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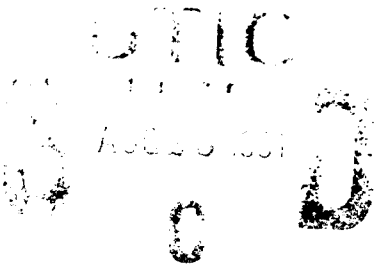
Compilation of 1990 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program

Volume 1 of 3 Volumes:
Tabs A, B



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The Navy initiated studies in 1982 for possible bioelectromagnetic effects from operation of their ELF transmitters in Michigan and Wisconsin. Since then, resident biota have been monitored for effects while transmitters were operated at both intermittent low-power and continuous full-power conditions. This ninth compilation of investigator reports documents the technical progress of biological studies that were performed near the Michigan transmitter through 1989-1990. Near the Wisconsin transmitter, similar studies were completed during 1989. To date, investigators have not found any effects on biota from either an intermittent or a fully energized transmitter.

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FOREWORD

During 1990, the Navy continued to conduct long-term studies monitoring for possible effects to biota from operation of their ELF Communications System. The Space and Naval Warfare Systems Command (SPAWAR) funded these studies through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management of monitoring studies performed by university subcontractors.

The reports compiled (Tabs A-H) in this three-volume document present the progress and findings of ongoing studies located near the Naval Radio Transmitting Facility--Republic, Michigan. At least four scientific peers reviewed each report. Study investigators considered the peer critiques prior to providing a final copy of their annual report to IITRI. These annual reports are compiled here without further change or editing by SPAWAR or IITRI. As is done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Past compilations and other program documents are listed under Tab I.

ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM

INDEX OF 1990 ANNUAL REPORTS

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: HERBACEOUS PLANT COVER AND TREE STUDIES

The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1990

SUBCONTRACT NUMBER: E06595-88-C-001

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INTRODUCTION

Forest vegetation is the dominant cover type on the ELF Communications Antenna System area. In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic (EM) fields cause changes in forest productivity and health. Work elements were initiated at control, antenna and ground treatment plots to establish a baseline of data that could be used to compare various aspects of these communities both before and after the antenna becomes activated. This approach is the the most rigorous for evaluating possible effects of ELF fields on forest ecosystems.

Our overall project 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,
6) insect and disease status of hardwood and pine stands.

Ultimately, the question of whether ELF electromagnetic 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

Much of the effort in this study has been dedicated to developing a statistically rigorous design to separate what may be very subtle ELF field effects on response variables from the existing natural variability caused by soil, stand and climatic factors (Mroz etal. 1985). 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 (Table 2). These measurements and associated analyses are discussed more fully in the various work element sections of this report. Work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypothesis (Table 2).

Table 1. Critical hypotheses that will be 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 rd oak trees or red pine seedlings before and after the ELF antenna becomes activated.
VIII.	There is no difference in the rate of development of *Armillaria* root disease on red pine seedlings before and after the ELF antenna becomes activated.

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

Hypothesis Number	Related Objectives	Measurements	Work Elements
I	1,2	*Weekly dendrometer band readings** climatic variables, soil nutrients, tree and stand characteristics.	1,2,3
II	1	*Annual diameter growth*, terminal bud size, plant moisture stress, microsite climatic variables, number of mycorrhizae.	1,2,3,5
III	1,2	*Weekly height growth, annual height growth*, terminal bud size, plant moisture stress, number of mycorrhizae, ambient measures.	1,2,3,5
IV	2	Periodic measures of plant dimensional variables including *leaf size* and phenological stages of *flowering, fruiting,* etc., climatic variables.	1,3
V	3	*Monthly counts of mycorrhizal root tips by type,* climatic variables, tree variables.	1,5
VI	5	*Periodic collections of litter, nutrient analyses,* climatical variables.	1,6
VII	4	*Periodic collections of foliage, nutrient analyses*, climatic variables.	1,6
VIII	6	*Monthly inventory of red pine mortality caused by Armillaria root disease,* soil texture, bulk density and rock content; hardwood stump characteristics and density.	2

*Italicized print designates response variables; others listed are covariates.

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. An understanding of this experimental design is essential because of the similarity in analyses for hypothesis testing and the complexity of the overall project. The rationale and progress for measurements in each work element of this study are unique and will be presented separately.

Field Design And Electromagnetic Exposure

At the outset of the project, it was known that the electromagnetic fields associated with the ELF system would be different at the antenna and ground locations (Anonymous, 1977). Measurements of 76 hz electric field intensities have been made at the antenna, ground, and control sites since 1986 when antenna testing began (Haradem etal. 1988). Background 60 Hz field levels were measured at all sites in 1985. Three types of electromagnetic (EM) fields are measured for each frequency: magnetic (mG), longitudinal (mV/m), and transverse (V/m). A short description of these follows as summarized from Haradem etal.(1987).

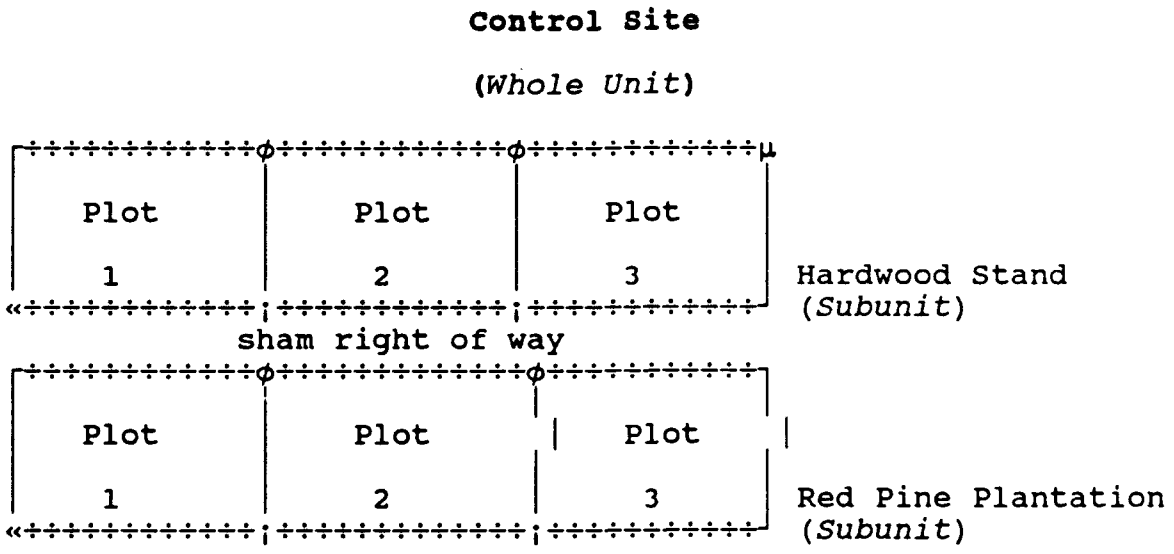
The magnetic field is generated by the antenna and is unchanged at the air/earth boundary. It is expected to diminish with increasing distance from the antenna (being negatively correlated with the inverse of distance) but should remain relatively stable over the length of the antenna. The longitudinal field is in the ground and is parallel, but in the opposite direction to the current in the antenna. Additional longitudinal fields are generated by the ground terminal currents. The longitudinal field is affected by soil conductivity and moisture, as well as other properties such as amount of rocks and roots. The longitudinal field will vary along the length of the antenna and with distance from the antenna. The transverse field is in the air and also diminishes with the inverse of distance from the antenna. The transverse field can be affected by vegetation and other conductive objects so it can also vary considerably over short distances and along the antenna. As a consequence of the differences in fields associated with antenna and ground sites, forest vegetation at each site could be differentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at the ground terminal, and at a control location some distance from the antenna.

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 (Pinus resinosa Ait.) plantations) (Figure 1). 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 electromagnetic 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 rerandomization. A combined analysis involving a split plot design is made to determine both the average treatment response (site difference) over all years and consistency of such responses from year to year (Steel and Torrie 1980).

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 sufficient exposure to ELF fields. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, it becomes irrelevant and falls out of the analysis. All other factors remain unchanged.

Figure 1. Diagram of the control plot as an example of the experimental design units.



Analysis of Covariance

Our experimental design directly controls error in the field to increase precision. Indirect, or statistical control, can also increase precision and remove potential sources of bias through the use of covariate analysis. This involves the use of covariates which are related to the variable of interest. Covariate analysis removes the effects of an environmental source of variation that would otherwise contribute to the 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 (Cochran 1957). Thus, determining covariates which are both biologically meaningful as well as independent of treatment effects continues to be one of the most important steps in our analysis.

Covariates under examination vary for a given variable of interest (Table 2). Most analyses use ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as variables computed from these data, such as air temperature degree days, soil temperature degree days and cumulative precipitation. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the variable; for example, covariates in the analysis of red pine height growth would include bud size, seedling diameter, and total height of the seedling at the beginning of the study in addition to ambient factors. Analyses are being conducted to determine which of these are both statistically significant as well as biological meaningful without violating the necessary assumptions of treatment independence required for the analysis of covariance (Cochran 1957). The most general and encompassing ANOVA table for the project is shown in Table 3. More detailed ANOVA tables can be found in each work element section of this report

Testing for ELF Field Effects

This report covers the seventh year (1984-1990) of actual data collection and evaluation for most elements although analyses requiring EM field intensities only include the sixth year of data (1984-1989). Only five years of weather related measurements are complete (1985 through 1989). Measurements of 60 Hz and 76 Hz field intensities are available for 1986 through 1989 (1990 measurements will be included in next year's report). Background fields are also available for 1985. Observations of field intensities are made once a year at the corners of the measurement plots and some other locations as described by Haradem *etal.* (1989). (This past year more intensive measures were taken along transect crossing the plots. Maps showing these results

were developed by James Gauger of IITRI and appear in appendix A.) The field intensities are affected by vegetative and soil factors and do not strictly behave according to EM theory. Also, treatment levels have not been uniform over time because of the various testing phases prior to antenna operation. To control variability in the actual treatment exposure and to improve our ability to detect what may be an extremely subtle response, we are attempting to interpolate field exposures for individual measurement points on the plots. This is true for individual tree locations in the productivity studies, the litter trap locations in the litter studies, and other such locations in other elements. After year-long discussions with IITRI scientists, we have come up with an approach to account for EM field variability across the sites and over time. This is described below. The form of the equation used for interpolation in 1988 was also used in 1989 and 1990 to obtain exposure data for locations within the plots.

Given the physical expectations for field strength behavior along and away from the antenna described above, a stepwise regression procedure was used to develop equations for interpolating field exposures from the plot corners to interior locations:

$$\text{Field Strength} = a_0 + a_1 X + a_2 / X + a_3 Y$$

where field strength is in mG, V/m, or mV/m depending on the field of interest, X is the perpendicular distance from the antenna, and Y is the distance along the antenna. The coordinate systems for each site are given in Appendix A. The resulting equation systems for calculating exposure levels within the plots are given in Appendix A.

From the interpolation equations, an average field exposure level is obtained for locations within the study plots. Records of the number of on-off cycles and hours of antenna operation are available for 1986 through 1989 (Haradem *et al.* 1989). Average field exposure, number of on-off cycles, hours of exposure, and interactions of these terms, have been used in the various elements to estimate EM field exposure levels and to investigate the effects of these fields on biological activities.

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 will examine differences in response variables between these and previous years, and differences between control, antenna and ground sites in 1987 through 1990 (Testing varies by element with those elements dependent on soil or foliar chemical analyses generally dealing only with data through 1989 at this time. This is due to the lag time in laboratory analyses.)

The most extensive comparisons will be the for yearly and site within year differences. For all hypotheses, ambient and other variables (Table 2.) will be used to

explain site and year differences. If there are no differences between 1987-89 and previous years, no differences between sites in 1987-89, and/or differences between sites is stable before and during 1987-89, we can then infer that the antenna operation had no detectable effects on the response variable. For those elements where analysis of covariance is used, we will test to insure that covariates are statistically independent and then see if fields explain site and year differences for a particular response variable. If site and year differences are apparent in the modelling effort, correlation will be used to determine whether residuals from these analyses are related to ELF fields.

Detection Limits

Where detection limits for response variables are described in an elements they equal the amount of change in the response variable for which there is a 50 percent chance of detecting (using a significance level of 0.05 unless otherwise noted) given the statistical design and sample size in this study. These are calculated as follows (Zar, 1974):

$$\text{Detection Limit} = (SE) * q_{.05,df,p=2}$$

where SE is the standard error for the response variable, $q_{.05,df,p=2}$ is the critical value of the Student-Newman-Keuls multiple range test using a significance level of 0.05 unless otherwise noted and p=2. There is a greater than 50 percent chance that an ELF induced change in the response variable will be detected by the study design if the change is greater than the detection limit; a change less than the detection limit has less than a 50 percent chance of being detected. In most cases, if detection limits did not increase or decrease more than 20% over last year (Mroz et al. 1988), they are not presented.

