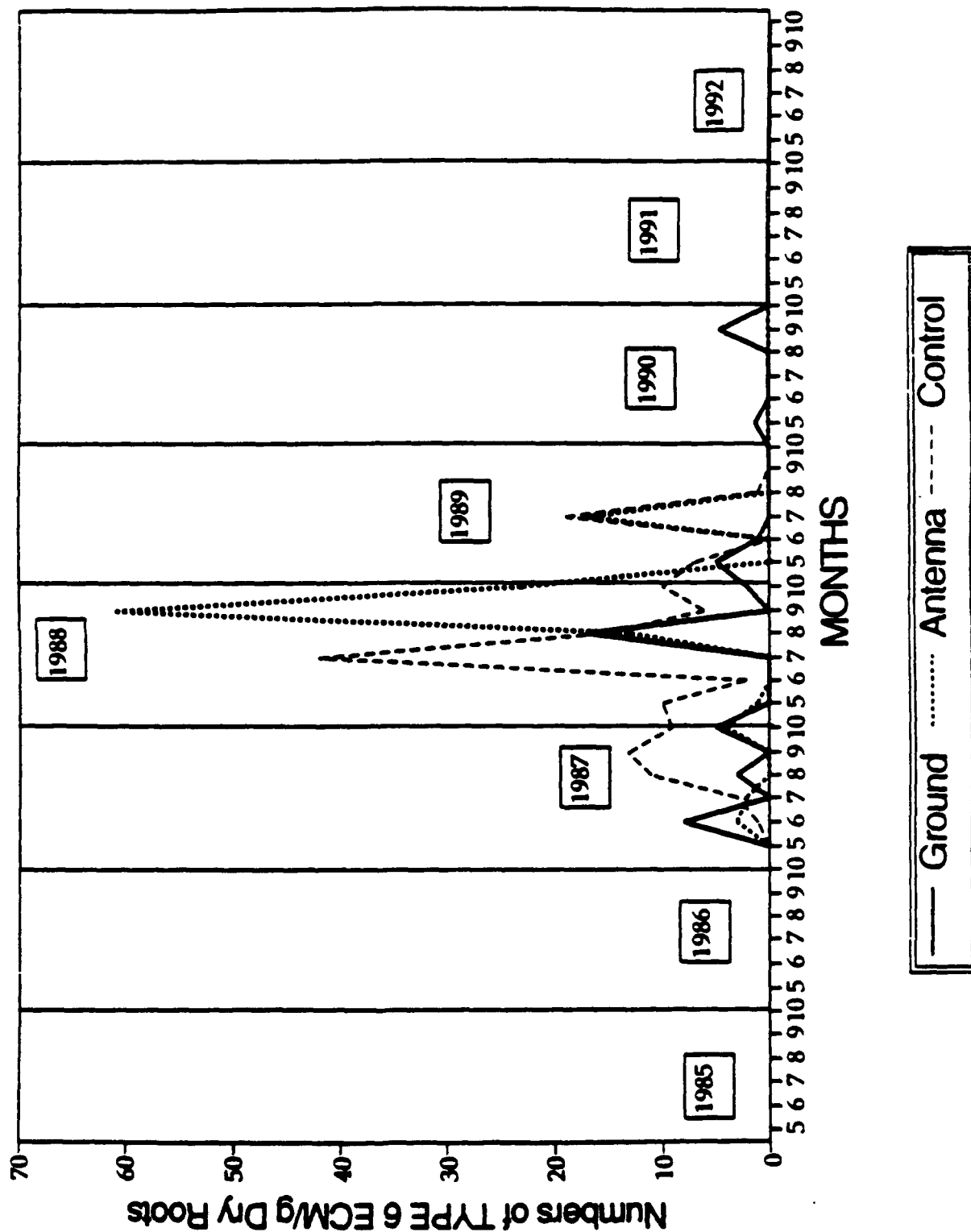


Figure 4.4: Yearly and monthly comparisons of the number of Type 6 mycorrhizal root tips (ECM) per gram of dry root.



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**
PRCDV=mean daily precipitation	.0505**
PRCMNDV=mean minimum daily precipitation	.0665**
PRCMXDV=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	.0261**
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.

<u>COVARIATE</u>	<u>SITE</u>	<u>YEAR</u>	<u>YEAR x SITE</u>
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 significant 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.

H₀: There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

H₀: 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 1m² meter litter traps are being used to monitor tree litter production on each permanent measurement 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 nutrients

<u>Source of Variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Plot	2	SS_P	MS_P	
$MS_P/MS_{E(S)}$				
Site	1	SS_S	MS_S	
$MS_S/MS_{E(S)}$				
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 m² 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.

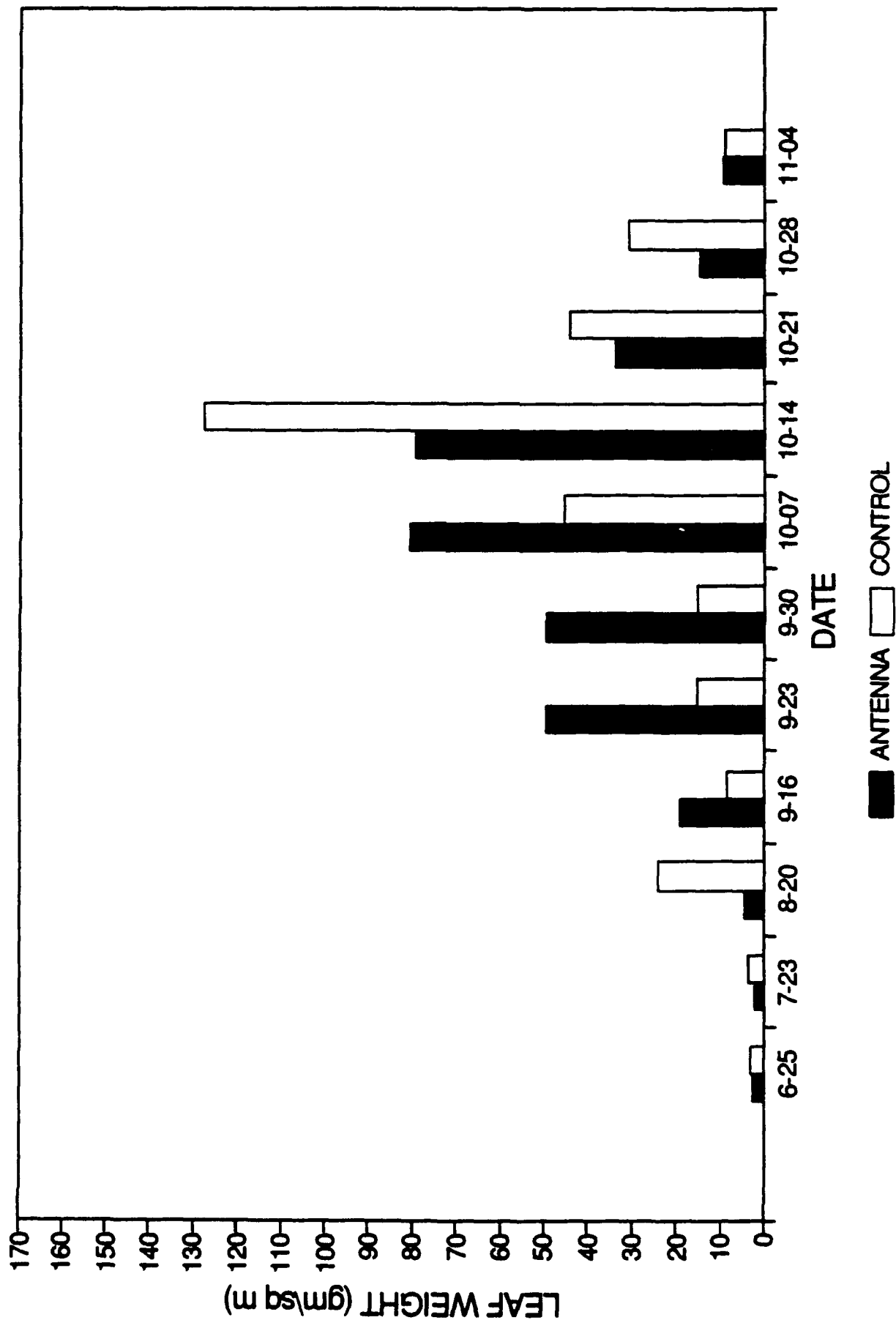
Progress

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

LEAF LITTER FALL 1992

Figure 5.1



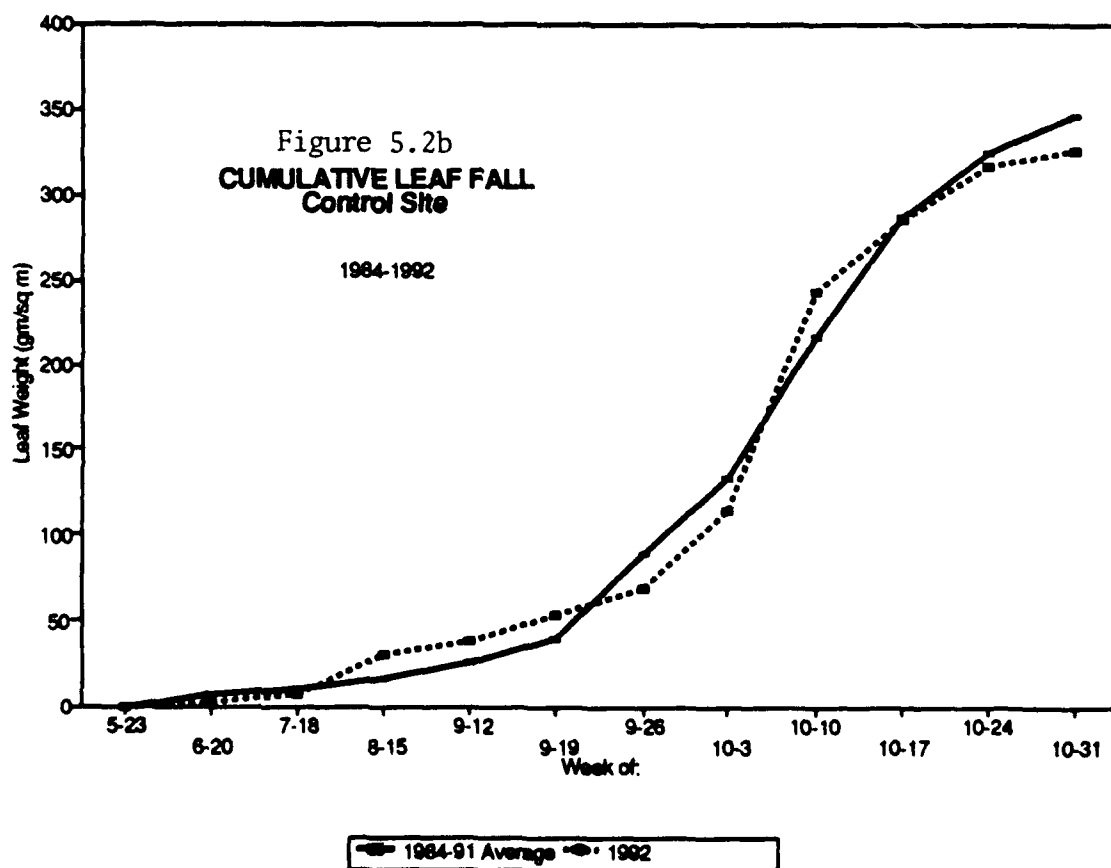
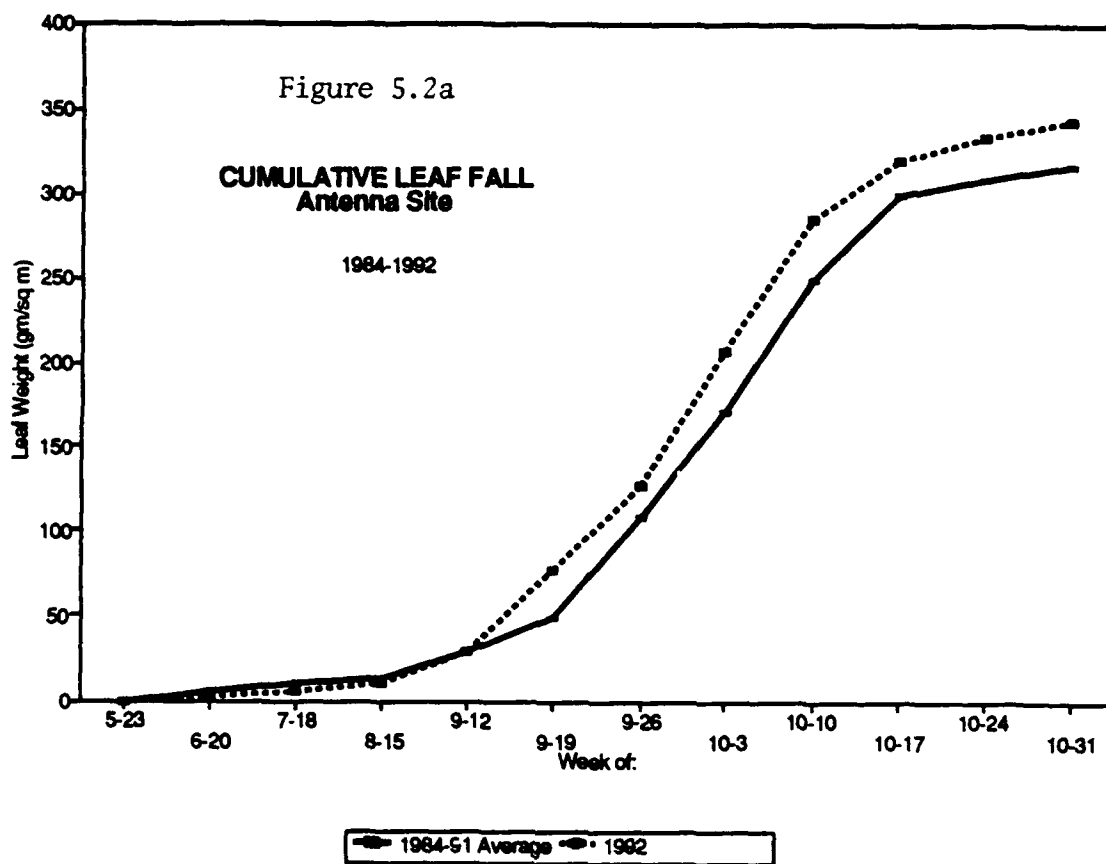


Table 5.2. Leaf litter fall by tree species at the antenna and control sites: 1985-1990.

Tree Species	Leaf Weight (g/m ²)					Σ of Total			
	1985	1986	1987	1988	1989	1990	1991	1985-1990	1991
Antenna									
Red Maple	135	147	142	143	127	103	129	43	37
Red Oak	93	120	105	116	95	71	132	32	38
B. Aspen	45	52	46	56	18	32	59	14	17
Q. Aspen	1	1	2	3	2	1	3	<1	1
P. Birch	25	21	25	28	28	24	21	8	6
Red Pine	1	1	2	2	2	1	1	<1	<1
Control									
Red Maple	42	55	47	41	48	41	49	15	13
Red Oak	227	266	208	230	223	184	293	70	78
B. Aspen	14	17	13	12	16	17	16	5	5
Q. Aspen	11	9	8	13	10	3	7	3	2
P. Birch	19	22	26	26	20	13	9	7	2
Red Pine	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 1991 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 significant 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

Covariate	<u>Litter Component</u> *		
	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, and 1991 (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 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 showed there were no significant site x year interactions for any foliage nutrient (Table 5.16). Nutrient detection limits for red oak foliage were quite good (under fifteen 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: 1985-1991

	<u>Antenna</u>		<u>Control</u>	
	1985-1990 (Average)	1991	1985-1990 (Average)	1991
	----- (kg/ha) -----			
Foliage				
N	23.3	25.8	24.0	26.1
P	4.6	3.8	6.2	4.2
K	11.1	13.0	14.7	16.0
Ca	35.8	45.8	39.6	48.8
Mg	5.8	5.5	6.0	5.5
Wood				
N	2.3	1.8	3.1	2.7
P	0.3	0.2	0.4	0.3
K	0.6	0.6	1.0	0.9
Ca	4.8	4.0	7.6	6.2
Mg	0.3	0.2	0.5	0.4
Miscellaneous				
N	6.3	3.1	5.0	2.3
P	0.7	0.2	0.6	0.1
K	2.1	0.7	1.9	0.6
Ca	3.6	2.9	4.3	2.9
Mg	0.5	0.2	0.4	0.2
Total				
N	31.9	30.7	32.1	31.1
P	5.5	4.2	7.2	4.6
K	13.8	14.3	17.6	17.5
Ca	44.3	52.6	51.4	58.0
Mg	6.6	5.9	6.9	6.0

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: 1985-1991

	<u>Antenna</u>	<u>Control</u>
	----- (%) -----	
Foliage		
N	0.72 (0.13)	0.69 (0.09)
P	0.14 (0.03)	0.17 (0.08)
K	0.35 (0.08)	0.42 (0.07)
Ca	1.12 (0.18)	1.14 (0.14)
Mg	0.18 (0.03)	0.17 (0.02)
Wood		
N	0.45 (0.12)	0.49 (0.13)
P	0.05 (0.01)	0.06 (0.01)
K	0.11 (0.04)	0.15 (0.05)
Ca	0.95 (0.22)	1.19 (0.27)
Mg	0.06 (0.01)	0.07 (0.01)
Miscellaneous		
N	1.13 (0.25)	1.01 (0.19)
P	0.12 (0.03)	0.13 (0.05)
K	0.38 (0.16)	0.39 (0.19)
Ca	0.65 (0.25)	0.87 (0.43)
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: 1985-1991

	<u>Antenna</u>	<u>Control</u>
	----- (%) -----	
Northern Red Oak		
N	0.72 (0.15)	0.65 (0.08)
P	0.13 (0.02)	0.17 (0.09)
K	0.33 (0.07)	0.39 (0.06)
Ca	1.01 (0.13)	1.07 (0.15)
Mg	0.12 (0.01)	0.15 (0.02)
Paper Birch		
N	0.82 (0.15)	0.81 (0.10)
P	0.17 (0.05)	0.18 (0.03)
K	0.42 (0.08)	0.55 (0.14)
Ca	1.44 (0.22)	1.24 (0.24)
Mg	0.27 (0.04)	0.28 (0.03)
Big Toothed Aspen		
N	0.82 (0.12)	0.72 (0.14)
P	0.13 (0.06)	0.15 (0.05)
K	0.36 (0.11)	0.48 (0.11)
Ca	1.36 (0.24)	1.52 (0.26)
Mg	0.26 (0.03)	0.21 (0.03)
Red Maple		
N	0.47 (0.06)	0.49 (0.10)
P	0.17 (0.04)	0.18 (0.02)
K	0.26 (0.09)	0.35 (0.09)
Ca	1.09 (0.12)	1.24 (0.17)
Mg	0.19 (0.02)	0.20 (0.02)

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: 1985-1991

	N	P	K	Ca	Mg
	-----p value-----				
<u>Leaf</u>	(ak) *	(cdk)	(dei) --	(k)	(acj)
Site	.776	.108	.629	.439	.788
Year	.008	.004	.000	.000	.125
Year x Site	.598	.001	.418	.509	.677

<u>Wood</u>	(af)	(o)	(dei)	(dj)	(cd)
Site	.307	.922	.637	.714	.229
Year	.001	.424	.003	.001	.059
Year x Site	.850	.772	.764	.095	.286

<u>Miscellaneous</u>	(l)	(acq)	(w)	(cjw)	(mu)
Site	.569	.327	.407	.937	.847
Year	.005	.000	.000	.000	.000
Year x Site	.025	.001	.001	.002	.047

*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: 1985-1991

	N	P	K	Ca	Mg
	-----p value-----				
Northern Red Oak	(ai)	(dk)	(ej)	(k)	(bi)
Site	.722	.576	.963	.929	.671
Year	.026	.117	.003	.000	.000
Year x Site	.854	.581	.935	.027.	.001

Hazelnut and Paper Birch	(x)	(w)	(i)	(gk)	(j)
Site	.812	.312	.989	.864	.596
Year	.001	.000	.000	.000	.092
Year x Site	.922	.002	.002	.044	.158

Big Toothed Aspen	(qy)	(qo)	(gk)	(fh)	(cy)
Site	.594	.930	.411	.569	.682
Year	.000	.000	.136	.000	.068
Year x Site	.001	.003	.113	.653	.076

Red Maple	(cj)	(e)	(sy)	(hi)	(gk)
Site	.630	.824	.848	.525	.398
Year	.000	.000	.000	.000	.000
Year x Site	.025	.000	.080	.013	.346

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

Table 5.13. Detection limits for litter nutrient concentrations by component: 1985-1991

<u>Component</u>	<u>Site</u>		<u>Year</u>		<u>Y x S</u>	
	<u>ppm</u>	<u>% of mean</u>	<u>ppm</u>	<u>% of mean</u>	<u>ppm</u>	<u>% of mean</u>
<u>Leaf</u>						
Ca	1737	15.4	1117	9.9	1580	14.0
Mg	2407	135.5	127	7.1	179	10.1
K	3706	96.3	467	12.1	661	17.2
N	924	13.0	1131	16.0	1600	22.6
P	466	29.0	389	24.2	550	34.2
<u>Wood</u>						
Ca	3539	33.0	2046	19.1	2893	27.0
Mg	103	16.1	122	19.1	173	27.0
K	1503	114.5	425	32.4	601	45.8
N	391	8.3	1068	22.7	1511	32.1
P	88	16.3	155	28.5	219	40.3
<u>Misc</u>						
Ca	1731	22.8	1763	23.2	2494	32.8
Mg	73	8.5	100	11.5	141	16.3
K	763	19.7	714	18.4	1010	26.0
N	913	8.5	1935	18.1	2736	25.6
P	322	25.8	227	18.2	322	25.8

*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: 1985-1991

<u>Species</u>	<u>Site</u>		<u>Year</u>		<u>Y x S</u>	
	<u>ppm</u>	<u>% of mean</u>	<u>ppm</u>	<u>% of mean</u>	<u>ppm</u>	<u>% of mean</u>
<u>NRO</u>						
Ca	621	6.8	414	4.5	585	6.4
Mg	518	3.8	74	5.4	105	7.7
K	784	21.7	518	14.3	733	20.2
N	1535	22.3	1210	17.6	1711	24.8
P	819	54.4	468	31.1	622	44.0
<u>CCPB</u>						
Ca	4993	37.2	987	7.4	1396	10.4
Mg	650	23.9	237	8.7	335	12.3
K	659	13.7	580	12.0	820	17.0
N	1161	14.2	1147	14.1	1622	19.9
P	422	24.5	284	16.5	401	23.4
<u>BTA</u>						
Ca	3692	25.6	1411	9.8	1996	13.8
Mg	358	15.0	261	10.9	369	15.4
K	1475	3.5	753	17.9	1065	25.3
N	2100	27.3	730	9.5	1033	13.4
P	668	48.2	343	24.7	485	35.0
<u>RM</u>						
Ca	924	7.9	719	6.2	1017	8.7
Mg	250	12.9	118	6.0	166	8.6
K	297	9.7	363	11.9	513	16.8
N	1051	22.9	404	8.4	572	11.9
P	280	16.1	190	10.9	269	15.4

*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 1991**

	Antenna		Control	
	<u>1985-1990</u>	<u>1991</u>	<u>1985-1990</u>	<u>1991</u>
	----- (%) -----	----- (%) -----	----- (%) -----	----- (%) -----
N	2.06	2.05	2.04	2.06
P	0.21	0.23	0.21	0.23
K	0.86	0.92	0.97	1.04
Ca	0.71	0.79	0.71	0.75
Mg	0.15	0.15	0.15	0.16

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:
1985-1991**

	N (1) *	P (2)	K (3)	Ca (4)	Mg (5)
-----p values-----					
Site					
Tree Diameter	.461	.077	.034	.505	.124
Site x Diameter	.577	.041	.839	.161	.082
	.577	.041	.839	.161	.082
Year					
Year x Site	.000	.163	.315	.001	.011
Year x Diameter	.149	.819	.426	.161	.082
Year x Site x Diameter	.347	.779	.000	.283	.461
	.255	.011	.043	.059	.329
Month					
Month x Site	.000	.000	.000	.000	.000
Month x Year	.068	.026	.310	.006	.285
Month x Year x Site	.000	.000	.000	.000	.000
	.109	.000	.000	.099	.017

* Covariates used

- 1 Average maximum air temperature, soil moisture at 5 cm, soil moisture at 10 cm, soil temperature degree days at 10 cm
- 2 Soil temperature degree days at 10 cm running total, soil moisture at 5 cm, soil moisture at 10 cm
- 3 Soil temperature at 5 cm, average maximum air temperature, soil moisture at 10 cm
- 4 Average maximum air temperature, soil temperature at 10 cm
- 5 Average maximum air temperature, soil moisture at 10 cm, soil temperature degree days at 10 cm

cm

Table 5.17. Detection limits for Northern Red Oak foliage nutrient concentrations: 1985-1991*

	<u>Site</u>		<u>Year</u>		<u>Year x site</u>	
	<u>ppm</u>	<u>% of mean</u>	<u>ppm</u>	<u>% of mean</u>	<u>ppm</u>	<u>% of mean</u>
N	1620	7.9	1585	7.7	2241	11.0
P	239	11.2	474	22.2	670	31.3
K	433	4.7	960	10.4	1358	14.8
Ca	674	9.3	565	7.8	799	11.0
Mg	113	7.4	90	5.9	126	8.4

*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)

	<u>p value</u>
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

Literature Cited

- Abrams, M.D. 1988. Sources of variation in osmotic potentials with special reference to North American tree species. *For. Sci.* 34(4):1030-1076.
- Alban, D.H. 1974. Red pine site index in Minnesota as related to soil and foliar nutrients. *For. Sci.* 20:261-269.
- Albert, D. A., S. R. Denton, and B. V. Barnes. 1986. Regional landscape ecosystems of Michigan. School of Natural Resources, University of Michigan, Ann Arbor. 32 p.
- Anderson, R. F. 1960. Forest and shade tree entomology. John Wiley and Sons, New York. 428 p.
- Anderson, R.C. and L.O. Loucks. 1973. Aspects of the biology of *Trientis borealis* Raf. *Ecology* 54: 789-808.
- Auchmoody, L. R. and S. M. Filip. 1973. Forest fertilization in the eastern United States: hardwoods. In Forest fertilization symposium proceedings. U. S. Dep. Agric. For. Serv. Gen. Tech. Rep. NE-3. pp.221-225.
- Auchmoody, L. R. and S. M. Filip. 1973. Forest fertilization in the eastern United States: hardwoods. In: Forest fertilization symposium proceedings. U. S. Dep. Agric. For. Serv. Gen. Tech. Rep. NE-3. pp.221-225.
- Becker, C.A., G.D. Mroz, and L.G. Fuller. 1987. The effects of plant moisture stress on red pine (*Pinus resinosa*) seedling growth and establishment. *Can. J. For. Res.* 17:813-820.
- Bickelhaupt, D.H., R. Lea, D.D. Tarbet and A.L. Leaf. 1979. Seasonal weather regimes influence interpretation of *Pinus resinosa* foliar analysis. *Soil Sci. Am. J.*, 43:417-420.
- Boone, R.D. 1992. Influence of sampling date and substrate on nitrogen mineralization: comparison of laboratory-incubation and buried-bag methods for two Massachusetts forest soils. *Can. J. For. Res.* 22:1895-1900.
- Bremner, J.M. 1965. Organic nitrogen in soils. In *Soil nitrogen*. [edited by Bartholomew, W. V. and F. E. Clark] American Society Agronomy. Madison, WI. pp.93-145.

- Brinkman, K.A. and E.I. Roe. 1975. Quaking aspen: silvics and management in the Lake States. USDA Agricultural Handbook 486. Washington, DC. 52 p.
- Carlyle, J.C. 1986. Nitrogen cycling in forest ecosystems. Forest Abstracts 47: 307-336.
- Clark, J. 1961. Birch dieback. Recent Advances in Botany. In: Lectures and symposia presented to the 9th International Botanical Congress, 1959. University of Toronto Press. p. 1551-1555.
- Clark, J. and G.W. Barter. 1958. Growth and climate in relation to dieback of yellow birch. Forest Sci. 4:343-363.
- Coffman, M.S., E. Alyanak, J. Kotar, and J. E. Ferris. 1983. Field Guide, Habitat Classification System for the Upper Peninsula of Michigan and Northeastern Wisconsin. CROFS, Department of Forestry, Michigan Technological University, Houghton, MI.
- Colombo, S.J. 1987. Changes in osmotic potential, cell elasticity and turgor relationships of second-year black spruce container seedlings. Can. J. For. Res. 17:365-369.
- Crow, T.R. 1978. Biomass and production in three contiguous forests in Northern Wisconsin. Ecology 59:265-273.
- Dighton, J. and R.A. Skeffington. 1987. Effects of artificial acid precipitation on the mycorrhizae of Scots pine seedlings. New Phytol. 107:191-202.
- Eyre, F.H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
- Fahey, T.J. and D.R. Young. 1984. Soil and xylem water potential and soil water content in contrasting *Pinus contorta* ecosystems, southeastern Wyoming, USA. Oecologia 61:346-351.
- Federer, C.A. 1982. Subjectivity in the separation of organic horizons of the forest floor. Soil Sci. Soc. Am. J. 46:1090-1093.
- Foster, N. W. 1989. Influences of seasonal temperature on nitrogen and sulfur mineralization/immobilization in a maple-birch forest floor in central Ontario. Can. J. Soil. Sci. 69:501-514.

- Fralish, J.S. 1972. Youth, maturity, and old age. In: Aspen: symposium proceedings. USDA Forest Service, General Technical Report NC-1. p. 74-82.
- Fries N. and G.M. Mueller. 1984. Incompatibility Systems, Cultural Features and Species Circumscriptions in the Ectomycorrhizal Genus *Laccaria* (Agaricales). *Mycologia*, 76:633-642.
- Grossnickle, S.C. 1988. Planting stress in newly planted jack pine and white spruce. 1. Factors influencing water uptake. *Tree Phys.* 4:71-83.
- Haradem, D.P., J.R. Gauger, and J.E.Zapotosky. 1988. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support -- 1987. Illinois Institute of Technology Research Institute Technical Report No.E06595-1
- Hart, S.C. and M.K. Firestone. 1992. Decomposition and nutrient dynamics of ponderosa pine needles in a Mediterranean-type climate. *Can. J. For. Res.* 22:306-314.
- Harvey, A.E., M.F. Jurgensen, M.J. Larsen, and R.T. Graham. 1987. Relationships among microsite, ectomycorrhizae and natural conifer regeneration of old growth forests in western Montana. *Can. J. For. Res.* 17:58-62.
- Hawboldt, L.S. 1947. Aspects of yellow birch dieback in Nova Scotia. *J. Forestry* 45:414-422.
- Hawboldt, L.S. 1952. Climate and birch "dieback". Nova Scotia Department of Lands and Forests. Halifax. Bull. No. 6. 37 p.
- Heiberg, S.O. and A.L. Leaf. 1961. Effects of forest debris on the amelioration of sandy soils. In *Recent Advances in Botany*, Univ. Toronto Press, Toronto, Canada.
- Helenurm, K. and S.C.H. Barrett. 1987. The reproductive biology of boreal forest herbs. II.186 phenology of flowering and fruiting. *Can. J. Bot.* 2047-2056.
- Hill, A.R. and M. Shackleton. 1989. Soil nitrogen mineralization and nitrification in relation to nitrogen solution chemistry in a small forested watershed. *Biogeochemistry* 8:167-184.
- Hinckley, T.M., J.P. Lassoic, and S.W. Running. 1978. Temporal and spatial variations in the water stress of forest trees. *For. Sci. Monograph* No. 20. 71p.

- Hoyle, M.C. and D.L. Mader. 1964. Relationships of foliar nutrients to growth of red pine in western Massachusetts. *For. Sci.* 10:337-347.
- Husch, B., C. I. Miller, and T. W. Beers. 1982. *Forest Measurements*. Third Edition. John Wiley and Sons, Inc., New York. 402 p.
- Jones, E.A. and D.D. Reed. 1991. Improved site index curves for young red pine plantations in the Northern Lake States. *N. Jour. App. For.* 8:59-63.
- Jones, E.A., D.D. Reed, P. J. Cattelino, and G. D. Mroz. 1991. Seasonal shoot growth of planted red pine predicted from air temperature degree days and soil water potential. *For. Ecol. and Man.* 46:201-214.
- Jones, M.D. and T.C. Hutchinson. 1986. The effect of mycorrhizal infection on the response of *Betula papyrifera* to nickel and copper. *New. Phytol.* 102:429-442.
- Keeney, D.R. 1980. Prediction of soil nitrogen availability in forest ecosystems: a literature review. *For. Sci.* 26:159.
- Kimmins, J.P. 1987. *Forest Ecology*. Macmillan Publishing Company, New York. 531 p.
- Kozlowski, T.T., J.H. Torrie, and P.E. Marshall. 1973. Predictability of shoot length from bud size in *Pinus resinosa* Ait. *Can. J. For. Res.* 3:34-38.
- Larcher, W. 1983. *Physiological Plant Ecology*. Springer-Verlag. Berlin, Heidelberg, New York, Tokyo. 303 p.
- Lundgren, A.L. and W.A. Dolid. 1970. Biological growth functions describe published site index curves for Lake States timber species. *U. S. For. Serv. Res. Pap.* NC-36.
- Madgwick, H.A.I. 1962. Studies in the growth and nutrition of *Pinus Resinosa* Ait. Ph.D. thesis. State Univ. Coll. of For. at Syracuse Univ., Syracuse N.Y.
- Marquis, D.A., D.S. Solomon, and J.C. Bjorkbom. 1969. A silvicultural guide for paper birch in the Northeast. USDA Forest Service, Research Paper NE-130. 47 p.
- Mejstrik, V. and P. Cudlin. 1987. Experiences with mycorrhizal seedlings inoculation used for reforestation in emission stress areas. *Angew. Botanik.* 61: 47-52.

- Miller, R. W. and R. L. Donahue. 1990. An Introduction to Soils and Plant Growth. sixth Edition, Prentice Hall, Englewood Cliffs, NJ. 07632.
- Miller, R. W. and R. L. Donahue. 1990. Soils -- An introduction to soils and plant growth. Sixth Edith. Prentice-Hall, Inc. A division of Simon & Schuster. Englewood Cliffs, New Jersey 07632.
- Millers, I., D. S. Shriner, and D.izzo. 1989. History of hardwood decline in the eastern United States. USDA Forest Service, General Technical Report NE-126. 75 p.
- Mladenoff, D. J. 1987. Dynamics of nitrogen mineralization and nitrification in Hemlock and hardwood treefall gaps. Ecology 68:1171-1180.
- Mroz, G.D., et al. 1986. Annual Report of the Herbaceous Plant Cover and Tree Studies. In: Compilation of the 1986 Annual Reports of the Navy ELF Communications Ecological Monitoring Program, Volume I. Illinois Institute of Technology Research Institute Technical Report No. E06549-38. p. 1-215.
- Mroz, G.D., et al. 1987. Annual Report of the Herbaceous Plant Cover and Tree Studies. In: Compilation of the 1986 Annual Reports of the Navy ELF Communications Ecological Monitoring Program, Volume I. Illinois Institute of Technology Research Institute Technical Report No. E06549-38. p. 1-215.
- Mroz, G.D., et al. 1988. Annual Report of the Herbaceous Plant Cover and Tree Studies. In: Compilation of the 1988 Annual Reports of the Navy ELF Communications Ecological Monitoring Program, Volume I. Illinois Institute of Technology Research Institute Technical Report No. E06595-6. p. 1-243.
- Mroz, G.D., et al. 1989. Annual Report of the Herbaceous Plant Cover and Tree Studies. In: Compilation of the 1988 Annual Reports of the Navy ELF Communications Ecological Monitoring Program, Volume I. Illinois Institute of Technology Research Institute Technical Report No. E06595-6. p. 1-243.
- Mroz, G.D., et al. 1990. Annual Report of the Herbaceous Plant Cover and Tree Studies. In: Compilation of the 1989 Annual Reports of the Navy ELF Communications Ecological Monitoring Program, Volume I. Illinois Institute of Technology Research Institute Technical Report No. E06595-6. p. 1-302.

- Nadelhoffer, K.J., J.D. Aber, and J.M. Melillo 1985. Fine roots, net primary production, and soil nitrogen availability: a new hypothesis. *Ecology* 66:1377-1390.
- Nambiar, E.K.S., G.D. Bowen, and R. Sands. 1979. Root regeneration and plant water status of *Pinus radiata* D. Don seedlings transplanted to different soil temperatures. *J. of Exp. Bot.* 30(119):1119-1131.
- Nash, R.W. and E.J. Duda. 1951. Studies on extensive dying, regeneration, and management of birch. Maine Forest Service, Augusta. Bull. No. 15. 82 p.
- Paul, E.A. and F.E. Clark. 1989. Soil Microbiology and Biochemistry. 26-28. Academic Press, San Diego, California.
- Perala, D.A. 1985. Predicting red pine shoot growth using growing degree days. *For. Sci.* 31:913-925.
- Redmond, D.R. 1957. The future of birch from the viewpoint of diseases and insects. *For. Chron.* 33:25-30.
- Reich, P.B., A.W. Schoettle, H. F. Stroo, J. Troiano and R.G. Admundson. 1985. Effects of O₃, SO₂, and acidic rain on mycorrhizal infection in northern red oak seedlings. *Can. J. Bot.* 63:2049-2055.
- Richie, G.A., and T.M. Hinkley. 1975. The pressure chamber as an instrument for ecological research. *Adv. Ecol. Res.* 9:165-254.
- Searle, S.R. 1971. *Linear Models*. John Wiley & Sons, N.Y. 532 p.
- Shafer, S.R., L.F. Grand, R.I. Bruck and A.S. Heagel. 1985. Formation of ectomycorrhizae of *Pinus taeda* seedlings exposed to simulated acid rain. *Can. J. For. Res.* 15:66-71.
- Smith, D.M. 1986. *The Practice of Silviculture*. Eighth Edition. John Wiley and Sons, Inc., New York. 527 p.
- Spurr, S.H. and B.V. Barnes. 1980. *Forest Ecology*. Third Edition. John Wiley and Sons, Inc., New York. 687 p.
- Stone, E.L. 1973. Regional objectives in forest fertilization. In *Forest Fertilization* USDA Forest Service, Gen. Tech. rep. NE-3, Upper Darby, PA.
- Stone, E.L. and A.L. Leaf. 1967. K deficiency and response in young conifer forests in eastern North America. In *Forest Fertilization: 5th Potassium Colloquium*, p. 217-

229, Jyraskyla, Finland. Intern. Potash Inst., Berne, Switzerland. 379 p.

Stroo, H.F. and M. Alexander. 1985. Effect of simulated acid rain on mycorrhizal infection of *Pinus strobus* L. *Water, Air, and Soil Pollution* 25:107-114.

Sucoff, E. 1972. Water potential in red pine: soil moisture, evapotranspiration, crown position. *Ecology* 53(4):681-686.

Technician. 1978. Ammonia in water and seawater. Industrial method 154-71 w/b. Technician industrial systems, Tarryton, New York. U.S.A.

Teskey, R.O., T.M. Hinckley, and C.C. Grier. 1984. Temperature-induced change in the water relations of *Abies amabilis* (Dougl.) Forbes. *Plant. Physiol.* 74:77-80.

Zahner, R. 1968. Water deficits and growth of trees. In "Water Deficits and Plant Growth" (T. T. Kozlowski, ed.), Vol. 2, pp 191-254. Academic Press, New York.

Zak, D.R. and K.S. Pregitzer. 1990. Spatial and temporal variability of nitrogen cycling in northern lower Michigan. *For. Sci.* 36:367-380.

Environmental Monitoring Program Of

The ELF Communications

Environmental Compatability Assurance Program

Upland Flora Project Publications

- Becker, C.A. 1986. The effects of plant moisture stress on red pine (*Pinus resinosa*) seedling growth and establishment. M.S. Thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, MI. 39p.
- Becker, C.A., G.D. Mroz and L.G. Fuller. 1988. The effects of plant moisture stress on red pine (*Pinus resinosa*) seedling growth and establishment. *Canadian Journal of Forest Research* 17:813-820.
- Becker, D.M., S.M. Paetchow, S.T. Bagley and J.N. Bruhn. 1990. Inhibition of vegetative growth of *Armillaria ostoyae* and *A. bulbosa* by red pine mycorrhizoplane streptomycetes. *Phytopathology* 80:1059 (Abstract).
- Brooks, R.H. 1988. Effects of whole tree harvesting on organic matter, cation exchange capacity and water holding capacity. M.S. thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, MI. 20p.
- Bruhn, J.N., J.B. Pickens and J.A. Moore. 1989. *Armillaria* root rot in *Pinus resinosa* plantations established on clercut mixed hardwood sites. In: D.J. Morrison, ed. *Proceedings of the Seventh International Conference on Root and Butt Rots*. 680p. Vernon and Victoria, British Colombia, Canada August 9-16, 1988. p437-446.
- Bruhn, J.N., J.B. Pickens, and J.A. Moore. 1988. *Armillaria* root disease in red pine plantations converted from hardwood stands. In: Michigan Forest Pest Report, 1987. B.A. Montgomery, ed. Michigan Cooperative Forest Pest Management Program Annual Report 88-2, p65-71.
- Cattelino, P.J., C.A. Becker, L.G. Fuller. 1986. Construction and installation of homemade dendrometer bands. *Northern Journal of Applied Forestry*, 3:73-75.
- Connaughton, P. 1987. The effects of acid precipitation on nutrient levels in a forest soil and foliage of red pine seedlings. M.S. thesis, Michigan Technological University, Houghton, MI. 54p.

- Desanker, P.V. and D.D. Reed. 1991. A stochastic model for simulating daily growing season weather variables for input into ecological models. In: Proceedings of the 1991 systems analysis in forest resources symposium, Charleston SC. p1-10.
- Desanker, P.V., D.D. Reed and E.A. Jones. 1993. Evaluating forest stress factors using various growth modeling approaches. Forest Ecology and Management. In Press.
- Fox, K.B. 1991. Effects of season and site conversion on mineral soil nutrient content in a northern hardwood forest ecosystem. M.S. Thesis, Michigan Technological University, Houghton, Michigan. 66p.
- Fuller, L.G. 1986. Modeling northern hardwood diameter growth using weekly climatic factors in northern Michigan. M.S. thesis Michigan Technological University, Houghton, MI. 69p.
- Fuller, L.G., D.D. Reed and M.J. Holmes. 1988. Modeling Northern Hardwood Diameter Growth Using Weekly Climatic Factors in Northern Michigan. In: Proceedings of the International Union of Forest Research Organizations: Forest Growth and Prediction Conference, Volume I, Minneapolis, MN. August 1987. p 467-474.
- Fuller, L.G., P.J. Cattelino and D.D. Reed. 1986. Dendrometer bands and climatic data collection: A system of ecological diameter growth model development. In: G.D. Mroz and D.D. Reed, eds., Proceedings of a Conference on the Northern Hardwood Resource: Management and Potential, Michigan Technological University, Houghton, MI. p425..
- Fuller, L.G., P.J. Cattelino, D.D. Reed. 1988. Correction equations for dendrometer band measurements of five hardwood species. Northern Journal of Applied Forestry. 5:111-113.
- Holmes, M.J. 1988. Competition indices for mixed species northern hardwoods. M.S. thesis, Michigan Technological University, Houghton, MI. 30p.
- Holmes, M.J. and D.D. Reed. 1991. Competition indices for mixed species Northern Hardwoods. Forest Science 37:1338-1349.
- Jones, E.A. and D.D. Reed. 1991. Improved site index curves for young red pine plantations in the Northern Lake States. Northern Journal of Applied Forestry 8:59-63
- Jones, E.A., D.D. Reed, P.J. Cattelino and G.D. Mroz. 1991. Seasonal shoot growth of planted red pine predicted from air temperature degree days and soil water potential. Forest Ecology and Management 46:201-214.

- Jones, E.A., D.D. Reed, G.D. Mroz, H.O. Liechty and P.J. Cattelino. 1993. Climate stress as a precursor to forest decline: paper birch in northern Michigan, 1986-1990. *Can. J. For. Res.* (In Press)
- Jones, E.A., D.D. Reed, and P.V. Desanker. 1992. Ecological implications of projected climate change scenarios of Central North America. In: *Proceedings of the Centennial International Union of Forest Research Organizations World Congress*. Berlin-Eberswald, Germany. p202.
- Jurgensen, M.F., J.N. Bruhn, M.R. Gale, R. Janke, J. Kotar, G.D. Mroz, C.C. Trettin and M. Anderson. 1983. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: *compilation of the 1982 Annual Reports of the Navy Communications System Ecological Monitoring Program*. IIT Research Institute Technical Report No. E06516-5. p 1-35.
- Jurgensen, M.F., A.E. Harvey, R.T. Graham, M.R. Gale, D. Page-Dumrose and G.D. Mroz. 1989. Harvesting and site preparation impacts on soil organic reserves. *Proceedings of the Society of American Foresters Annual Meeting*, Spokane, WA. p. 212-216.
- Jurgensen, M.F., A.E. Harvey, R.T. Graham, M.R. Gale, D. Page-Dumrose and G.D. Mroz. 1990. Timber harvesting and site preparation effects on soil organic contents. In: Bo-Qun Lin ed., *Proceedings of the First International Symposium on Forest Soils*. Harbin, Peoples Republic of China. p.229-236.
- Jurgensen, M.J., M.J. Larsen, G.D. Mroz and A.E. Harvey. 1987. Timber harvesting soil organic matter and site productivity. In: C.T. Smith, ed., *Proceedings: Productivity of Northern Forests Following Biomass Harvesting*, University of New Hampshire, Durham, NH. p43-52.
- Larsen, G.W. 1990. Relationship between above and belowground vertical distribution of red pine (*Pinus resinosa* Ait.) seedlings as a key to productivity. M.S. Thesis, Michigan Technological University, 82p.
- Lederle, K.A. 1987. Nutrient status of bracken, *Pteridium Aquilinum* (L.) Kuhn, following whole tree harvesting in Upper Michigan. M.S. thesis, Michigan Technological University, Houghton, MI. 42p.
- Lederle, K.A. and G.D. Mroz. 1991. Nutrient status of bracken, *Pteridium Aquilinum* (L.) Kuhn, following whole tree harvesting in Upper Michigan. *Forest Ecology and Management*. 40:119-130.

- Liechty, H.O., M.J. Holmes, D.D. Reed and G.D. Mroz. 1992. Changes in microclimate after stand conversion in two northern hardwood stands. *Forest Ecology and Management*. 50:253-264.
- Moore, Joni A. 1988. Distribution of *Armillaria* clones including models of red pine seedling mortality, on ELF plantation site in Michigan's Upper Peninsula. M.S. thesis, Michigan Technological University, Houghton, MI. 127p.
- Mroz, G.D. and D.D. Reed. 1990. Forest soil sampling efficiency: The need to match laboratory analyses and field sampling procedures. *Soil Science Society of America Journal* 55:1413-1416.
- Mroz, G.D., C.A. Becker P.J. Cattelino, L. Fuller, M.F. Jurgensen, K.A. Lederle, H.O. Liechty, D.D. Reed, E.J. Reed, D.L. Richter and C.C. Trettin. 1986. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1985 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06549-26. p 1-240.
- Mroz, G.D., C.A. Becker, R.H. Brooks, J.N. Bruhn, P.J. Cattelino, P. Connaughton, L. Fuller, M.R. Gale, M.J. Holmes, M.F. Jurgensen, K.A. Lederle, H.O. Liechty, D.D. Reed, E.J. Reed, and D.L. Richter, 1987. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1986 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06549-38. p 1-213.
- Mroz, G.D., C.A. Becker, R.H. Brooks, J.N. Bruhn, P.J. Cattelino, M.R. Gale, M.J. Holmes, M.F. Jurgensen, H.O. Liechty, J.A. Moore, D.D. Reed, E.J. Reed, D.L. Richter, Y.F. Zhang, 1988. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1987 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06595-2. p 1-316.
- Mroz, G.D., K.T. Becker, J.N. Bruhn, P.J. Cattelino, P. Desanker, K.B. Fox, M.R. Gale, M.J. Holmes, M.F. Jurgensen, G.W. Larsen, H.O. Liechty, D.D. Reed, E.J. Reed, D.L. Richter, Y. Wu, Y.F. Zhang, 1990. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1989 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06620-4. p 1-275.

- Mroz, G.D., K.T. Becker, R.H. Brooks, J.N. Bruhn, P.J. Cattelino, P. Desanker, M.R. Gale, K.B. Fox, G.W. Larsen, M.J. Holmes, M.F. Jurgensen, H.O. Liechty, J.A. Moore, D.D. Reed, E.J. Reed, D.L. Richter, Y. Wu, Y.F. Zhang, 1989. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1988 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06595-6. p 1-243.
- Mroz, G.D., M. Anderson, J.N. Bruhn, P.J. Cattelino, G.W. Lenz, M.F. Jurgensen, H.O. Liechty, E.J. Reed, J. Schultz and C.C. Trettin. 1985. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1984 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06549-17. p 1-193.
- Mroz, G.D., M. Anderson, J.N. Bruhn, P.J. Cattelino, R. Janke, M.F. Jurgensen, E.J. Reed, and C.C. Trettin. 1984. ELF communications system ecological monitoring program: herbaceous plant cover and trees. In: compilation of the 1983 Annual Reports of the Navy Communications System Ecological Monitoring Program. IIT Research Institute Technical Report No. E06549-8. p 1-145.
- Mroz, G.D., C.M. Bliss, P.J. Cattelino, P.V. Desanker, M.R. Gale, M.F. Jurgensen, H.O. Liechty, H. Ouyang, D.D. Reed, E.J. Reed, Y. Wu, Y.F. Zhang. 1992. ELF communications system ecological monitoring program: herbaceous plant cover and tree studies. In: Compilation of 1991 annual reports of the Navy ELF communications system ecological monitoring program. IIT Research Institute Technical Report D06200-2. p1-302.
- Mroz, G.D., P.J. Cattelino and C.A. Becker. 1988. Terminal buds can be a useful indicator of early red pine planting survival. *Northern Journal of Applied Forestry*. 5:14.
- Paetchow, S.M., S.T. Bagley and J.N. Bruhn. 1990. Characterization of mycorrhizoplane-associated streptomycete effects on ectomycorrhizal fungi. *Phytopathology* 80:1032. (Abstract).
- Reed, D.D. 1990. Investigating the effects of regional air pollution on forest ecosystem productivity. In: *Proceedings of the 1990 Annual Meeting of the Society of American Foresters*, Washington, D.C. p107-110.
- Reed, D.D. and P.V. Desanker. 1992. Ecological implications of projected climate change scenarios in northern Michigan, USA. *Biometeorology* 36:99-107.

- Reed, D.D., E.A. Jones, G.D. Mroz and H.O. Liechty. 1992. Impacts of annual weather conditions on forest productivity. *Biometeorology* 36:51-57.
- Reed, D.D., E.A. Jones, M.J. Holmes and L.G. Fuller. 1992. Modeling diameter growth as a function of climate: a case study involving four North American deciduous species. *Forest Ecology and Management*. 54:95-104.
- Reed, D.D., H.O. Liechty and A. Burton. 1989. A simple procedure for mapping tree locations in forest stands. *Forest Science* 35:657-662.
- Reed, D.D., M.J. Holmes, E.A. Jones, H.O. Liechty, G.D. Mroz. 1990. An ecological growth model for northern hardwood species in Upper Michigan. In: *Forest Growth: Process Modeling of Response to Environmental Stress*. R.K. Dixon, R.S. Meldahl, G.A. Ruark and W.G. Warren, eds. Timber Press, Portland OR. p 288-293.
- Richter, D.L. 1989. Shifts in mycorrhizal fungus colonization of red pine seedlings following outplanting on cleared northern hardwood sites in the Upper Peninsula of Michigan. Ph.D. dissertation, School of Forestry and Wood Products, Michigan Technological University, Houghton, MI. 279p.
- Richter, D.L. and J.N. Bruhn. 1989. *Pinus resinosa* mycorrhizae: Seven host-fungus combinations synthesized in pure culture. *Symbiosis* 7:211-228.
- Richter, D.L. and J.N. Bruhn. 1989. Revival of saprotrophic and mycorrhizal basidiomycete cultures from cold storage in sterile water. *Canadian Journal of Microbiology* 35:1055-1060.
- Richter, D.L. and J.N. Bruhn. 1989. Survival of containerized red pine and jack pine seedlings inoculated with mycelium/agar slurries of mycorrhizal fungi and planted on a dry sandy plain in Northern Michigan. *New Forests* 3:247-258.
- Richter, D.L. and J.N. Bruhn. 1990. *Scleroderma citrinum* Pers. (Gastromycetes, Sclerodermatales) and *Larix Decidua* Mill. form ectomycorrhizae in pure culture. *Nova Hedwigia* 50:355-360.
- Richter, D.L. and J.N. Bruhn. 1986. Pure culture synthesis of *Pinus resinosa* ectomycorrhizae with *Scleroderma Aurantium*. *Mycologia* 78(1): 139-142.
- Richter, D.L., T.R. Zuellig, S.T. Bagley, and J.N. Bruhn. 1988. Effects of red pine mycorrhizosphere streptomycetes on in vitro growth of ectomycorrhizal fungi. *Phytopathology* 77:1760.

- Richter, D.L., T.R. Zuellig, S.T. Bagley, and J.N. Bruhn. 1989. Effects of red pine (*Pinus resinosa* Ait.) Mycorrhizoplane - associated actinomycetes on in vitro growth of ectomycorrhizal fungi. *Plant and Soil* 115:109-116.
- Richter, D.L. and J.N. Bruhn. 1993. Shifts in mycorrhizal fungus colonization of *Pinus resinosa* Ait. seedlings planted on northern hardwood sites. *Soil Biology and Biochemistry*. In press.
- Smith, M.L., L.C. Duchesne, J.N. Bruhn and J.B. Anderson. 1990. Mitochondrial genetics in a natural population of *Armillaria*, a plant pathogen. *Genetics* 126:575-582.
- Smith, M.L., J.N. Bruhn and J.B. Anderson. 1992. The fungus *Armillaria bulbosa* is among the largest and oldest living organisms. *Nature* 356:428-431.
- Wu, Y. 1991. Effects of seedling, climate and soil characteristics on ectomycorrhizal populations of red pine (*Pinus resinosa* Ait.). M.S. Thesis, Michigan Technological University, 89p.
- Zhang, Y.F., D.D. Reed, P.J. Cattelino, M.R. Gale, E.A. Jones, H.O. Liechty and G.D. Mroz. 1993. A process based growth model for young red pine. *Forest Ecology and Management*. In Press.

Environmental Monitoring Program Of
The ELF Communications
Environmental Compatability Assurance Program
Upland Flora Project Presentations

Becker, C.A., G.D. Mroz, and L.G. Fuller. 1986. Effects of moisture stress on red pine (*Pinus resinosa* Ait.) seedling root and mycorrhizae development. Presented at the Conference on Roots in Forest Soils: Biology and Symbiosis, Victoria, British Columbia.

Brooks, R.H., M.F. Jurgensen and G.D. Mroz. 1988. Effects of whole tree harvesting on organic matter, cation exchange capacity and water holding capacity. Presented at the American Society of Agronomy Meeting, Anaheim, CA.

Bruhn, J.N. and S.T. Bagley. 1988. Actinomycetes associated with red pine mycorrhizae in the field versus nursery stock. Presented at the Third International Congress on Microbial Ecology, East Lansing, MI.

Cattelino, P.J. 1983. An overview of the Ecological Monitoring Program: Trees and Herbaceous Plants Study. Presented to Golden K Kiwanis meeting, Iron Mountain, MI.

Cattelino, P.J. 1984. An overview of the Ecological Monitoring Program: Trees and Herbaceous Plants Study. Presented to Rotary International, Hancock, MI.

Cattelino, P.J. 1989. An overview of the ELF ecological monitoring program: Trees and Herbaceous plants study. Presented to the Range Lions Club, South Range, MI.

Cattelino, P.J., G.D. Mroz and E.A. Jones. 1985. Soil/climatic factors affecting red pine seedling growth in Northern Michigan. Presented at the American Society of Agronomy annual meeting, Chicago, IL.

Cattelino, P.J., G.W. Larsen and M.R. Gale. 1989. Moisture stress in planted re pine following whole tree harvesting in Northern Michigan. Presented at the Society of American Foresters Annual Meeting, Spokane, WA September 24-27.

Cattelino, P.J., H.O. Liechty, G.D. Mroz and D.L. Richter. 1986. Relationships between initiation of red pine seedling growth, ectomycorrhizae counts,

and microclimate in Northern Michigan. Presented at the Conference on Roots in Forest Soils: Biology and Symbiosis, Victoria, British Columbia.

Cattelino, P.J., M.F. Jurgensen, H.O. Liechty, G.D. Mroz and D.D. Reed. 1991. Climatic and site factors effecting litter weights in northern hardwood stands. Presented at the American Society of Agronomy Meeting, Denver, CO.

Cattelino, P.J., M.F. Jurgensen, H.O. Liechty, G.D. Mroz and D.D. Reed. 1991. Climate and site factors affecting litter weights in northern hardwood stands. Annual Meeting, American Society of Agronomy, Denver, Colorado. Agronomy Abstracts p346.

Cattelino, P.J., R.H. Brooks, M.F. Jurgensen and G.D. Mroz. 1988. Determination of coarse fragment volume in northern hardwood forest soils. Presented at the American Society of Agronomy meeting, Anaheim, CA.

Cattelino, P.J. 1992. Does Project ELF effect Upper Michigan Forests? Presented to Rotary International, Hancock, MI.

Cattelino, P.J. 1992. Does Project ELF effect Upper Michigan Forests? Presented to Kiwanis International, Houghton, MI.

Cattelino, P.J. 1993. Does Project ELF effect Upper Michigan Forests? Presented to Republic Lions Club, Republic, MI.

Gale, M.R., M.F. Jurgensen, G.D. Mroz, R.H. Brooks and P.J. Cattelino. 1988. Soil organic matter changes following whole tree harvest of second growth northern hardwood stands. Conference on: Sustained Productivity of Forest Land, 7th North American Forest Soils Conference. Vancouver, British Columbia.

Gale, M.R., P.J. Cattelino, H.O. Liechty and K.A. Lederle. 1990. Effects of harvesting on plant diversity in two northern hardwood stands. Ecological Society of American annual meeting, Snowbird, UT.

Gale, M.R., P.J. Cattelino, K.T. Becker and K.A. Lederle. 1990. Phenological changes in *Trientalis borealis* Raf. due to yearly climatic shifts. p456. In: International Union of Forest Resource Organizations World Congress. Montreal, Canada. Vol. 2. Presented at the XIX IUFRO World Congress, Montreal, Canada

Gale, M.R., P.J. Cattelino, K.T. Becker and K.A. Lederle. 1991. Do yearly changes in temperature affect plant diversities on harvested and unharvested areas? In: Proceedings, Air pollution climate change and

biodiversity, emerging issues in northern hardwood management. Mackinac Island Mi. p36.

Jones, E.A. and D.D. Reed. 1990. Seasonal shoot growth of planted red pine predicted from air temperature degree days and soil water potential. In: Proceedings International Union of Forest Resource Organizations World Congress. Montreal, Canada. Vol. 4. Presented at the XIX IUFRO World Congress, Montreal, Canada.

Jones, E.A., D.D. Reed and P.V. Desanker. 1992. Ecological implications of projected climate change scenarios in forest ecosystems of central North America. In: Proceedings of the Centennial International Union of Forest research Organizations World Congress. Berlin-Eberswald, Germany. P202.

Larsen, G.W. and M.R. Gale. 1989. Monthly differences in above- and belowground biomass distributions in red pine (*Pinus resinosa* Ait.) seedlings. Presented at the meeting of the International Union of Forest Research Organizations Meeting: Dynamics of Ecophysiological Processes in tree Crowns and Forest Canopies September 24-29 Rhinelander, WI.

Liechty, H.O., G.D. Mroz and P.J. Cattelino. 1991. Variation in red pine foliar nutrient concentration in relation to climate and soil nutrient content. Presented at the American Society of Agronomy Meeting, Denver, CO.

Liechty, H.O., G.D. Mroz, M.J. Holmes and D.D. Reed. 1988. Changes in microclimate after clearcutting and plantation establishment in two second growth Northern Hardwood stands. Presented at the American Society of Agronomy Meeting, Anaheim, CA.

Mroz G.D., P.J. Cattelino and M.F. Jurgensen. 1985. Whole tree harvest effects on forest floor and soil/climatic factors affecting red pine seedling growth in Northern Michigan. Presented at the American Society of Agronomy annual meeting, Chicago, IL.

Mroz, G.D., J.N. Bruhn, P.J. Cattelino, M.R. Gale, H.O. Liechty, E.A. Jones, M.F. Jurgensen, D.D. Reed and J.E. Zapotosky. 1990. Ecosystem level studies of extremely low frequency electromagnetic fields on forests. Annual Review of Research on Biological Effects of 50 and 60 HZ Electric and Magnetic Fields. Sponsored by US Department of Energy, American Public Power Association and the Edison Electric Institute. Denver, Colorado. Published Abstract.

- Richter, D.L. and J.N. Bruhn. 1990. Shifts in mycorrhizal fungus colonization of *Pinus resinosa* seedlings following outplanting. Annual meeting of the Mycological Society of America. Madison WI.
- Richter, D.L. and J.N. Bruhn. 1987. *Scleroderma* spp. ectomycorrhizae for use in greenhouse and nursery to increase *Pinus resinosa* seedling outplanting success. Annual Meetings of the mycological Society of America and the Canadian Pytopathological Society. Ottawa, Canada.
- Wu, Y., M.R. Gale, P.J. Cattelino and H.O. Liechty. 1991. Modelling the effects of soil, climate and red pine seedling characteristics on ectomycorrhizae. Presented at the American Society of Agronomy Meeting, Denver, CO.
- Wu, Y., M.R. Gale, P.J. Cattelino and H.O. Liechty. 1991. Modelling the effects of soil, climate and red pine seedling characteristics on ectomycorrhizae (ECM). Annual Meeting, American Society of Agronomy, Denver, Colorado. Agronomy Abstracts p357.
- Wu, Y., M.R. Gale, P.J. Cattelino, D.L. Richter and J.N. Bruhn. 1990. Temporal changes in number of ectomycorrhizae and red pine seedling characteristics. Annual Meeting, American Society of Agronomy, San Antonio TX. 575-582.

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.



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

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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
4C	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.

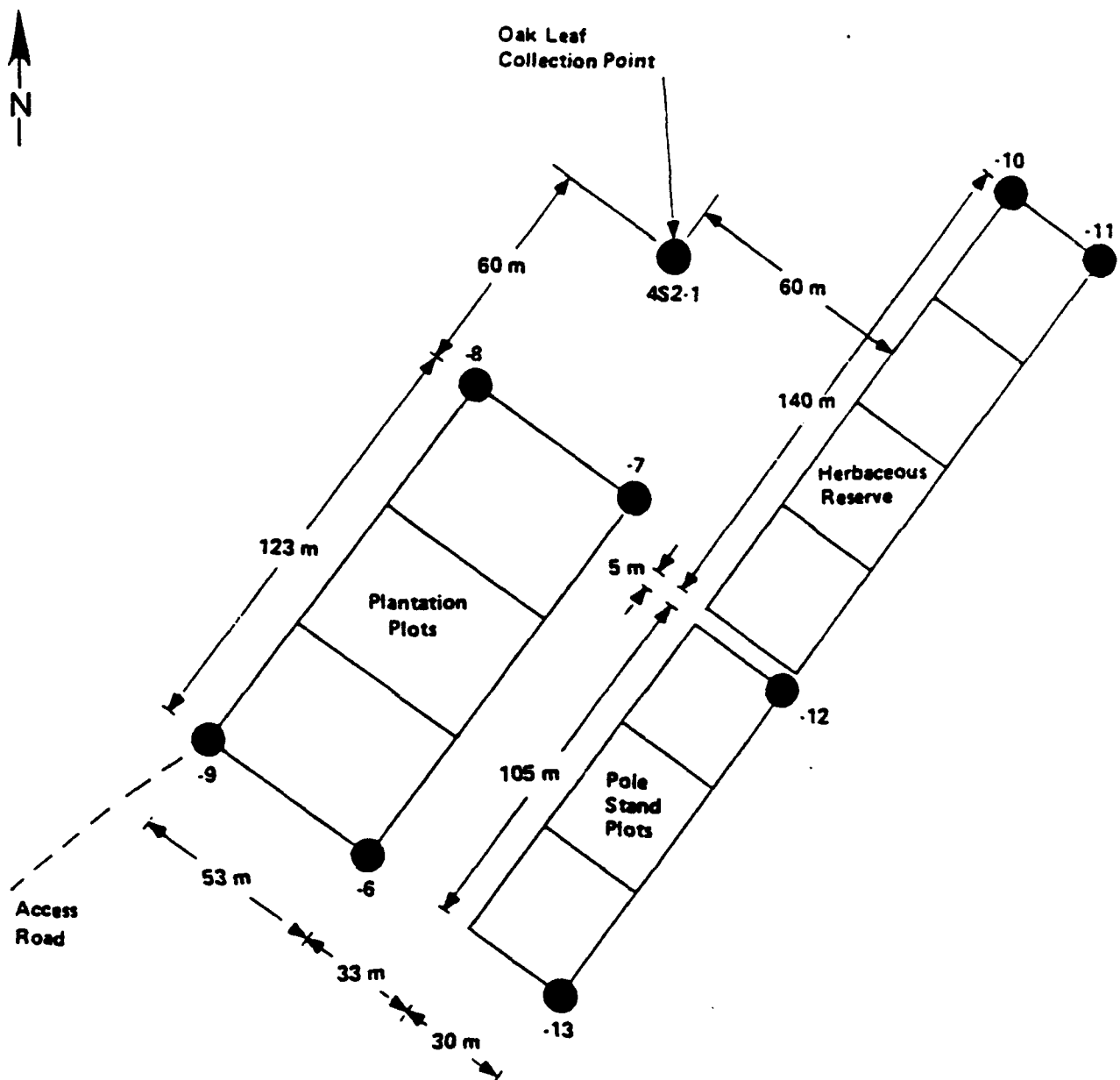


FIGURE 1. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

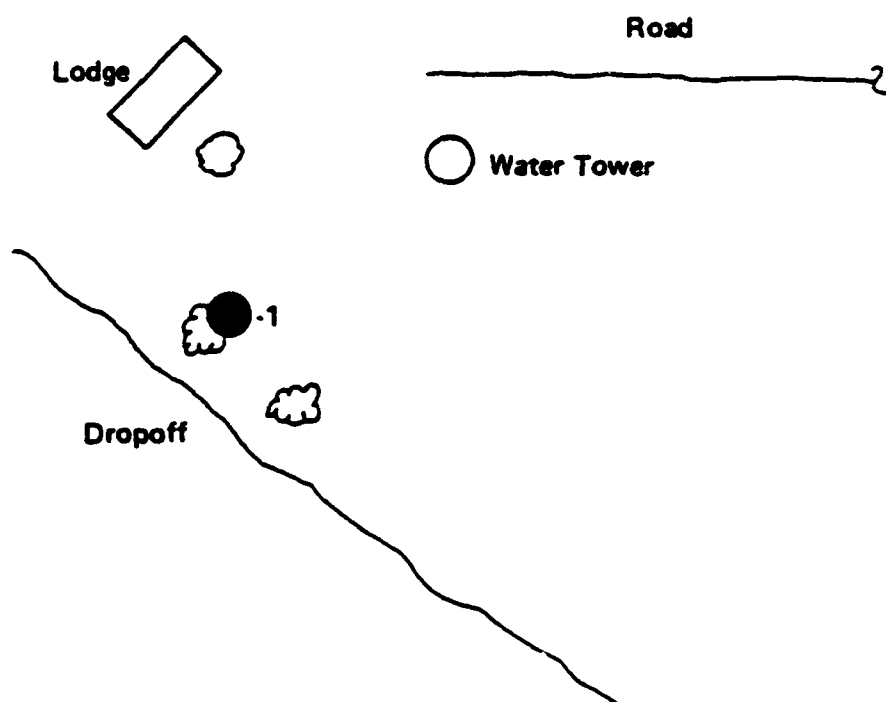
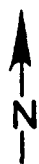


FIGURE 2. MEASUREMENT POINT AT RED MAPLE LEAF COLLECTION SITE; 4S1-1.

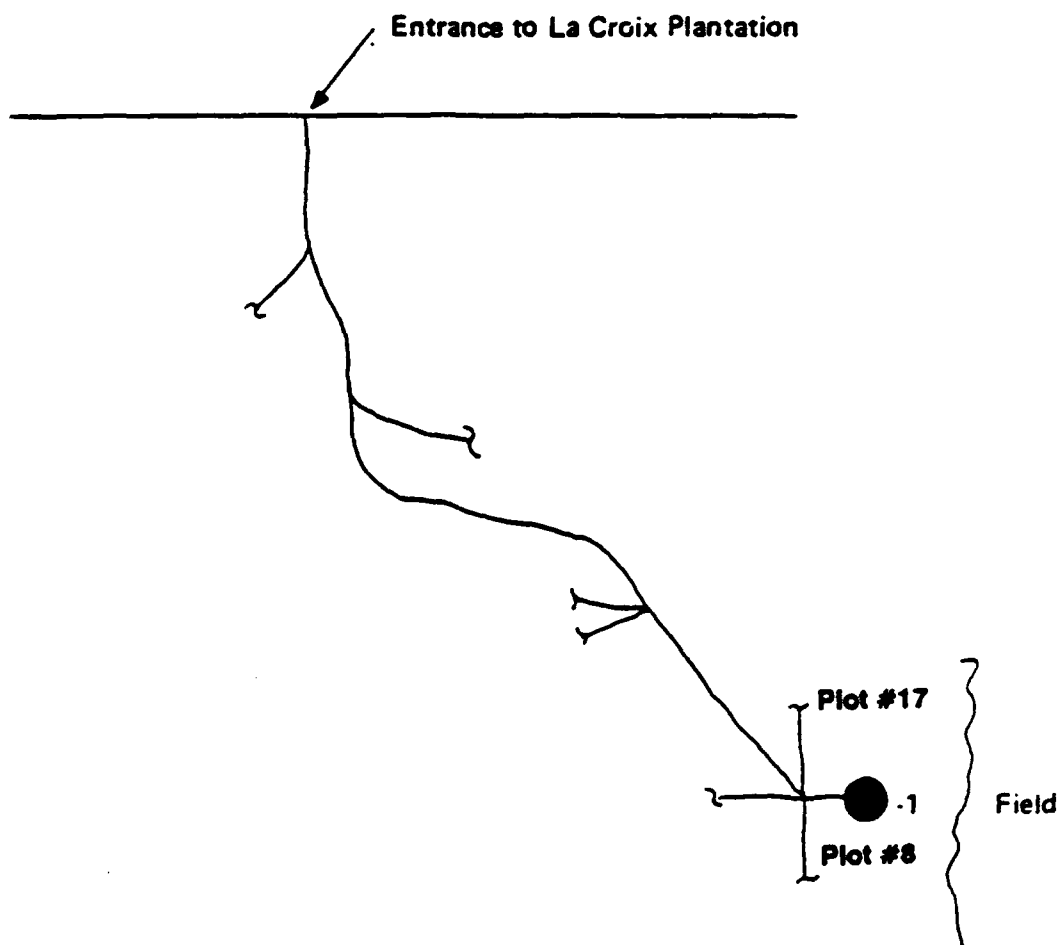
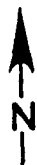


FIGURE 3. MEASUREMENT POINT AT THE PINE NEEDLE COLLECTION SITE; 4S3-1.