Work Elements

As stated earlier, 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.

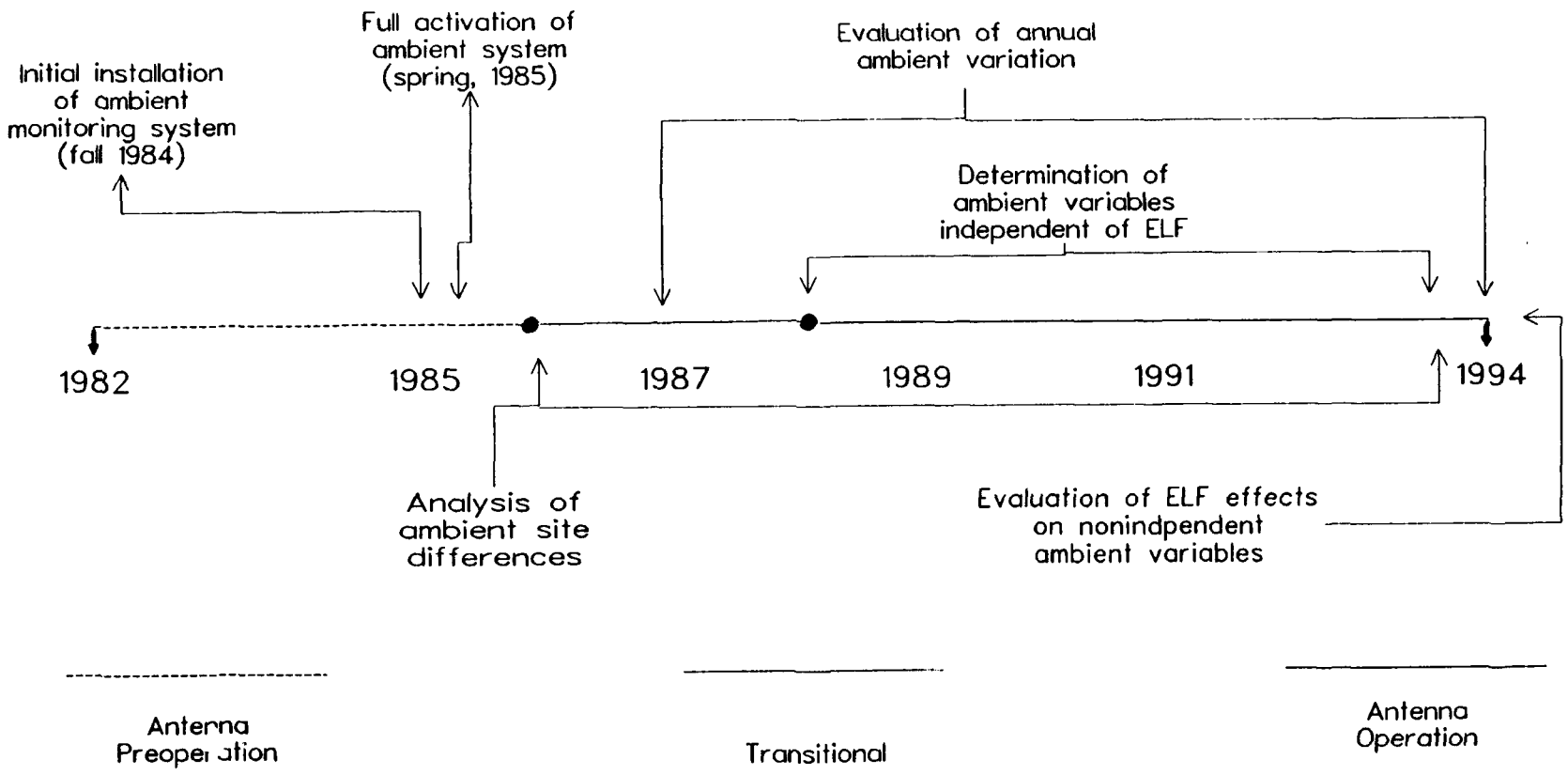
2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.

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

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

Accomplishing these objectives will not only document ambient differences among sites and annual changes in these conditions but also quantify ambient variables which are 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.

Figure 1.1 Schedule and initiation of ambient monitoring objectives.



Work on the Upland Flora Project during the past six years has indicated that soil and possibly precipitation chemistry is important to the project's growth modeling efforts. Thus an increased emphasis has been placed on the collection and analysis of these variables. The ambient monitoring element is separated into two sections: climatic monitoring and nutrient monitoring.

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.

Because of the location of individual sensors precipitation, relative humidity, and global solar radiation are considered to be independent of possible ecological changes caused by ELF electromagnetic fields. Air temperature, soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) may be sensitive to ecological changes related to stand characteristics and thus by possible effects of ELF electromagnetic fields.

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 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 calculated from the cores and readings 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 soil moisture between consecutive months which would be attributed to the monthly adjustment, the weighting equation (1.1) is used to determine the actual monthly soil moisture sensor adjustments. The equation's adjustments for a given month are weighted more heavily to the month of adjustment.

Equation 1.1 Monthly adjustment for a specific plot

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

CSM = Core Soil Moisture from the plot

M = Month of Adjustment

M+1 = Following Month

PSM = Probe Soil Moisture from the plot

M-1 = Previous Month

As stated in the 1986 Herbaceous Plant Cover and Tree Studies Annual Report, 1985 soil moisture measurements could not be used in any analyses. Thus the 1989 measurements were only the fourth 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 small 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 six 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 on 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 air temperature and precipitation have met these criteria on the ground and antenna site in the past four 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 sensor, plot, and site combination with the missing data as the dependent variable and the observed average daily plantation observation from the other 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 1985-89 have been presented in previous Herbaceous Plant Cover and Tree Studies annual reports. The 1990 equations are presented in Appendix B (Table 1-7) of this report. Improved performance of the ambient system in the past two years has eliminated any long term use of these data replacement methods. This year criteria 3 was only used to estimate 3 days of missing datat at the ground site during system startup in early April and 6 to 8 days of antenna information in July. Criteria 4 was used to estimate 8-10 days of information at the control site in July.

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 postoperational 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 the 0.05 probability level 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 tests.

Table 1.2. General analysis of variance of Element 1.

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

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

Progress

This year concludes the sixth full year of data collection by the ambient monitoring system and the third year of the operation of the ELF antenna. In previous reports summarization and statistical comparison of the ambient variables have included the most current year of measurement. However, a number of other elements in the study which use the ambient information lag one year behind in data analysis and presentation of results. Electromagnetic field strengths measured at the site are also reported from the previous but not current year. In order to be more consistent this years report will include summaries through 1990 but no statistical analysis of this data. Next years report will include these same summaries as well as the statistical analysis through 1990. This years report will also include analyses to determine if the ambient variables are related to the electromagnetic fields which have been measured at the sites during 1985-1989. The objective of this effort is to determine if ambient and climatic factors are correlated to the field exposure 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 that 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 either growing season averages or totals for each plot and site for each of the years 1985-1989. Average field exposures for each plot are determined by integrating the equations for each field (Appendix A) over the area of the plot. The electromagnetic measurements chosen for the correlations are the 76 hz magnetic flux, 76 hz transverse electric field, and 76 hz longitudinal electric field 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: Differences in air temperature between the control and test sites in 1990 were similar to differences found in previous years (Table 1.3). The mean air temperature during the growing season at the control plantation was respectively 0.9 and 0.6 ^{o}C warmer than at the ground and antenna plantations during 1990. Mean air temperature at the control hardwood stand was 0.8^{o}C warmer than at the antenna hardwood stand. Differences in air temperature between the control and test sites were reduced in 1990 compared to differences in 1988 or 1989. This may be due to a proportional higher increase in red pine height at the test plantations than at the control in 1988 and 1989 (refer to Element 2). The larger proportional increase in height of the test plantations could reduce differences in air temperature among the sites attributed to absorption and transmittance of short and longwave radiation by the canopy at the sensor height. On going development of the red pine canopy in the future will continue to have an effect on the air temperature at the plantations.

Annual Comparisons: Air temperatures at the sites in 1990 were lower than all years except 1985 (Table 1.3). Mean air temperatures during the 1990 growing season were approximately 1.0 to 2.0 ^{o}C lower than mean air temperatures during the warmest years of the study (1987 and 1988) and 0.0 to 0.4 ^{o}C higher than the coolest year of the study (1985). Comparisons of the average monthly temperatures during 1985-1989 and monthly temperatures in 1990 indicated that temperatures during May and July were below normal. Figures 1.2 and 1.3 show these comparisons for the control plantation and hardwood stands.

Summary: Air temperature at the control site has been found in previous years to be significantly higher than at the test sites. This years results show no indication of changing this trend. Last year's analyses also found that differences in air temperature between the hardwood stands at the control and antenna stand had remained stable over the duration of the study. However, it has been found that differences in air temperature between the control and test plantations have increased during the years 1986-1989. These changes in air temperature have been related to the greater productivity of the control plantation compared to the test plantations. Differences in air temperature between the control and antenna hardwood stands in 1990 have continued to remain stable. For the first time during the study differences in air temperature between the control and test plantations have decreased.