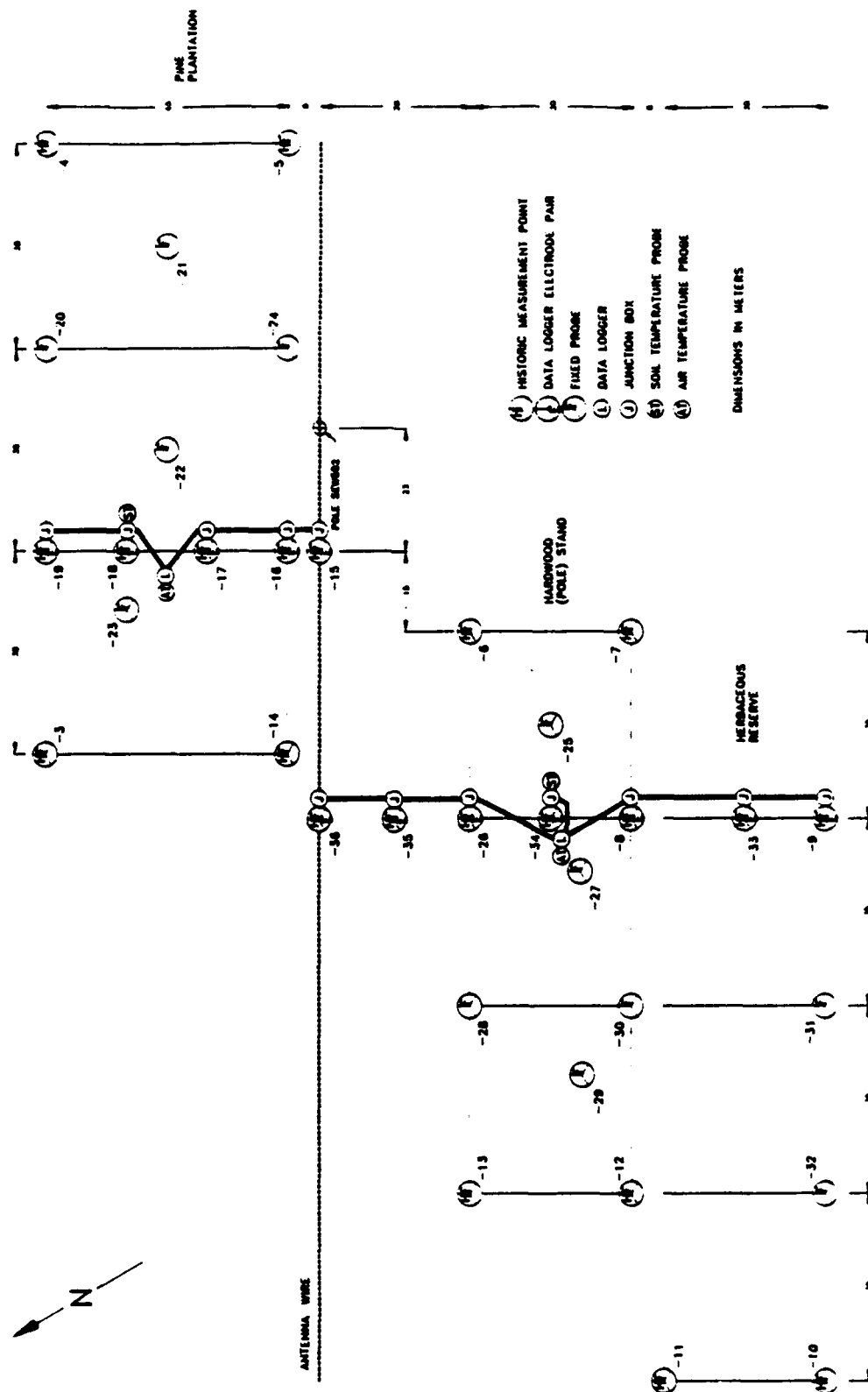


FIGURE 4. MTU ANTENNA SITE--MARTELL'S LAKE (OVERHEAD): MI MEASUREMENT POINTS; 412--3 THROUGH 56.

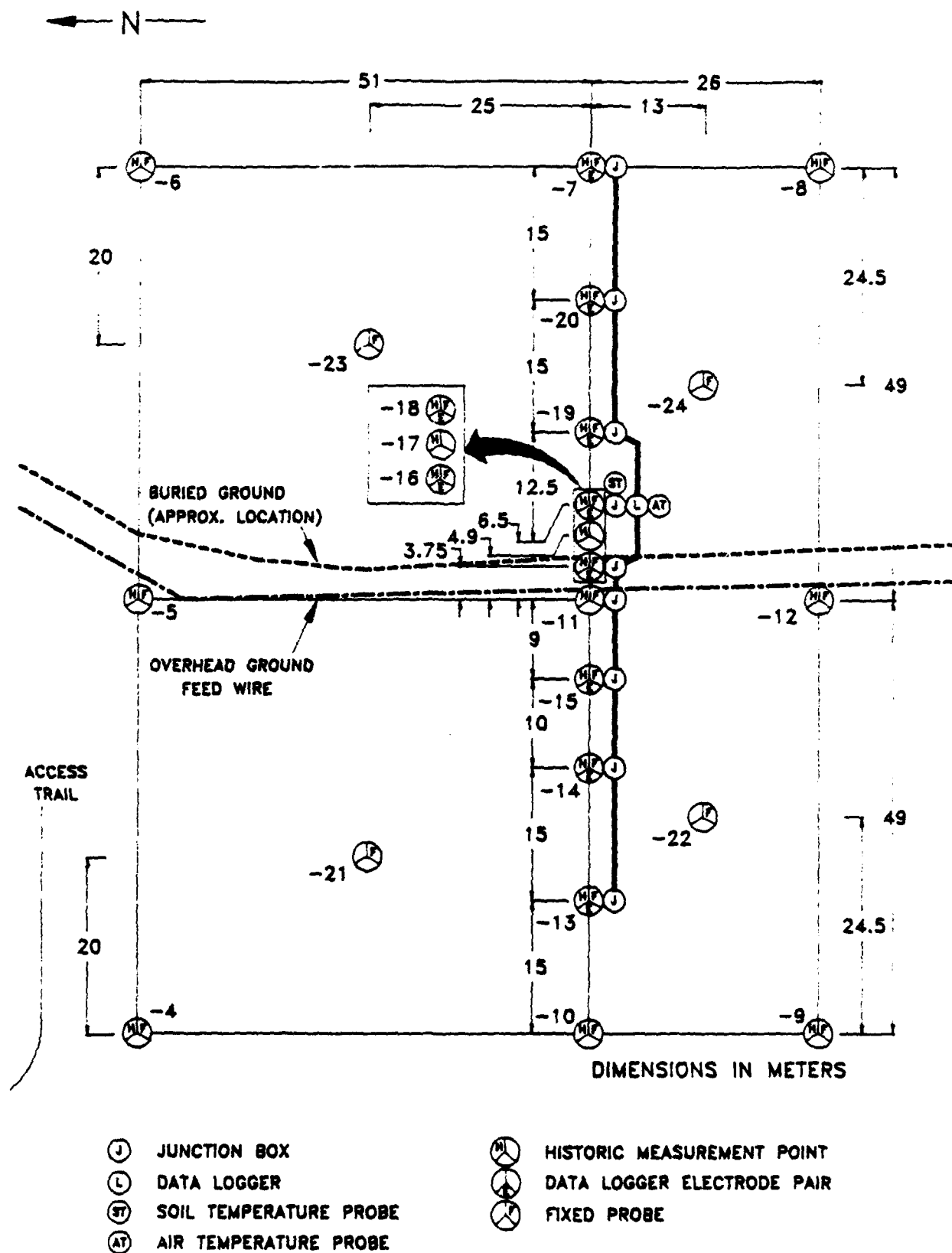


FIGURE 5. MTU GROUND SITE-MARTELL'S LAKE (BURIED):EP MEASUREMENT POINTS 4T4-4 THROUGH -24.

TABLE 2. 60 Hz AIR ELECTRIC FIELD INTENSITIES (V/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	-	0.003	<	<	<	<	< ^d	< ^b	< ^d
4C1-7	-	0.006	<	<	<	<	< ^d	< ^b	< ^d
4C1-8	-	0.004	<	<	<	<	< ^d	< ^b	< ^d
4C1-9	-	0.002	<	<	<	<	< ^d	< ^b	< ^d
4C1-10	-	-	<	<	<	<	< ^d	< ^b	< ^d
4C1-11	-	-	<	<	<	<	< ^d	< ^b	< ^d
4C1-12	-	-	<	<	<	<	< ^d	< ^b	< ^d
4C1-13	-	-	<	<	<	<	< ^d	< ^b	< ^d
4T2-3	-	0.001	<	<	<	0.002	# ^d	# ^d	/
4T2-4	-	-	<	<	<	0.001	# ^d	# ^j	/
4T2-5	-	-	<	<	<	0.011	# ^d	# ^d	/
4T2-6	-	-	<	<	<	<0.001	# ^d	# ^d	/
4T2-7	-	-	<	<	<	<0.001	# ^d	# ^d	/
4T2-8	-	-	<	<	<	/	# ^d	# ^d	/
4T2-9	-	-	<	<	<	<	# ^d	# ^d	/
4T2-10	-	-	<	<	<	<	# ^d	# ^d	/
4T2-11	-	-	<	<	<	<	# ^d	# ^d	/
4T2-12	-	-	<	<	<	/	# ^d	# ^d	/
4T2-13	-	-	<	<	<	<0.001	# ^d	# ^d	/
4T2-14	-	-	<	<	<	0.011	# ^d	# ^d	/
4T2-15	-	-	-	-	-	-	# ^d	# ^d	/
4T2-16	-	-	-	-	-	-	# ^d	# ^d	/
4T2-17	-	-	-	-	-	-	# ^d	# ^d	/
4T2-18	-	-	-	-	-	-	# ^d	# ^d	/
4T2-19	-	-	-	-	-	-	# ^d	# ^d	/
4T2-26	-	-	-	-	-	-	# ^d	# ^d	/
4T2-33	-	-	-	-	-	-	# ^d	# ^d	/
4T2-34	-	-	-	-	-	-	# ^d	# ^d	/
4T2-35	-	-	-	-	-	-	# ^d	# ^d	/
4T2-36	-	-	-	-	-	-	# ^d	# ^d	/

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

Site No., Mess. 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.

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	0.068	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	# ^d	0.61 ^b
4T2-33	-	-	-	-	-	-	# ^d	# ^d	0.75 ^b
4T2-34	-	-	-	-	-	-	# ^d	# ^d	0.81 ^b
4T2-35	-	-	-	-	-	-	# ^d	# ^d	0.73 ^b
4T2-36	-	-	-	-	-	-	# ^d	# ^d	0.60 ^b

TABLE 3. 60 Hz EARTH ELECTRIC FIELD INTENSITIES (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	1991
4T4-4	-	0.72	0.42	0.185	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	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	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	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	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	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	0.044	0.150
4T2-8	<	<	0.004	0.007	0.002	0.012	/	/	0.124	0.112	0.045	0.103	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	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	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	0.042	0.132
4T2-12	<	<	0.002	0.003	0.002	0.014	/	/	0.095	0.096	0.041	0.086	0.041	0.086
4T2-13	<	<	0.005	0.008	0.002	0.112	0.010	0.121	0.125	0.130	0.036	0.125	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	0.23	1.68
4T2-15	-	-	-	-	-	-	-	-	2.3	1.67	0.32	0.58	0.32	0.58
4T2-16	-	-	-	-	-	-	-	-	1.92	1.84	0.46	1.17	0.46	1.17
4T2-17	-	-	-	-	-	-	-	-	0.69	0.59	0.075	0.27	0.075	0.27
4T2-18	-	-	-	-	-	-	-	-	0.28	0.21	0.039	0.152	0.039	0.152
4T2-19	-	-	-	-	-	-	-	-	0.107	0.105	0.029	0.092	0.029	0.092
4T2-26	-	-	-	-	-	-	-	-	-	0.182	0.059	0.136	0.059	0.136
4T2-33	-	-	-	-	-	-	-	-	-	0.141	0.042	0.146	0.042	0.146
4T2-34	-	-	-	-	-	-	-	-	-	0.144	0.041	0.129	0.041	0.129
4T2-35	-	-	-	-	-	-	-	-	-	0.24	0.101	0.38	0.101	0.38
4T4-36	-	-	-	-	-	-	-	-	-	4.7	0.94	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	0.005	<	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	<	<	0.009	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

TABLE 6. 76 Hz EARTH ELECTRIC FIELD INTENSITIES (mV/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	0.33	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. / = measurement point not established.

EW = east-west antenna. / = measurement not taken.

NEW = northern EW antenna element. / = data cannot be extrapolated.

SEW = southern EW antenna element.

B = NS + EW antennas, standard phasing.

EX = extrapolated data.

A = amperes

TABLE 7. 76 Hz MAGNETIC FLUX DENSITIES (mG)
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	"	<0.001	<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	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. / = measurement point not established.

EW = east-west antenna. / = measurement not taken.

NEW = north EW antenna element.

SEW = south EW antenna element.

B = NS + EW antennas, standard phasing.

EX = extrapolated data.

A = amperes.

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	103	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																Mean	S.D.	Coeff. of Variab.	
	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
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	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	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	7/10	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.
414-4	31	29	27	28	31	31	32	32	12	9	8.7	8.3	23	9.9	0.42
414-5	1670	1800	1830	1950	2100	2000	2000	1980	1720	1740	1980	1910	1900	134	0.071
414-6	117	115	115	125	136	138	141	143	148	140	142	140	133	11.4	0.086
414-7	135	132	130	132	137	135	137	139	144	146	145	149	138	6.0	0.043
414-8	113	108	105	106	109	105	108	109	112	113	109	111	109	2.7	0.025
414-9	42	42	42	43	42	43	43	44	18	20	20	22	35	10.7	0.31
414-10	32	30	30	30	30	29	32	33	35	37	37	37	33	3.0	0.090
414-11	1890	1940	2200	2300	2000	2100	2000	2000	2200	2200	2400	2500	2200	185	0.086
414-12	1600	1610	1700	1820	1850	1820	1900	1960	1820	1770	1820	1860	1790	104	0.058
414-21	109	107	91	97	122	127	131	134	146	135	132	136	122	16.5	0.135
414-22	148	137	139	148	153	154	159	169	177	174	170	165	158	12.8	0.081
414-23	330	340	330	350	380	370	390	400	410	380	370	390	370	25	0.069
414-24	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																	Mean	S.D.	Coeff. of Variab.
	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			
414-4	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
414-5	2100	2100	2200	2200	1850	480	480	410	1780	1780	1850	1910	1900	1900	1850	1460	1580	1890	210	0.109
414-6	131	131	135	135	100	32	29	30	123	125	133	140	141	143	141	132	110	130	11.8	0.091
414-7	136	147	135	155	134	37	36										145	142	7.7	0.054
414-8	108	112	109	115	108	30	29	29	110	102	102	105	105	108	108	112	110	108	3.6	0.033
414-9	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
414-10	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
414-11	2600	2800	3200	2900	2400	550	550	480	2000	2200	2400	2100	2100	2100	2200	1790	2000	2300	390	0.167
414-12	2500	2300	2600	2700	1890	470	450	380	1550	1520	1580	1700	1800	1900	1830	1400	1520	1910	420	0.22
414-13													76	79				78	1.5	0.019
414-14												260	220	230	230	200	270	310	128	0.42
414-15										640	850	790	790	790	800	710	750	760	60	0.079
414-16										3500	3600	3100	3100	3200	3300	3400	3600	3300	194	0.058
414-18										4100	4400	4100	4200	4400	4400	4500	5000	4400	270	0.062
414-19												750	780	820	840	710	700	770	55	0.072
414-20																	220	220	0.0	0.0
414-21	128	123	120	149	92	39	34	33	113	89	100	124	130	128	130	111	98	117	16.5	0.141
414-22	154	148	143	161	123	52	44	46	133	149	152	156	152	157	160	151	129	148	11.2	0.076
414-23	390	380	400	390	310	91	88	83	340	370	390	400	390	400	400	340	320	370	30	0.081
414-24	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.

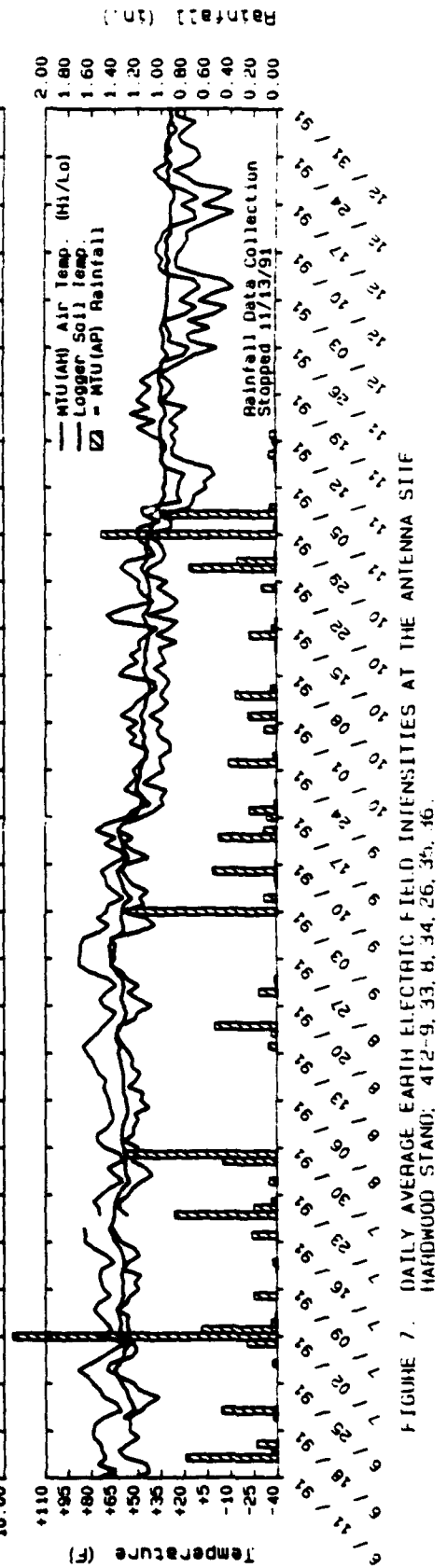
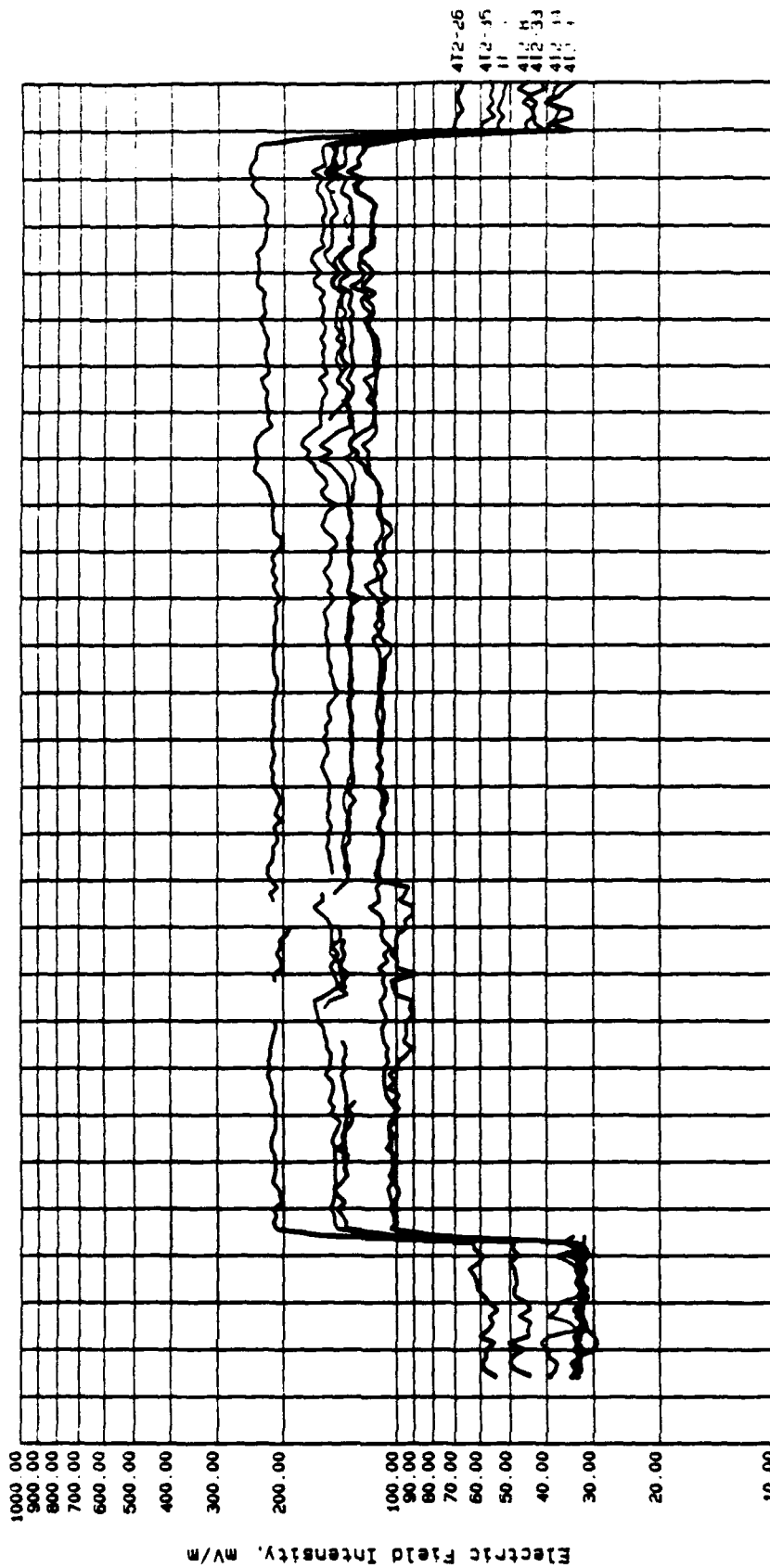
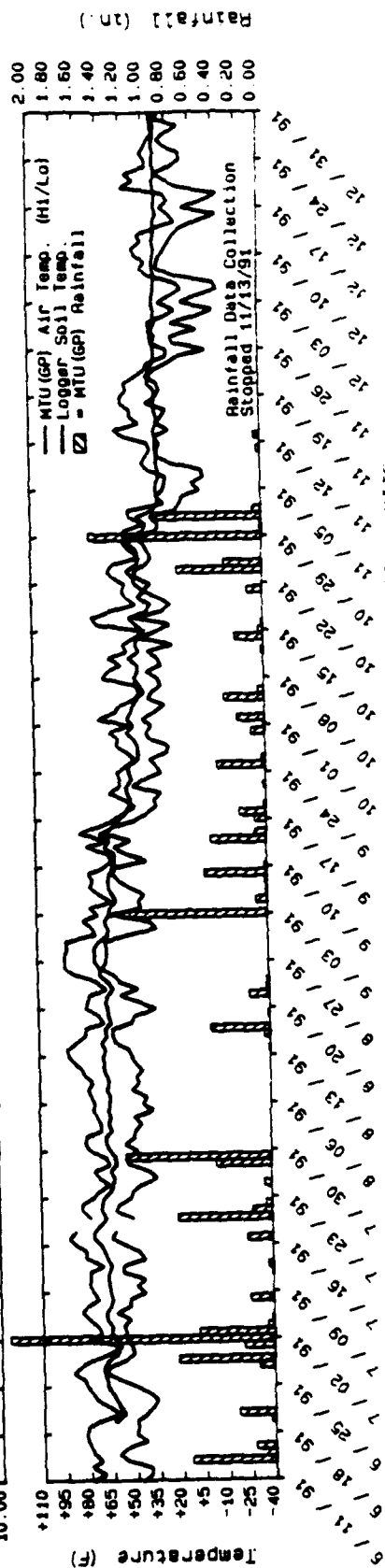
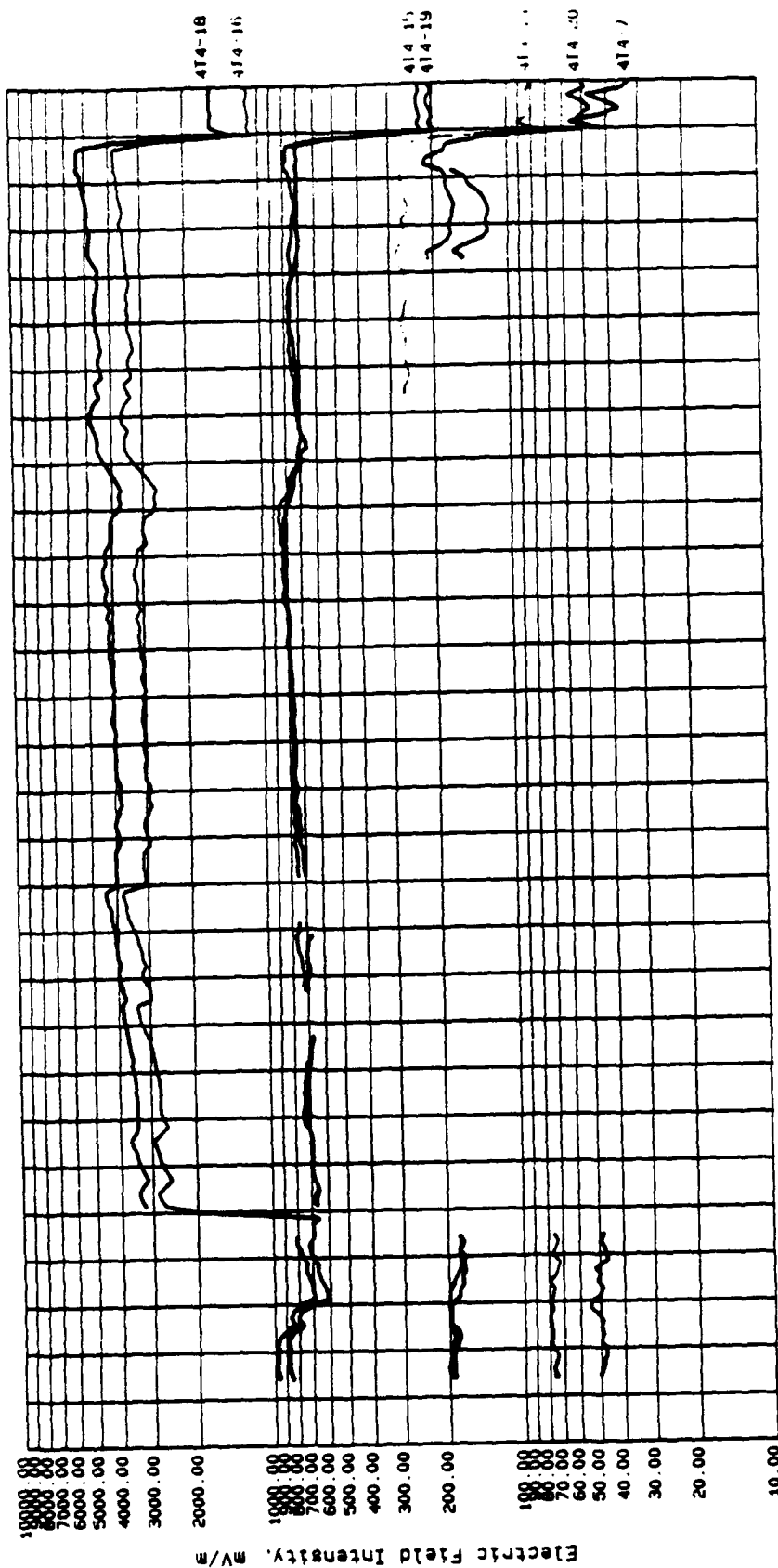


FIGURE 7. DAILY AVERAGE EARTH ELECTRIC FIELD INTENSITIES AT THE ANTENNA SITE
HARDWOOD STAND; 412-9, 33, 8, 34, 26, 35, 36.



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

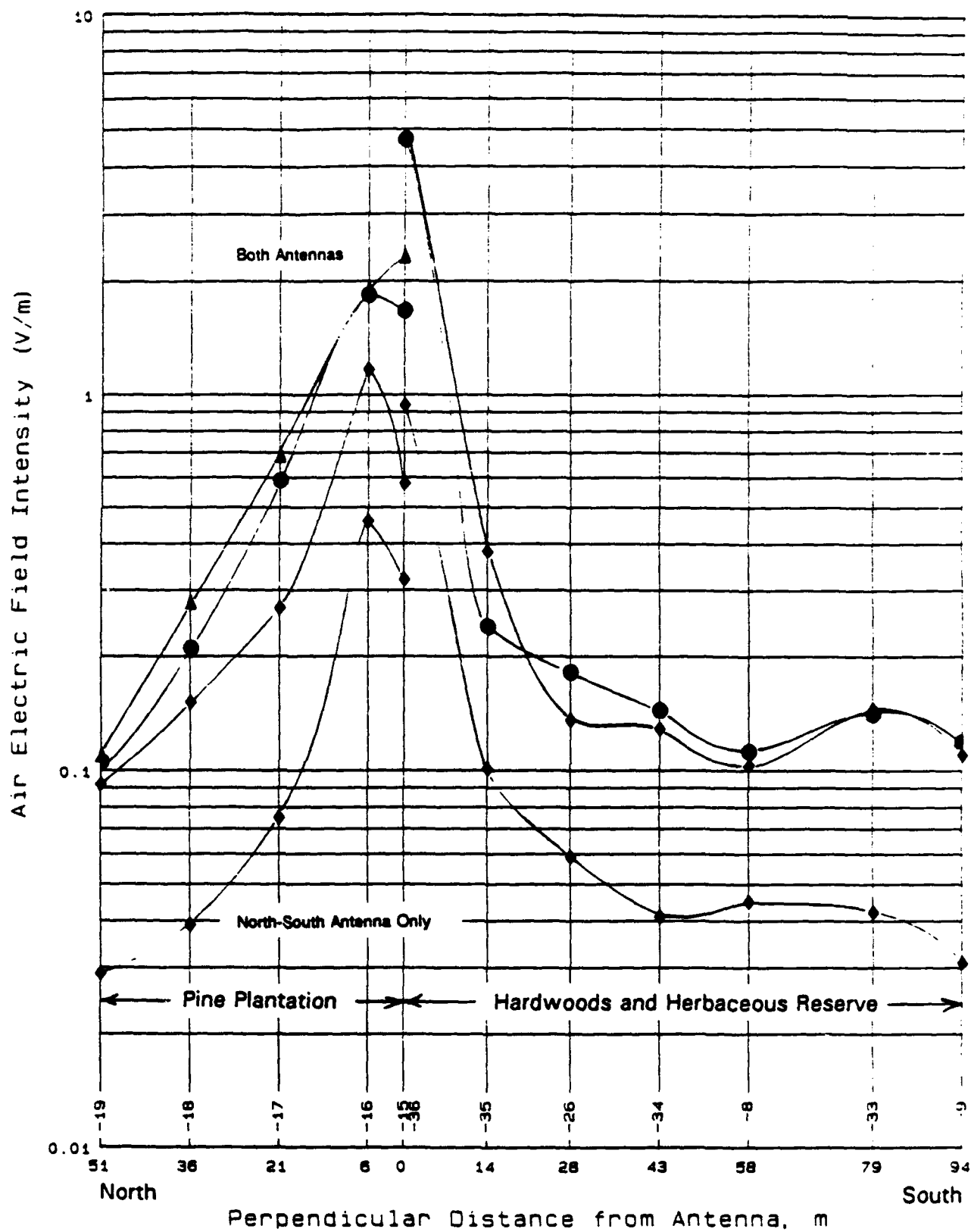


FIGURE 9. 76 Hz AIR ELECTRIC FIELD PROFILES
MARTELL'S LAKE (OVERHEAD): ML: 4T2-8, 9, 15-19, 26, 33-36.

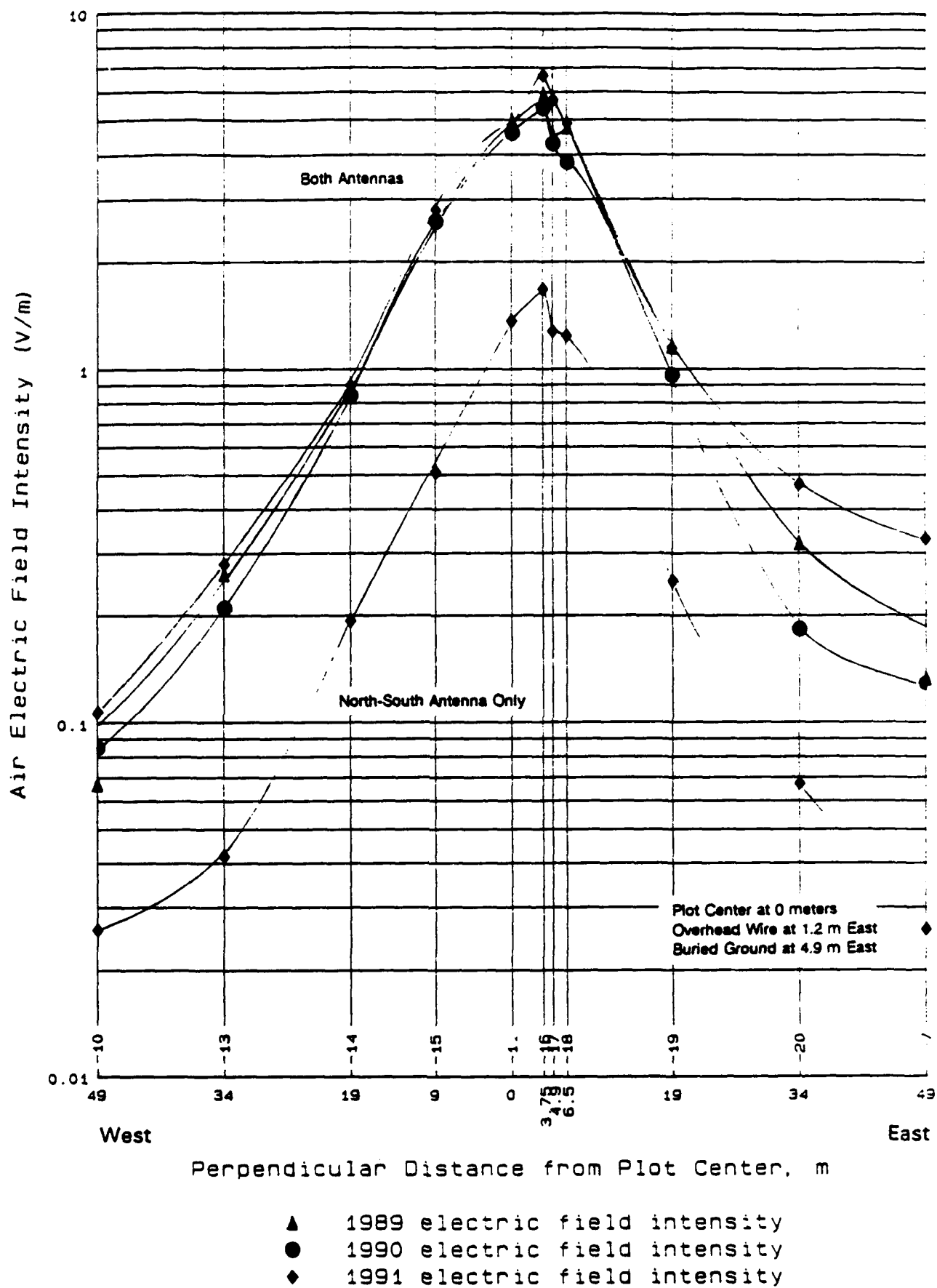


FIGURE 10. 76 Hz AIR ELECTRIC FIELD PROFILES
MARTELL'S LAKE (BURIED): EP; 4T4-7, 10, 11, 13-20.

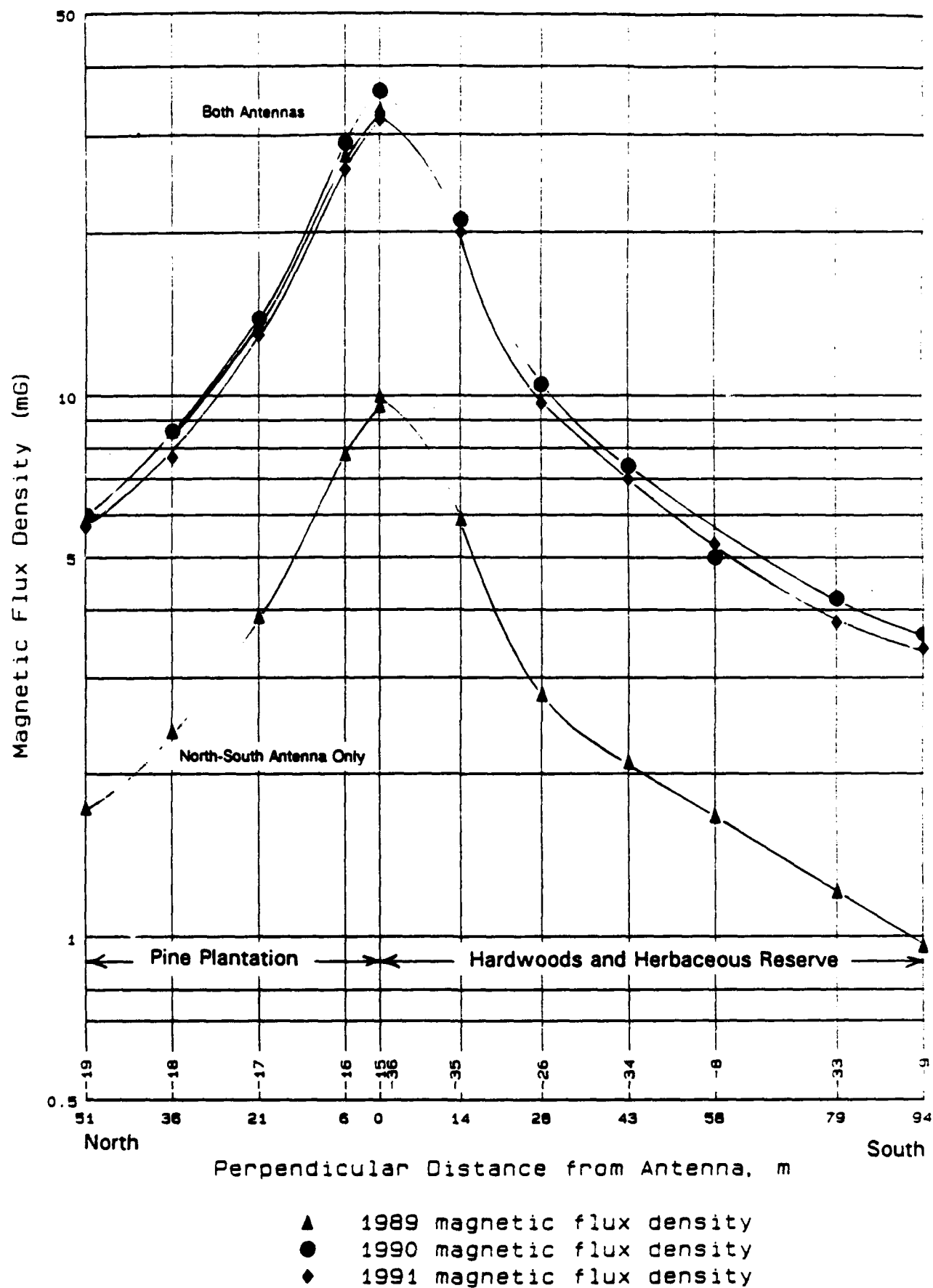


FIGURE 11. 76 HZ MAGNETIC FLUX DENSITY PROFILES
 MARTELL'S LAKE (OVERHEAD): ML; 4T2-8, 9, 15-19, 26, 33-36.