Figure 1.2

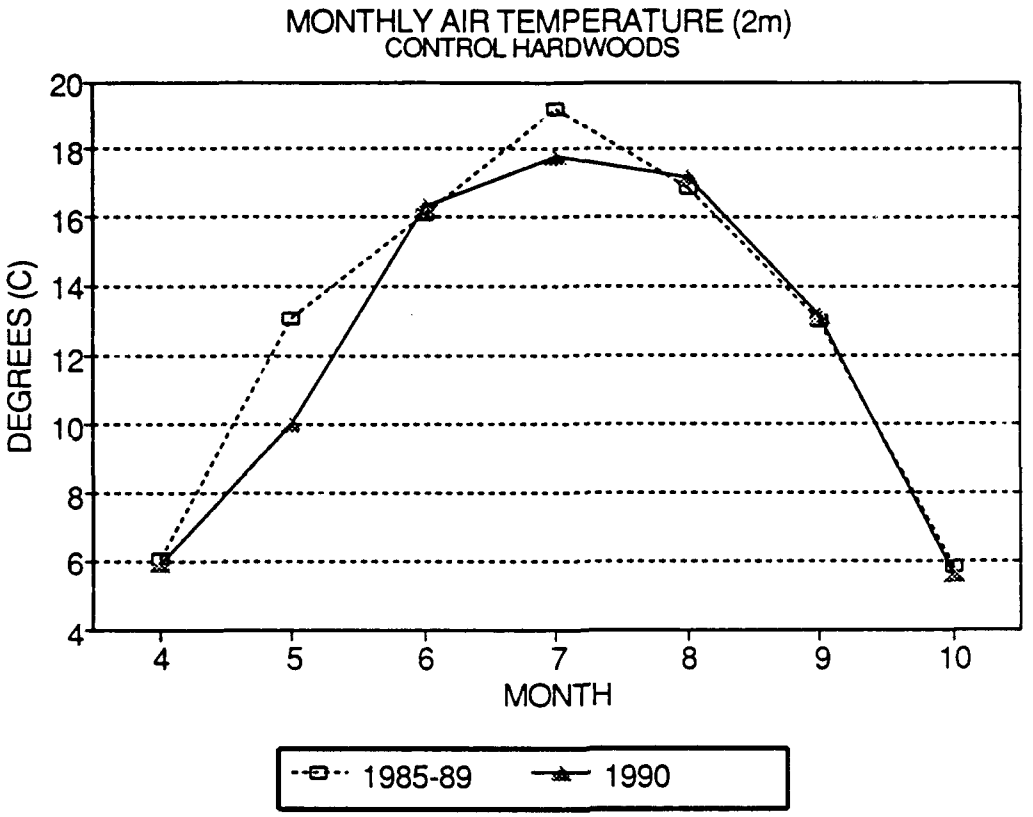


Figure 1.3

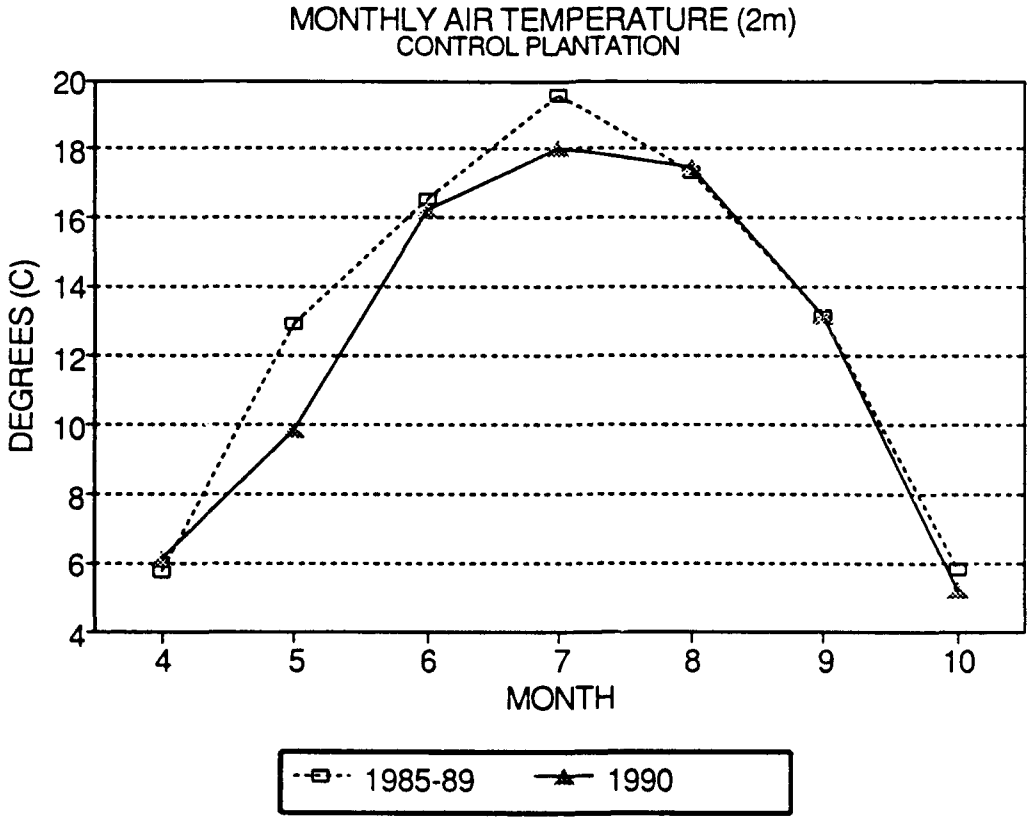


Table 1.3 Comparison of mean air temperature (^{o}C) 2 m above ground during the 1985-90 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	11.4	11.5	11.9	0.5	0.4
1986	11.9	12.1	12.7	0.8	0.6
1987	12.7	12.9	13.6	0.9	0.7
1988	12.3	12.9	13.8	1.5	0.9
1989	11.8	12.1	13.2	1.4	1.1
1990	11.4	11.7	12.3	0.9	0.6
Ave.	11.9	12.2	12.9	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
Ave.		12.0	12.8		0.8

Site Comparison

Control	Ground
12.9	11.9

Control	Antenna
12.9	12.1

Annual Comparison

	Control & Ground	Control & Antenna
1985	11.7	11.8
1986	12.3	12.4
1987	13.1	13.2
1988	13.1	13.1
1989	12.5	12.4
1990	11.9	12.0

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 between average daily soil temperatures (5 cm) at the control and test plantations have remained less than 0. 5 ^{o}C for all years except 1989 (Table 1.4). However, differences between the control and test plantations have generally not been consistent. For example three out of the six study years mean soil temperatures (5 cm) at the control plantation were lower than at the antenna plantation. Soil temperatures at the control plantation were higher or equivalent to soil temperatures measured in the antenna plantation the remaining three years. Soil temperature at the control hardwoods have consistently been warmer than at the antenna hardwoods during the entire study period. Statistical analyses in past years have not shown that these differences to be significant ($p \leq 0.05$).

Annual Comparisons: Mean growing season soil temperatures (5 cm) were lower at the ground and antenna plantations than in any prior year of study. Temperatures were respectively 0.2 and 0.3 ^{o}C lower at the antenna and ground plantations in 1990 than in 1985. During 1990 mean soil temperatures (5 cm) in the control plantation and hardwoods were only 0.1 and 0.3 ^{o}C higher than in 1985. The low soil temperatures at the study sites appear to be a result of lower than normal air temperatures and higher than normal soil moisture contents experienced in 1990 (refer to soil moisture section).

Comparisons of the average monthly soil temperatures (5 cm) at the hardwood stands (1985-1989) to monthly soil temperatures (5 cm) at the hardwood stands in 1990 showed below normal temperatures in May and July (Figure 1.4 and

Table 1.4 Comparison of mean soil temperature (°C) at a depth of 5 cm during the 1985-90 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.5	12.9	12.5	0.0	-0.4
1986	13.3	13.5	13.5	0.2	0.0
1987	13.4	13.7	13.6	0.2	-0.1
1988	13.2	13.5	13.7	0.5	0.2
1989	12.3	12.6	13.2	0.9	0.6
1990	12.2	12.7	12.6	0.4	-0.1
Ave.	12.8	13.2	13.2	0.4	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
Ave.		10.9	11.4		0.5

Site Comparison

Control	Ground
13.2	12.8

Control	Antenna
12.3	12.1

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.5	11.6
1986	13.4	12.5
1987	13.6	12.9
1988	13.5	12.5
1989	12.7	11.9
1990	12.4	11.8