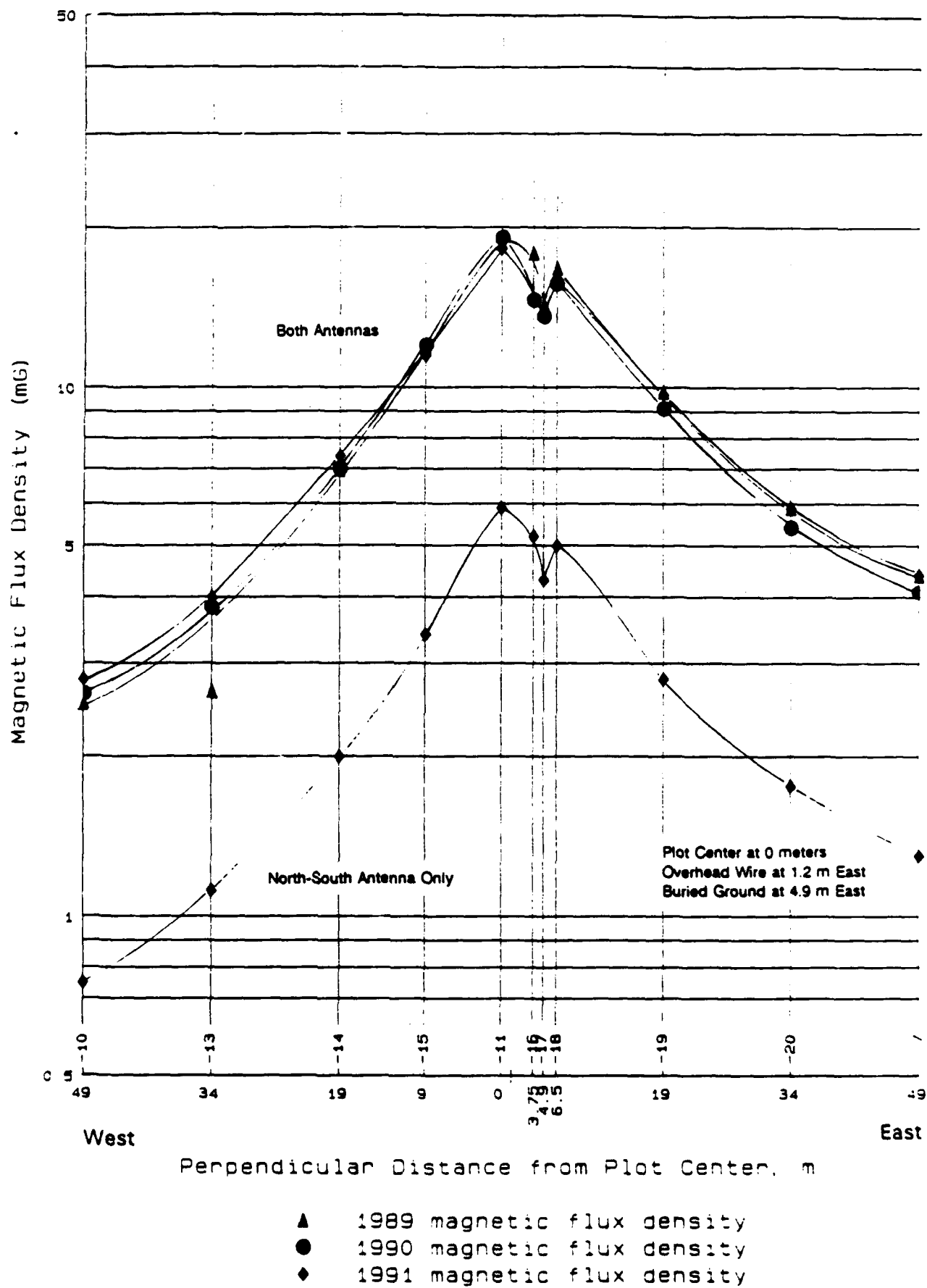


FIGURE 12. 76 Hz MAGNETIC FLUX DENSITY PROFILES
MARTELL'S LAKE (BURIED): EP; 4T4-7, 10, 11, 13-20.

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.

Earth Electric Field Intensity Profiles

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
<u>ANT/HWD</u>									
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	139
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
<u>ANT/PIN</u>									
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
<u>GND/PIN</u>									
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

**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
<u>ANT/HWD</u>									
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
<u>ANT/PIN</u>									
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
<u>GND/PIN</u>									
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 ($\pm$ 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

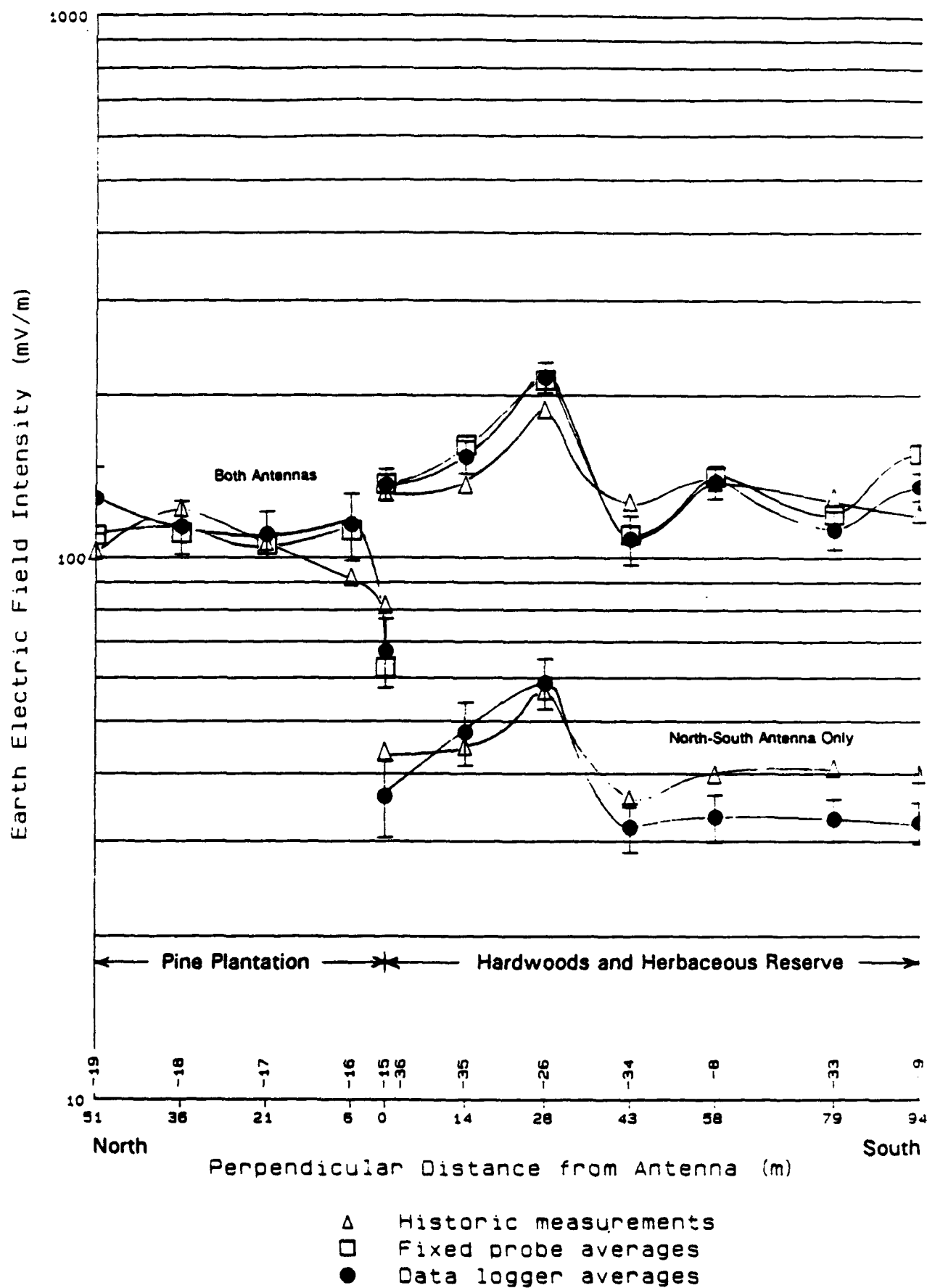


FIGURE 13. COMPARISON OF 76 HZ EARTH ELECTRIC FIELDS AT SITE 17E. ERROR BARS ARE +/- ONE STD. DEV. OF THE LOGGER DATA.

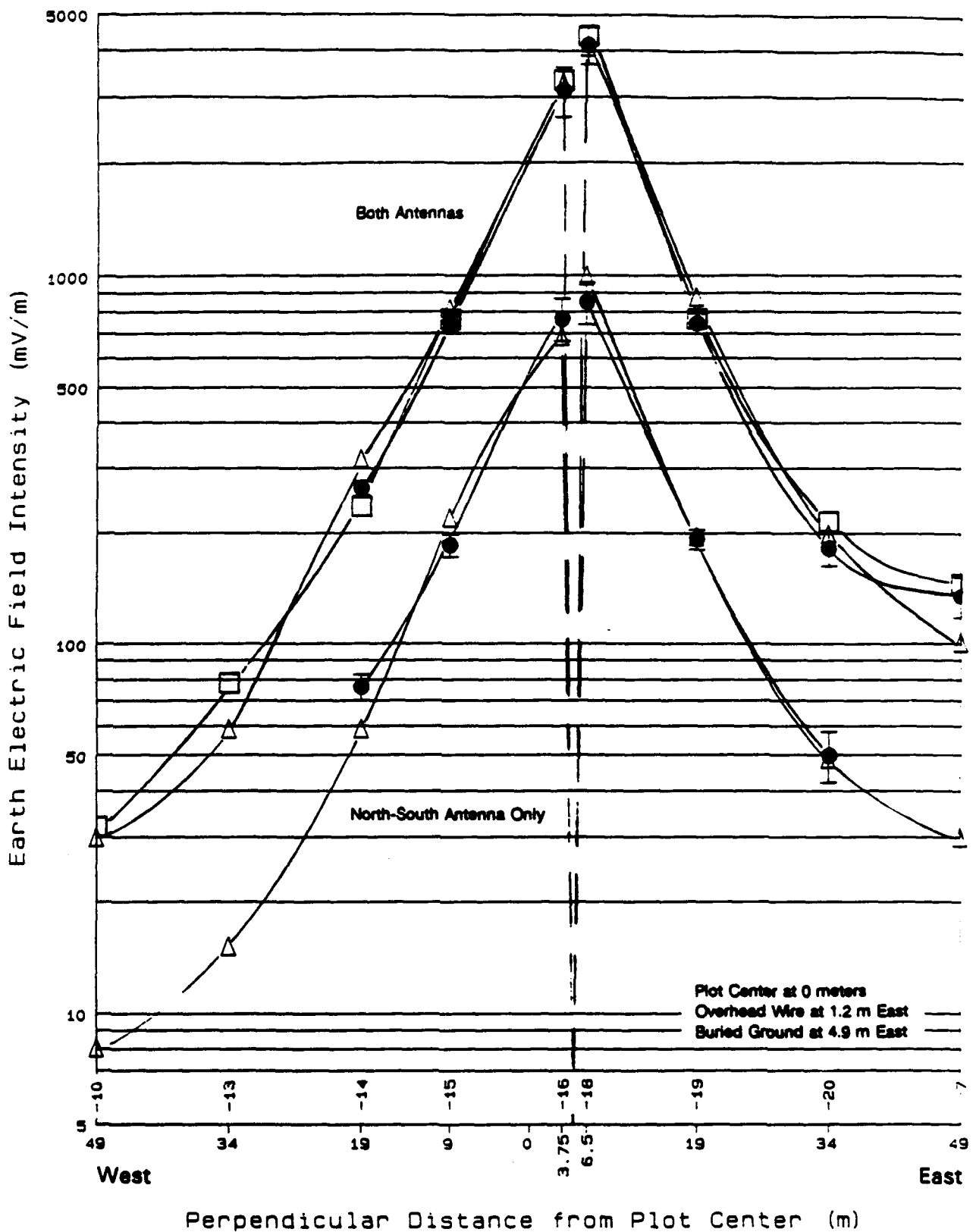


FIGURE 14. COMPARISON OF 76 Hz EARTH ELECTRIC FIELDS AT SITE 47. ERROR BARS ARE $\pm$ ONE STD. DEV. OF THE LOGGER DATA.

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 combination of these influences. Furthermore, non-homogenous 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 ($\text{std./mean} \times 100\%$) 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
<u>ANT/HWD</u>									
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%	68 8.4%
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%
<u>ANT/PIN</u>									
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%	69 13.6%	61 17.1%	28 31%
<u>GND/PIN</u>									
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%	750 3.2%	820 3.7%	740 3.8%	710 2.8%	210 6.4%
4T4-18	940 6.2%	750 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%	690 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%					260 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.

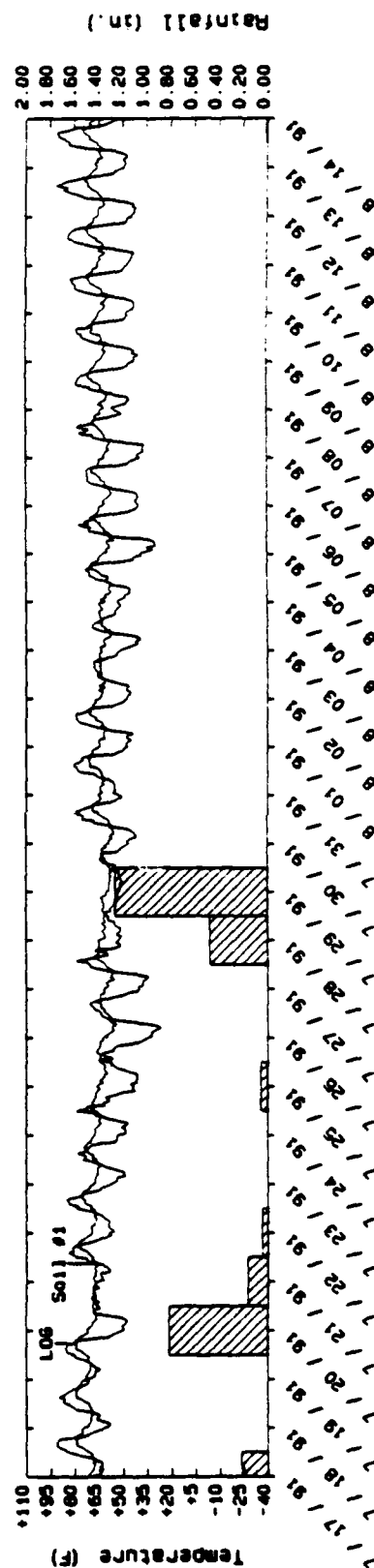
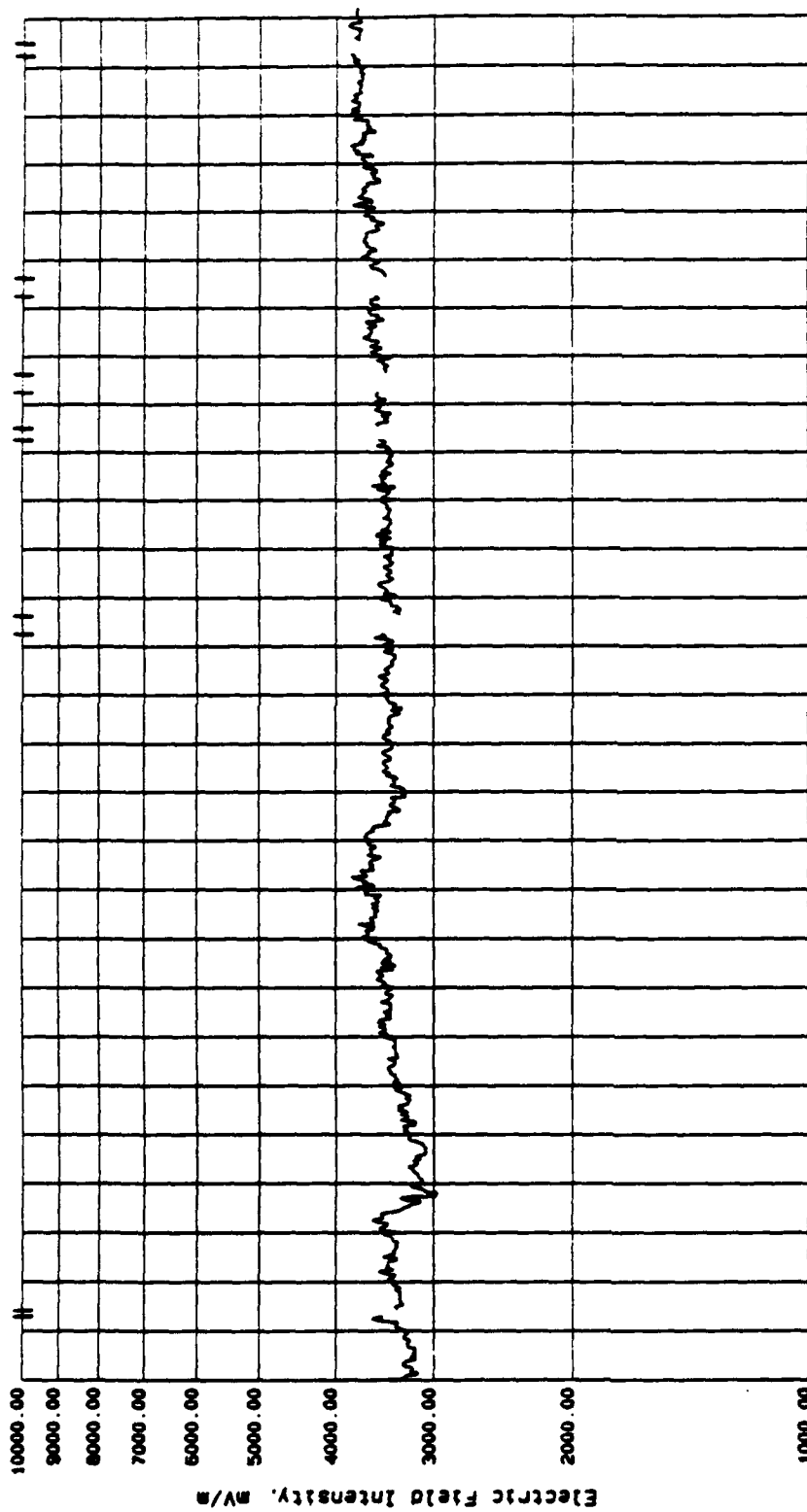


FIGURE 15. HOURLY EARTH ELECTRIC FIELD INTENSITIES AT THE GROUND SITE PINE PLANTATION; MEASUREMENT POINT 474-18.

Temperature
[] - MTU(GP) Water Equi

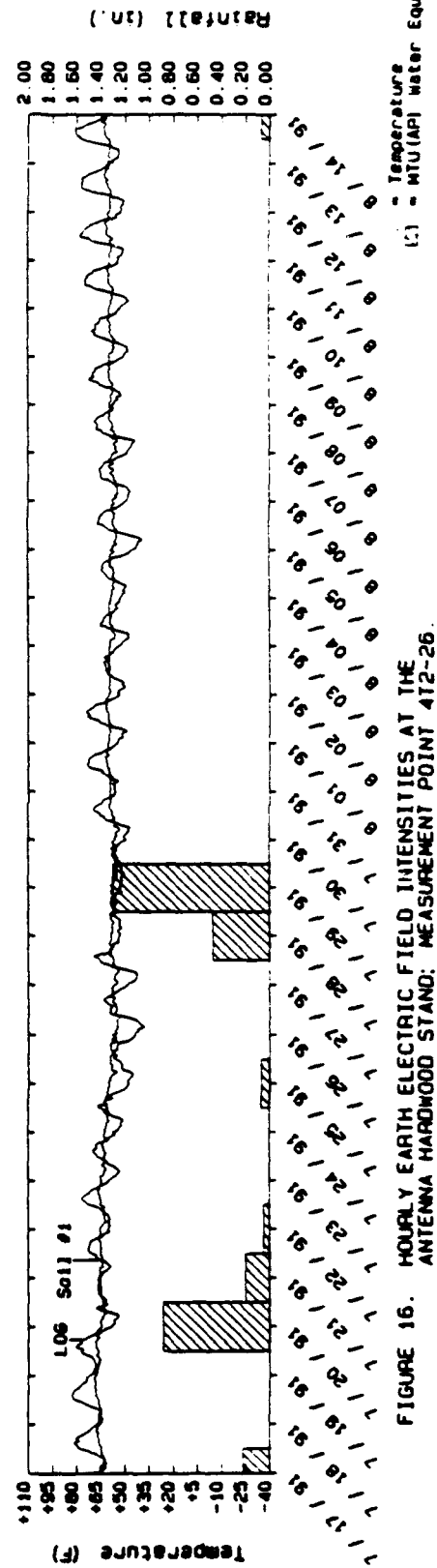
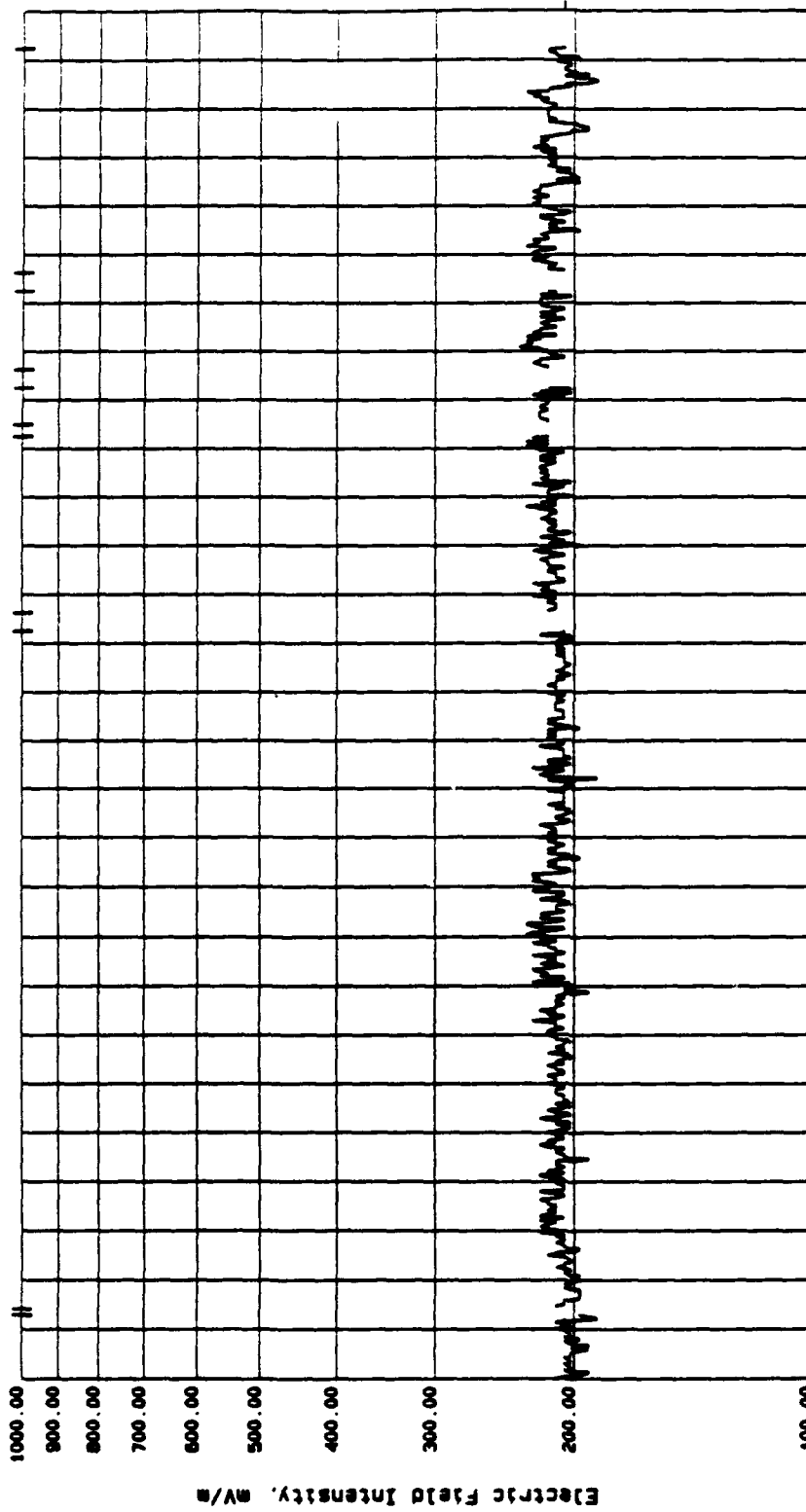


FIGURE 16. HOURLY EARTH ELECTRIC FIELD INTENSITIES AT THE ANTENNA HARDWOOD STAND; MEASUREMENT POINT 4T2-26.

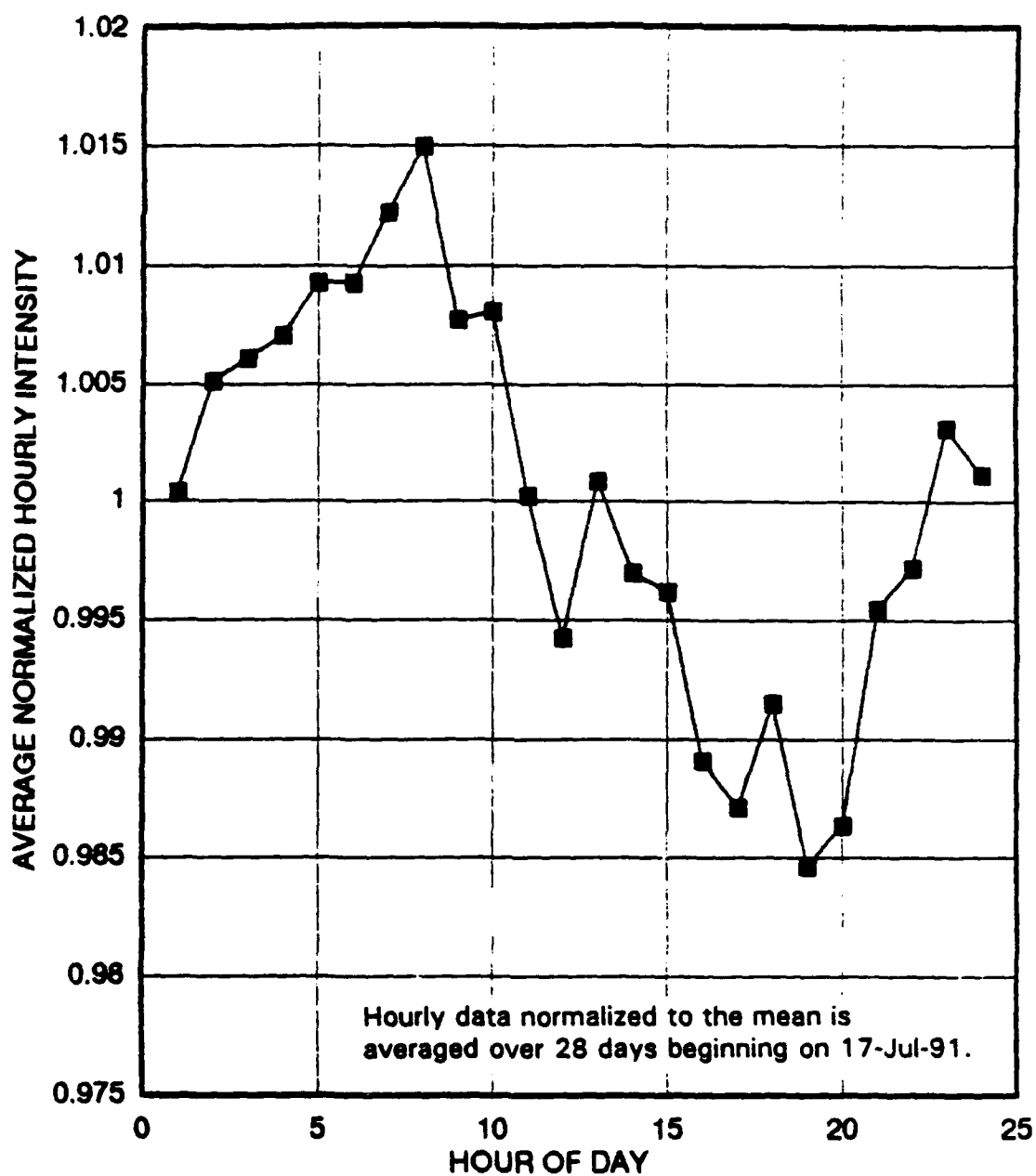


FIGURE 17. EARTH ELECTRIC FIELD DIURNAL CYCLE AT THE GROUND SITE PINE PLANTATION; MEASUREMENT POINT 4T4-18.

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.

1992 Schedule

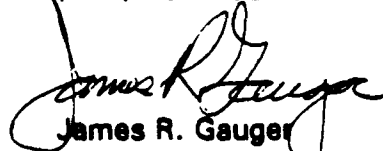
The NRTF-Republic is expected to continue full-time 150 ampere operation, except during scheduled maintenance periods in 1992. The annual EM measurements are expected to be conducted in the fall of 1992. If you require any special engineering assistance or EM measurements in addition to those normally conducted or already discussed above, please inform us immediately so that these activities may be scheduled.

Sincerely,

IIT RESEARCH INSTITUTE



David P. Haradem
Research Engineer
(312) 567-4622



James R. Gauger
Engineering Advisor
(312) 567-4480

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	100
Plot 2	0.0000	10.1800	22.3900	90.8300	211.0900	185.6800	300
Plot 3	0.0000	13.5000	29.6900	120.4300	279.8700	246.1900	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:			1991ns	Regression Output:		
	Constant		0.413401		Constant		4.915485
	Std Err of Y Est		0.065915		Std Err of Y Est		0.587383
	R Squared		0.951806		R Squared		0.904997
	No. of Observations		9		No. of Observations		17
	Degrees of Freedom		6		Degrees of Freedom		14
1987	X Coefficient(s)	-0.00592	1.449598	1989-91	X Coefficient(s)	-0.08199	-0.05436
	Std Err of Coef.	0.004479	1.185233		Std Err of Coef.	0.007469	0.066066
	Regression Output:				Regression Output:		
	Constant		1.09875		Constant		16.41759
	Std Err of Y Est		0.152989		Std Err of Y Est		1.879233
	R Squared		0.953923		R Squared		0.911485
1988	No. of Observations		9		No. of Observations		17
	Degrees of Freedom		6		Degrees of Freedom		14
	X Coefficient(s)	-0.01606	2.915353		X Coefficient(s)	-0.27282	-0.1837
	Std Err of Coef.	0.010395	2.750936		Std Err of Coef.	0.023897	0.211366
	Regression Output:				Regression Output:		
	Constant		5.740808		Constant		12.69044
	Std Err of Y Est		0.547943		Std Err of Y Est		9.852722
	R Squared		0.97487		R Squared		
	No. of Observations		9		No. of Observations		
	Degrees of Freedom		6		Degrees of Freedom		
	X Coefficient(s)	-0.08476	12.69044		X Coefficient(s)		
	Std Err of Coef.	0.037231	9.852722		Std Err of Coef.		

Figure 1. Magnetic flux interpolation equations for the ground site.

$$mG = a_0 + a_1 X + a_2 / X$$

1986	Regression Output:			1991	Regression Output:				
	Constant		0.306765		Constant		2.63242		
	Std Err of Y Est		0.03114		Std Err of Y Est		0.443738		
	R Squared		0.991864		R Squared		0.964369		
	No. of Observations		12		No. of Observations		20		
	Degrees of Freedom		9		Degrees of Freedom		17		
X Coefficient(s)			-0.00248	4.360294	X Coefficient(s)			-0.0239	30.79394
Std Err of Coef.			0.000535	0.266561	Std Err of Coef.			0.005775	2.919799
1987	Regression Output:			1989-91ns	Regression Output:				
	Constant		0.85487		Constant		8.752003		
	Std Err of Y Est		0.101768		Std Err of Y Est		1.449636		
	R Squared		0.984606		R Squared		0.967304		
	No. of Observations		12		No. of Observations		56		
	Degrees of Freedom		9		Degrees of Freedom		53		
X Coefficient(s)			-0.00685	9.885593	X Coefficient(s)			-0.08037	110.1662
Std Err of Coef.			0.001747	0.871151	Std Err of Coef.			0.011356	5.618626
1988	Regression Output:				Regression Output:				
	Constant		3.543742		Constant		3.543742		
	Std Err of Y Est		0.304458		Std Err of Y Est		0.304458		
	R Squared		0.994488		R Squared		0.994488		
	No. of Observations		12		No. of Observations		12		
	Degrees of Freedom		9		Degrees of Freedom		9		
X Coefficient(s)			-0.02727	52.81739	X Coefficient(s)			-0.02727	52.81739
Std Err of Coef.			0.005226	2.606209	Std Err of Coef.			0.005226	2.606209

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.

$$\text{mV/m} = a_0 + a_1 Y$$

Appendix B: Climatic Monitoring Information

Table 1a. Replacement equations for missing ambient data 1991.

1991 Missing Data Equations					
<u>Plot</u>	<u>Equation</u>	<u>$\bar{Y}$</u>	<u>Standard Error</u>	<u>R^2</u>	<u>Confidence Interval at X_1</u>
Soil Temperature Ground Plantation Plots (5 cm)					
1	$Y = .168 + 1.028(X_1)$	10.8	.166	.954	$Y \pm .33$
2	$Y = -.231 + 1.148(X_1)$	12.8	.115	.982	$Y \pm .23$
3	$Y = .100 + .982(X_1)$	14.2	.250	.992	$Y \pm .51$
X_1 = average daily soil temperature 10 cm at ground site Y = average daily soil temperature 5 cm at ground site					
Soil Moisture (%) Ground Plantation Plots (5 cm)					
1	$Y = .986(X_1) + 2.565$	15.9	.316	.808	$Y \pm .65$
2	$Y = .783(X_1) + 3.178$	14.5	.606	.606	$Y \pm .41$
3	$Y = .431(X_1) + 8.670$	15.6	.302	.302	$Y \pm .62$
X_1 = average daily soil moisture 10 cm at ground site Y = average daily soil temperature 5 cm at ground site					
Air Temperature Antenna Plantation Plots					
1	$Y = 1.009(X_1) + .183$	10.6	.102	.990	$Y \pm .21$
2	$Y = 1.013(X_1) - .013$	10.4	.090	.992	$Y \pm .19$
3	$Y = .995(X_1) + .363$	10.6	.013	.987	$Y \pm .03$
X_1 = average daily air temperature at ground site Y = average daily air temperature at antenna site					
Air Temperature Antenna Hardwood Plots					
1	$Y = .998(X_1) + .524$	10.8	.148	.980	$Y \pm .30$
2	$Y = .990(X_1) + .332$	10.5	.143	.981	$Y \pm .29$
3	$Y = .992(X_1) - .038$	10.2	.103	.990	$Y \pm .21$
X_1 = average daily air temperature at ground site Y = average daily air temperature at antenna site					

Table 1b. Replacement equations for missing ambient data 1991.