Figure 1.4

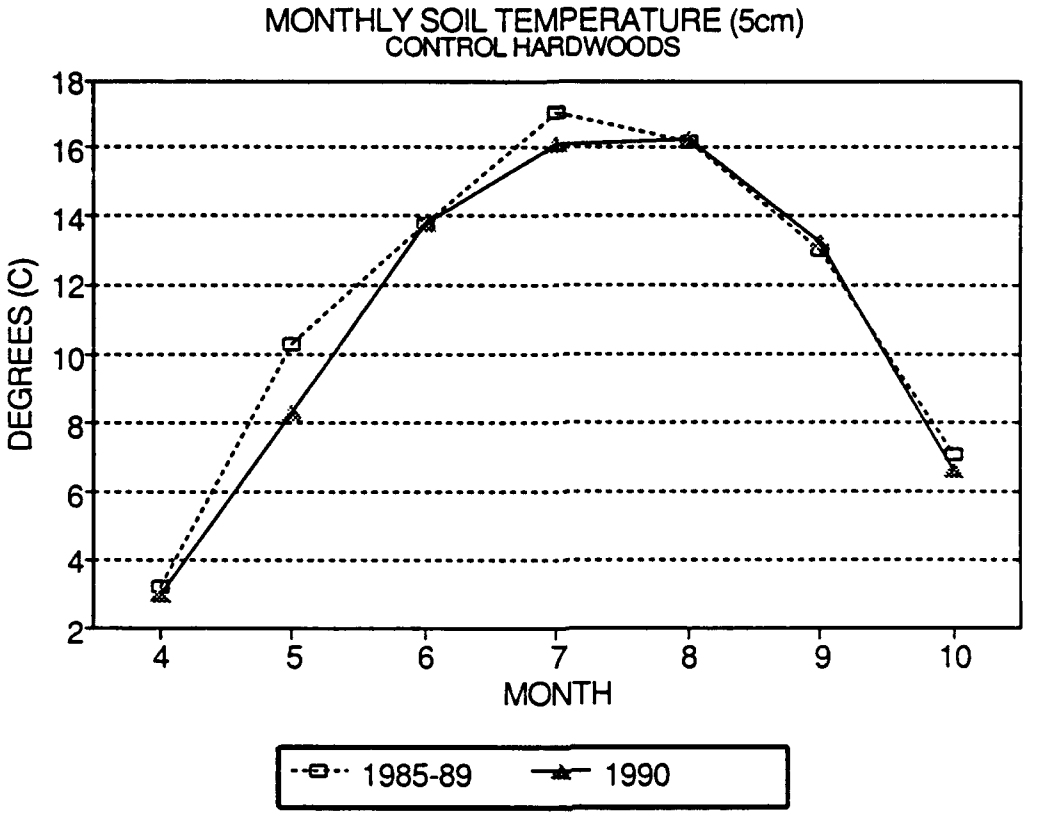


Figure 1.5

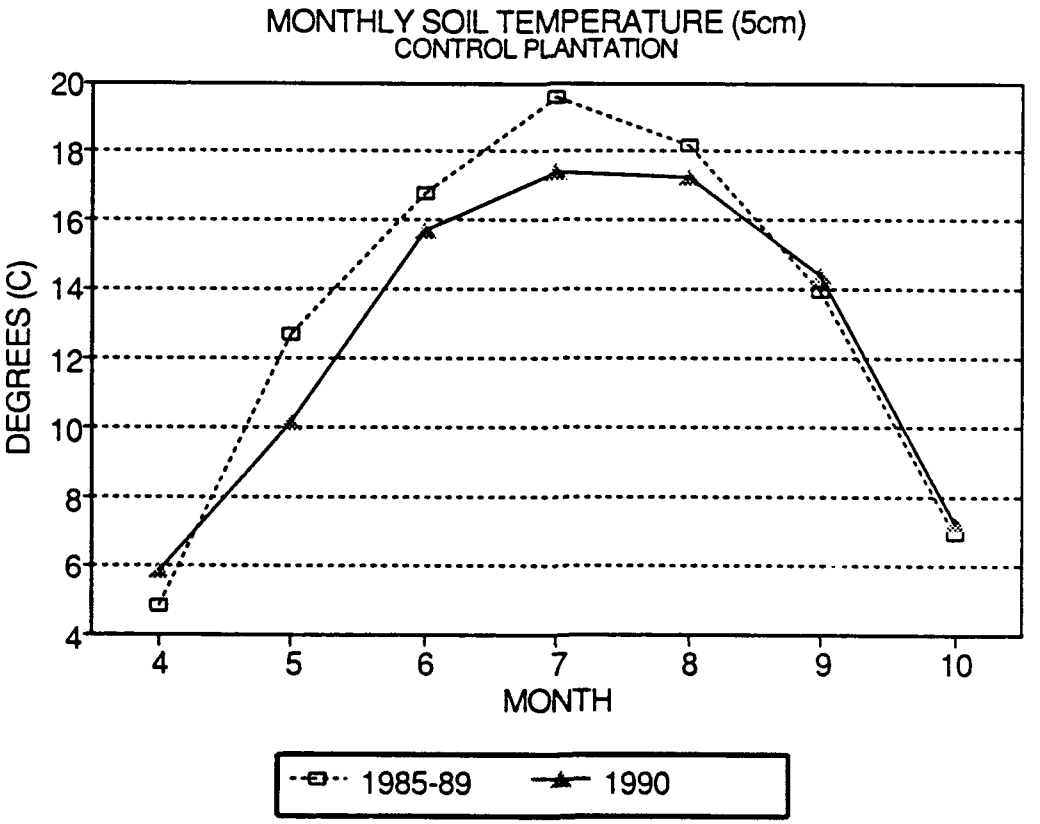


Figure 1.6

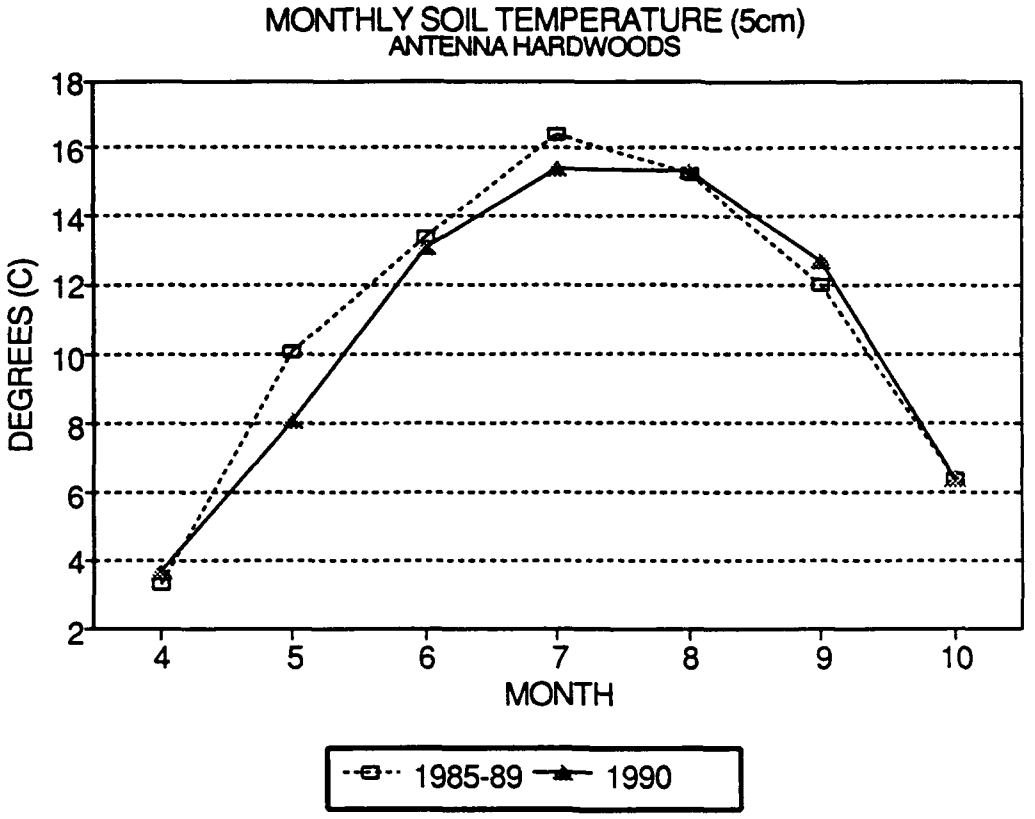
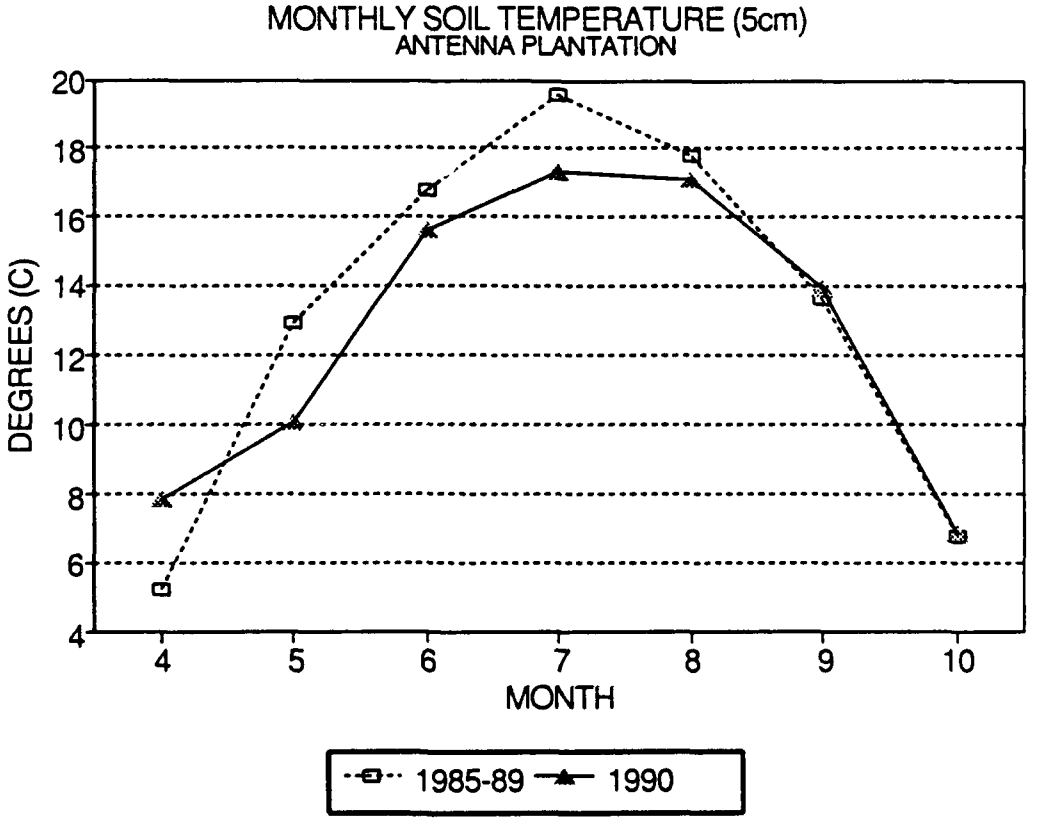


Figure 1.7



1.6). The May and July 1990 soil temperatures reflected the below normal air temperatures during these months. However, soil temperatures in the plantations during 1990 were below normal for June and August as well as May and July (Figure 1.5 and 1.7). The below normal soil temperatures at the plantation appear to be not only caused by the lower air temperatures in May and July of 1990 but also, the decreased insolation at the soil surface as a result of an increased canopy area. The increased effect of the canopy on soil temperatures could possibly increase differences in soil temperatures among the plantations due to contrasts in foliage biomass and area among the sites. This may have occurred in 1990. Soil temperature in the control plantation was 0.6 ^{o}C lower in 1990 than in 1989. Temperatures at the ground and antenna plantations were only 0.0 to 0.1 ^{o}C lower than in 1989.

Soil Temperature (depth 10 cm)

Site Comparisons: In previous years soil temperatures (10 cm) at the control site and test sites have not been found to be significantly different ($p \leq 0.05$). The additional year of measurement has not given any indication that the soil temperature relationships among sites have changed (Table 1.5). Differences in soil temperature (10 cm) between the control and ground plantation and between the control and antenna hardwoods are of the same magnitude found in previous years. Differences in soil temperature (10 cm) between the control and antenna plantation were greater than has been found in previous years.

Annual Comparisons: Mean soil temperatures (10 cm) at the plantations in 1990 were lower than any other year in the study. Soil temperatures in the hardwood stand were slightly warmer in 1990 than in 1985 or 1989 but cooler than in the years 1986-1988. Temperatures at a depth of 10 cm were lower than normal in May and July at the hardwood stands while being lower than normal in May through August at the plantations (Figure 1.8-1.9).

Summary: Currently there has been no indication that the ELF fields have affected the soil temperatures (5 cm and 10 cm) at the test sites. Presently it appears that the increasing size of the red pine canopy is beginning to have an important influence on the soil temperatures in the plantations. With the increased importance of the red pine canopy on soil temperatures, any foliar responses to the ELF fields should be reflected by a change in the soil temperature at the test site plantations.

Table 1.5 Comparison of soil temperature (10 cm) during the 1985-90 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.2	12.6	12.4	0.2	-0.2
1986	13.0	13.4	13.3	0.3	-0.1
1987	13.2	13.5	13.6	0.4	0.1
1988	13.3	13.2	13.2	-0.1	0.0
1989	12.0	12.5	12.7	0.7	0.2
1990	11.7	12.4	11.9	0.2	-0.5
Ave.	12.6	12.9	12.9	0.3	0.0
			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
Ave.		10.7	11.1		0.4

Site Comparison

Control	Ground
12.9	12.6

Control	Antenna
12.0	11.8

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.3	11.4
1986	13.1	12.3
1987	13.4	12.6
1988	13.3	12.2
1989	12.3	11.6
1990	11.8	11.4

Figure 1.8

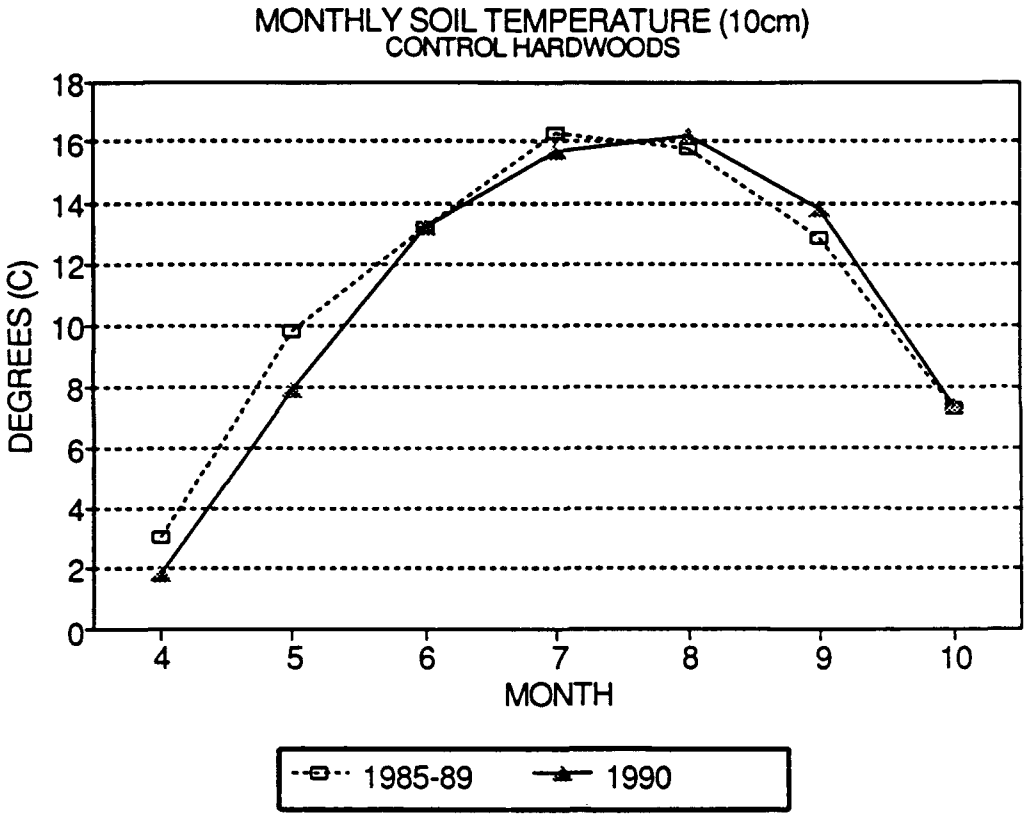
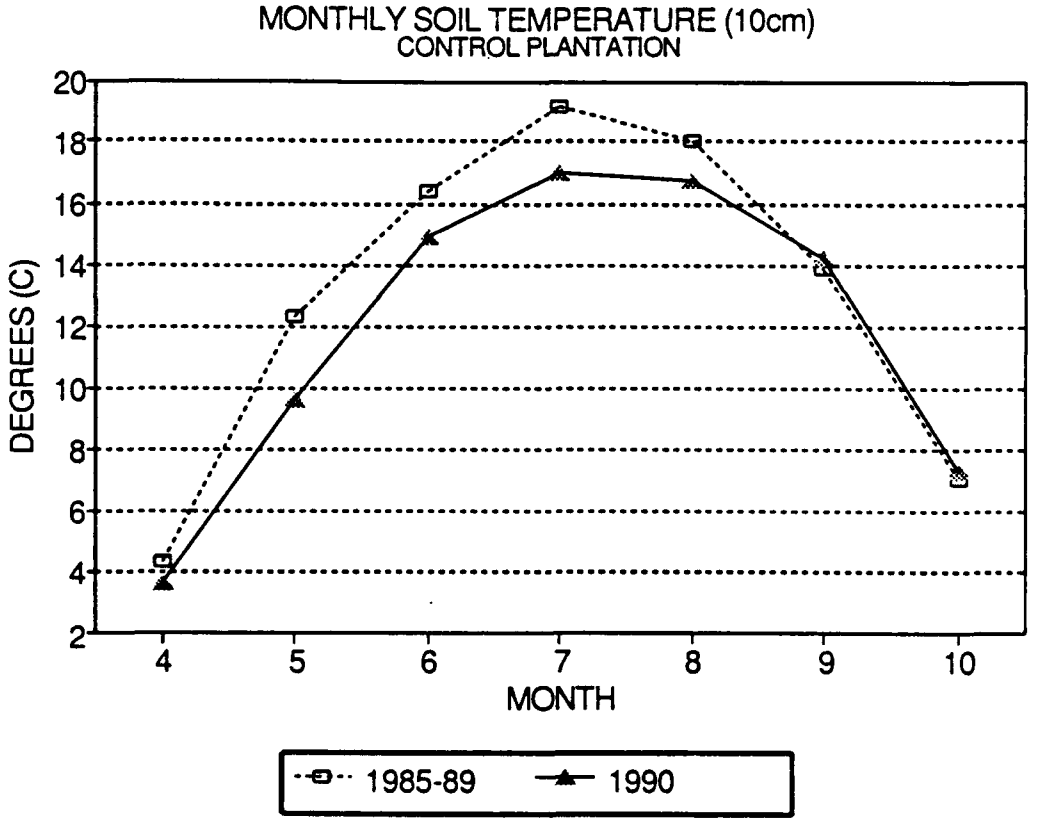


Figure 1.9



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: Average soil moisture content (5 cm) over the study period has been consistently higher at the control site than at the test sites. Previous years statistical comparisons have indicated that these differences are significant ($p \leq 0.05$). Soil moisture content observed in 1990 was also higher at the control sites than at the test sites. Differences between the control and test sites were greater than differences observed in 1987-1989. The increase in differences between the control and test sites in 1990 appears to have been caused by a greater amount of precipitation at the control than at the test sites.

Last year's report showed no significant differences in soil water potential (5 cm) between the control and ground site. However, differences between the control and antenna differed significantly ($p \leq 0.05$). Soil water potentials in 1990 were higher (less negative) at the control than at the ground plantation while soil water potentials were lower at the control site than the antenna site. Differences between the control and antenna sites in 1990 were smaller than any other year of the study.