1991 Missing Data Equations					
Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
Soil Temperature Antenna Plantation Plots (5 cm)					
1	$Y = .777 + 1.028(X_1) - .237(X_2)$	18.0	.001	.998	$Y \pm .01$
2	$Y = .183 + 1.082(X_1) - .142(X_2)$	9.3	.061	.995	$Y \pm .12$
3	$Y = .470 + 1.117(X_1) - .152(X_2)$	10.2	.087	.992	$Y \pm .18$
X_1 = average daily soil temperature 10 cm at antenna site X_2 = month of year (i.e...4,5) Y = average daily soil temperature 5 cm at antenna plantation plots					
Soil Temperature Antenna Hardwood Plots (5 cm)					
1	$Y = 2.663 + 1.036(X_1) - .544(X_2)$	7.7	.040	.997	$Y \pm .08$
2	$Y = 3.171 + 1.059(X_1) - .665(X_2)$	7.4	.038	.997	$Y \pm .08$
3	$Y = 4.987 + 1.057(X_1) - 1.107(X_2)$	7.6	.054	.995	$Y \pm .11$
X_1 = average daily soil temperature 5 cm on antenna site X_2 = month of year (i.e...4,5) Y = average daily soil temperature 5 cm on antenna hardwood plots					
Soil Temperature Antenna Plantation Plots (10 cm)					
1	$Y = .075 + 1.015(X_1)$	9.0	.106	.982	$Y \pm .21$
2	$Y = 14.860 + 1.270(X_1)$	9.3	.241	.921	$Y \pm .49$
3	$Y = 10.264 + 1.263(X_1)$	9.3	.120	.981	$Y \pm .24$
X_1 = average daily soil temperature 10 cm at ground site Y = average daily soil temperature 10 cm at antenna plantation plots					

Table 1c. Replacement equations for missing ambient data 1991.

1991 Missing Data Equations					
Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1
Soil Temperature Antenna Hardwood Plots (10 cm)					
1	$Y = 3.469 + 1.052(X_1) - 1.183(X_2)$	7.3	.132	.971	$Y \pm .27$
2	$Y = 2.733 + .926(X_1) - .934(X_2)$	6.9	.126	.969	$Y \pm .25$
3	$Y = 1.070 + .981(X_1) - .557(X_2)$	7.1	.120	.975	$Y \pm .24$
X_1 = average daily soil temperature 10 cm at ground site X_2 = month of year (i.e...4,5) Y = average daily soil temperature 10 cm at antenna hardwood plots					
Relative Humidity Antenna Site					
	$Y = 24.56 + .755(X_1)$	79.4	.493	.808	$Y \pm .99$
X_1 = daily relative humidity at ground site Y = daily relative humidity at antenna site					
Control Average Vegetation Temperature (30 cm)					
	$Y = .199 + .964(X)$	13.6	.071	.996	$Y \pm .14$
X_1 = average daily air temperature Control air temperature in hardwoods Y = average vegetation temperature at control site					

Appendix C: Hardwood Growth Modeling Manuscript

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 perturbation 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 $46^{\circ}10'N$, $88^{\circ}30'W$ and Site 2 is at $46^{\circ}20'N$, $88^{\circ}10'W$. 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 Cattellino 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 $\times$ 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 ($\text{m}^2 \text{ha}^{-1}$)	Density (stems ha^{-1})	Site index (m @ 50 years)	Age (years)
<i>Site 1</i>						
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
<i>Site 2</i>						
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_i , 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_{*i*}).

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

$$d_i = \text{PG} \times \text{IC} \times \text{SPC} \times \text{SGP}_i \quad (1)$$

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
<i>Annual potential diameter growth component</i>				
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)

<i>Intertree competition component</i>				
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)
<i>Site physical, chemical and climatic factor component</i>				
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)
<i>Seasonal growth pattern component</i>				
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 $32 \text{ m}^2 \text{ ha}^{-1}$ 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 ($<0.01 \text{ m}$) 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 $\times$ 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

$$CI_i = \sum (DBH_j / DBH_i) \quad (5)$$

where CI_i is the value of the competition index for the i th (subject) tree, DBH_i is the diameter of the subject tree, DBH_j is the diameter of the j th 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

$$CI_i = \sum [(a_{ij}/A_i) \times (DBH_j/DBH_i)^3] \quad (6)$$

where CI_i is the value of the competition index for the i th (subject) tree, DBH_i is the diameter of the subject tree, DBH_j is the diameter of the j th competitor, A_i is the area of the influence zone (as defined by the open grown crown radius given by Ek (1974)) of the i th tree, and a_{ij} is the area of the overlap of the influence zones of the i th tree and the j th 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

$$IC = e^{-(a \times CI)} \quad (7)$$

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

$$SPC = \frac{(DBH + c_0 + c_1 X_1 + c_2 X_2 + c_3 X_3)}{DBH} \quad (8)$$

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_{t1}) and end (ATD_{t2}) of week t and average soil water potential at 5 cm in week t (SWP_t)

$$SGP_t = [e^{-(ATD_{t1}/d_1)d_2} - e^{-(ATD_{t2}/d_1)d_2}] \times [e^{-d_3(SWP_t - 0.101)}] \quad (9)$$

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)	$H_0: \mu_R = 0$ $H_a: \mu_R \neq 0$
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

$$PVE = \frac{\sum (Y_i - \bar{Y})^2 - \sum (Y_i - \hat{Y}_i)^2}{\sum (Y_i - \bar{Y})^2}$$

where Y_i is the observed growth for the i th tree; $\hat{Y}_i$ is the predicted growth for the i th tree; $\bar{Y}$ is the average growth for all trees of the same species as the i th 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	
<i>Northern red oak</i>						
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
<i>Paper birch</i>						
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
<i>Aspen</i>						
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
<i>Red maple</i>						
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 aboveground)	1	12.9	13.5	13.3
	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.

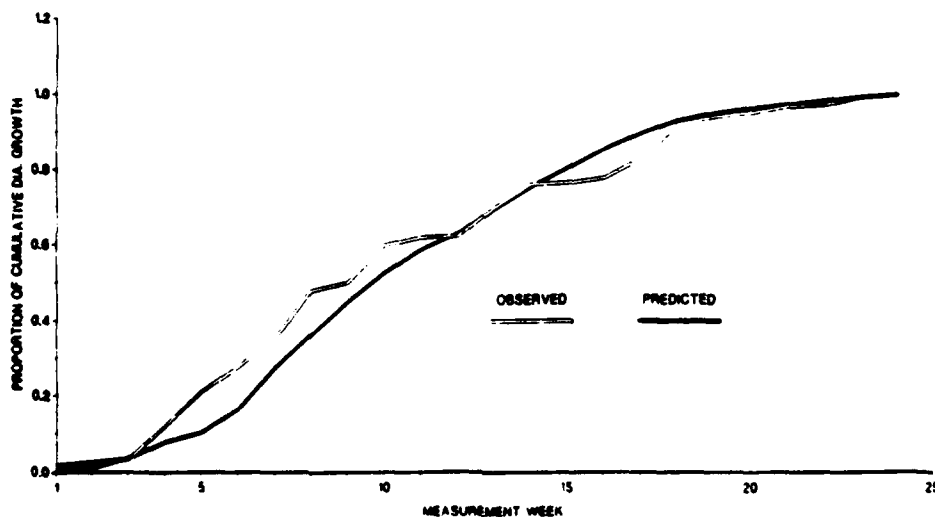


Fig. 1. Observed and predicted seasonal growth patterns for northern red oak on Plot 2, Site 2 in 1988.

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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REFERENCES

- Albert, D.A., Denton, S.R. and Barnes, B.V., 1986. Regional landscape ecosystems of Michigan. School of Natural Resources, University of Michigan, Ann Arbor, 32 pp.
- Belcher, D.W., Holdaway, M.R. and Brand, G.J., 1982. A description of STEMS—the stand and tree evaluation and modeling system. USDA Forest Service, General Technical Report No. NC-79.
- Bella, I.E., 1971. A new competition model for individual trees. *For. Sci.*, 17: 364–372.
- Botkin, D.B., Janak, J.F. and Wallis, J.R., 1972. Some ecological consequences of a computer model of forest growth. *J. Ecol.*, 60: 849–873.
- Botkin, D.B., Nisbet, R.A. and Reynales, T.E., 1989. The effects of climate change on the forests of the Great Lakes states. *Bull. Ecol. Soc. Am.*, 69: 77.
- Carter, K.K., 1991. An examination of the effects of climate on tree growth in multi-location provenance tests. In: D.D. Reed and G.D. Mroz (Editors), *Abstracts and Papers from the Conference on Emerging Issues in Northern Hardwood Management: Air Pollution, Climate Change, and Biodiversity*. School of Forestry and Wood Products, Michigan Technological University, Houghton. Ford Forestry Center Publication No. 91-1, p. 41.
- Cattellino, P.J., Becker, C.A. and Fuller, L.G., 1986. Construction and installation of homemade dendrometer bands. *North. J. Appl. For.*, 3: 73–75.
- Charles-Edwards, D.A., Doley, D. and Rimmington, G.M., 1986. *Modelling Plant Growth and Development*. Academic Press Australia, Sydney, 235 pp.
- Coffman, M.S., Alyanak, E., Kotar, J. and Ferris, J.E., 1983. Field guide, habitat classification system for the Upper Peninsula and Michigan and Northern Wisconsin. Cooperative for Research on Forest Soils, Department of Forestry, Michigan Technological University, Houghton, 147 pp.
- Crow, T.R., 1978. Biomass and production in three contiguous forests in northern Wisconsin. *Ecology*, 59: 265–273.
- Desanker, P.V., Reed, D.D. and Jones, E.A., 1993. Evaluating forest stress factors using various forest growth modeling approaches. *For. Ecol. Manage.*, in press.
- Ek, A.R., 1974. Dimensional relationships of forest and open grown trees in Wisconsin. School of Natural Resources, University of Wisconsin–Madison, Forest Research Notes, July 1974.
- Ek, A.R. and Monserud, R.A., 1974. FOREST—a computer model for simulating the growth and reproduction of mixed species stands. University of Wisconsin, College of Agriculture and Life Sciences, Research Report R2655, 10 pp.
- Ek, A.R., Birdsall, E.T. and Spears, R.J., 1984. A simple model for estimating total and merchantable tree heights. USDA Forest Service, Research Note NC-309, 5 pp.
- Fowells, H.A., 1965. *Silvics of forest trees of the United States*. USDA Forest Service, Agriculture Handbook No. 271, 762 pp.

- Fuller, L.G., 1986. Modeling northern hardwood diameter growth using weekly climatic factors in northern Michigan. MS Thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, 69 pp.
- Fuller, L.G., Reed, D.D. and Holmes, M.J., 1987. Modeling northern hardwood diameter growth using weekly climatic factors in northern Michigan. In: A.R. Ek, S.R. Shifley and T.E. Burk (Editors), *Proceedings of the IUFRO Conference on Forest Growth Modeling and Prediction*, Vol. I. University of Minnesota, St. Paul, pp. 464-474.
- Harlow, W.M. and Harrar, E.S., 1969. *Textbook of Dendrology*, 5th edn. McGraw-Hill, New York, 512 pp.
- Harrison, W.C., Burk, T.E. and Beck, D.E., 1986. Individual tree basal area increment and total height equations for Appalachian mixed hardwoods after thinning. *South. J. Appl. For.*, 10: 99-104.
- Holdaway, M.R., 1987. The relationship between tree diameter growth and climate in the Lake States. In: A.R. Ek, S.R. Shifley and T.E. Burk (Editors), *Forest Growth Modelling and Prediction*. USDA Forest Service, General Technical Report No. NC-120, pp. 490-497.
- Holmes, M.J., 1988. Competition indices for mixed species northern hardwoods. M.S. Thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, 30 pp.
- Holmes, M.J. and Reed, D.D., 1991. Competition indices for mixed species northern hardwood stands. *For. Sci.*, 37: 1338-1349.
- Lorimer, C.G., 1983. Tests of age-independent competition indices for individual trees in natural hardwood stands. *For. Ecol. Manage.*, 6: 343-360.
- Reed, D.D., Liechty, H.O. and Burton, A.J., 1989. A simple procedure for mapping tree locations in forest stands. *For. Sci.*, 35: 657-662.
- Reed, D.D., Holmes, M.J., Jones, E.A., Liechty, H.O. and Mroz, G.D., 1990. An ecological growth model for northern hardwood species in Upper Michigan. In: *Process Modeling of Forest Growth Response to Environmental Stress*. Timber Press, Portland, OR, pp. 288-293.
- Reed, D.D., Jones, E.A., Liechty, H.O., Mroz, G.D. and Jurgensen, M.F., 1992. Impacts of annual weather conditions on forest productivity: a case study involving four North American deciduous tree species. *Int. J. Biometeorol.*, 36: 51-57.
- Reed, K.L., 1980. An ecological approach to modeling growth of forest trees. *For. Sci.*, 26: 35-50.
- Shetron, S.G., 1972. Forest site productivity among soil taxonomic units in northern Lower Michigan. *Soil Sci. Soc. Am. Proc.*, 36: 358-363.
- Shugart, H.H., 1984. *Theory of Forest Dynamics*. Springer, New York, 278 pp.
- Shugart, H.H. and West, D.C., 1977. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of chestnut blight. *J. Environ. Manage.*, 5: 161-179.
- Smith, D.M., 1986. *The Practice of Silviculture*, 8th edn. Wiley, New York, 527 pp.
- Spurr, S.H. and Barnes, B.V., 1980. *Forest Ecology*, 3rd edn. Wiley, New York, 687 pp.
- USDA Soil Conservation Service, 1975. *Soil Taxonomy*. USDA Agriculture Handbook 436. US Government Printing Office, Washington, DC.

Appendix D: Birch Decline Manuscript

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Climate stress as a precursor to forest decline: paper birch in northern Michigan, 1985-1990

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Widespread paper birch (*Betula papyrifera* Marsh.) mortality associated with the activity of the bronze birch borer (*Agrilus ansius* Gory.) was observed across northern Michigan in 1991. This mortality occurred at two study sites on which paper birch growth has been intensively monitored since 1985. Recent warmer than normal growing seasons and lower than normal moisture availability are statistically associated with a reduction in annual diameter growth. On one study site 62% of the paper birch study trees were dead and 13% were visibly declining; on the other study site, although no trees were dead, 25% of the paper birch study trees were visibly declining. Growth reductions since 1985 suggest that the species was under climatic stress, making it more vulnerable to pest-pathogen activity. The evidence of the role of climatic conditions acting as a precursor to decline and mortality on these sites is of serious concern given recent projections of warmer temperatures and lower precipitation for this region by several global climate models.

JONES, E.A., REED, D.D., MROZ, G.D., LICHITY, H.O., et CAITELINO, P.J. 1993. Climate stress as a precursor to forest decline: paper birch in northern Michigan, 1985-1990. Can. J. For. Res. 23: 000-000.

Beaucoup de mortalité a été observée chez le bouleau à papier (*Betula papyrifera* Marsh.) en relation avec l'activité de l'agrite du bouleau (*Agrilus ansius* Gory.) dans tout le nord du Michigan en 1991. Il y a eu de la mortalité dans deux sites expérimentaux où la croissance du bouleau à papier a été suivie de près depuis 1985. Récemment, des saisons de croissance plus chaudes et une plus faible disponibilité en eau ont été statistiquement associées à une diminution de la croissance annuelle en diamètre. Dans un des sites, 62% des bouleaux à papier étudiés étaient morts et 13% montraient des signes évidents de dépérissement; dans l'autre site, bien qu'il n'y avait pas de mortalité, 25% des bouleaux à papier étudiés montraient des signes évidents de dépérissement. Les diminutions de croissance observées depuis 1985 suggèrent que cette espèce a été affectée par un stress climatique qui l'a rendue plus vulnérable à l'activité des insectes ou des agents pathogènes. Le rôle évident des conditions climatiques, en tant que facteurs précurseurs du dépérissement et de la mortalité dans ces sites, suscite de sérieuses préoccupations étant donné que les simulations récentes, effectuées à l'aide de plusieurs modèles sur le climat général, prédisent un réchauffement des températures et une diminution des précipitations dans ces régions.

(Traduit par la rédaction)

Introduction

Paper birch (*Betula papyrifera* Marsh.), an important commercial hardwood species in the paper and veneer industries, is widespread throughout the northern United States and Canada (Fowells 1975). Paper birch is a short-lived species, with trees that mature in approximately 60-75 years. It is not uncommon for pure birch stands to suffer heavy mortality sometime between the ages of 50 and 75 years (Eyre 1980). In mixed hardwood stands they often do not decline until several years later (Marquis *et al.* 1969).

An insect, the bronze birch borer (*Agrilus ansius* Gory.), is often associated with both the dieback and the decadence of paper birch (Balch and Prebble 1940). Most experts, however, do not consider the insect to be the cause of the dieback, but instead, it may be a determining factor in whether trees die or recover. In this discussion of the bronze birch borer, Anderson (1960) states the following:

When dying trees are heavily infested with *Agrilus* the insects commonly are thought to be the cause of tree death. Most of those who have worked on this problem, however, think that these borers are in the dying trees because the host material is suitable and are not the primary cause of tree decadence. Sometimes, however, they do kill trees such as the European varieties of white birch. Droughts also predispose trees to attack by causing temporary partial to complete cessation of radial growth.

Anderson goes on to state that drying and heating of the surface soil causes excessive root mortality and subsequent tree decadence.

Millers *et al.* (1989) report numerous cases of widespread paper birch mortality in the Lake States region (Wisconsin in 1979-1980, Minnesota in 1979-1986, Wisconsin in 1984-1986, and Michigan, Minnesota, and Wisconsin in 1985). In all of these cases, insect activity, frost damage, and heavy seed crops have been implicated as the cause of the mortality. There were reports of drought and warmer weather being implicated in birch dieback in the 1940s (Hawboldt 1947, 1952; Nash and Duda 1951), but these were discounted by some authors (Clark 1961; Clark and Barter 1958; Redmond 1957).

Widespread mortality associated with activity of the bronze birch borer was quite evident across northern Michigan in 1991 (R. Heyd and T. Sharik, personal communication). This mortality and associated bronze birch borer activity was observed at two study sites on which paper birch and associated other species' growth has been intensively monitored since 1985 (Mroz *et al.* 1990). Reed *et al.* (1992a) reported a strong negative correlation ($r = -0.67$, $p < 0.01$) between annual paper birch diameter increment and growing season air temperature degree-days (4-4°C basis) from 1985 through

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TABLE 1. Summary of hardwood stand information for sites 1 and 2 at the beginning of the 1990 growing season

	Average DBH (cm)	Basal area (m ² /ha)	No. of hands in 1990	No. of stems per hectare	Site index (m ²)	Age (years)
Site 1						
Northern red oak	21.68	22.42	177	562	22	56
Paper birch	16.81	2.94	39	124	18	58
Aspen ^a	23.77	6.24	43	137	20	59
Red maple	11.87	0.78	22	70	18	49
Site 2						
Northern red oak	24.55	1.33	49	156	21	51
Paper birch	21.03	0.95	8	25	20	59
Aspen	26.71	2.79	15	48	21	54
Red maple	15.53	9.41	148	470	17	46

^aHeight at 50 years.^bThe two aspen species are combined.

1988 on these sites. This paper reports the decline of paper birch annual diameter growth on these sites since 1985 and presents evidence that suggests that the current decline episode was preceded by several years of climatic stress, with the final mortality in 1990 being due to bronze birch borer activity.

Site description

The study is composed of two sites located in the central Upper Peninsula of Michigan. Site 1 is in Iron County at approximately 46°10'N and 88°10'W. Site 2 is located in Marquette County at approximately 46°20'N and 88°10'W. Each study site consists of three contiguous 30 × 35 m measurement plots.

The stands on these sites are primarily undisturbed second-growth deciduous stands. They consist of four major overstory species of approximately the same age and site index (Table 1). These species include northern red oak (*Quercus rubra* L.), paper birch, red maple (*Acer rubrum* L.), and aspen (mainly *Populus grandidentata* Michx., with a few individuals of *Populus tremuloides* Michx. on site 1). Each species' crown class position within the stands is similar between the sites, although the relative abundances of the four differ. The sites have similar understory vegetation and are classified as the *Acer-Quercus-Vaccinium* habitat type (Coffman *et al.* 1983).

Both sites are in the same regional ecosystem, providing comparable climate and geology (Iron District, Crystal Falls Subdistrict (Albert *et al.* 1986)). Climatic influences from the Great Lakes produce short growing seasons (87 days) and minor moisture stress (generally during the month of July). These sites are typical of forests found on well-drained, sandy soils in the region. The soils, though morphologically similar in surface horizons, were classified differently. The soil at site 1 is classified as an alfic haplorthod, sandy, mixed, and frigid. At site 2 the soil is classified as an entic haplorthod, sandy, mixed, and frigid (USDA Soil Conservation Service 1975). These soils have sandy textures and low water-retention capacities. They are thin and have relatively fertile surface layers with relatively infertile subsurface layers.

Methods

Tree measurements

Dendrometer bands were installed on all trees greater than 10 cm DBH at each site in 1984 (Cattaneo *et al.* 1986). A total of 226 northern red oak, 170 red maple, 58 aspen, and 47 paper birch had bands at the end of the 1991 growing season. The dendrometer bands were read weekly to the nearest 0.001 mm from 1985 through 1991, and diameter growth was recorded.

Ambient measurements

A Handar 540 A¹ ambient monitoring platform was located in a cleared area at both of the study areas. The platform contained sensors to measure precipitation, relative humidity, and solar radiation. Each of the three plots within a study site was equipped with sensors to measure air temperature (2 m above the ground) and soil temperature and moisture (5- and 10-cm depths). Three hour averages were summarized and retrieved via National Earth Satellite System (NESS) transmissions. These daily weather and soil data were then processed to obtain other ambient measures, which include minimum and maximum daily air temperature, growing degree days (4.4 °C basis), total precipitation, and soil water potential.

Results and discussion

Tree mortality

Cambial activity is very responsive to environmental effects (Kramer and Kozlowski 1979; Smith 1985), and a strong correlation exists between DBH and total tree biomass (Crow 1978). Soon after the dendrometer band measurements began in the spring of 1991, paper birch dieback was evident. Many paper birch on site 1 did not leaf out; from a total of 39 banded trees at this site, 24 trees (62%) were dead, 5 trees (13%) were visibly declining (as indicated by crown dieback), and 10 trees (25%) appeared healthy. Emergence holes in the dead paper birch trees indicated the presence of the bronze birch borer. There were 8 banded trees at site 2 and, of this total, no trees were dead, 2 (25%) appeared to be declining, and 6 (75%) appeared healthy. The paper birch trees in these stands are slightly younger (59 and 58 years at sites 1 and 2, respectively) than the age at which decline and mortality would be expected (Marquis *et al.* 1969; Eyre 1980), although they are approaching the ages where natural mortality occurs.

Areas in the surrounding stands were surveyed for bronze birch borer activity. In the surveyed area near site 1, there were a total of 134 paper birch trees, and 97 (72%) of these were standing dead, although some of these had been dead for more than 1 year. Twenty-two trees (16%) appeared to be in decline, and 15 (11%) appeared healthy. The surveyed area near site 2 had a total of 137 living and dead paper birch. Of these, 71 (52%) were dead, 22 (16%) were declining, and 44 (32%) appeared healthy. From these data it appears that

¹Brand names and trademarks are given for information purposes only; no recommendation or endorsement is intended or implied.

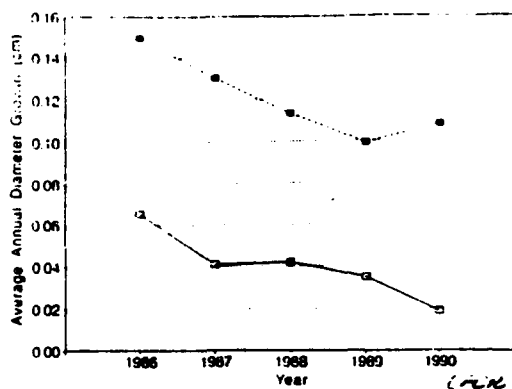


FIG. 1. Average annual paper birch diameter growth rates at the two study sites (1986–1990). ○, Site 1; ■, Site 2.

the paper birch mortality was present to an equivalent extent in the surrounding stands and was not merely due to monitoring activities at the study sites.

Average annual diameter growth of the birch trees on the study sites has been declining since diameter measurements first began in 1984 on site 1 and since 1985 on site 2 (Fig. 1). There was a slight increase in average annual diameter growth on site 2 in 1990.

A model was developed to predict the cumulative diameter growth of paper birch during the growing season (Reed *et al.* 1992b). This model is a modification of the original JABOWA (Botkin *et al.* 1972) diameter-growth model. The modified model utilizes a weekly timestep with site-specific species attributes and observed relationships between diameter growth, competition, and site physical, chemical, and climatic properties which are incorporated into four model components: (i) annual potential growth; (ii) adjustment of annual potential growth due to intertree competition; (iii) adjustment of annual potential growth due to site physical, chemical, and annual climatic properties; and (iv) seasonal growth pattern and further adjustment of annual potential growth due to weekly climatic factors. The growth model was calibrated for each of the two study sites. Potential growth (PG) for paper birch on these study sites was defined as follows:

$$PG = \frac{139.23D(1 - D/60)}{274 + 3b_2D - 4b_3D^2}$$

where b_2 and b_3 are 68.91 and 0.57, respectively, for site 1 and 71.67 and 0.59, respectively, for site 2 and D is tree DBH. 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. Residuals (the difference between the observed annual diameter growth and the predicted annual diameter growth) were obtained by site and year. An examination of the residuals from this model found that the residuals were not different from zero on either site in 1986–1988, but were significantly ($p = 0.05$) less than zero on both sites in 1989 and on site 1 in 1990. This difference indicates a significantly ($p = 0.05$) lower than expected growth rate on site 1 in 1989 and 1990 and site 2 in 1989 (Fig. 2).

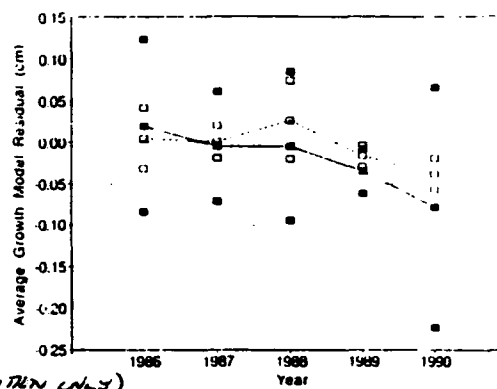


FIG. 2. Average diameter growth model residuals (observed growth minus predicted growth) with studentized 95% confidence limits (1986–1990). ○, Site 1; ■, Site 2.

Desanker *et al.* (1992) examined the growth of all species on the study sites as predicted by several models (STEMS (Belcher *et al.* 1982), FOREST (Ek and Monserud 1974), JABOWA/FORET (Botkin *et al.* 1972; Shugart 1984), and FORSKA (Leemans and Prentice 1989). All of the models generally overpredicted the observed paper birch growth on the sites. The STEMS model, which does not include climate effects, is the most widely accepted model for management in the Lake States. Using the STEMS model, Desanker *et al.* (1992) found a steady increase in the residuals from 1984 through 1990, indicating an increasing divergence in paper birch growth on the sites from that which was expected due to age and (or) stand conditions.

Soil and climate effects

Litter production was monitored on both sites each year. Although litter production did vary from year to year, there was no noticeable decline in the paper birch litter production on either site until 1990. In 1990 paper birch litter production (which contained a small portion of hazel litter, which cannot be easily sorted out) was 13.0 g/m² at site 1 and 24.0 g/m² at site 2 in 1990 as compared with an average of 22.6 g/m² at site 1 and 25.4 g/m² at site 2 from 1985 through 1989.

The average growing season (April–October) air temperature growing degree-days (4.4°C) was always higher for site 1 than for site 2. Site 1 average growing season air temperature degree-days ranged from a low of 1710 in 1985 to a high of 2013 in 1987 and 2027 in 1988. The same trend was found at site 2, where the low was 1526 in 1985 and the high was 1850 in 1987 and 1883 in 1988. Soil temperature growing degree-days (4.4°C) at both 5 and 10 cm followed the same pattern as air temperature growing degree-days for the respective growing seasons at each study site. Albert *et al.* (1986) indicate an average May–September temperature of 15.0°C in this climatic district, which roughly corresponds to 12.4°C during the April–October time period. On this basis, the growing seasons in 1986 through 1989 were warmer than normal, with 1987 and 1988 as much as 1°C warmer than normal. It has been demonstrated that artificial heating of the soil during the growing season will cause rootlet mortality and symptoms similar to those of birch dieback (Redmond

1957). Others have speculated that climate-induced increases in soil temperatures could be the cause of this dieback (Hawboldt 1952; Anderson 1960). This relationship is particularly interesting, since a number of projected climate-change scenarios indicate an average summer temperature increase of 2°C for central North America (Karl *et al.* 1991), which is even greater than the warmer than normal conditions found in 1987 and 1988 for this study.

Annual growing season (April–October) precipitation on the study sites varied considerably. Albert *et al.* (1986) indicate average May–September precipitation in this climatic district to be approximately 2.0 cm per week. This average of 2.0 cm per week is more than the amount of precipitation observed on the study sites in any year except 1985. On average, from 1985 to 1991, site 1 received 1.55 cm per week and site 2 received 1.72 cm per week. However, this apparent moisture deficit may be deceiving in that much of the early growing season moisture demand in this region is met by water stored in the soil during snowmelt, and the trees are not that dependent on rainfall early in the year.

Average April–October soil moisture (5-cm depth) also varied from year to year, but on site 1 in 1986 and in 1990 the values were considerably higher (14.1 and 16.2%, respectively) than those that occurred in 1987 through 1989 (between 10.6 and 11.2%). In 1990 a soil moisture of 12.6% on site 2 was considerably higher than the range of 9.5–10.8% that occurred in 1986 through 1989. Average April–October soil water potential is higher at site 2 than at site 1. This implies that site 1 has more available water, but more water is transpired because of higher temperatures, thus reducing soil water potential. At site 1, 1988 and 1989 were the driest years in terms of available soil moisture, even though 1989 was a cooler year than 1988.

The average April through October relative humidity illustrates some of the combined effects of temperature and moisture. The relative humidity at site 1 was consistently lower than site 2 by approximately 15%. At both sites, relative humidity in 1989 was the lowest observed during the entire study period. It dropped from 70.0% in 1987 to 58.3% in 1989 at site 1 and from 84.1% in 1987 to 73.1% in 1989 at site 2. This further indicates that 1986 through 1989 was a period of greater than normal climatic stress because of the combination of higher temperature and lower moisture.

Summary

Paper birch mortality at the study sites, in the surrounding stands, and probably across northern Michigan appears to be a natural phenomenon; stands are approaching the age of expected decline, they have suffered several years of climatic stress, and a number of individuals have succumbed to bronze birch borer induced mortality. This conclusion is based on the following:

- (1) At the beginning of the 1990 growing season, paper birch was 59 years old at site 1 and 58 years old at site 2. These trees are close to the age where senescence is expected, and they may be vulnerable to climatic stress and pest-pathogen activity.
- (2) Emergence holes in the dead paper birch trees indicate that the bronze birch borer was associated with the dieback of paper birch on site 1 (and across Upper Michigan).
- (3) In recent years, particularly 1987 and 1988, the growing seasons were warmer than normal on both study sites,

whereas in 1988 and 1989 lower than normal moisture availability was evident at site 1. Given the sensitivity of paper birch to temperature and moisture in the surface soil horizons and the reduced growth rates observed on the study sites during these years, it is highly likely that these trees were under climatic stress in recent years. This is further evidenced by the examination of residuals from the diameter-growth model developed on these sites. Residuals from the model indicate that the trees behaved as expected in 1986–1988, even though growth was reduced. In 1989, however, diameter growth was reduced by a greater than expected amount on both sites.

The evidence of the role of climatic conditions acting as a precursor to decline and mortality indicated on these sites is particularly interesting given recent projections of future climate from several global-climate models (Schneider 1989; Manabe and Wehner 1986; Intergovernmental Panel on Climate Change 1990). Summer temperatures in central North America are projected to increase 2°C, which is close to the increase in the above-normal temperature observed on the study sites in 1987 and 1988. These projected temperature increases are accompanied by projected decreases in summer precipitation of up to 15%. Drought and extreme temperatures have been related to widespread regional tree mortality for a number of eastern species besides paper birch: northern red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), American beech (*Fagus grandifolia* Ehrh.), quaking aspen (*Populus tremuloides* Michx.), and a number of other species (Millers *et al.* 1989). This suggests a greater need to understand the relationships between climate, tree production, and pest-pathogen activity in the northern deciduous forests of the United States and Canada.

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- Albert, D.A., Denton, S.R., and Barnes, B.V. 1986. Regional landscape ecosystems of Michigan. School of Natural Resources, University of Michigan, Ann Arbor.
- Anderson, R.F. 1960. Forest and shade tree entomology. John Wiley & Sons, New York.
- Balch, R.E., and Prebble, J.S. 1940. The bronze birch borer and its relation to the dying of birch in New Brunswick forests. For. Chron. 16: 179–201.
- Belcher, D.W., Hoklaway, M.R., and Brand, G.J. 1982. A description of STEMS—the stand and tree evaluation and modeling system. U.S. For. Serv. Gen. Tech. Rep. NC-79.
- Borkin, D.B., Janak, J.F., and Wallis, J.R. 1972. Some ecological consequences of a computer model of forest growth. J. Ecol. 60: 849–872.

- Hindman, K.A., and Poy, E.A. 1975. *Quaking aspen: Values and management in the Lake States*. U.S. Dep. Agric. Agric. Handb. 196.
- Calclimo, P.J., Becker, C.A., and Fuller, L.G. 1986. Construction and installation of homemade dendrometer bands. *North. J. Appl. For.* 3: 73-75.
- Clark, J. 1961. Birch dieback. In *Recent Advances in Botany*. Lectures and symposia presented to the 9th International Botanical Congress, 1959. University of Toronto Press, Toronto. pp. 1551-1555. *Montreal, Canada*.
- Clark, J., and Barner, G.W. 1958. Growth and climate in relation to dieback of yellow birch. *For. Sci.* 4: 343-363.
- Coffman, M.S., Alyanak, E., Kotar, J., and Ferns, J.E. 1983. Field guide: habitat classification system for the Upper Peninsula of Michigan and northeastern Wisconsin. Cooperative for Research on Forest Soils, Department of Forestry, Michigan Technological University, Houghton.
- Crow, T.R. 1978. Biomass and production in three contiguous forests in northern Wisconsin. *Ecology*, 59: 265-273.
- Ek, A.R., and Monserud, R.A. 1974. FOREST: A computer model for simulating the growth and reproduction of mixed species stands. Univ. Wis. Madison Coll. Agric. Life Sci. Res. Div. Rep. R2655.
- Eyre, F.H. (Editor). 1980. *Forest cover types of the United States and Canada*. Society of American Foresters, Washington, D.C. 148 p.
- Fowells, H.A. (Editor). 1965. *Silvics of forest trees of the United States*. U.S. Dep. Agric. Agric. Handb. 271.
- Frish, J.B. 1973. Youth, maturity, and old age. In *Aspen: Symposium Proceedings*. U.S. For. Serv. Gen. Tech. Rep. NC-1. pp. 74-82.
- Hawtholdt, L.S. 1947. Aspects of yellow birch dieback in Nova Scotia. *J. For.* 45: 414-422.
- Hawtholdt, L.S. 1952. *Climate and birch "dieback"*. N.S. Dep. Lands For. Bull. 6.
- Intergovernmental Panel on Climate Change. 1990. *Scientific assessment of climate change*. World Meteorological Organization, United Nations Environment Programme, Geneva, Switzerland.
- Karl, T.R., Heim, R.H., Jr., and Quayle, R.G. 1991. The greenhouse effect in central North America: if not now, when? *Science* (Washington, D.C.), 25: 1058-1061.
- Kramer, P.J., and Kozlowski, T.T. 1979. *Physiology of woody plants*. Academic Press, Orlando, Fla.
- Leemans, R., and Prentice, I.C. 1989. *FORESCY*, a general forest succession model. Meddelanden Fran Vaxthologiska Institutionen, Uppsala, Sweden. No. 2.
- Manabe, S., and Wetherald, R. 1986. Reduction in summer soil wetness induced by an increase in atmospheric carbon dioxide. *Science* (Washington, D.C.), 232: 626-628.
- Marquis, D.A., Solomon, D.S., and Bjorkbom, J.C. 1969. *A silvicultural guide for paper birch in the Northeast*. USDA For. Serv. Res. Pap. NE-130.
- Millers, L., Shriner, D.S., and Rizzo, D. 1989. *History of hardwood decline in the eastern United States*. USDA For. Serv. Gen. Tech. Rep. NE-126.
- Mroz, G.D. 1990. Annual report of the herbaceous plant cover and tree studies. In *Compilation of the 1989 Annual Reports of the Navy ELF Communications Ecological Monitoring Program*. Vol. 1, III. Inst. Technol. Res. Inst. Tech. Rep. F00620-4.
- Nash, R.W., and Duda, E.J. 1951. *Studies on extensive dying, regeneration, and management of birch*. Maine For. Serv. Bull. 15.
- Redmond, D.R. 1957. The future of birch from the viewpoint of diseases and insects. *For. Chron.* 33: 25-30.
- Reed, D.D., Jones, E.A., Liechty, H.O., Mroz, G.D., and Jorgensen, M.F. 1992a. Impacts of annual weather conditions on forest productivity: a case study involving four North American deciduous forest species. *Int. J. Biometeorol.* 36: 51-57.
- Reed, D.D., Jones, E.A., Holmes, M.J., and Fuller, L.G. 1992b. Modeling diameter growth in local populations: a case study involving four North American deciduous species. *For. Ecol. Manage.* XXX: 54-XXX-XXX.
- Schneider, S.H. 1989. *The greenhouse effect: science and policy*. Science (Washington, D.C.), 243: 771-781.
- Shugart, H.H. 1984. *A theory of forest dynamics*. Springer-Verlag, New York.
- Smith, D.M. 1985. *The practice of silviculture*. 8th ed. John Wiley & Sons, New York.
- USDA Soil Conservation Service. 1975. *Soil taxonomy*. U.S. Dep. Agric. Agric. Handb. 436.

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**ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:
LITTER DECOMPOSITION AND MICROFLORA
The Michigan Study Site**

ANNUAL REPORT 1992

SUBCONTRACT NUMBER: EO6549-84-C-002

**MICHIGAN TECHNOLOGICAL UNIVERSITY
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SUBCONTRACT NUMBER: EO6549-84-C-002

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ABSTRACT

Eight years of litter decomposition study have 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 experimental sample units consist of bagged bulk leaf samples of each litter species, for determination of dry matter mass loss.

Precision in the annual data sets has generally been slightly higher for the hardwood stand subunits than for the plantation subunits. For several reasons, though, the hardwood stand subunits have provided a much more stable environment for making comparisons of litter mass loss among years than have 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.

Among the three study litter species, pine and oak have provided more precise data than maple. Maple litter generally fragments to a greater extent than do either pine or oak litter. Bulk samples of pine, oak and maple leaves lost approximately 25 to 27 percent, 31 to 38 percent, and 25 to 37 percent of initial dry matter mass, respectively, during 1991/92.

Two types of ANACOV model are being used to evaluate year-by-site interactions. First, the traditional Effects Model ANACOV examines the data set for differences among years, sites, and months, with blocking by plot nested within site, and for year-by-site interaction. Second, the mathematically equivalent Means Model ANACOV looks for differences among categorical "siteyears" (e.g., control1985, antennal1985, ground1985, control1986, 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 year-by-site interactions, using covariates unrelated to ELF field exposures, and 2) to evaluate the temporal patterns of remaining differences relative to ELF EM field variables.

Covariates have proven useful for explaining differences among sites, years, and months, and siteyears. We settled in 1991 on 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. We recognize that the utility of this ecologically appropriate set of covariates may be compromised if their temporal distribution patterns can not be shown to be statistically independent of ELF EM field variables.

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 eight year study, the patterns of annual change in overall X_w have tended to be similar for both study hardwood stands. Nevertheless, ANACOV indicates 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. This tendency was not statistically significant for all years, and was most pronounced for oak litter. The largest difference observed between the hardwood stands in a given year was approximately 5 percent X_w , for maple in 1988. However, the difference in X_w between the hardwood stands in 1992 was not statistically significant for either maple or pine. Results of the 1992/93 experiment will be of great interest.

Emphasis in the Red Pine Mycorrhizoplane Streptomycete studies focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings in the three plantations. Seven years (through 1991) of mycorrhizoplane streptomycete population data have been collected in all three study plantations. Counts of both total streptomycete levels and streptomycete morphotype numbers were made. Each morphotype has been characterized for ability to degrade complex organic compounds.

In contrast to the litter decomposition work element, there is no indication of any ELF EM field effect through 1991 on mycorrhizoplane streptomycete populations. ANACOV (using annual running totals of degree days and precipitation variables as covariates) has explained all differences among sites and months, as well as the year-by-site interaction, for streptomycete morphotype numbers. Morphotype numbers have decreased since plantation establishment in 1984. We suspect that the decrease in morphotype numbers with plantation age is associated with the establishment of red pine monocultures on sites which formerly supported more diverse mixed-wood forests. A similar ANACOV explained the differences among sites and the year-by-site interaction for total streptomycete levels. Levels have not followed a recognizable pattern over the years. Seasonally, levels are lower in October than during May through September.

Obtaining sufficient statistical power to detect subtle effects of ELF EM fields has been a major difficulty with respect to estimating total streptomycete population levels. A change of 26 to 50 percent between two "siteyears" (used to evaluate site-by-year interaction) would be detected only 50 percent of the time. Large detectable differences for morphotype numbers (20 to 37 percent for siteyears) are not a problem, because the numbers detected are very low. Nevertheless, ranging from 2 to 4

morphotypes per sample, shifts of this magnitude would likely require declines in abundance (or outright loss) of several of the approximately 20 streptomycete morphotypes observed over the past six years.

The Armillaria root disease epidemics in all three plantations have been documented since their onset in 1986. This disease has killed from 2 to 41 percent of the red pine plantation quarter-plot populations, and there is good reason to expect that mortality will continue to occur. 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, probably due to the markedly cool wet weather. 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.

ANOVA has been used to compare the monomolecular rates of disease progress in the three study plantations, based on rate coefficients calculated for all of the 12 quarter-plots comprising each plantation. Preliminary ANOVA results indicate that rates of disease progress are highest in the overhead antenna plantation and lowest in the ground antenna plantation. We view these results as unrealistic, because the ground antenna plantation is only partially occupied by the pathogen. It seems most appropriate to base rates of disease progress on units of land area colonized by individual Armillaria ostoyae genets, rather than on units of land area only partially colonized by one (or more) genets. We are presently preparing a similar analysis of disease progress which 1) will be based on the land area occupied by individual Armillaria genets, and 2) will include relevant covariates, to explain differences between the plantation areas occupied by the individual genets.

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EXECUTIVE SUMMARY

Maple, oak, and pine leaf litter decomposition have been studied from 1985 through 1992, and pine mycorrhiza-associated streptomycete bacteria populations have been 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. We continue to use oak, maple, and pine foliar litterfall as the substrates for our decomposition studies. These species differ in composition, each favoring different components of the decomposer community. Maple litter generally decays fastest (with considerable fragmentation), providing the most variable data. Pine litter decays most slowly, providing the least variable data. Oak litter is intermediate in these regards. Nevertheless, the statistically detectable change in decomposition progress is very low for all three species in both stand types.

The statistical technique employed for this study 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. However, because climatic conditions vary among sites and years, the observed decomposition data must be adjusted for temperature and precipitation variation using covariate analysis (ANACOV). Covariates have explained many of the differences among sites, years, and months, and much of the site-year interaction. The site-year interaction is important because it 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 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.

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.

Mycorrhizoplane Streptomycetes: There is no indication of any ELF EM field effect through 1991 on red pine mycorrhiza-associated streptomycete bacteria populations. ANACOV using temperature- and precipitation-related covariates has explained all differences among sites and months, as well as the year-site interaction, for numbers of streptomycete morphological types (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. A similar ANACOV explained the differences among sites and the year-site interaction for total streptomycete levels. 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: Armillaria root disease has killed from 2 to 41 percent of the red pine plantation quarter-plot populations. ANOVA has been used to compare the rates of disease progress in the 36 quarter-plots comprising the three plantations. Preliminary results indicate that rates of disease progress are highest in the overhead antenna plantation and lowest in the ground antenna plantation. We view these results as unrealistic, because the ground antenna plantation is only partially occupied by the pathogen. We are presently preparing a similar analysis of disease progress which 1) will be based on the land area occupied by individual Armillaria genets, 2) will include relevant covariates, to explain differences between the plantation areas occupied by the individual genets, and 3) will lower detection limits for differences in rate of 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 examining 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 share 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 complement and extend the program of the Upland Flora Studies project. The information obtained will be 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, the litter decomposition and Armillaria root disease studies have each provided preliminary evidence of possible ELF EM field effects, whereas the mycorrhizoplane streptomycete studies have not. Unfortunately, financial constraints necessitated the discontinuation of one of these work elements, and so we concluded the mycorrhizoplane streptomycete studies in FY92. This 1992 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

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.

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 streptomyces 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.

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 12 quarterplots which comprise each plantation. Additional future root disease models will use individual *Armillaria* genets as the experimental units.

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. Covariates will have to be shown to be unaffected (both directly and indirectly) by ELF EM fields before they can be legitimately used 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 will be 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 (litter decomposition, as dry matter mass loss), the log10 transformation of raw data (streptomycete levels and morphotype numbers), or the raw data itself (Armillaria root disease progress rate). 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 after 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 ($\beta = 0.50$):

$$Z = (\text{LSMEAN1} - \text{LSMEAN2}) / (\text{SE}_{\text{LSMEAN1}}^2 + \text{SE}_{\text{LSMEAN2}}^2)^{0.5}$$

Because $\alpha = 0.05$, the Z value is 1.96. Therefore,

$$1.96 = (\text{LSMEAN1} - \text{LSMEAN2}) / (0.03224^2 + 0.03224^2)^{0.5}, \text{ and}$$

$$\text{LSMEAN1} - \text{LSMEAN2} = 1.96 * (0.03224^2 + 0.03224^2)^{0.5}$$

$$= 1.96 * 0.04559$$

$$= 0.08936$$

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

$$5.3622 \leq \text{LSMEAN} \leq 5.5410$$

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 meaningful if translated back to the original units:

$$10^{5.3622} \leq (\text{observed value} = 10^{5.4516}) \leq 10^{5.5410}, \text{ or}$$

$$230,250 \leq (\text{observed value} = 282,879) \leq 348,498$$

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.

$$\begin{aligned} \text{LSMEAN1} - \text{LSMEAN2} &= 1.96 * (0.05699^2 + 0.05699^2)^{0.5} \\ &= 0.15798 \end{aligned}$$

It follows that LSMEANS outside the following range would be significantly different from the 1985 mean.

$$5.1708 \leq \text{LSMEAN} \leq 5.4868$$

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:

$$148,184 \leq (\text{observed value} = 213,206) \leq 306,761$$

As a proportion of the back-transformed LSMEAN, the detection limit is approximately:

$$0.5 * (306,761 - 148,184) / 213,206 = 0.3719$$

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 (e.g., 0.2090 and 0.3719, for 1989 and 1985, respectively).

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 AND NUTRIENT FLUX

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.

Eight 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 will be 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. Dry matter mass loss from freshly fallen foliar litter samples has been widely used as a measure of fully integrated litter decomposition (Kendrick 1959, 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 installed in 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 are placed in the field in December, and subsets are retrieved at approximately monthly intervals from early May to early November. Snow cover at the study sites dictates the earliest and latest possible recovery dates from the plantation subunits. The experimental design regarding bulk litter envelopes remains unaltered. Two clusters of samples are placed on each of the three plots comprising each plantation and hardwood stand type. One envelope per species is retrieved each month from each of the 6 clusters per plantation or hardwood stand.

Raw data are expressed as the proportion (X_w) of original dry matter mass remaining over time. Sufficient samples are 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 are transformed to the arc sine square root of X_w , 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.

We will continue to fully analyze the bulk standard samples representing the parent litter collections. We will also continue to archive all bulk samples retrieved from the field. However, we have suspended nutrient analysis of retrieved samples, in order to devote available resources to mass loss studies.

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 being 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, antennal1985, ground1985, control1986, etc.). When significant differences exist among siteyears, multiple comparisons can be used to identify site trends among years. Our principle objectives are 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. We recognize that the utility of this ecologically appropriate set of covariates may be compromised if their temporal distribution patterns can not be shown to be statistically independent of ELF EM field variables.

1991/92 Study

Fresh-fallen red pine litter was again collected on nylon netting spread in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its remoteness from interfering ELF (76 Hz) electromagnetic fields. Fresh-fallen red maple litter was again collected near the Covered Drive, seven miles from Houghton, for the same reasons. Northern red oak litter was again collected near the northeast edge of the control plantation plot 3.

Bulk pine sample envelopes measured 22 cm x 28 cm; each contained 10 g (air dry mass) of the parent collection. Bulk maple and oak sample envelopes measured 44 cm x 28 cm; each contained 15 g (air dry mass) of the parent collection.

The experimental design remains unaltered. Ten 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.

1992/93 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter were collected again in 1992 as described for the 1991/92

study. The same experimental design established for the 1984/85 through 1991/92 studies is being followed for bulk litter samples in the 1992/93 study.

Description of Progress

1991/92 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 1992 (by sampling date, site and stand type), along with standard deviations and minimum 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. Pine

1. Plantation Subunits: $\leq 5\%$
2. Hardwood Stand Subunits: $\leq 5\%$

B. Oak

1. Plantation Subunits: $\leq 13\%$
2. Hardwood Stand Subunits: $\leq 9\%$

C. Maple

1. Plantation Subunits: $\leq 11\%$
2. Hardwood Stand Subunits: $\leq 8\%$

Figures 1 and 2 present comparisons of monthly dry matter mass loss progress for bulk pine fascicles during the 1991/92 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 percent confidence intervals. Figures 3 and 4, and 5 and 6, present analogous comparisons for bulk oak and maple leaf samples, respectively.

Table 3. Mean proportion^a of initial dry matter mass (30°C) remaining at different times in 1992, for bulk red pine foliar litter samples disbursed in December, 1991.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean ^a	S.D. ^b	% ^c	Mean	S.D.	%
6 May	0.90	0.01	2	0.91	0.01	1
2 June	0.88	0.01	2	0.89	0.02	2
6 July	0.85	0.02	2	0.85	0.01	2
2 August	0.84	0.03	4	0.84	0.01	2
30 August	0.80	0.01	2	0.80	0.02	3
3 October	0.76	0.02	3	0.76	0.01	1
31 October	0.73	0.04	5	0.74	0.02	3

Table 3. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.91	0.01	1	0.90	0.01	1
2 June	0.88	0.02	2	0.89	0.01	1
6 July	0.86	0.02	2	0.88	0.01	2
2 August	0.83	0.01	1	0.82	0.04	5
30 August	0.80	0.01	1	0.81	0.02	2
3 October	0.75	0.01	1	0.77	0.03	3
31 October	0.75	0.03	4	0.75	0.02	3

Table 3. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.90	0.01	1
2 June	0.87	0.02	3
6 July	0.86	0.01	2
2 August	0.83	0.02	3
30 August	0.79	0.03	4
3 October	0.78	0.03	3
31 October	0.75	0.01	2

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

Table 4. Mean proportion^a of initial dry matter mass (30°C) remaining at different times in 1992, for bulk northern red oak foliar litter samples disbursed in December, 1991.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean ^a	S.D. ^b	% ^c	Mean	S.D.	%
6 May	0.86	0.04	4	0.90	0.02	2
2 June	0.86	0.02	3	0.87	0.02	3
6 July	0.83	0.02	3	0.82	0.01	2
2 August	0.81	0.05	6	0.78	0.05	6
30 August	0.75	0.09	13	0.75	0.04	5
3 October	0.72	0.04	6	0.68	0.02	3
31 October	0.69	0.04	6	0.63	0.02	4

Table 4. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.89	0.01	2	0.89	0.01	1
2 June	0.85	0.05	6	0.85	0.01	1
6 July	0.82	0.03	3	0.84	0.02	2
2 August	0.77	0.02	3	0.76	0.03	4
30 August	0.75	0.03	5	0.73	0.03	4
3 October	0.68	0.02	3	0.71	0.02	3
31 October	0.62	0.04	6	0.63	0.05	9

Table 4. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.91	0.02	2
2 June	0.85	0.01	2
6 July	0.81	0.03	4
2 August	0.77	0.03	3
30 August	0.73	0.03	4
3 October	0.70	0.01	2
31 October	0.67	0.02	3

- 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

Table 5. Mean proportion^a of initial dry matter mass (30°C) remaining at different times in 1992, for bulk red maple foliar litter samples disbursed in December, 1991.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean ^a	S.D. ^b	% ^c	Mean	S.D.	%
6 May	0.88	0.01	1	0.90	0.02	2
2 June	0.83	0.02	3	0.85	0.02	2
6 July	0.77	0.03	4	0.82	0.02	3
2 August	0.74	0.03	4	0.81	0.02	2
30 August	0.73	0.02	3	0.79	0.01	2
3 October	0.67	0.02	3	0.73	0.03	4
31 October	0.68	0.04	6	0.71	0.03	4

Table 5. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.87	0.03	3	0.88	0.02	3
2 June	0.84	0.01	1	0.84	0.04	5
6 July	0.82	0.04	5	0.83	0.03	3
2 August	0.78	0.04	5	0.81	0.03	4
30 August	0.78	0.07	9	0.81	0.01	2
3 October	0.69	0.05	7	0.75	0.06	8
31 October	0.70	0.07	11	0.75	0.04	6

Table 5. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.88	0.03	3
2 June	0.83	0.02	3
6 July	0.79	0.01	2
2 August	0.74	0.02	3
30 August	0.71	0.02	3
3 October	0.68	0.04	7
31 October	0.63	0.03	5

- 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

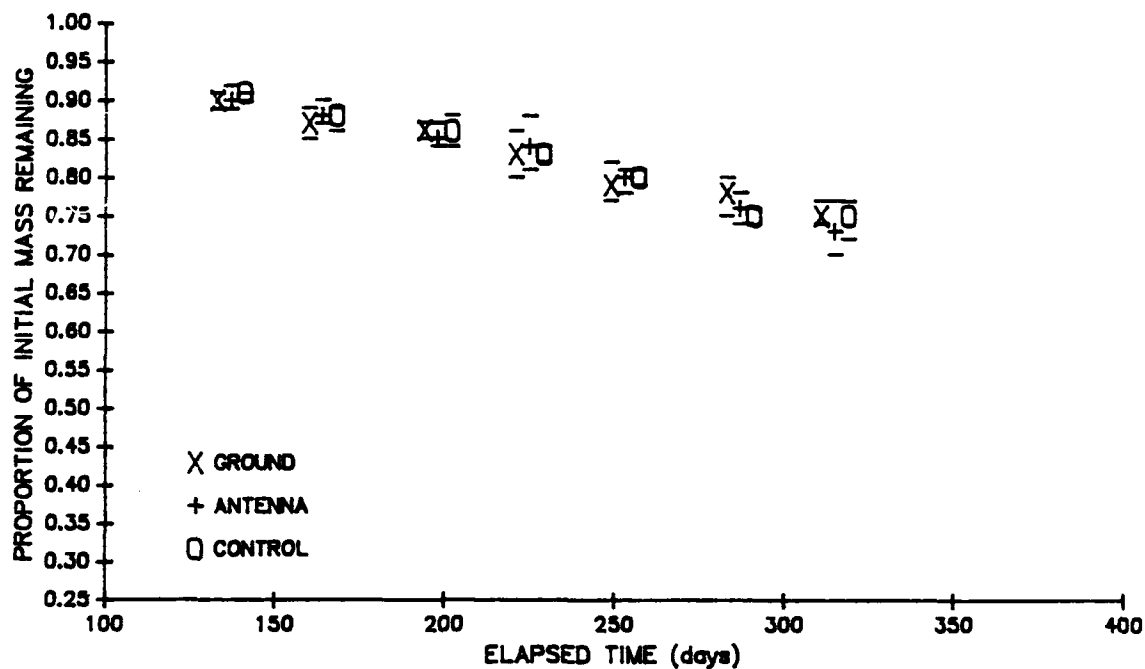


FIGURE 1. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the three plantation subunits during the 1991-1992 experiment.

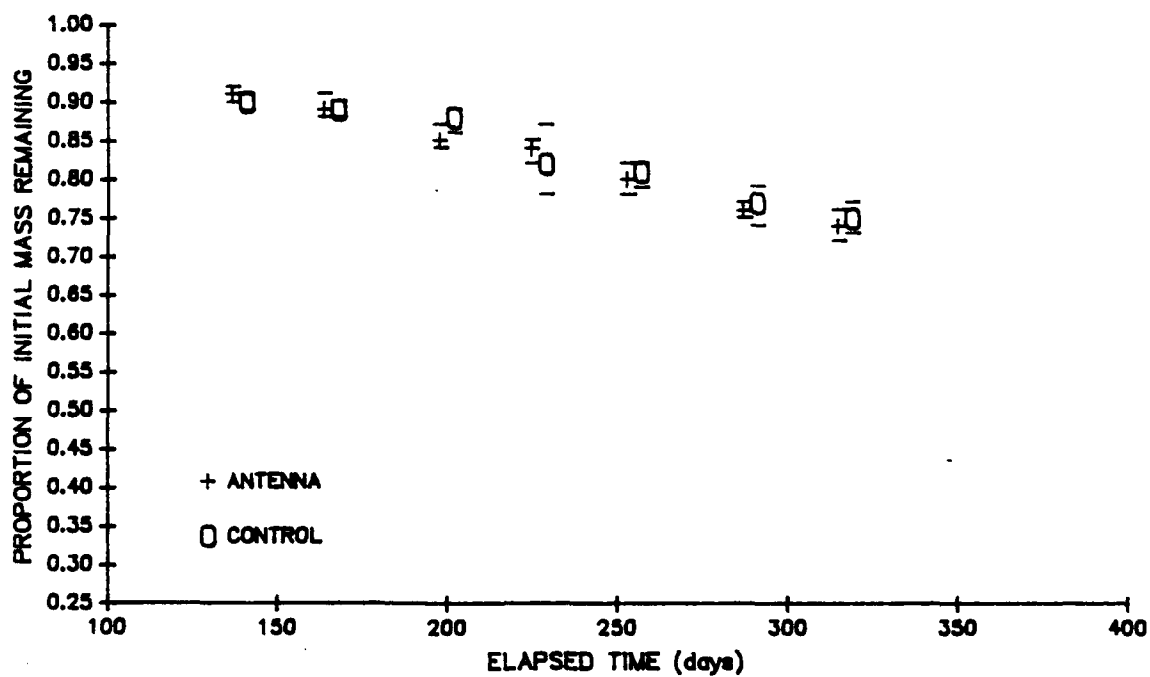


FIGURE 2. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the two hardwood stand subunits during the 1991-1992 experiment.

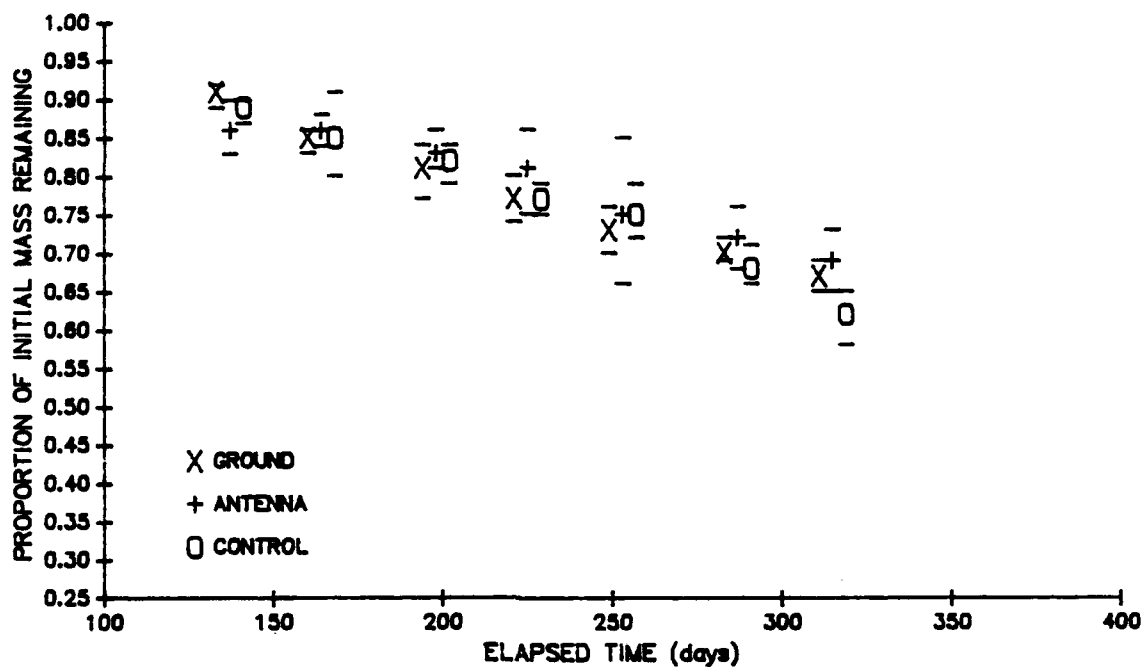


FIGURE 3. Proportion (X) of Initial dry matter mass remaining for bulk oak leaf samples retrieved from the three plantation subunits during the 1991-1992 experiment.

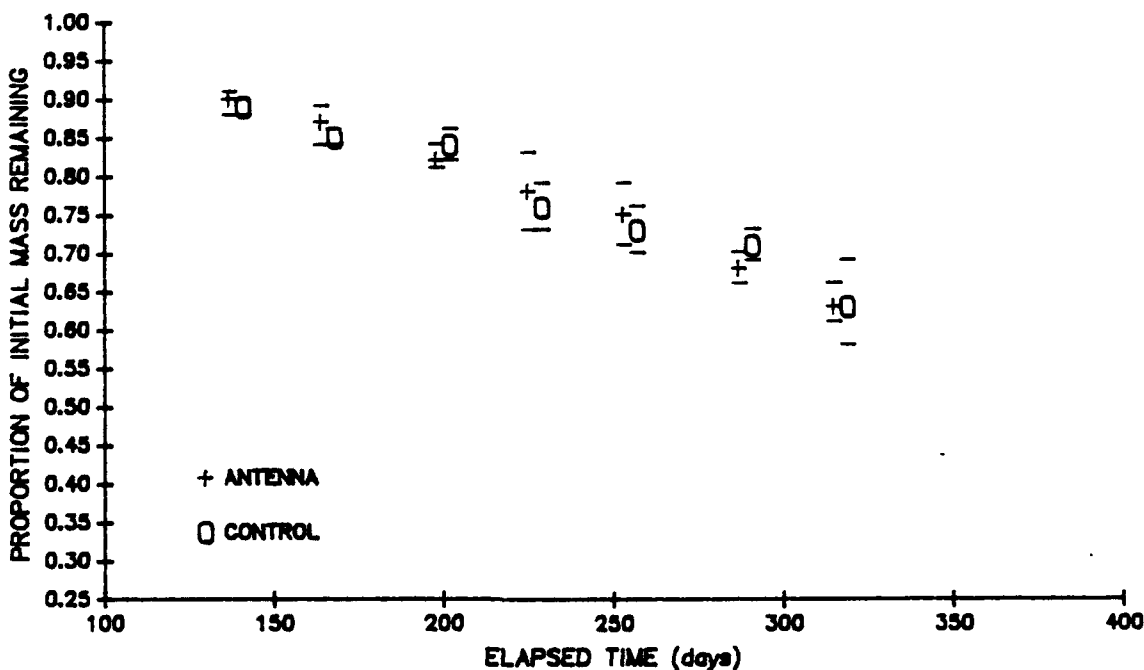


FIGURE 4. Proportion (X) of Initial dry matter mass remaining for bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1991-1992 experiment.

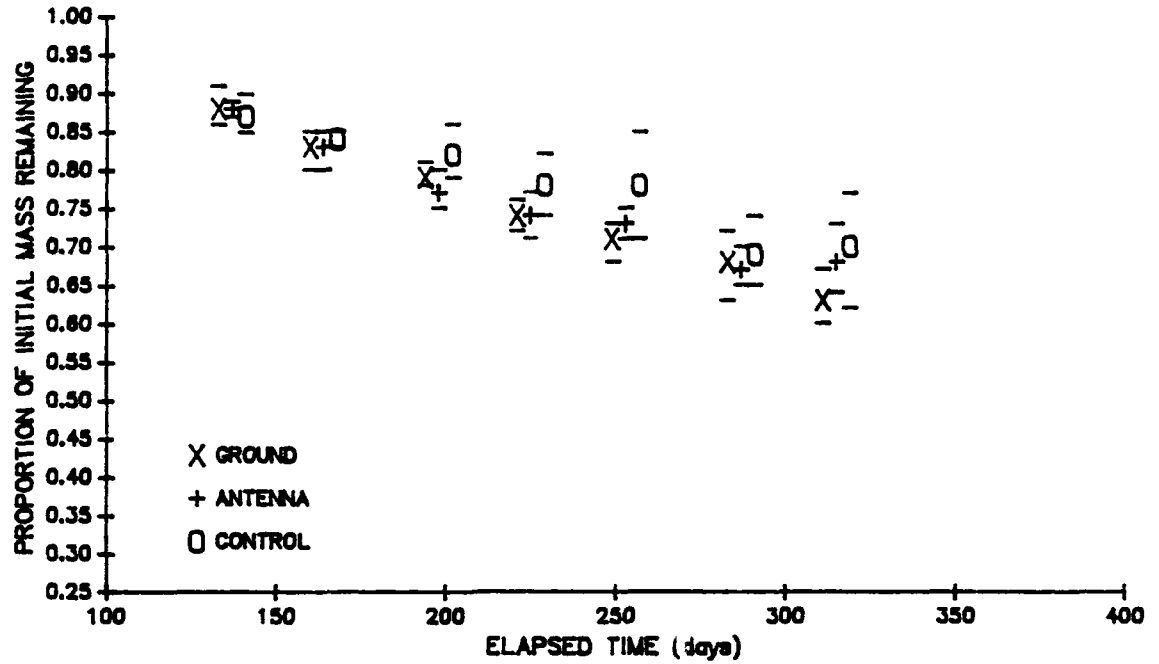


FIGURE 5. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the three plantation subunits during the 1991-1992 experiment.

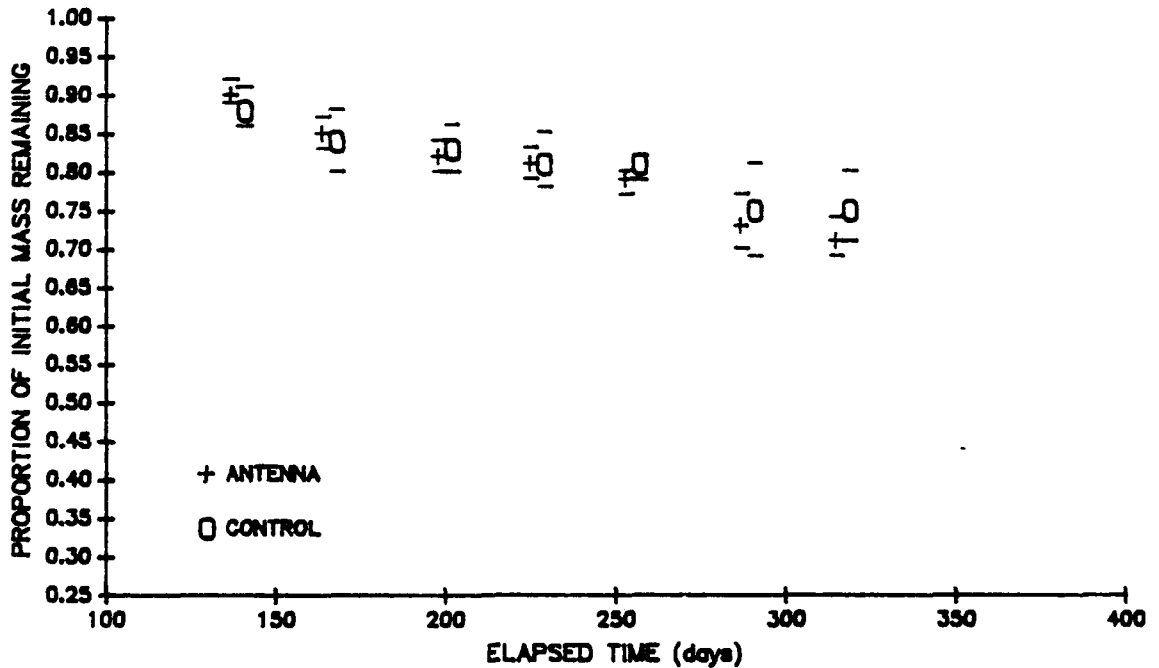


FIGURE 6. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1991-1992 experiment.

1985 through 1992 Studies

Mean dry matter mass loss values for each year, litter species, and month (through 1992), along with their associated coefficients of variation (CV), are presented in Tables 6 through 10 (for the ground plantation, antenna plantation and hardwood stand, control plantation and 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 within the annual data sets is slightly higher for the hardwood stands than for the plantations. Also, the hardwood stands represent more stable environments for making comparisons 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.

Pine has provided the most precise mass loss data over the years, and maple the least precise. In 1991/92, bulk pine, oak and maple litter samples lost approximately 25 to 27 percent, 31 to 38 percent, and 25 to 37 percent of initial dry matter mass.