Figure 1.10

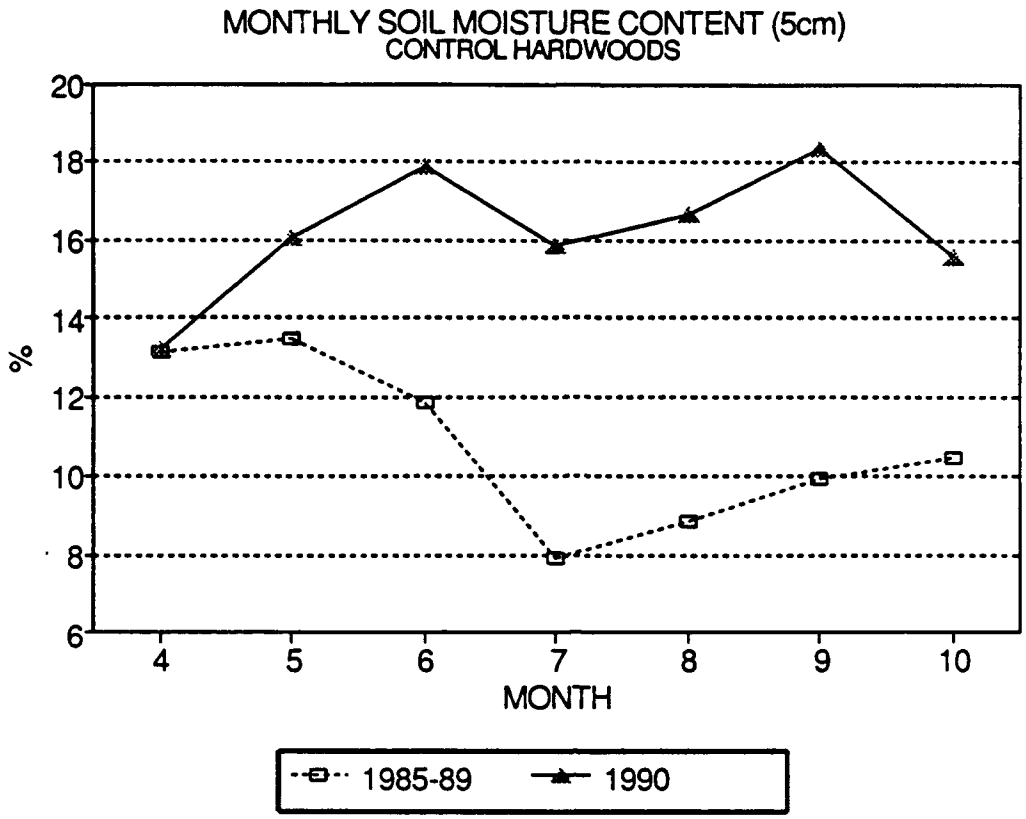


Figure 1.11

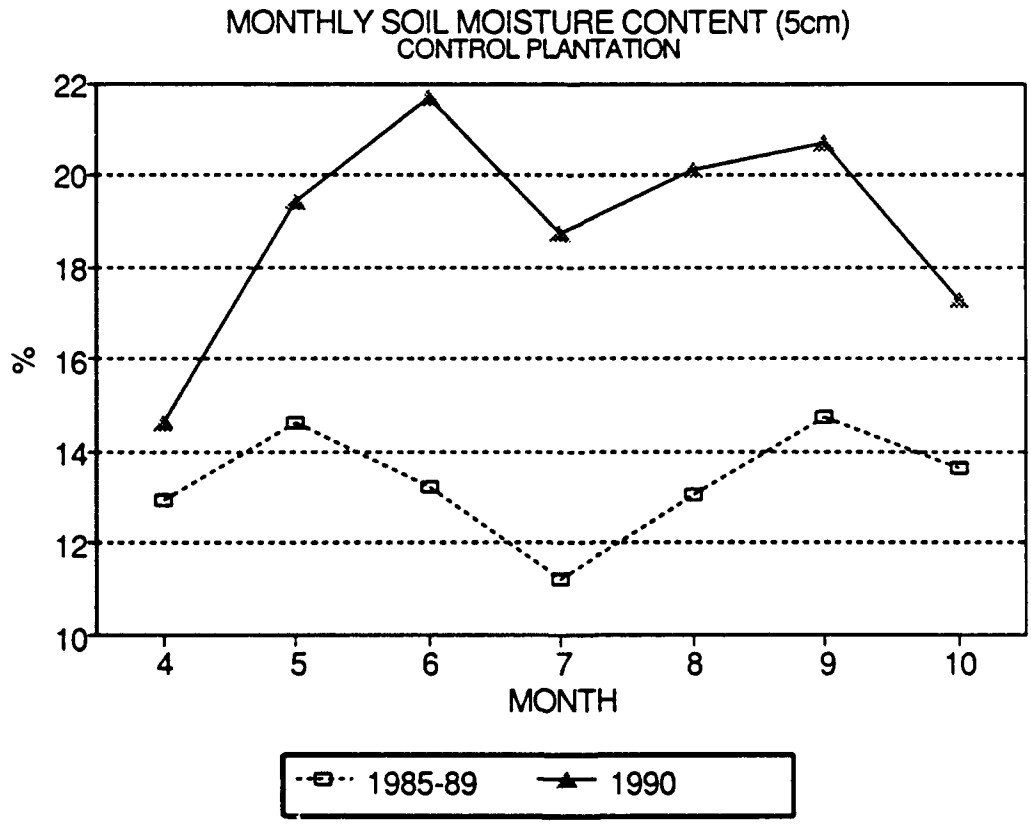


Table 1.6 Comparison of soil moisture content (%) and soil water potential(-mpa) at a depth of 5 cm during the 1986-90 growing seasons (April-Oct).

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	.015	13.7	.009	18.9	.010	2.3	-.005	5.2	.001
Ave.	13.6	.022	11.3	.015	15.1	.017	1.5	-.005	4.2	.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
Ave.			10.6	.021	12.6	.030			2.0	.009

Site Comparison

	Control	Ground
Moisture Content	15.1	13.6
Soil Water Pot.	.017	.022

	Control	Antenna
Moisture Content	13.9	11.0
Soil Water Pot.	.024	.018

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-mpa	%	-mpa
1986	14.6	.018	12.4	.020
1987	13.6	.020	11.6	.021
1988	12.3	.027	11.1	.026
1989	13.6	.018	11.4	.024
1990	17.8	.012	15.4	.011

Annual Comparisons: Soil moisture contents and water potentials were higher in 1990 than in any other year of the study (Table 1.6). Increase moisture content and soil water potential can be attributed to relatively high levels of precipitation, a very uniform distribution of precipitation during the growing season, and low levels of evapotranspiration due to below normal air temperatures (refer to precipitation section). Average moisture content and soil water potential in 1990 was approximately 20 to 30% higher than in any previous year. As shown by Figures 1.10-1.11 soil moisture content was above normal for all months except April. Although differences in soil moisture content and water potential (5 cm) between the control and test sites were larger than found in previous years, these differences appear to be related to the higher levels of precipitation in all the sites during 1990.

Soil Moisture Status (depth 10 cm)

Site Comparisons: Relationships in soil moisture content (10 cm) among sites were similar to those found for soil moisture content at depths of 5 cm. Moisture contents at 10 cm were consistently higher at the control site than at the each of the test sites (Table 1.7). In previous years, differences between sites have only been found significant for the control vs antenna comparison ($p \leq 0.05$). No significant differences ($p \leq 0.05$) in soil water potential have been found for the control vs ground comparison or the control vs antenna comparisons. Differences between the control plantation and test plantations as well as the control hardwoods and antenna hardwoods were larger in 1990 than in any previous year.

Annual Comparisons: Soil moisture content (10 cm) was greater in 1990 at the antenna and control sites than in any other year. The high moisture contents and soil water potential reflect the higher amounts precipitation levels received and lower temperature levels found in 1990.

Summary: Previous reports have found that there has been no detectable effects of EM fields on soil moisture content and soil water potential at the test sites. This conclusion is based on the following results and observations: 1) moisture status although significantly different among sites and years show no consistent trends related to increasing levels of ELF antenna operation 2) changes in the relationship of soil moisture regimes among the sites during the study period appear to be related to climatic factors such as precipitation rather than treatment effects 3) although differences in soil moisture regimes of the two stand types are not consistent at the control and antenna site, these differences have been stable over the duration of the study and appear to be related to inherent variability within the

Table 1.7 Comparison of soil moisture content (%) and soil water potential(-mpa) at a depth of 10 cm during the 1986-90 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
Ave.	13.9	.018	10.4	.014	15.4	.016	1.3	-.002	5.0	.002
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
Ave.			10.8	.019	12.9	.022			2.1	.003

Site Comparison

	Control	Ground
Moisture Content	15.4	13.9
Soil Water Pot.	.016	.018

	Control	Antenna
Moisture Content	14.1	10.6
Soil Water Pot.	.019	.018

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-mpa	%	-mpa
1986	14.9	.017	11.6	.020
1987	14.7	.018	12.2	.017
1988	13.6	.021	12.0	.019
1989	14.2	.023	11.5	.020
1990	16.0	.014	14.6	.010

sites and not to the operation of the ELF antenna. At this time it is not evident that inclusion of the 1990 measure refutes these previous conclusions.

Precipitation

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

Site Comparisons: Total amount and distribution of precipitation has been relatively similar among sites during 1985-1989 (Figure 1.11) During this period the control site averaged 6.7 cm less precipitation than the antenna or ground site. The majority of this deficit occurred during July and August (Figure 1.12). During these two months the ground and antenna site have received respectively 4.3 and 4.6 cm more precipitation than the control. Although the test sites during 1985-1989 received on the average 15.4% more precipitation each week than the control site, ANOVA tests have not showed significant differences ($p \leq 0.05$) between average weekly amounts of precipitation at the control and ground or the control and antenna sites.

In 1990 5 to 12% more precipitation was received at the control site than at the test sites (Table 1.8, Figure 1.13). During the growing season the control site received a total of 6.65 and 2.66 cm more precipitation than the ground and antenna sites respectively. A greater amount of precipitation was received at the control than the two test sites in May, July, and September of 1990 (Figure 1.14-1.16) This was the first year that average weekly precipitation at the control exceeded the average weekly precipitation at the test sites by more than 0.08 cm. (Table 1.8)

Annual Comparisons: Average weekly precipitation received during April through October 1990 at each site was more than was received during the same time period in 1986, 1988, and 1989. Distribution of precipitation during the 1990 growing season appeared to be more uniform than in previous years. For example during 1985-1989 the amount of precipitation received during May or June averaged less than 10% of the total recorded precipitation (March-October). In 1990 the amount of precipitation received during May and June was 14 to 18% of the total recorded precipitation in 1990 (Figures 1.17-1.19).

Summary: The amount of precipitation received at the control site was greater than at the test sites during 1990. Differences between the weekly amounts of precipitation