Explanation of all differences in decomposition rate among years is probably 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

Table 6. Monthly mean X_w^a and corresponding percent CV^b for bulk litter envelopes retrieved from the Antenna Ground Plantation.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.64	0.59	0.55	0.52	0.45	0.40	0.40
		CV	9.3	2.2	3.2	6.1	8.3	9.1	29.2
	Oak	Xw	0.92	0.88	0.85	0.81	0.75	0.69	0.68
		CV	2.1	1.8	1.6	2.5	4.2	4.8	6.3
	Pine	Xw	0.90	0.85	0.83	0.82	0.76	0.71	0.70
		CV	0.8	0.9	1.3	2.6	2.9	1.9	8.2
1986	Maple	Xw	0.80	0.80	0.76	0.70	0.61	0.54	0.47
		CV	3.9	3.9	2.1	5.1	7.3	10.6	23.1
	Oak	Xw	0.93	0.93	0.90	0.86	0.81	0.74	0.67
		CV	1.1	1.8	1.6	2.0	2.3	4.3	8.4
	Pine	Xw	0.91	0.87	0.88	0.84	0.81	0.72	0.71
		CV	1.8	3.6	4.8	3.8	1.4	2.6	1.5
1987	Maple	Xw	0.84	0.78	0.74	0.70	0.62	0.61	0.58
		CV	6.8	8.6	7.1	9.6	9.5	8.1	12.6
	Oak	Xw	0.92	0.94	0.87	0.80	0.79	0.76	0.74
		CV	9.8	1.3	11.9	15.5	2.6	5.0	3.3
	Pine	Xw	0.93	0.92	0.90	0.85	0.78	0.74	0.75
		CV	1.5	2.1	1.5	2.2	1.6	4.6	1.7
1988	Maple	Xw	0.77	0.70	0.68	0.63	0.56	0.51	0.50
		CV	3.0	4.0	3.5	4.0	4.6	5.2	5.4
	Oak	Xw	0.92	0.89	0.88	0.84	0.77	0.72	0.66
		CV	2.0	1.7	3.7	3.0	3.4	3.4	11.7
	Pine	Xw	0.91	0.91	0.89	0.87	0.78	0.75	0.74
		CV	1.5	3.0	0.6	1.5	2.5	1.9	5.2
1989	Maple	Xw	0.89	0.85	0.80	0.77	0.73	0.67	0.71
		CV	1.4	1.5	4.3	2.7	5.3	4.0	3.7
	Oak	Xw	0.91	0.86	0.83	0.77	0.73	0.70	0.67
		CV	4.4	3.1	2.7	4.1	4.6	4.9	6.9
	Pine	Xw	0.90	0.87	0.85	0.81	0.78	0.73	0.75
		CV	2.2	2.3	2.0	3.2	2.8	5.0	2.8
1990	Maple	Xw	0.88	0.84	0.80	0.72	0.71	0.65	0.58
		CV	2.5	4.7	5.8	4.1	8.5	5.2	4.4
	Oak	Xw	0.96	0.93	0.89	0.85	0.82	0.78	0.75
		CV	0.9	0.9	1.4	2.4	2.9	2.0	5.5
	Pine	Xw	0.94	0.92	0.87	0.86	0.83	0.79	0.75
		CV	1.1	1.8	1.6	0.6	2.4	2.4	1.3
1991	Maple	Xw	0.82	0.75	0.71	0.68	0.64	0.62	0.57
		CV	3.5	4.4	4.2	4.2	5.2	6.2	10.3
	Oak	Xw	0.92	0.87	0.82	0.78	0.75	0.68	0.66
		CV	2.1	0.7	2.2	2.1	3.1	6.0	5.2
	Pine	Xw	0.93	0.89	0.86	0.83	0.79	0.77	0.75
		CV	1.3	2.5	1.9	1.0	3.0	2.1	1.7
1992	Maple	Xw	0.88	0.83	0.79	0.74	0.71	0.68	0.63
		CV	3.0	2.8	1.9	2.5	3.3	6.6	4.8
	Oak	Xw	0.91	0.85	0.81	0.77	0.73	0.70	0.67
		CV	1.8	1.5	4.1	3.3	3.4	1.9	2.8
	Pine	Xw	0.90	0.87	0.86	0.83	0.79	0.78	0.75
		CV	0.9	2.6	1.5	3.0	3.4	3.3	1.8

a/ X_w is the proportion of dry matter mass remaining at sample retrieval.

b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 7. Monthly mean X_w^a and corresponding percent CV^b for bulk litter envelopes retrieved from the Overhead Antenna Plantation.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.70	0.63	0.59	0.54	0.53	0.45	0.46
		CV	2.9	8.1	7.7	6.9	10.5	5.2	21.1
	Oak	Xw	0.92	0.87	0.86	0.83	0.78	0.70	0.74
		CV	3.1	3.3	2.9	2.8	3.3	6.7	10.6
	Pine	Xw	0.92	0.88	0.86	0.84	0.78	0.72	0.72
		CV	1.1	1.5	1.8	2.5	4.0	1.7	2.3
1986	Maple	Xw	0.82	0.82	0.75	0.68	0.62	0.52	0.48
		CV	3.3	2.1	3.5	2.5	7.8	5.9	6.5
	Oak	Xw	0.93	0.93	0.90	0.87	0.80	0.73	0.69
		CV	2.0	0.7	1.6	1.0	1.5	3.4	9.2
	Pine	Xw	0.92	0.90	0.89	0.86	0.81	0.76	0.74
		CV	1.4	1.8	1.8	1.4	1.9	6.7	2.9
1987	Maple	Xw	0.81	0.75	0.69	0.65	0.61	0.54	0.54
		CV	9.2	7.8	8.6	9.2	7.7	9.9	6.6
	Oak	Xw	0.94	0.86	0.88	0.81	0.76	0.74	0.71
		CV	2.8	9.0	6.5	10.6	2.5	5.3	3.5
	Pine	Xw	0.94	0.94	0.91	0.86	0.80	0.77	0.75
		CV	1.4	2.3	2.8	2.6	2.6	1.5	2.3
1988	Maple	Xw	0.76	0.70	0.68	0.63	0.56	0.51	0.50
		CV	2.8	4.0	3.8	3.7	9.7	5.5	5.6
	Oak	Xw	0.91	0.90	0.87	0.84	0.76	0.74	0.67
		CV	1.6	1.4	1.6	2.8	4.9	4.3	5.6
	Pine	Xw	0.90	0.89	0.88	0.86	0.81	0.79	0.73
		CV	2.0	1.3	1.3	2.1	2.1	3.3	2.5
1989	Maple	Xw	0.92	0.85	0.83	0.77	0.76	0.70	0.68
		CV	3.3	2.8	2.2	2.8	5.3	5.2	11.0
	Oak	Xw	0.92	0.89	0.85	0.80	0.73	0.72	0.69
		CV	4.1	2.7	2.1	8.4	6.2	6.7	7.2
	Pine	Xw	0.91	0.89	0.86	0.84	0.78	0.76	0.76
		CV	1.5	2.5	3.0	2.2	3.0	2.2	3.2
1990	Maple	Xw	0.93	0.83	0.78	0.74	0.70	0.67	0.61
		CV	3.4	5.5	3.4	3.7	5.5	6.1	11.1
	Oak	Xw	0.97	0.94	0.91	0.89	0.85	0.78	0.74
		CV	1.4	1.2	1.3	1.7	2.1	6.2	1.8
	Pine	Xw	0.95	0.93	0.90	0.88	0.84	0.79	0.74
		CV	1.3	2.6	2.5	2.4	3.3	3.7	3.6
1991	Maple	Xw	0.83	0.76	0.73	0.68	0.65	0.63	0.60
		CV	4.0	4.2	5.0	4.7	3.5	3.4	4.4
	Oak	Xw	0.93	0.88	0.83	0.78	0.75	0.70	0.67
		CV	1.6	2.5	3.7	1.9	2.4	5.1	2.1
	Pine	Xw	0.93	0.89	0.86	0.81	0.79	0.75	0.74
		CV	2.5	2.2	2.0	1.5	3.0	2.1	2.5
1992	Maple	Xw	0.88	0.83	0.77	0.74	0.73	0.67	0.68
		CV	1.1	2.7	3.5	3.6	2.7	3.1	6.0
	Oak	Xw	0.86	0.86	0.83	0.81	0.75	0.72	0.69
		CV	4.0	2.4	3.0	6.2	11.9	5.5	5.3
	Pine	Xw	0.90	0.88	0.85	0.84	0.80	0.76	0.73
		CV	1.5	1.4	2.0	3.5	1.8	2.4	4.8

a/ X_w is the proportion of dry matter mass remaining at sample retrieval.

b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 8. Monthly mean X_w^a and corresponding percent CV^b for bulk litter envelopes retrieved from the Overhead Antenna Hardwood Stand.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.71	0.63	0.69	0.64	0.60	0.55	0.54
		CV	3.4	4.8	6.2	2.6	1.2	4.9	6.6
	Oak	Xw	0.92	0.88	0.89	0.88	0.81	0.73	0.78
		CV	1.7	0.9	2.2	3.5	3.2	5.7	12.1
	Pine	Xw	0.89	0.83	0.84	0.84	0.77	0.71	0.71
		CV	0.6	0.7	2.4	5.8	1.6	1.3	3.5
1986	Maple	Xw	0.86	0.85	0.84	0.78	0.76	0.71	0.63
		CV	1.1	2.1	3.8	3.4	4.4	6.2	4.6
	Oak	Xw	0.94	0.95	0.94	0.91	0.87	0.81	0.74
		CV	2.3	0.7	1.1	1.7	2.2	2.6	5.2
	Pine	Xw	0.94	0.91	0.91	0.86	0.79	0.75	0.72
		CV	0.9	1.9	0.9	1.0	2.0	2.4	1.7
1987	Maple	Xw	0.85	0.84	0.83	0.77	0.72	0.66	0.67
		CV	5.3	6.0	5.0	6.7	6.8	7.7	8.1
	Oak	Xw	0.96	0.97	0.92	0.87	0.80	0.75	0.75
		CV	1.3	3.3	2.0	2.0	2.6	3.4	2.5
	Pine	Xw	0.94	0.93	0.89	0.82	0.77	0.74	0.73
		CV	1.3	1.3	1.9	1.2	1.1	1.2	1.5
1988	Maple	Xw	0.75	0.73	0.72	0.67	0.64	0.55	0.56
		CV	2.5	3.3	1.6	5.1	4.7	6.0	4.4
	Oak	Xw	0.93	0.93	0.91	0.90	0.78	0.74	0.68
		CV	1.7	0.8	2.6	2.6	3.3	2.5	5.5
	Pine	Xw	0.92	0.91	0.89	0.88	0.77	0.74	0.73
		CV	0.6	0.6	1.0	1.2	0.8	1.5	1.7
1989	Maple	Xw	0.92	0.87	0.87	0.82	0.77	0.73	0.77
		CV	2.0	1.1	3.3	2.2	5.5	3.3	2.7
	Oak	Xw	0.93	0.89	0.84	0.79	0.73	0.71	0.68
		CV	1.1	3.5	3.3	3.3	2.4	6.3	4.2
	Pine	Xw	0.90	0.89	0.86	0.83	0.78	0.74	0.74
		CV	1.0	2.2	1.7	1.4	0.5	1.2	2.3
1990	Maple	Xw	0.93	0.85	0.82	0.75	0.71	0.63	0.67
		CV	4.2	3.5	2.7	4.0	8.7	5.9	12.6
	Oak	Xw	0.97	0.95	0.91	0.88	0.82	0.75	0.75
		CV	0.9	0.7	1.7	1.9	2.3	1.8	8.6
	Pine	Xw	0.94	0.93	0.88	0.83	0.81	0.74	0.73
		CV	0.8	1.6	2.2	2.3	2.7	1.4	1.8
1991	Maple	Xw	0.82	0.76	0.75	0.72	0.66	0.66	0.65
		CV	3.0	2.5	7.1	6.8	4.5	6.5	7.7
	Oak	Xw	0.93	0.88	0.82	0.77	0.73	0.64	0.61
		CV	1.4	1.7	2.0	1.2	3.0	6.3	2.3
	Pine	Xw	0.93	0.89	0.85	0.79	0.76	0.75	0.73
		CV	1.2	1.9	1.8	2.4	2.7	0.9	1.7
1992	Maple	Xw	0.90	0.85	0.82	0.81	0.79	0.73	0.71
		CV	1.8	2.2	2.7	2.0	1.8	4.2	3.6
	Oak	Xw	0.90	0.87	0.82	0.78	0.75	0.68	0.63
		CV	1.7	2.8	1.6	5.9	5.0	2.6	3.5
	Pine	Xw	0.91	0.89	0.85	0.84	0.80	0.76	0.74
		CV	0.9	1.8	1.6	1.6	2.5	1.0	2.4

a/ X_w is the proportion of dry matter mass remaining at sample retrieval.

b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 9. Monthly mean X_w^a and corresponding percent CV^b for bulk litter envelopes retrieved from the Control Plantation.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.70	0.62	0.57	0.56	0.50	0.53	0.48
		CV	3.7	7.7	6.4	5.4	6.8	15.6	15.0
	Oak	Xw	0.95	0.90	0.85	0.84	0.79	0.75	0.69
		CV	1.5	2.3	2.9	2.1	3.8	10.2	16.8
	Pine	Xw	0.89	0.86	0.83	0.80	0.80	0.73	0.71
		CV	1.6	1.3	1.2	0.7	6.2	4.5	2.9
1986	Maple	Xw	0.82	0.81	0.76	0.69	0.68	0.59	0.57
		CV	2.3	3.1	2.8	3.0	7.2	21.3	11.4
	Oak	Xw	0.94	0.92	0.90	0.87	0.83	0.76	0.68
		CV	1.0	1.1	1.3	2.1	2.9	5.2	11.5
	Pine	Xw	0.90	0.87	0.87	0.84	0.78	0.76	0.70
		CV	1.4	5.5	2.8	2.2	2.8	4.1	4.5
1987	Maple	Xw	0.85	0.79	0.77	0.72	0.65	0.62	0.60
		CV	1.4	2.4	2.2	3.7	4.5	6.2	4.7
	Oak	Xw	0.95	0.92	0.90	0.85	0.78	0.74	0.73
		CV	2.6	1.7	3.4	1.5	3.6	7.9	4.9
	Pine	Xw	0.92	0.91	0.88	0.84	0.77	0.74	0.74
		CV	1.9	1.3	2.6	0.6	1.2	1.5	1.9
1988	Maple	Xw	0.77	0.72	0.68	0.64	0.57	0.54	0.49
		CV	3.7	3.6	3.1	5.4	7.5	3.6	9.9
	Oak	Xw	0.95	0.90	0.89	0.87	0.79	0.75	0.68
		CV	1.0	2.2	3.6	1.8	2.6	3.4	6.1
	Pine	Xw	0.92	0.89	0.88	0.88	0.79	0.76	0.73
		CV	0.5	2.7	1.0	2.3	1.4	1.7	1.3
1989	Maple	Xw	0.91	0.86	0.83	0.81	0.73	0.72	0.72
		CV	2.8	3.5	1.9	3.0	5.5	4.0	4.7
	Oak	Xw	0.92	0.88	0.84	0.81	0.75	0.70	0.68
		CV	1.7	1.3	2.7	2.5	2.9	2.5	5.5
	Pine	Xw	0.91	0.88	0.85	0.81	0.79	0.73	0.76
		CV	2.2	1.8	1.3	3.1	1.7	1.7	5.6
1990	Maple	Xw	0.93	0.82	0.77	0.72	0.69	0.63	0.62
		CV	3.3	2.4	3.3	6.5	6.1	4.5	11.8
	Oak	Xw	0.97	0.94	0.90	0.87	0.82	0.76	0.72
		CV	1.0	1.6	1.9	2.4	1.9	3.0	2.5
	Pine	Xw	0.93	0.93	0.90	0.87	0.83	0.78	0.74
		CV	2.6	1.4	2.0	3.3	2.4	3.9	3.9
1991	Maple	Xw	0.80	0.77	0.73	0.71	0.65	0.64	0.60
		CV	1.4	4.8	3.6	5.3	4.6	8.9	7.5
	Oak	Xw	0.92	0.88	0.83	0.79	0.74	0.67	0.66
		CV	1.4	1.4	4.8	3.0	2.1	4.2	6.5
	Pine	Xw	0.92	0.89	0.86	0.82	0.78	0.75	0.74
		CV	1.6	1.2	1.9	2.6	2.4	1.9	3.7
1992	Maple	Xw	0.87	0.84	0.82	0.78	0.78	0.69	0.70
		CV	3.0	1.2	4.4	5.1	8.9	6.5	10.6
	Oak	Xw	0.89	0.85	0.82	0.77	0.75	0.68	0.62
		CV	1.6	5.8	3.2	3.0	4.6	3.2	5.8
	Pine	Xw	0.91	0.88	0.86	0.83	0.80	0.75	0.75
		CV	0.7	1.8	1.8	1.2	1.3	1.3	3.7

a/ X_w is the proportion of dry matter mass remaining at sample retrieval.

b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 10. Monthly mean X_w^a and corresponding percent CV^b for bulk litter envelopes retrieved from the Control Hardwood Stand.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.72	0.65	0.64	0.64	0.58	0.54	0.51
		CV	3.0	2.5	2.4	3.2	3.7	5.5	4.7
	Oak	Xw	0.93	0.90	0.87	0.87	0.79	0.70	0.68
		CV	1.1	1.6	1.0	5.4	2.5	4.5	4.1
	Pine	Xw	0.89	0.83	0.83	0.81	0.77	0.71	0.70
		CV	0.9	0.6	1.1	2.4	1.8	1.9	3.4
1986	Maple	Xw	0.84	0.85	0.82	0.77	0.75	0.69	0.63
		CV	2.7	1.1	3.1	3.8	2.2	4.4	4.0
	Oak	Xw	0.94	0.95	0.93	0.91	0.85	0.78	0.72
		CV	0.6	1.1	1.0	1.5	2.4	0.7	1.6
	Pine	Xw	0.93	0.92	0.89	0.85	0.79	0.75	0.72
		CV	0.9	2.0	2.2	1.3	1.8	1.2	1.8
1987	Maple	Xw	0.87	0.83	0.84	0.81	0.75	0.71	0.70
		CV	1.7	2.3	2.4	3.5	5.7	4.8	5.0
	Oak	Xw	0.95	0.93	0.90	0.86	0.80	0.71	0.74
		CV	1.4	1.8	1.9	1.7	3.5	10.0	3.1
	Pine	Xw	0.94	0.92	0.88	0.83	0.77	0.74	0.73
		CV	1.3	1.4	1.2	1.0	2.0	2.4	2.3
1988	Maple	Xw	0.80	0.76	0.75	0.71	0.66	0.64	0.62
		CV	2.4	3.2	4.6	4.0	5.7	4.7	8.4
	Oak	Xw	0.95	0.94	0.94	0.92	0.84	0.77	0.73
		CV	1.1	1.1	1.8	1.8	2.7	4.0	4.1
	Pine	Xw	0.94	0.92	0.92	0.92	0.82	0.78	0.75
		CV	0.8	0.7	1.1	0.8	1.5	1.5	2.8
1989	Maple	Xw	0.92	0.90	0.88	0.87	0.81	0.80	0.80
		CV	3.3	2.7	2.1	2.8	1.9	3.6	3.1
	Oak	Xw	0.92	0.90	0.86	0.82	0.78	0.75	0.73
		CV	1.8	3.0	3.6	3.5	4.2	3.8	4.9
	Pine	Xw	0.92	0.89	0.87	0.83	0.81	0.78	0.77
		CV	2.2	2.6	2.7	2.4	1.6	2.0	1.1
1990	Maple	Xw	0.93	0.87	0.84	0.80	0.76	0.67	0.69
		CV	3.7	5.8	3.7	4.4	5.8	6.4	5.6
	Oak	Xw	0.97	0.96	0.93	0.89	0.83	0.76	0.74
		CV	0.5	0.8	2.2	1.8	1.2	1.2	4.3
	Pine	Xw	0.96	0.96	0.92	0.88	0.84	0.76	0.74
		CV	0.9	0.8	1.8	2.8	5.8	1.4	3.5
1991	Maple	Xw	0.81	0.76	0.76	0.70	0.66	0.62	0.64
		CV	2.5	2.7	5.2	3.1	3.3	4.6	5.1
	Oak	Xw	0.93	0.87	0.82	0.79	0.73	0.68	0.65
		CV	3.0	1.7	1.8	2.3	4.4	4.6	4.6
	Pine	Xw	0.94	0.91	0.87	0.82	0.78	0.75	0.74
		CV	0.9	1.6	1.5	3.2	0.7	2.0	2.1
1992	Maple	Xw	0.88	0.84	0.83	0.81	0.81	0.75	0.75
		CV	2.7	4.6	3.2	4.2	1.6	7.8	5.9
	Oak	Xw	0.89	0.85	0.84	0.76	0.73	0.71	0.63
		CV	1.3	1.2	2.2	3.6	3.8	2.4	8.3
	Pine	Xw	0.90	0.89	0.88	0.82	0.81	0.77	0.75
		CV	1.2	1.4	1.4	5.1	2.0	3.3	2.4

a/ X_w is the proportion of dry matter mass remaining at sample retrieval.

b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

affects decomposition rate, and that years rank differently in quality for each litter species, it should be expected that years would 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) are presented in Table 11. Mean X_w detection limits for years, sites, and siteyears are comparable across the hardwood stands and the plantations. Litter species generally rank maple $\geq$ oak $\geq$ pine, in order of decreasing detection limits. Detection limits for years were $\leq$ 8, 4, and 3 percent for maple, oak, and pine, respectively. All detection limits for site changes were well below 2 percent (below 1 percent for oak and pine). Detection limits for siteyears were $\leq$ 10, 5, and 3 percent for maple, oak, and pine, respectively. The largest detection limits were for the month of November, and particularly in the plantations (where detection limits reached 24, 18, and 11 percent, for maple, oak, and pine, respectively). Overall, these low detection limits have challenged our ability to effectively explain differences among years, sites, siteyears, and most months.

A summary of recent statistical analyses and corresponding preliminary results is presented as Table 12. All covariate names are defined in Table 13. The models referenced in Table 12 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) suggests that ELF EM fields may slightly accelerate the rate of litter decomposition. Means Model ANACOV results are presented in Tables 14 and 15, Tables 16 and 17, and Tables 18 and 19, for maple, oak, and pine (respectively) in the hardwood stands. Throughout the eight year study, the patterns

Table 11. Detection limits for X_w^a derived from ANACOV LSMEANS for bulk maple, oak, and pine foliage samples from 1985 - 1992.

Litter Species	Stand Type	ANACOV Model Type	Effect	Detection Limit Range	
				ΔASSRX_w^b	$\% \text{LSMEANX}_w^c$
Maple	Hardwoods ^d	Effects	Year	0.022 - 0.047	2 - 7
			Site	0.009	1
			Month	0.047 - 0.141	5 -16
		Means	Siteyear	0.023 - 0.053	2 - 6
	Plantation ^d	Effects	Year	0.020 - 0.046	2 - 8
			Site	0.008 - 0.010	1
			Month	0.056 - 0.163	7 -26
		Means	Siteyear	0.025 - 0.053	3 -10
Oak	Hardwoods ^e	Effects	Year	0.015 - 0.045	1 - 3
			Site	0.007	1
			Month	0.034 - 0.100	3 - 9
		Means	Siteyear	0.020 - 0.054	2 - 5
	Plantation ^d	Effects	Year	0.019 - 0.045	2 - 4
			Site	0.008 - 0.010	1
			Month	0.054 - 0.157	4 -18
		Means	Siteyear	0.024 - 0.051	2 - 4
Pine	Hardwoods ^e	Effects	Year	0.011 - 0.033	1 - 3
			Site	0.005 - 0.006	1
			Month	0.025 - 0.072	2 - 6
		Means	Siteyear	0.014 - 0.039	1 - 3
	Plantation ^d	Effects	Year	0.013 - 0.030	1 - 3
			Site	0.005 - 0.006	1
			Month	0.036 - 0.103	3 -11
		Means	Siteyear	0.016 - 0.034	1 - 3

a/ X_w is the proportion of dry matter mass remaining at sample retrieval.

b/ ΔASSRX_w is the detectable change in the LSMEAN, expressed in arcsin square-root transformed X_w units.

c/ $\% \text{LSMEANX}_w$ is the approximate detectable percentage change in the LSMEAN (calculated in original units of X_w).

d/ Weather covariates used were seasonally accumulated 1) soil temperature degree days (4°C, 5 cm depth), 2) total precipitation, and 3) numbers of days with precipitation ≥ 0.10 in.

e/ Weather covariates used were seasonally accumulated 1) soil temperature degree days (4°C, 5 cm depth), 2) total precipitation, and 3) numbers of days with precipitation ≥ 0.01 in.

Table 12. Summary of statistical analyses and results for measured variables, Element 1.

Variable	Model	Test Procedure ^a	Covariates ^b	Treatments	Findings Through 1992 ^c
X_w (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 13. Definitions for names of variables used in ANACOV models presented in this proposal.

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.
PRWRT	-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.

Table 14. Means Model ANACOV table for detection of differences in red maple litter dry matter mass loss (arcsin square root of X_w , the proportion of initial mass remaining) in the two hardwood stands, by siteyear and month^a.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r ²
Model	37	8.63		127.61	0.0001	0.88
Siteyear	15		1.98	72.28	0.0001	
Month	6		0.08	6.91	0.0001	
ST5DDSPR	1		0.05	25.63	0.0001	
ST5DDSUM	1		0.01	7.82	0.0053	
ST5DDFAL	1		0.00	1.02	0.3133	
PRWSPR	1		0.01	7.23	0.0074	
PRWSUM	1		0.00	0.62	0.4315	
PRWFAL	1		0.00	0.09	0.7581	
PR.01SPR	1		0.00	1.74	0.1881	
PR.01SUM	1		0.01	6.63	0.0103	
PR.01FAL	1		0.00	0.02	0.8776	
DEV*MONTH	7		0.04	3.30	0.0019	
Error	632	1.16				
Corrected Total	669	9.79				

a/ Covariates are defined in Table 13.

Table 15. Adjusted means, standard errors, and significantly different pairs of means, based on the Means Model presented in Table 14, for maple litter in the hardwood stands.

Source of Variation	Adjusted Mean ^a	Standard Error ^b	Significant Differences ^c
Siteyear			1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
A85	0.93	0.018	A85
A86	1.05	0.015	A86 *
A87	1.08	0.015	A87 *
A88	0.94	0.011	A88 * *
A89	1.14	0.011	A89 * * * *
A90	1.09	0.009	A90 * * * *
A91	1.02	0.009	A91 * * * *
A92	1.12	0.014	A92 * * * *
C85	0.91	0.019	C85 * * * *
C86	1.03	0.015	C86 * * * *
C87	1.08	0.019	C87 * * * *
C88	0.99	0.010	C88 * * * * *
C89	1.17	0.017	C89 * * * * *
C90	1.14	0.010	C90 * * * * *
C91	1.04	0.016	C91 * * * * *
C92	1.12	0.008	C92 * * * * *
Month			M J J A S O
May	1.15	0.032	May
June	1.00	0.033	June *
July	1.03	0.021	July * *
August	1.05	0.017	Aug *
September	1.07	0.029	Sept
October	1.04	0.032	Oct
November	1.04	0.051	Nov

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ $\alpha = 0.05$, Least Squares Means procedure

Table 16. Means Model ANACOV table for detection of differences in red oak litter dry matter mass loss (arcsin square root of X_w , the proportion of initial mass remaining) in the two hardwood stands, by siteyear and month^a.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r ²
Model	37	11.13		182.64	0.0001	0.91
Siteyear	15		1.12	45.28	0.0001	
Month	6		0.01	1.22	0.2959	
ST5DDSPR	1		0.00	1.00	0.3167	
ST5DDSUM	1		0.01	5.79	0.0164	
ST5DDFAL	1		0.00	2.34	0.1266	
PRWSPR	1		0.03	16.44	0.0001	
PRWSUM	1		0.04	21.49	0.0001	
PRWFAL	1		0.00	0.03	0.8698	
PR.01SPR	1		0.00	2.31	0.1287	
PR.01SUM	1		0.01	4.14	0.0423	
PR.01FAL	1		0.01	7.35	0.0069	
DEV*MONTH	7		0.04	3.63	0.0008	
Error	634	1.04				
Corrected Total	671	12.18				

a/ Covariates are defined in Table 13.

Table 17. Adjusted means, standard errors, and significantly different pairs of means, based on the Means Model presented in Table 16, for oak litter in the hardwood stands.

Source of Variation	Adjusted Mean ^a	Standard Error ^b	Significant Differences ^c
Siteyear			1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
A85	1.24	0.019	A85
A86	1.16	0.013	A86 *
A87	1.23	0.013	A87 *
A88	1.14	0.010	A88 *
A89	1.11	0.010	A89 *
A90	1.21	0.007	A90 *
A91	1.11	0.015	A91 *
A92	1.05	0.011	A92 *
C85	1.18	0.016	C85 *
C86	1.16	0.012	C86 *
C87	1.19	0.014	C87 *
C88	1.20	0.010	C88 *
C89	1.14	0.011	C89 *
C90	1.25	0.008	C90 *
C91	1.15	0.020	C91 *
C92	1.08	0.010	C92 *
Month			M J J A S O
May	1.20	0.027	May
June	1.19	0.027	June
July	1.18	0.017	July
August	1.17	0.012	Aug
September	1.14	0.023	Sept
October	1.13	0.026	Oct
November	1.14	0.036	Nov

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ $\alpha = 0.05$, Least Squares Means procedure

Table 18. Means Model ANACOV table for detection of differences in red pine litter dry matter mass loss (arcsin square root of X_w , the proportion of initial mass remaining) in the two hardwood stands, by siteyear and month^a.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r ²
Model	37	6.75		209.27	0.0001	0.92
Siteyear	15		0.42	32.04	0.0001	
Month	6		0.03	5.29	0.0001	
ST5DDSPR	1		0.01	11.50	0.0007	
ST5DDSUM	1		0.04	51.41	0.0001	
ST5DDFAL	1		0.00	0.00	0.9684	
PRWSPR	1		0.01	9.54	0.0021	
PRWSUM	1		0.02	17.84	0.0001	
PRWFAL	1		0.00	3.46	0.0635	
PR.01SPR	1		0.00	2.73	0.0992	
PR.01SUM	1		0.00	0.13	0.7146	
PR.01FAL	1		0.03	32.67	0.0001	
DEV*MONTH	7		0.02	3.41	0.0014	
Error	632	0.55				
Corrected Total	669	7.30				

a/ Covariates are defined in Table 13.

Table 19. Adjusted means, standard errors, and significantly different pairs of means, based on the Means Model presented in Table 18, for pine litter in the hardwood stands.

Source of Variation	Adjusted Mean ^a	Standard Error ^b	Significant Differences ^c																
Siteyear				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A85	1.12	0.014	A85																
A86	1.14	0.010	A86																
A87	1.15	0.010	A87	*															
A88	1.16	0.007	A88	*	*														
A89	1.15	0.008	A89																
A90	1.18	0.005	A90	*	*	*		*											
A91	1.16	0.011	A91	*															
A92	1.13	0.008	A92				*		*	*									
C85	1.08	0.011	C85	*	*	*	*	*	*	*	*								
C86	1.14	0.008	C86				*		*			*							
C87	1.15	0.010	C87	*					*			*							
C88	1.21	0.007	C88	*	*	*	*	*	*	*	*	*	*	*	*				
C89	1.17	0.008	C89	*	*			*			*	*	*		*				
C90	1.23	0.006	C90	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
C91	1.20	0.014	C91	*	*	*	*	*		*	*	*	*	*	*			*	
C92	1.14	0.007	C92				*		*			*			*	*	*	*	*
Month										M	J	J	A	S	O				
May	1.17	0.020	May																
June	1.10	0.020	June		*					*									
July	1.13	0.013	July		*					*	*								
August	1.16	0.009	Aug							*	*	*							
September	1.19	0.017	Sept							*	*	*	*						
October	1.17	0.019	Oct																
November	1.18	0.026	Nov																

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ $\alpha = 0.05$, Least Squares Means procedure

of annual change in overall X_w have tended to be similar for both study hardwood stands. Nevertheless, ANACOV indicates 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. This tendency was not statistically significant for all years, and was most pronounced for oak litter. The largest difference observed between the hardwood stands in a given year was approximately 5 percent X_w , for maple in 1988. However, the difference in X_w between the hardwood stands in 1992 was not statistically significant for either maple or pine. Results of the 1992/93 experiment will be 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

Introduction

Streptomyces 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 Pokojaska-Burdziej 1984, Strzelczyk *et al.* 1987, Richter *et al.* 1989). Streptomyces 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 streptomyces are not considered to undergo great population changes in stable ecosystems (Orchard 1984). For these reasons, streptomyces 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, for several reasons. First, we have found no indication of any ELF field effect on mycorrhizoplane streptomyces populations through 1991. Second, occasional problems with obtaining appropriate samples, or especially with fungal contamination of samples, have resulted in incomplete streptomyces data sets (for which the planned sample size was already modest). In contrast, the litter decomposition and root disease mortality data sets are both larger and complete.

Methods

Six washed mycorrhizal red pine fine root samples were collected and prepared monthly, from late May to late October at the ground, antenna, and control site plantations. Five seedlings

were excavated per month on each of the three plots comprising each plantation, as has been the case since 1984. Two independent composite samples were derived from two to three of the seedlings from each plot. These samples were stored at 4°C and processed within 12 hours of receipt by the Environmental Microbiology lab in the Department of Biological Sciences. As in 1990, an average of 8.5 days (ranging from 7 to 10 days) was required for processing of field samples, from the time root samples were collected in the field to the delivery of washed root samples for streptomycete analysis. Total numbers of streptomycete colonies and numbers of morphotypes per sample were determined using the methods reported previously (1990 Annual Report).

Both the numbers and identity (with respect to recurrence) of distinct streptomycete morphotypes found in the 1991 samples were compared to observations from similar samples for 1984 through 1990. This allowed us to determine if some of the same types are still present after the red pine seedlings have been in the field for seven years, and to determine whether the same types are present in all three ELF study site plantations.

Data for streptomycete levels and morphotype numbers were transformed to $\log_{10}$ for statistical analysis (Orchard 1984). All statistical analyses were conducted on the mainframe computer using PROC GLM of the Statistical Analysis System (SAS 1985). Covariates were used to help explain differences in streptomycete levels and/or morphotype numbers among years, plantations, sampling dates, and siteyears. Table 13 presented the abbreviated names and definitions of all covariates used in any of the ANACOV models included in this report. The covariates used are weather-related variables, due both to their effectiveness and to their presumed independence of ELF field influence. Wherever covariance analysis detected significant differences, pairwise comparisons (SAS, PROC GLM, Least Squares Means option) of means were examined. The power of our

experimental design was calculated as detection limits, the percentage difference between to sample means which would be detected 50 percent of the time with alpha 0.05.

Description of Progress

Levels of Mycorrhizoplane Streptomycetes

The mean levels of mycorrhizoplane streptomycetes, with their associated CV values, are presented in Tables 20 through 22, for each sampling date, at the three study plantations (ground, antenna, and control sites, respectively). The relatively large CV values (and missing data) for 1989 through 1991 are associated with insufficient or inadequate samples (less than six samples provided per site or insufficient sample mass provided) and/or with bacterial or fungal contamination of several of the samples.

The results of ANACOV for the 1985 through 1991 streptomycete levels data are presented in Tables 23 and 24. For streptomycete levels, ANACOV utilizing ST5DDRT, PRWRT, and PR.01RT explained all differences between sites ($p = 0.4832$) as well as the year-by-site interaction ($p = 0.0950$). However, this ANACOV did not explain the lower levels consistently detected in October, and failed to explain about half of the comparisons among years. No pattern was discerned among the unexplained year-to-year comparisons. Detection limits for streptomycete levels are presented in Table 25. Shifts in streptomycete levels of 21 to 37 percent among years, or of 12 to 13 percent among plantations, should be detectable 50 percent of the time. Numbers of

Numbers of Mycorrhizoplane Streptomycete Morphotypes

The mean numbers of mycorrhizoplane streptomycete morphotypes recovered, with their associated CV values, are presented in Tables 20 through 22, for each sampling date, at the three study plantations (ground, antenna, and control sites, respectively).

Table 20. Levels of streptomycetes ($\times 10^5$) and numbers of streptomycete types, with corresponding percent CVA, isolated from washed type 3 red pine mycorrhizal fine roots at the Antenna Ground Plantation.

Year			Month					
			May	Jun	Jul	Aug	Sep	Oct
1985	Levels	Avg	9.04	3.91	4.14	4.59	3.56	9.25
		CV	77.0	89.9	71.2	37.3	93.1	13.7
	Types	Avg	7	6	5	5	6	4
		CV	13.7	0.0	20.4	10.9	18.7	43.5
1986	Levels	Avg	3.84	4.56	2.18	2.86	2.87	1.19
		CV	27.2	35.1	24.6	37.5	45.0	26.0
	Types	Avg	7	6	4	4	4	3
		CV	30.5	21.9	12.3	22.0	22.0	22.4
1987	Levels	Avg	3.81	3.57	5.15	4.24	5.99	1.52
		CV	38.4	54.6	28.8	28.4	31.9	28.4
	Types	Avg	4	3	3	3	3	3
		CV	22.3	14.9	23.5	23.5	14.9	30.6
1988	Levels	Avg	3.17	4.49	5.01	4.74	6.00	2.15
		CV	28.1	13.7	12.5	21.0	9.0	33.5
	Types	Avg	4	4	3	3	4	3
		CV	29.9	22.0	41.4	41.0	18.1	30.6
1989	Levels	Avg	2.29	3.42	3.96	2.24	2.53	1.67
		CV	-	25.3	14.6	45.8	39.9	35.1
	Types	Avg	3	3	3	3	2	2
		CV	-	25.3	0.0	33.2	23.3	71.1
1990	Levels	Avg	2.88	-	3.98	4.33	3.60	-
		CV	56.6	-	-	32.9	29.5	-
	Types	Avg	3	-	3	3	3	2
		CV	45.7	-	-	25.9	25.9	0.0
1991	Levels	Avg	1.39	3.32	5.11	0.98	0.14	0.50
		CV	48.1	35.9	32.1	80.5	-	62.0
	Types	Avg	3	2	3	2	2	2
		CV	47.3	25.3	29.2	22.8	-	0.0

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 21. Levels of streptomycetes ($\times 10^5$) and numbers of streptomycete types, with corresponding percent CVA^a, isolated from washed type 3 red pine mycorrhizal fine roots at the Overhead Antenna Plantation.