Figure 1.12

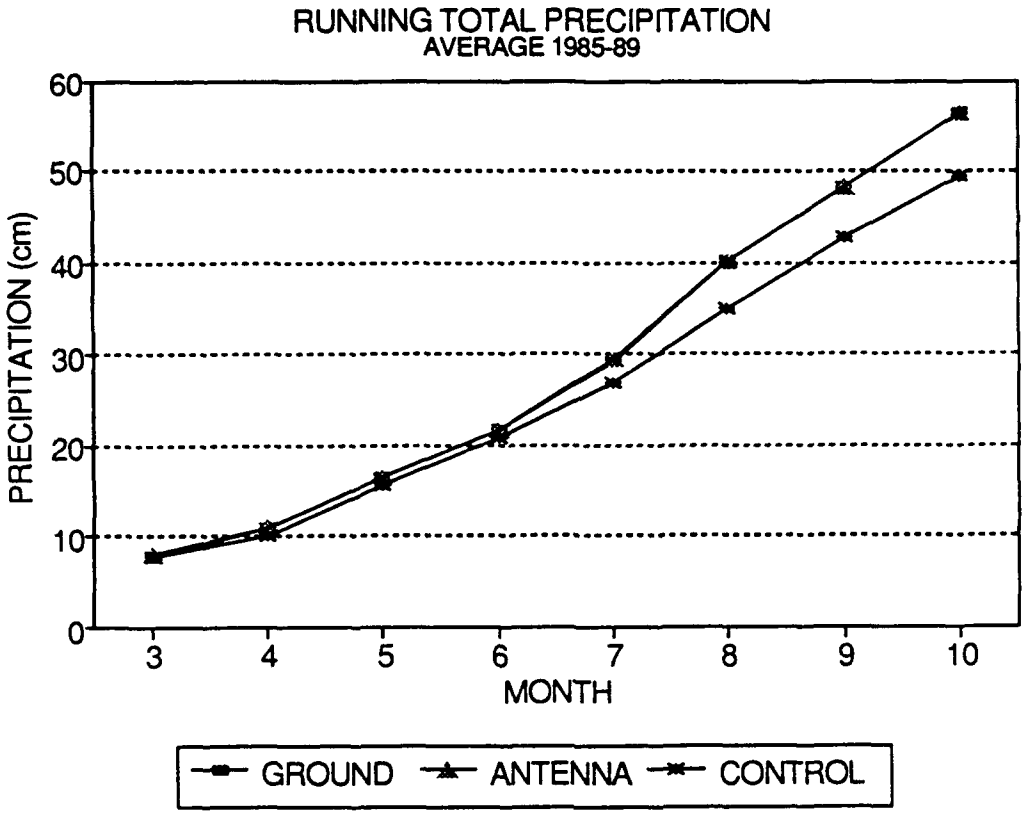


Figure 1.13

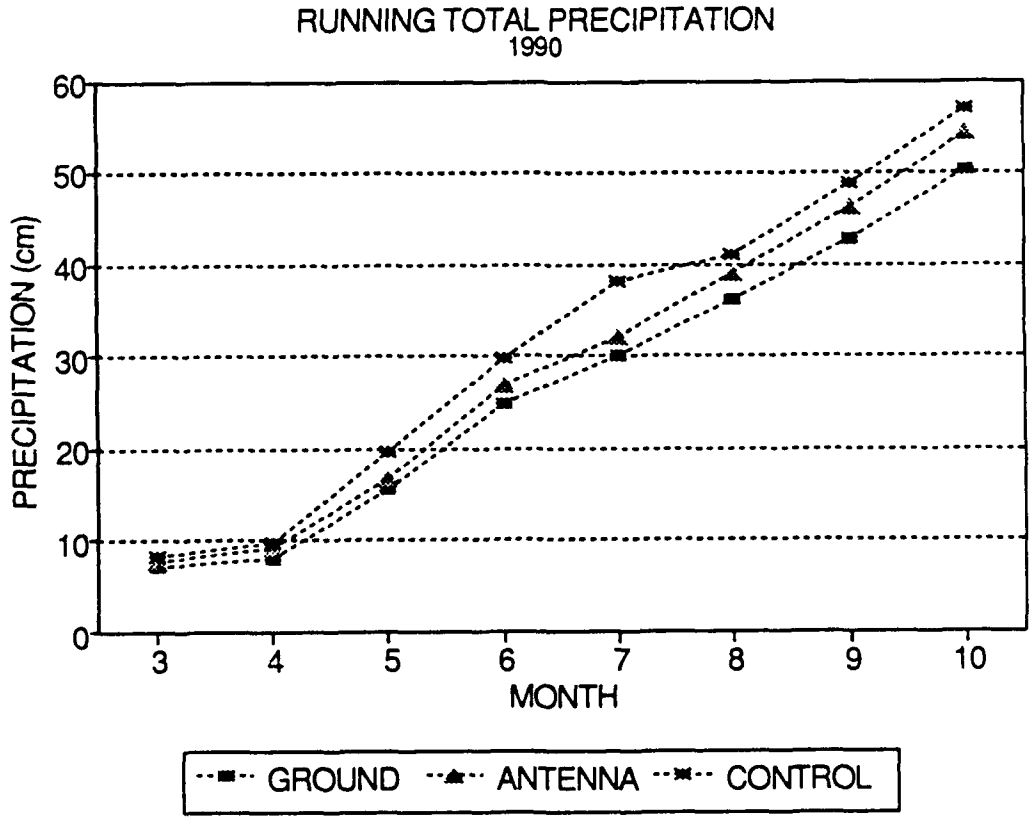


Figure 1.14

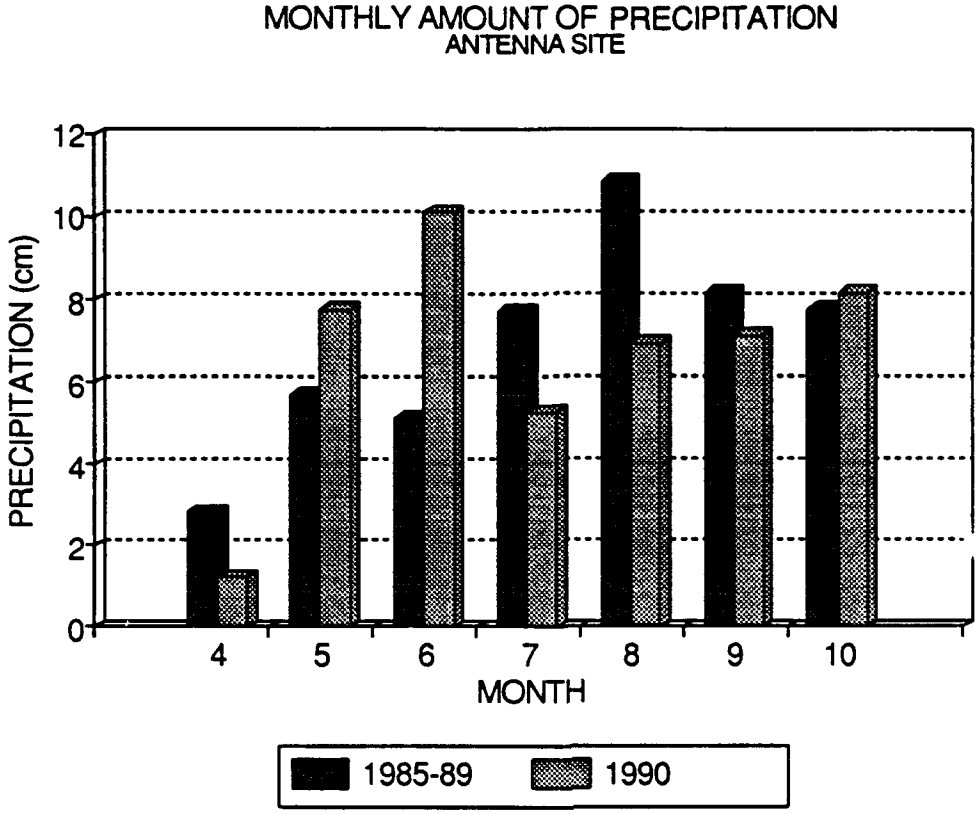


Figure 1.15

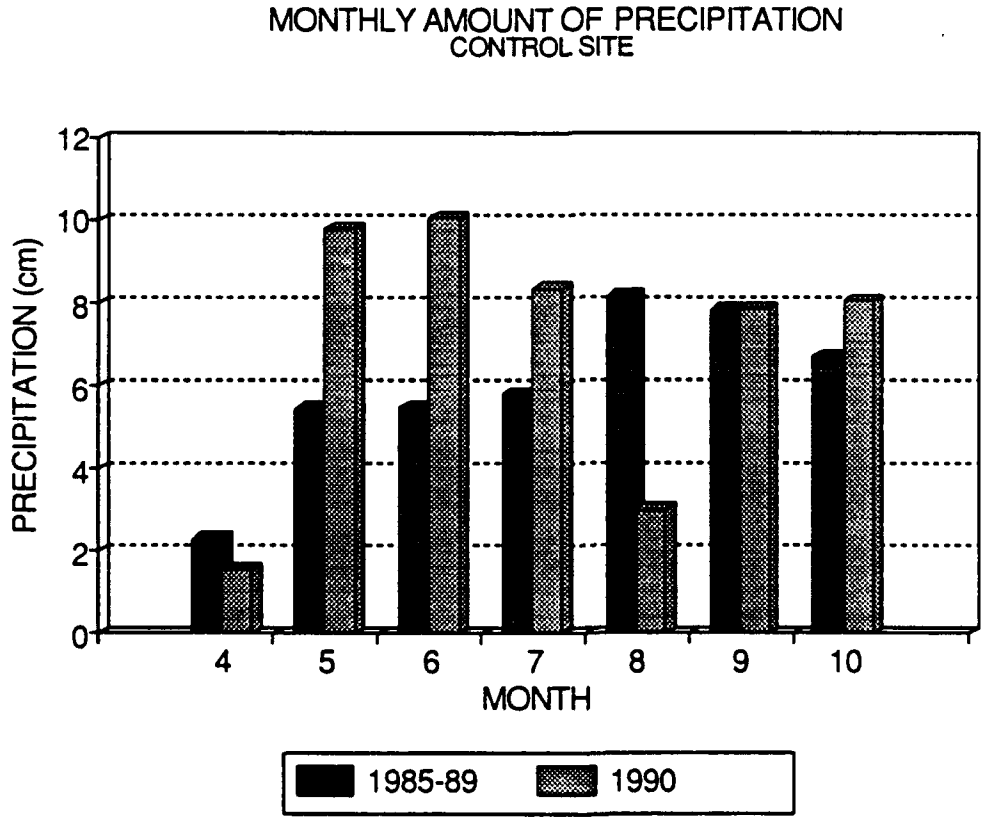


Figure 1.16

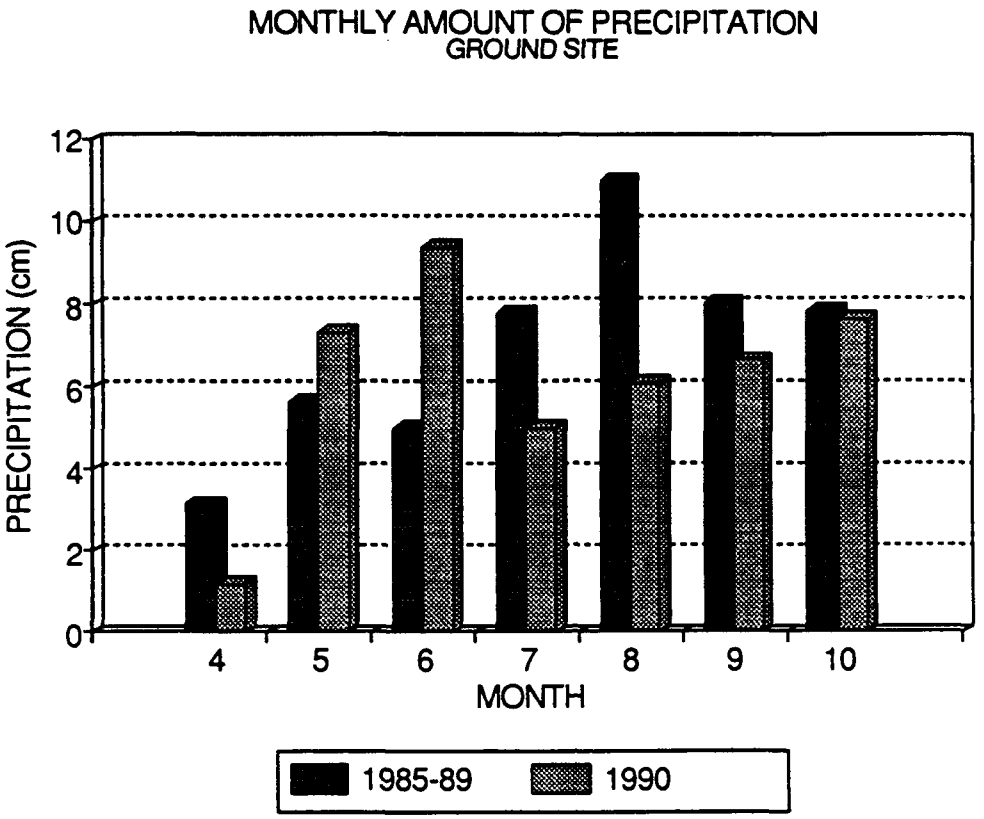

MONTHLY AMOUNT OF PRECIPITATION
GROUND SITE
PRECIPITATION (cm)
0
2
4
6
8
10
12
4
5
6
7
8
9
10
MONTH
1985-89
1990

Table 1.8 Comparison average precipitation amounts (cm) during the 1985-90 growing seasons (April-Oct).

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	2.41	2.46	1.97	-0.44	-0.49
1986	1.25	1.18	1.26	0.01	0.08
1987	1.78	1.87	1.78	0.00	-0.09
1988	1.80	1.77	1.49	-0.31	-0.28
1989	1.48	1.40	0.98	-0.50	-0.42
1990	1.60	1.72	1.80	0.20	0.09
Ave.	1.72	1.73	1.55	-0.17	-0.18

Site Comparison

Control	Ground
1.55	1.72

Control	Antenna
1.55	1.73

Annual Comparison

	Control & Ground	Control & Antenna
1985	2.22	2.19
1986	1.25	1.22
1987	1.82	1.78
1988	1.63	1.65
1989	1.23	1.19
1990	1.70	1.76

received at the control and test sites were greater in 1990 than any other year. The uniform distribution of precipitation during the growing season appears to have contributed to the overall higher moisture contents of the sites in 1990.

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 continually monitored at the study sites.

Figure 1.17

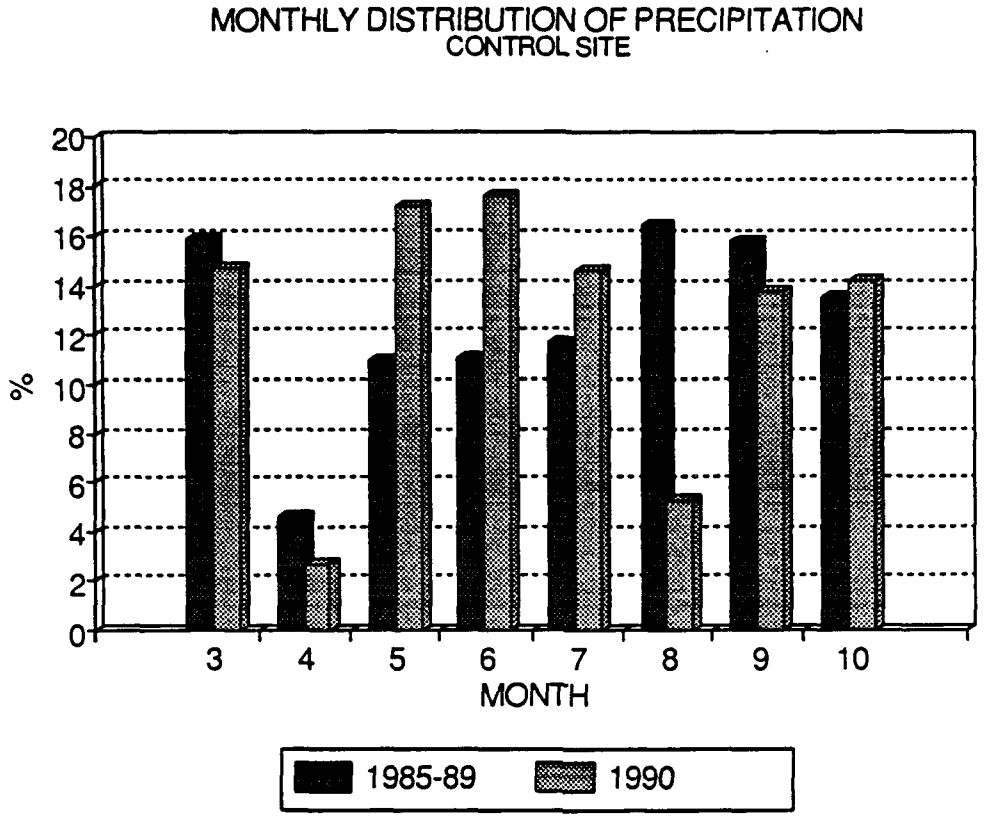


Figure 1.18

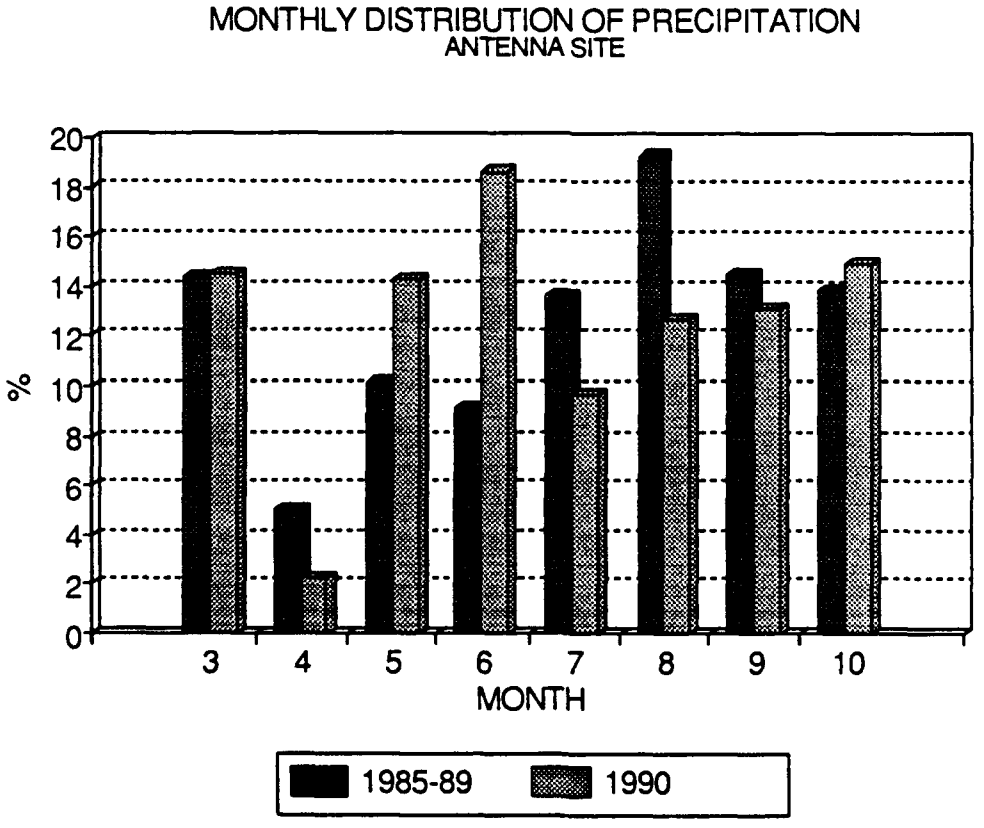
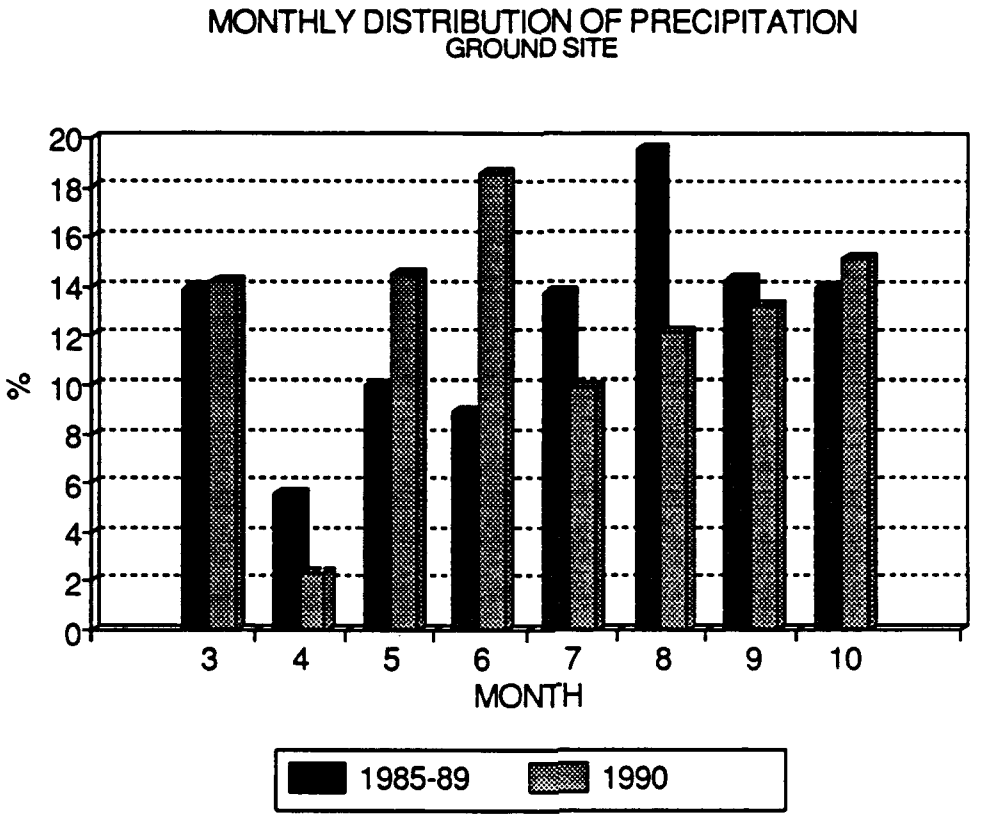


Figure 1.19


MONTHLY DISTRIBUTION OF PRECIPITATION
GROUND SITE
20
18
16
14
12
10
8
6
4
2
0
%
3
4
5
6
7
8
9
10
MONTH
1985-89
1990

Comparisons of global solar radiation did not include July of 1987 or April of 1988. Data from July of 1987 was not available due to the lightning strike at the ground site and the sensor 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 1.20). Average global solar radiation during 1990 was 363.5 Langleys/day (Table 1.9). Average daily global solar radiation measured in May and June were among the lowest values recorded for these months.

Table 1.9 Average global solar radiation during the 1985-1990 adjusted growing seasons and detection limits for year and month by year factors (p=.05)

Global Solar Radiation[1/] (Langleys/Day)					
1985	**1986**	**1987**	**1988**	**1989**	**1990**
385.1	360.9 a	364 a	331.0	383.2	363.5

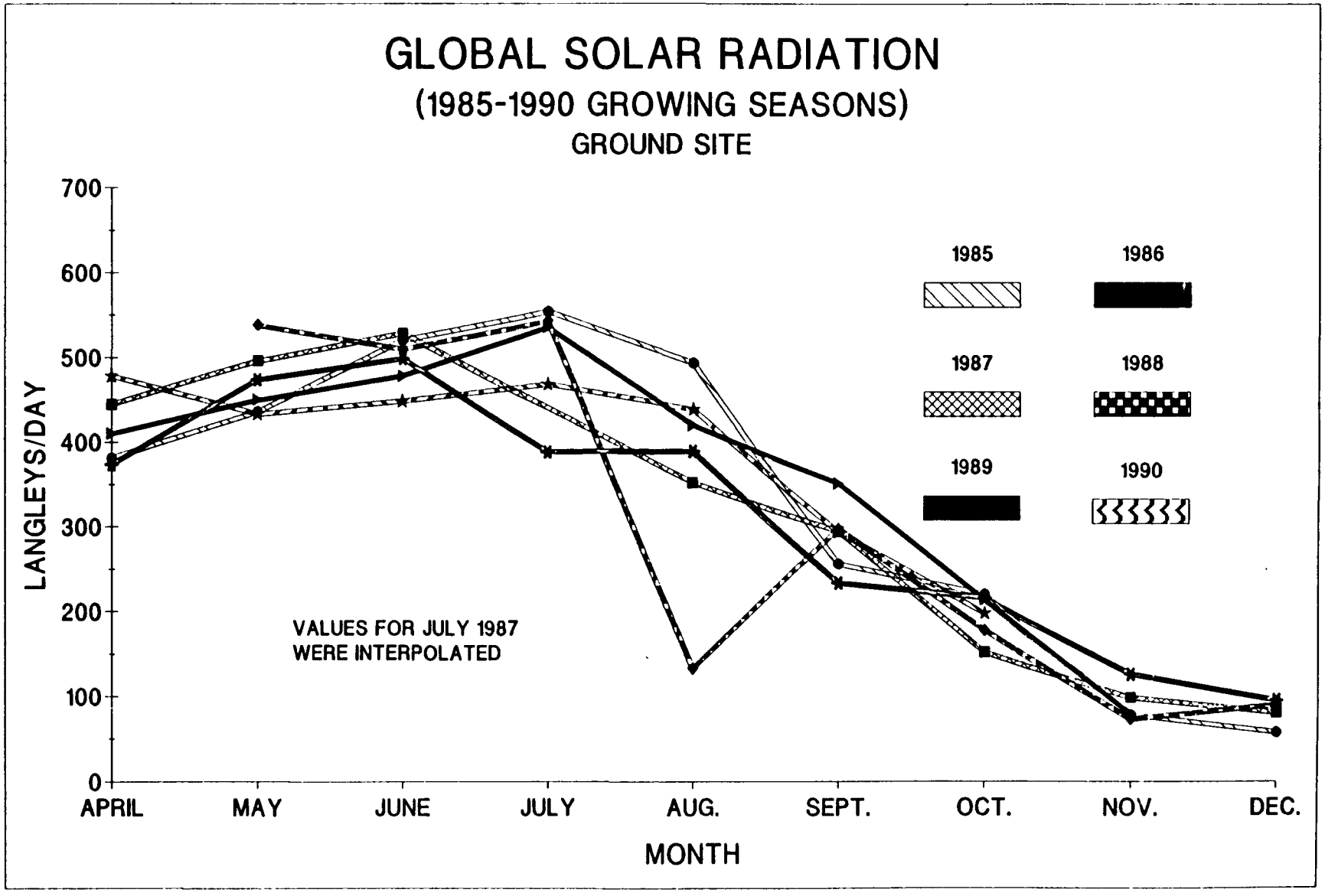
[1/]Averages and analysis using May-June, August-October. July was excluded from the analysis due to missing information from July 1987 and April 1988.

Relative Humidity

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

As a result of sensor repairs and system failures this is the fourth year that relative humidity has been monitored

Figure 1.20


GLOBAL SOLAR RADIATION
(1985-1990 GROWING SEASONS)
GROUND SITE
LANGLEYS/DAY
700
600
500
400
300
200
100
0
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
MONTH
1985
1986
1987
1988
1989
1990
VALUES FOR JULY 1987
WERE INTERPOLATED

during the entire growing season. Thus annual comparisons and site comparisons are limited to 1987-1990. 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 this years analysis.

Site Comparisons: During 1987-1989 relative humidity has been higher at the test sites than at the control site (Table 1.10, Figure 1.21). Differences were significant for the control vs antenna and the control vs ground comparisons ($p \leq 0.05$) during these years. However, relative humidity was lower at the ground than control site in 1990. Differences among sites in 1990 compared to previous years may be due to differences in calibration of the sensors. A recalibration of the sensors will be done to determine if values from 1990 are accurate for each site.