Year			Month					
			May	Jun	Jul	Aug	Sep	Oct
1985	Levels	Avg	4.50	5.14	4.54	2.73	4.53	1.47
		CV	34.9	54.6	7.3	42.4	51.9	49.1
	Types	Avg	6	6	5	6	5	4
		CV	32.9	33.1	10.9	9.5	45.2	35.4
1986	Levels	Avg	4.73	3.91	3.35	2.79	2.60	1.14
		CV	44.5	32.8	40.9	36.8	33.4	18.9
	Types	Avg	7	6	5	4	3	3
		CV	13.3	24.7	15.9	15.0	36.9	26.5
1987	Levels	Avg	3.58	5.06	4.60	4.55	6.75	1.78
		CV	42.9	27.6	44.8	45.0	24.4	15.8
	Types	Avg	3	5	3	4	4	3
		CV	30.9	11.4	14.9	29.9	29.9	29.6
1988	Levels	Avg	3.62	3.35	4.07	4.76	5.97	1.83
		CV	27.2	29.0	13.2	14.8	12.1	51.3
	Types	Avg	3	3	3	3	5	3
		CV	24.3	34.6	45.4	41.4	14.8	19.8
1989	Levels	Avg	2.69	2.19	1.61	2.10	2.73	1.91
		CV	26.9	21.3	8.1	66.8	34.6	43.5
	Types	Avg	5	4	4	3	3	3
		CV	31.0	39.6	33.5	16.6	30.0	82.5
1990	Levels	Avg	2.84	2.16	4.54	3.77	3.64	-
		CV	61.3	46.2	58.0	24.7	35.2	-
	Types	Avg	4	3	2	4	4	3
		CV	37.2	22.1	25.3	34.2	30.6	23.6
1991	Levels	Avg	1.34	2.10	3.25	1.75	4.25	0.60
		CV	45.1	51.5	50.7	48.0	11.7	-
	Types	Avg	4	3	3	2	4	2
		CV	22.0	36.4	21.5	19.3	41.9	-

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 22. Levels of streptomycetes ($\times 10^5$) and numbers of streptomycete types, with corresponding percent cv^a, isolated from washed type 3 red pine mycorrhizal fine roots at the Control Plantation.

Year			Month					
			May	Jun	Jul	Aug	Sep	Oct
1985	Levels	Avg	4.54	9.09	1.65	-	1.34	1.04
		CV	62.1	23.7	52.0	-	52.2	44.5
	Types	Avg	7	5	4	-	5	4
		CV	9.0	22.1	13.8	-	22.1	24.9
1986	Levels	Avg	4.20	4.14	3.49	2.18	2.22	1.09
		CV	42.0	56.2	52.5	25.5	60.1	23.5
	Types	Avg	7	5	4	3	4	3
		CV	29.0	19.9	18.1	14.9	27.9	26.5
1987	Levels	Avg	3.97	5.66	4.14	6.27	6.53	1.56
		CV	35.0	32.6	39.7	24.9	21.5	60.1
	Types	Avg	4	4	3	3	3	3
		CV	22.0	22.3	23.7	23.7	30.6	22.4
1988	Levels	Avg	3.35	3.81	4.81	5.31	6.03	1.74
		CV	32.5	33.0	19.3	15.8	19.3	42.3
	Types	Avg	3	2	3	3	4	3
		CV	19.8	22.6	41.4	30.9	37.4	19.8
1989	Levels	Avg	3.07	2.62	3.13	2.13	3.19	1.39
		CV	30.2	56.2	33.6	34.0	35.1	22.0
	Types	Avg	4	3	4	4	4	3
		CV	30.6	16.6	23.7	30.6	27.3	46.0
1990	Levels	Avg	3.96	3.57	2.75	3.95	3.85	-
		CV	44.5	32.8	16.6	11.3	51.3	-
	Types	Avg	3	2	2	4	4	2
		CV	25.9	0.0	23.3	19.9	35.1	33.4
1991	Levels	Avg	1.20	3.48	2.78	1.79	0.70	0.58
		CV	28.3	40.8	45.1	56.4	3.5	42.6
	Types	Avg	3	3	2	2	2	2
		CV	30.6	36.4	33.4	22.8	25.3	0.0

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 23. Covariance analysis table for detection of differences in streptomycete levels associated with type 3 red pine mycorrhizae ($\log_{10}$ -transformed data), among the three plantation subunits, by year and by month (May - October), using ST5DDRT, PRWRT, and PR.01RT as covariates^a.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r ²
Model	31	23.39		11.58	0.0001	0.43
Year	6		6.99	20.98	0.0001	
Plantation	2		0.08	0.73	0.4832	
Year*Plantation	12		1.05	1.57	0.0950	
Plot(Plantation)	3		0.22	1.32	0.2675	
Month	5		5.16	18.58	0.0001	
ST5DDRT	1		0.03	0.48	0.4894	
PRWRT	1		0.51	9.17	0.0026	
PR.01RT	1		0.10	1.78	0.1824	
Error	553	30.72				
Corrected Total	584	54.11				

a/ ST5DDRT is the running total number of soil temperature degree days (5 cm depth, 4.4°C basis); PRWRT is the running total of rainfall for the year; PR.01RT is the running total of the number of days with precipitation events delivering at least 0.01 inch of rain.

Table 24. Adjusted means, standard errors, and significantly different pairs of means, based on the levels model analyzed in Table 23.

Source of Variation	Adjusted mean ^a	Standard Error ^b	Significant Differences ^c
Year			5 6 7 8 9 0
1985	5.33	0.057	1985
1986	5.44	0.042	1986
1987	5.57	0.054	1987 *
1988	5.56	0.034	1988 * *
1989	5.45	0.032	1989 *
1990	5.44	0.039	1990 *
1991	5.12	0.038	1991 * * * * *
Month			M J J A S
May	5.59	0.174	May
June	5.62	0.110	June
July	5.54	0.041	July
August	5.40	0.053	Aug
September	5.40	0.122	Sept
October	4.95	0.177	Oct * * * *
Plantation			G A
Ground	5.41	0.020	Ground
Antenna	5.44	0.019	Antenna
Control	5.40	0.020	Control

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ $\alpha = 0.05$, Least Squares Means procedure

Table 25. Detection limits for streptomycete levels and morphotype numbers derived from ANACOV LSMEANS for 1985 through 1991.

Variable	ANACOV Model		Detection Limit Range	
	Type	Effect	$\Delta \log_{10}X^a$	%LSMEANX ^b
Levels ^c	Effects	Year	0.089 - 0.158	21 - 37
		Site	0.052 - 0.056	12 - 13
		Month	0.113 - 0.491	26 - 139
	Means	Siteyear	0.112 - 0.209	26 - 50
Morphotype Numbers ^d	Effects	Year	0.060 - 0.110	14 - 26
		Site	0.036 - 0.039	8 - 9
		Month	0.085 - 0.350	20 - 90
	Means	Siteyear	0.087 - 0.156	20 - 37

- a/ $\Delta \log_{10}X$ is the detectable change in the LSMEAN, expressed in transformed units.
- b/ % LSMEANX is the approximate detectable percentage change in the LSMEAN (calculated in original units).
- c/ Weather covariates used were cumulative soil temperature degree days (4°C, 5 cm depth), total precipitation, and cumulative numbers of days with at least 0.01 in. precipitation.
- d/ Weather covariates used were cumulative soil temperature degree days (4°C, 5 cm depth) and cumulative numbers of days with at least 0.01 in. precipitation.

Again, the relatively large CV values and missing data for 1989 through 1991 are associated with insufficient or inadequate samples, and/or with bacterial or fungal contamination of several of the samples. Considering the small numbers of morphotypes characteristically recovered from any given sample, a reduction in this variable of 1.0 morphotype per sample might well be detected. Nevertheless, because most morphotypes are not routinely recovered from every sample, it might be necessary for several of the less abundant morphotypes to decline in abundance in order to effect a reduction of 1.0 in morphotype numbers recovered.

For morphotype numbers, ANACOV utilizing ST5DDRT, and PR.01RT (Tables 26 and 27) explained all differences between sites ($p = 0.7474$) as well as year-by-site interaction ($p = 0.4996$). Differences between sampling dates were also explained. Morphotype numbers have declined noticeably since 1985 in all 3 plantations, possibly due to vegetation conversion from mixed hardwoods to red pine monoculture. This initial decline and then stabilization may reflect the establishment and persistence of those streptomycete types most capable of growth and survival with the red pine mycorrhizae at these sites. Detection limits for streptomycete morphotype numbers are presented in Table 25. Shifts in streptomycete morphotype numbers of 14 to 26 percent among years, or of 8 to 9 percent among plantations, should be detectable 50 percent of the time. Shifts of this magnitude would likely require declines in abundance (or outright loss) of several of the approximately 20 streptomycete morphotypes observed over the past six years.

Morphotype Distribution and Characterization

Patterns of streptomycete morphotype recovery from type 3 washed mycorrhizal fine roots during the 1991 sampling season are listed in Table 28. In general, the same morphotypes and same general incidence patterns were found during the 1991 sampling season as

Table 26. Covariance analysis table for detection of differences in numbers of streptomycete types associated with type 3 red pine mycorrhizae ($\log_{10}$ -transformed data), among the three plantation subunits, by year and month (May - October), using ST5DDRT, and PR01RT as covariates^a.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r ²
Model	30	6.25		6.83	0.0001	0.27
Year	6		3.74	20.48	0.0001	
Plantation	2		0.02	0.29	0.7474	
Year*Plantation	12		0.35	0.95	0.4996	
Plot(Plantation)	3		0.05	0.52	0.6670	
Month	5		0.25	1.66	0.1432	
ST5DDRT	1		0.02	0.50	0.4797	
PR01RT	1		0.18	5.83	0.0160	
Error	567	17.27				
Corrected Total	597	23.52				

a/ ST5DDRT is the running total number of soil temperature degree days (5 cm depth, 4.4°C basis); PR.01RT is the running total of the number of days with precipitation events delivering at least 0.01 inch of rain.

Table 27. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 26.

Source of Variation	Adjusted Mean ^a	Standard Error ^b	Significant Differences ^c
Year			5 6 7 8 9 0
1985	0.79	0.040	1985
1986	0.56	0.029	1986 *
1987	0.57	0.036	1987 *
1988	0.46	0.025	1988 * * *
1989	0.51	0.022	1989 *
1990	0.46	0.027	1990 * * *
1991	0.42	0.024	1991 * * * *
Month			M J J A S
May	0.54	0.126	May
June	0.53	0.081	June
July	0.50	0.031	July
August	0.53	0.037	Aug
September	0.59	0.085	Sept
October	0.54	0.122	Oct
Plantation			G A
Ground	0.52	0.014	Ground
Antenna	0.55	0.013	Antenna
Control	0.54	0.013	Control

a/ adjusted mean of transformed data

b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM

c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $(t_{0.05, n-1} * S.E. / \text{Mean})$, and expressed as a percentage of the sample mean

d/ $\alpha = 0.05$, Least Squares Means procedure

Table 28. Streptomycete morphotypes associated with washed mycorrhizal type 3 fine roots.

Sampling Date (1991)	Study Site ^a	Nb	Streptomycete Morphotype																			
			A	B	C	D	E	F	G	H	J	K	N	O	P	Q	R	S	T	U	V	W
22 May	C	6	X ^C X ^C			X	X				X						X ^C					X
	A	6	X ^d X ^C			X ^d			X			X ^C					X ^C X	X				X ^C
	G	5	X ^d X	X							X	X					X ^C	X				X ^C
18 June	C	3	X ^d X ^C			X ^d											X		X	X ^C		X ^C
	A	6	X ^C X ^C X			X ^C				X	X ^C X ^C						X	X ^d X				X ^C
	G	6		X		X						X ^C					X ^C	X	X			
16 July	C	4	X	X ^C		X ^C					X ^C								X			
	A	5	X ^C X ^C			X ^C					X ^d						X ^C					X
	G	6	X	X		X ^C					X				X ^C							X ^C
13 August	C	4	X ^C X			X					X								X ^C			X ^C
	A	6	X ^d X ^C			X						X										X ^C
	G	4	X	X		X																X ^C
9 September	C	3		X				X									X	X			X	X ^C
	A	3	X	X ^C		X					X				X	X	X	X ^C			X	
	G	1	X											X								
14 October	C	2		X		X					X											
	A	1		X															X			
	G	3		X				X			X			X								X ^C

^a C = Control Plantation; A = Antenna Plantation; G = Ground Plantation

^b N = number of replicate samples/plantation

^c Morphotype detected in two or more replicate samples/plantation

^d Predominant morphotype in two or more replicate samples/plantation

in 1986 through 1990. With one exception, morphotype B was detected at each plantation on each sampling date. It was often found in multiple samples per plantation per sampling date, but not often as the predominant type. Morphotypes D, J, S, and T were again commonly detected, similar to 1987 through 1990. Morphotype F occurrence was similar to 1989 and 1990 (i.e., much less frequent than prior to 1989). Incidences of morphotypes A, K, and W were slightly increased over those found in 1990; both the 1990 and 1991 patterns of occurrence of these morphotypes were more similar to those found prior to 1989. Frequencies of isolation of morphotypes E, H, and N were even lower in 1991 than in 1990; however, these levels were still more similar to those found prior to 1989. Morphotype R increased in incidence in many of the 1991 root samples, to approximately the same incidence levels reported in 1989. As noted earlier, detection of morphotypes was made difficult during 1991 due to the increased overgrowth of sample plates by saprophytic fungi and non-streptomycete bacteria. This was particularly the case with the ground plantation samples, in general, which have had an increased incidence of "contamination" in past years; however, samples from all sites had occasions of non-streptomycete overgrowth, particularly with the October root samples.

Additional similarities were present in morphotype incidence patterns among those plantation site samples consisting only of mycorrhizal type 3 fine roots, i.e., 1986 - 1991. For the control plantation, the incidence pattern found in 1991 was very similar to that found in 1989 and 1990, as well as in many of the previous years. The key exception was that the type S levels were slightly lower than those found previously. In general, the overall 1991 antenna plantation morphotype incidence patterns were very similar to the 1990 patterns, particularly for the more common morphotypes B, D, J, T, and W. Morphotype A incidence increased to that found before 1988. Morphotype H was again detected only from the antenna plantation, but only once during the season. There were again relatively few ground plantation

sample morphotype data for the 1991 season, primarily due to contamination problems (as noted above). In spite of this, morphotypes A, B, and W were commonly detected. Overall, morphotypes B, J, K, N, P, R, and T were found in about the same levels as in previous sampling seasons at the ground plantation, and morphotypes A and D were present in levels about the same as 1989 and earlier. In contrast to previous years, no morphotype S was detected in any of the ground plantation samples during 1991.

Representatives of each streptomycete type detected during the 1991 sampling season were tested for ability to degrade calcium oxalate, cellulose and lignocellulose. The same results were found as in all past seasons in terms of which morphotypes could degrade one or more of these compounds, again indicating little change detectable in either morphotypes or their activities in the past four sampling seasons.

Summary of Results

The results of statistical analyses for both streptomycete levels and morphotype numbers data are summarized in Table 29. ANACOV has been successfully used to explain all differences in either streptomycete levels or morphotype numbers among study plantations. Year-by-site interaction was also explained, as were differences among monthly samples for morphotype numbers. Morphotype numbers have declined since 1985 in all 3 plantations. This initial decline and then stabilization may reflect the establishment and persistence of those streptomycete types most capable of growth and survival with the red pine mycorrhizae at these sites. No potential effect of ELF EM field exposure has been identified through the 1991 field season.

Detection limits calculated for both streptomycete levels and morphotype numbers indicate that we have a 50 percent chance or better (with $\alpha = 0.05$) of detecting shifts in either of these variables of 37 percent among years, and 13 percent among

Table 29. Summary of statistical analyses and results for measured variables, Element 2.

Variable	Test Procedure ^a	Covariates ^b	Treatments	Findings Through 1991 ^c
M_ycorrhiplane Streptomycete Levels				
	ANACOV	ST5DDRT, PRWRT, PR01RT	Year, Site Siteyear Month	No Detectable Effect
M_ycorrhiplane Streptomycete Morphotype Numbers				
	ANACOV	ST5DDRT, PR01RT	Year, Site Siteyear Month	No Detectable Effect

a/ ANACOV = Analysis of Covariance (Proc GLM, SAS)

b/ Covariate names are defined in Table 13.

c/ All statistical tests are at $\alpha = 0.05$.

plantations. Shifts of this magnitude would likely require declines in abundance (or outright loss) of several of the approximately 20 streptomycete morphotypes observed over the past six years.

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 the only plant disease which has received attention in the Ecological Monitoring Program. Armillaria species colonize woody debris, stumps, and moribund root systems, causing white-rot type wood decay. These foodbases are colonized either by means of airborne spores or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize the next. 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 microorganisms. Armillaria species are represented in the study plantations by very large and long-lived individuals, which have remarkable potential for vegetative growth and spread (Smith et al. 1990, 1992). 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 clones. Field work must continue at least through 1993 to provide sufficient data for evaluation of possible ELF EM field effects on this important factor affecting forest health.

The decision to continue data collection for the Armillaria root disease work element is based on somewhat different criteria from those applied to the litter decomposition study element. 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 to complete the statistical analysis for the Armillaria root disease work element has been made based on the following criteria:

1. Armillaria root disease, the only lethal disease of red pine present in the study plantations, is the only plant disease under study in the Ecological Monitoring Program. This disease has killed between 2 and 41 percent of the host populations in plantation quarter-plots.
2. There is good reason to expect that additional mortality due to this disease will continue to occur, 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 A. ostoyae.
4. Because Armillaria root disease is readily diagnosed, it is possible to accurately map and statistically model disease progress.

5. Mapping data are now available for the entire plantation red pine populations, and for the estimated historic distribution of ELF EM field exposures. Our picture of the spatial distributions of Armillaria genets in the red pine plantations (essential to disease progress modeling) will be completed by mid-1993.

Methods

It is clear, from the uneven spatial distributions of host seedlings in the three study plantations, that comparison of mortality counts among plantations (or quarterplots) is a totally inappropriate test of ELF EM field effects on Armillaria root disease progress. 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. The initial host seedling population is defined as the number of living seedlings at the beginning of the 1986 field season. This starting point was selected because 1) the first Armillaria root disease 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 are simplified by the absence of other lethal infectious diseases in the study plantations. The analysis reported here is based on disease progress in each of the 12 quarterplots comprising each plantation. Y_i is calculated as the cumulative mortality count divided by the initial host seedling count reduced by the number of healthy seedlings removed for experimental purposes.

The pathogen is isolated into pure culture from each seedling killed by Armillaria root disease. Isolates are also obtained each autumn from Armillaria mushrooms collected in the plantations. Isolates are grown in confrontation with each other in Petri dish culture for identification of vegetatively

compatible groups of isolates. Vegetatively compatible isolates have been shown to belong to the same vegetative individual or genet (Smith et al. 1990, 1992). Each clone is then identified to species. So far, all identified clones responsible for red pine mortality in the study plantations belong to a single species, A. ostoyae (Romagnesi) Herink. Clones of A. gallica Marxmuller & Romagnesi are also widespread in the plantations, but are not pathogenic toward red pine.

Construction of historical (1986 to present) maps of the spatial distribution of genets of each species is nearly up-to-date. Once we are able to estimate the spatial boundaries of each genet, we will be able to determine the host population basis for the area occupied by each genet. This will permit statistical analysis of the rate of disease progress on an individual genet basis, as well as on a quarterplot basis (see below). Analyses based on the areas occupied by individual genets are attractive, because they restrict calculations of disease progress to the portion of the host population accessible by genets of the pathogen.

The distributions of target host plants vary greatly within and among plantations, largely due to initial planting failures. It was essential (for calculation of Y_i) to document these spatial distributions, in order to establish initial host populations within quarterplot or genet boundaries. Therefore, the entire live seedling populations in the 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, logistic, and Richards

models. The integrated forms of these models are:

monomolecular: $y = K(1 - Be^{-rt})$

Gompertz: $y = K \exp(-Be^{-rt})$

logistic: $y = K / (1 + \exp(-(B + rt)))$

Richards: $y = K(1 - Be^{-rt})^{1/(1-m)}$, when $m < 1$, and
 $K(1 + Be^{-rt})^{1/(1-m)}$, when $m > 1$.

The linearized forms of these models are:

monomolecular: $\ln(K/(K-y)) = -\ln(B) + rt$

Gompertz: $-\ln(-\ln(y/K)) = -\ln(B) + rt$

logistic: $\ln(y/(K-y)) = \ln(y_0/(K-y_0)) + rt$

Richards: $\ln(1/(1-(y/K)^{(1-m)})) = -\ln(B) + rt$, when $m < 1$, and
 $\ln(1/((y/K)^{(1-m)} - 1)) = -\ln(B) + rt$, when $m > 1$.

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} , $\exp$ represents e raised to some specified power, and m is a shape parameter with values ranging from 0 to infinity.

Rate constants for disease progress were estimated for each of the 12 quarterplots comprising each plantation, using each of the models listed above. 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 quarterplot 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 36 quarter-plots were best fit by the monomolecular model, rate parameter estimates were compared directly, using ANOVA (Madden 1986).

In addition to comparing the three plantations using rate constants based on all years, we plan to compare rate constants derived from "roughly" pre- and post-operational years' data for each of the three plantations. This analysis will require field data for 1993, in order to have four years of "post"-operational data (1990-1993) to compare with our four years of "pre"-operational data (1986-1989).

All regressions and ANOVAs 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. Significant differences detected by ANOVA have been identified by the Least Square Means pairwise comparison option, within PROC GLM.

We expect ANACOV to play an important role in explaining the differences in disease progress rate detected by ANOVA among the genets residing in the three plantations. Covariates to be considered will include precipitation-related variables, seedling height, and hardwood stump foodbase characteristics (all relevant to disease progress). The same ANACOV model form will be used to recalculate rates of monomolecular disease progress for each genet, and the resulting set of rate parameters will be analyzed by ANOVA for differences among sites.

Description of Progress

Our preliminary maps of Armillaria genets (see Figures 3.1 through 3.3, 1991 Annual Report) indicate that genets of the same Armillaria species overlap little, whereas genets of different Armillaria species overlap freely. It is therefore possible to analyze rates of disease progress within the boundaries of individual A. ostoyae genets. This will address concern regarding the variation among quarterplots in the proportion of their land area occupied by A. ostoyae.

Annual disease progress (percent mortality) since plantation establishment is presented in Table 30. Monomolecular rate parameter values for disease increase in each of the 36 quarterplots are presented in Table 31. The results of preliminary ANOVA for detection of differences in rate among the three plantations are presented in Tables 32 and 33. Significant differences among plantations were detected by ANOVA ($p = 0.0015$), and the least squares means pairwise comparison procedure ranked disease progress rates as antenna > control > ground, in order of descending magnitude. Detection limits for each plantation are also presented in Table 33. Their relatively large size may simplify the matter of explaining the differences detected by ANOVA. On the other hand, genet-based analysis will probably provide lower CV values and detection limits than have the quarterplot-based analysis reported here.

Summary of Results

Preliminary maps of the spatial distribution of Armillaria genets for all three plantations indicate that individual genets of A. ostoyae overlap very little. As a result, it will be possible to compare disease progress rates based on the land area occupied by individual genets. Analysis on an individual genet basis, rather than on a quarterplot basis, should substantially reduce detection limits, by including only that portion of each plantation which is colonized by the pathogen.

Preliminary ANOVA study of the rates of disease increase for all quarterplots found that r was greatest in the overhead antenna plantation and lowest in the antenna ground plantation. It must be noted that A. ostoyae genets occupy a smaller proportion of the antenna ground plantation than of either the overhead antenna or the control site plantation. Therefore, plantation rankings may be different for the upcoming (and preferred) analysis of disease progress rates based on individual genets.

Table 30. Armillaria root disease progress (percent red pine mortality) since plantation establishment in 1984.

Year									
Plantation	Plot	1985	1986	1987	1988	1989	1990	1991	1992
Ground	1	0.0	0.0	0.6	1.8	2.7	4.0	4.2	5.0
	2	0.0	0.6	1.6	4.2	6.1	8.0	8.5	9.0
	3	0.0	0.6	4.0	8.1	11.1	12.1	12.5	12.7
	Total	0.0	0.4	1.9	4.4	6.3	7.8	8.1	8.6
Antenna	1	0.0	2.1	3.7	9.4	11.3	12.4	12.6	13.1
	2	0.0	0.6	2.5	7.0	16.0	18.4	19.2	20.4
	3	0.0	0.4	5.2	17.6	25.2	30.1	31.1	32.1
	Total	0.0	1.0	4.1	12.0	18.0	21.0	21.7	22.5
Control	1	0.0	1.0	6.5	13.3	17.0	19.9	20.6	21.7
	2	0.0	0.8	6.3	10.2	14.4	16.9	17.3	18.3
	3	0.0	0.3	2.2	5.7	8.7	10.0	10.5	11.2
	Total	0.0	0.7	4.9	9.6	13.2	15.4	15.9	16.9

Table 31. Rates of monomolecular disease increase¹ from disease progress curves for mortality caused by Armillaria root disease on each of the plantation study quarter-plots.

Site	Block	Quarter-plot	Monomolecular r
1	1	1	0.1177
1	1	2	0.0181
1	1	3	0.1412
1	1	4	0.0348
1	1	5	0.0518
1	2	6	0.0653
1	2	7	0.0912
1	2	8	0.1426
1	3	9	0.2632
1	3	10	0.2304
1	3	11	0.0929
1	3	12	0.0215
2	1	13	0.1315
2	1	14	0.1637
2	1	15	0.0586
2	1	16	0.1177
2	2	17	0.1428
2	2	18	0.1559
2	2	19	0.2030
2	2	20	0.4215
2	3	21	0.2620
2	3	22	0.5446
2	3	23	0.2958
2	3	24	0.3913
3	1	25	0.3121
3	1	26	0.1488
3	1	27	0.2186
3	1	28	0.1712
3	2	29	0.1257
3	2	30	0.1661
3	2	31	0.1899
3	3	32	0.1611
3	3	33	0.1341
3	3	34	0.1089
3	3	35	0.0718
3	3	36	0.0976

¹ The monomolecular model has the following linearized form: $\ln[K/(K-y)] = -\ln(B) + rt$, where y is the proportion of the host population diseased (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).

Table 32. ANOVA table for detection of differences in monomolecular rate of disease increase, from the Armillaria root disease mortality progress models for each of the plantation quarter-plots.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r ²	CV
Model	8	0.27889		5.26	0.0005	0.61	48
Site	2		0.11071	8.35	0.0015		
Plot (Site)	6		0.16818	4.23	0.0040		
Error	27	0.17906					
Corrected Total	35	0.45796					

Table 33. Adjusted means, standard errors, detection limits, and significantly different pairs of means, based on the model analyzed in Table 32.

Source of Variation	Adjusted Mean ^a	Standard Error	Detection Limit ^b	Significant Differences ^c		
Site				1	2	3
1	0.1059	0.0235	22.41	1		
2	0.2407	0.0235	26.38	2	*	
3	0.1588	0.0235	41.99	3		*

^a mean of r values

^b percentage change in the variable for which there is a 50 percent chance of detection at p = 0.05.

We will continue documenting the seedling mortality caused by individual genets of A. ostoyae during 1993. This will give us three years of study with the fully-operational ELF system. We will use the resulting data to analyze disease progress rates on both an individual genet basis and on a quarterplot basis. In addition to comparing the three plantations using rate constants based on all years, we will explore the possibility of comparing rate constants derived from pre- and post-operational years' data for each of the three plantations. We propose to use ANACOV to explain differences among genets and plantations in disease progress rates (r') detected by ANOVA. Potential covariates include precipitation-related variables, mean seedling height, and variables which characterize the hardwood stump population.

LITERATURE CITED

- Andrews, J. H. and C. M. Kenerley. 1979. The effects of a pesticide program on microbial population from apple leaf litter. Canadian Journal of Microbiology 12:1331-1344.
- Antai, S.P., and D. L. Crawford. 1981. Degradation of softwood, hardwood and grass lignocelluloses by two Streptomyces strains. Applied and Environmental Microbiology 42:378-380.
- Becker, D.M., S.M. Paetchow, S.T. Bagley, and J.N. Bruhn. 1990. Inhibition of vegetative growth of Armillaria ostoyae and A. bulbosa by red pine mycorrhizoplane streptomycetes. Phytopathology 80:1059.
- Berg, B., G. Ekbohm, and C. McClaugherty. 1984. Lignin and holocellulose relations during long-term decomposition of some forest litters. Long-term decomposition in a Scots pine forest. IV. Canadian Journal of Botany 62:2540-2550.
- Blair, J.M., Parmelee, R.W., and Beare, M.H. 1990. Decay rates, nitrogen fluxes, and decomposer communities of single- and mixed-species foliar litter. Ecology 71: 1976-1985.
- Bruhn, J. N., D. L. Richter, and J. B. Pickens. 1992. The influence of litter bulking and bagging on pine, oak, and maple foliage decomposition in pine plantations and hardwood stands. Submitted to the Canadian Journal of Botany.
- Bruhn, J. N., J. B. Pickens, and J. A. Moore. 1989. Armillaria root rot in Pinus resinosa plantations established on clearcut mixed hardwood sites. Pages 437-446 in D. J. Morrison, ed. Proceedings of the Seventh International Conference on Root and Butt Rots. I.U.F.R.O. Working Party S2.06.01. Forestry Canada, Pacific Forestry Center, Victoria. 680 p.

Campbell, C.L. 1986. Interpretation and uses of disease progress curves for root diseases. Pages 38-54 in: Leonard, K.J., and W.E. Fry, eds. Plant Disease Epidemiology, Volume 1. Macmillan Publishing Company, New York.

Campbell, C.L., and L.V. Madden. 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, Inc., New York.

Cochran, W. S. 1957. Analysis of covariance: it's nature and uses. *Biometrics* 13:261-281.

Coffman, M. S., E. Alyanak, J. Kotar, and J. E. Ferris. 1983. Field Guide. Habitat Classification System for the Upper Peninsula of Michigan and Northeastern Wisconsin. CROFS; Department of Forestry, Michigan Technological University, Houghton, Michigan.

Crawford, D. L. 1978. Lignocellulose decomposition by selected Streptomyces strains. *Applied and Environmental Microbiology* 35:1041-1045.

Fogel, R., and K. Cromack, Jr. 1977. Effect of habitat and substrate quality on Douglas fir litter decomposition in western Oregon. *Canadian Journal of Botany* 55:1632-1640.

Goodfellow, M. and D. Dawson. 1978. Qualitative and quantitative studies of bacteria colonizing Picea sitchensis litter. *Soil Biology and Biochemistry* 10:303-307.

Graustein, W. C., K. Cromack, Jr., and P. Sollins. 1977. Calcium oxalate: Occurrence in soils and effect on nutrient and geochemical cycles. *Science* 198:1252-1254.

Jayasuriya, G. C. N. 1955. The isolation and characteristics of an oxalate-decomposing organism. *Journal of General Microbiology* 12:419-428.

Jensen, V. 1974. Decomposition of angiosperm tree leaf litter. Pages 69-104 in C. H. Dickinson and G. J. F. Pugh, editors. Biology of Plant Litter Decomposition, Volume 1. Academic Press. New York. 146 p.

Keast, D., and C. Tonkin. 1983. Antifungal activity of West Australian soil actinomycetes against Phytophthora and Pythium species and a mycorrhizal fungus, Laccaria laccata. Australian Journal of Biological Science 36:191-203.

Keast, D., P. Rowe, B. Bowra, L. San Feliere, E. O. Stopley, and H.B. Woodruff. 1984. Studies on the ecology of West Australian actinomycetes: Factors which influence the diversity and types of actinomycetes in Australian soils. Microbial Ecology 10:123-136.

Kendrick, W. B. 1959. The time factor in the decomposition of coniferous leaf litter. Canadian Journal of Botany 27:907-912.

Klemmedson, J.O. 1992. Decomposition and nutrient release from mixtures of Gambel oak and ponderosa pine leaf litter. For. Ecol. and Manage. 47: 349-361.

Knutson, D. M., A. S. Hutchins, and K. Cromack, Jr. 1980. The association of calcium oxalate-utilizing Streptomyces with conifer ectomycorrhizae. Antonie van Leeuwenhoek 46: 611-619.

Madden, L.V. 1986. Statistical analysis and comparison of disease progress curves. Pages 55-84 in: Leonard, K.J., and W.E. Fry, eds. Plant Disease Epidemiology, Volume 1. Macmillan Publishing Company, New York.

Madden, L.V., and C.L. Campbell. 1990. Nonlinear disease progress curves. Pages 181-229 in: Kranz, J., ed. Epidemics of Plant Diseases. Mathematical Analysis and Modeling. 2nd ed. Springer Verlag, Berlin.

Marx, D. H. 1982. Mycorrhizae in interactions with other microorganisms. B. Ectomycorrhizae. Pages 225-228 in N. C. Schenck, editor. Methods and Principles of Mycorrhizal Research. American Phytopathological Society. St. Paul. 244 p.

McCarthy, A. J. and P. Broda. 1984. Screening for lignin-degrading actinomycetes and characterization of their activity against [^{14}C] lignin-labelled wheat lignocellulose. *Journal of General Microbiology* 130:2905-2913.

Meentemeyer, V., and B. Berg. 1986. Regional variation in rate of mass loss of Pinus sylvestris needle litter in Swedish pine forests as influenced by climate and litter quality. *Scandinavian Journal of Forest Research* 1:167-180.

Melillo, J.M., J.D. Aber, and J.F. Muratore. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63:621-626.

Millar, C. S. 1974. Decomposition of coniferous leaf litter. Pages 105-128 in C. H. Dickinson and G. J. F. Pugh, editors. Biology of Plant Litter Decomposition, Volume I. Academic Press. New York. 146 p.

Milliken, G. A., and D. E. Johnson. 1984. Analysis of Messy Data. Volume 1 - Designed Experiments. Van Nostrand Reinhold. New York. 473 p.

Mitchell, C. P., and C. S. Millar. 1978. Effect of lime and urea on decomposition of senescent Corsican pine needles colonized by Lophodermium pinastri. *Transactions of the British Mycological Society* 71:375-381.

Mize, C. W., and R. C. Schultz. 1985. Comparing treatment means correctly and appropriately. *Canadian Journal of Forest Research* 15:1142-1148.

Moore, J. A. 1989. Distribution of Armillaria Clones, Including Models of Red Pine Seedling Mortality, on ELF Plantation Sites in Michigan's Upper Peninsula. M.S. Thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, MI.

Orchard, V. A. 1984. Actinomycete population changes on leaves, litter and in soil from a grazed pasture treated with nematicides. Soil Biology and Biochemistry 16:145-152.

Paetchow, S. 1990. The characterization of mycorrhizoplane-associated streptomycetes and their effects on ectomycorrhizal fungi. M.S. Thesis, Department of Biological Sciences, Michigan Technological University, Houghton, MI.

Richter, D. L., T. R. Zuellig, S. T. Bagley, and J. N. Bruhn. 1989. Effects of red pine (Pinus resinosa Ait.) mycorrhizoplane-associated actinomycetes on in vitro growth of ectomycorrhizal fungi. Plant and Soil 115:109-116.

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5 Edition. SAS Institute Inc., Cary, NC, USA. 956 p.

Smith, M.L., J.N. Bruhn, and J.B. Anderson. 1992. The root-infecting fungus Armillaria bulbosa may be among the largest and oldest living organisms. Nature 356: 428-431.

Smith, M.L., L.C. Duchesne, J.N. Bruhn, and J.B. Anderson. 1990. Mitochondrial genetics in a natural population of the plant pathogen Armillaria. Genetics 126:575-582.

Smith, R. E. 1977. Rapid tube test for detecting fungal cellulase production. Applied and Environmental Microbiology 33:980-981.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and Procedures of Statistics. Second edition. McGraw - Hill, New York.

Strzelczyk, E., H. Dahm, M. Kampert, A. Pokojaska, and H. Rozycki. 1987. Activity of bacteria and actinomycetes associated with mycorrhiza of pine. *Angew. Botanik* 61:53 & 64.

Strzelczyk, E., and A. Pokojaska-Bundziej. 1984. Production of auxins and gibberellin-like substances by mycorrhizal fungi, bacteria, and actinomycetes isolated from soil and the mycorrhizosphere of pine (*Pinus silvestris* L.). *Plant and Soil* 81:185-197.

Sutherland, J. B. 1985. Polymeric dye medium for isolation of lignocellulose-degrading bacteria from soil. Abstract, Annual Meeting, American Society for Microbiology.

Thomas, W.A. 1968. Decomposition of loblolly pine needles with and without addition of dogwood leaves. *Ecology* 49: 568-571.

Thorntwaite, C.W., and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. *Publications in Climatology* 10:183-308.

Witkamp, M. and B. S. Ausmus. 1976. Processes in decomposition and nutrient transfer in forest systems. Pages 375-396 in J. M. Andersen and A. McFadyen, editors. The Role of Terrestrial and Aquatic Organisms in Decomposition Processes. Blackwell Scientific Publications. Oxford. 474 p.

Zar, J. H. 1984. Biostatistical Analysis. Second edition. Prentice - Hall, Inc. Englewood Cliffs, N.J.

GLOSSARY

Actinomycete	A large group of true bacteria, characterized by a mycelial vegetative structure.
AET	Actual evapotranspiration: a measure of the cumulative and concurrent availability of energy and moisture.
Basal Area	The area of the cross section of a tree at DBH.
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 <u>Armillaria</u> species.
Genet	A fungal individual, 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 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.