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 at the control and antenna site also appears to be related to the increase in precipitation during this year. The ranking of average annual relative humidity during the growing season is as follows 1987>1988>1990>1989 (Table 1.10).

Summary: In previous reports significant site by year interactions were found for the control vs ground comparisons. Multiple range tests performed at that time did not indicate any specific trend which could be related to increasing EM fields. At this time we have no evidence to contradict this conclusion.

Table 1.10 Comparison of relative humidity during the 1987- and 1990 (May-Oct.) and detection limits associated with site and year factors (p=0.05).

Relative Humidity (1987-1989)

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1987	81.0	84.1	70.0	-11.0	-14.1
1988	80.0	80.0	62.5	-17.5	-17.5
1989	65.9	73.1	58.3	-7.6	-14.8
1990	58.0	86.2	68.2	10.2	-18.0
Mean	71.2	80.9	64.8	-6.40	-16.1

Relative Humidity
%

Control	Ground
64.8	71.2
Control	**Antenna**
64.8 b	80.9

	1987	1988	1989	1990
Control vs Ground	75.5	71.2	62.1	63.1
Control vs Antenna	77.1	71.2	65.7	77.2

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 related changes in the canopy of the hardwood stand. Reduction of foliage biomass or changes in the timing of leaf expansion or leaf fall 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.

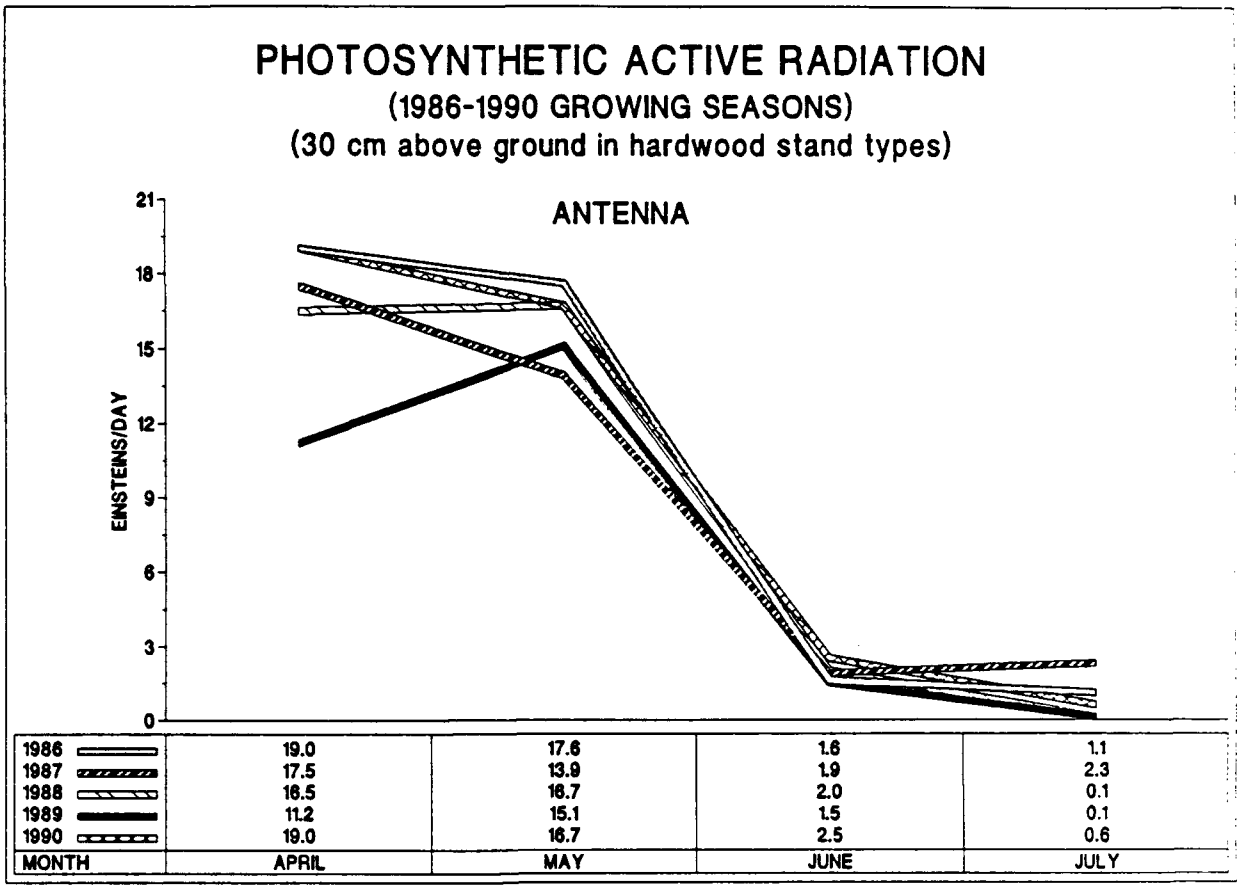
Sensor and system failures have limited the amount of months of data which can be used for this analysis. We have measurements for this variable for May through July of 1986-1989 and have used this data set for ELF effect testing. Measurements during this time span should give a good indication of any 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, due to the downtime of the platforms. Since PAR sensors were not operational until June of 1985, 1986 through 1989 are the only years used in PAR comparisons. Figure (1.22) shows that PAR is dramatically reduced during May and June when leaf expansion of the hardwood stands occur.

Average PAR was 1.29 Einsteins/day higher at the antenna site than at the control site during 1986-1990. Average PAR had decreased 1.13 Einsteins/day during the 1986-1989 measurement period (Table 1.11). However, in 1990 PAR measurements at both sites were approximately 1.00 Einstens/day greater than in 1986. The increase in PAR during 1990 appears to be related to the decreased foliage production (refer to Element 5) and possibly late initiation of leaf expansion. Foliage production in 1990 was lower than in any previous measurement year. The decreased production of foliage would decrease the total leaf area of the canopy thereby increasing insolation at the ground surface. Differences in PAR at the two sites was also lower in 1990 than in any other year.

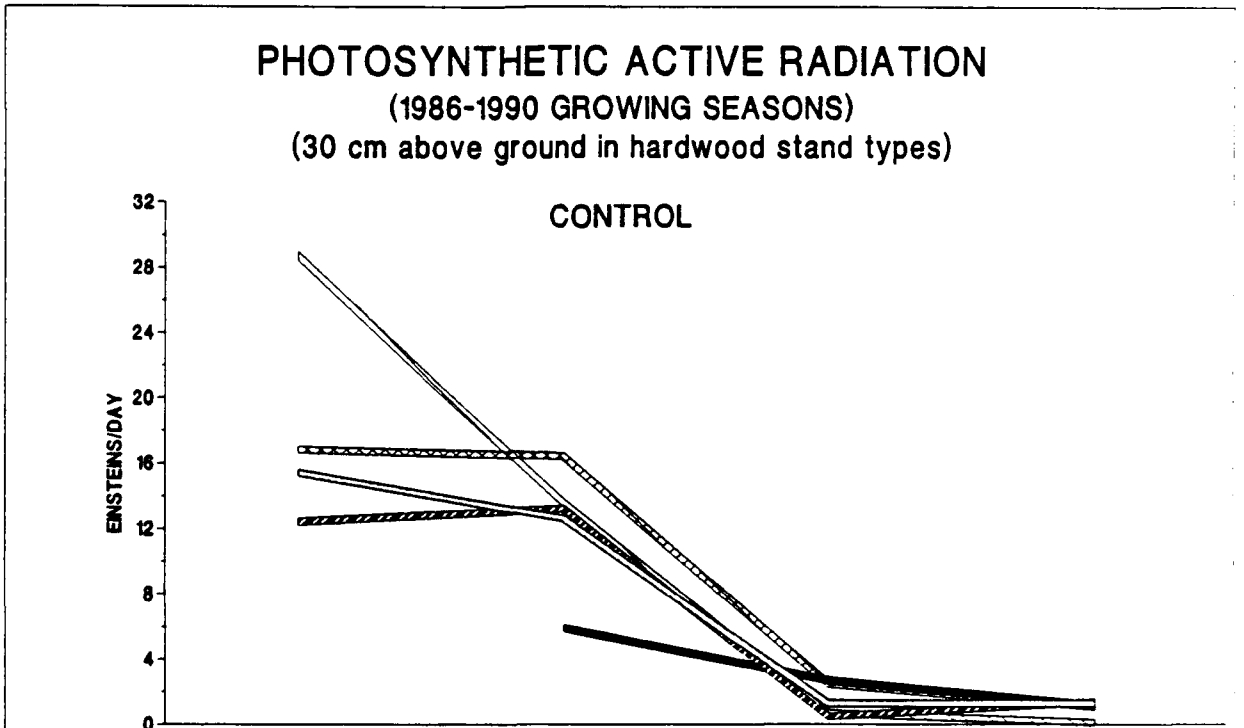
Summary: PAR is directly related to the amount of solar radiation received and the canopy present in any given year. In 1990 PAR at the two hardwood stands increased. This was in part due to a decrease in the leaf area of the canopy. During 1990 differences of the average PAR values at the two sites were lower than in previous year. At this time these changes in PAR can not be attributed to operation of the ELF antenna.

Figure 1.21



	APRIL	MAY	JUNE	JULY
1986	19.0	17.6	1.6	1.1
1987	17.5	13.9	1.9	2.3
1988	16.5	16.7	2.0	0.1
1989	11.2	15.1	1.5	0.1
1990	19.0	16.7	2.5	0.6
MONTH				

Figure 1.22



	APRIL	MAY	JUNE	JULY
1986	15.4	12.6	1.3	1.3
1987	12.4	13.2	0.5	1.4
1988	28.7	13.6	0.7	0.1
1989		5.9	2.7	1.2
1990	16.8	16.4	2.5	1.1
MONTH				

Table 1.11. Comparison of photosynthetically active radiation during 1986 -1990 (May-July).

	Average Daily PAR (Einsteins/Day)					
	1986	**1987**	**1988**	**1989**	**1990**	**X**
Control	4.77	5.06	4.53	3.27	6.42	4.81
Antenna	6.33	5.83	6.10	5.56	6.69	6.10
Control-Antenna	-1.56	-0.77	-1.57	-2.29	-0.25	1.29
Average	5.55	5.45	5.31	4.42	6.55	5.47

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 1988-1990 measurements.

Site Comparisons: Average air temperature (30 cm) was 1.0 ^{o}C warmer at the control than at the antenna hardwood stand for the five years of measurements (Table 1.12). Differences in temperature (1.0 ^{o}C) between sites at 30 cm above the ground were similar in magnitude to site differences in average air temperature at 2 m above the ground. Differences in air temperature (30 cm) between the two sites were greater in 1988-1990 than in the first two measurement years. Previous statistical comparisons have shown significant differences between sites but not significant site by year interactions ($p \leq 0.05$).

Annual Comparisons: The 1990 average air temperature (30 cm) was lower than in any other year of the study. The decrease in temperatures during 1990 were of a similar magnitude to those found for air temperature at a height of 2 m.

Summary: Given the results of statistical analyses performed last year, we can not conclude the ELF antenna

operation has affected this ambient variable. Differences in air temperature exist between the sites at this height above the ground, but these differences have not been shown to significantly ($p \leq 0.05$) change over the duration of the study.

Table 1.12 Comparison of air temperature 30 cm above the ground at the control and antenna hardwood stands during 1985, 1986, 1988, 1989, 1990

	Average Daily Air Temperature 30 cm (^{o}C)					
	1985	**1986**	**1988**	**1989**	**1990**	$\bar{X}$
Control	12.2	12.7	13.4	12.8	12.2	12.7
Antenna	11.5	12.0	12.1	11.7	11.0	11.7
Control-Antenna	0.7	0.7	1.3	1.1	1.2	1.0
$\bar{X}$	11.8	12.4	12.8	12.3	11.6	12.2

Summary

A large number of climatic factors have been found to vary significantly among sites and/or years (Table 1.13-1.14). Air temperature (2m), soil moisture content at 5 cm and 10 cm depths, soil moisture content (10 cm), water potential at 10 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 and soil moisture potential, and precipitation change annually at the sites. Any of these climatic variables which differ among sites or years would be 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 shown that they are not correlated to ELF antenna operation.

We expect that any changes in a climatic variable as a result of ELF antenna operation would correspond to changes of 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

Table 1.13 Significant differences for control vs ground site comparisons (1985-1989)

	FACTOR		
Variable	Site	Year	Site by Year
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<=.05.

Factors denoted by - p>.05

Table 1.14 Significant differences for the control vs antenna comparisons (1985-1989)

	FACTORS				
Variable	Site	Year	Site by Year	Site by Stand Type	Site by Stand Type by Year
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<=.05

Factors denoted by - p>.05

of the test sites. These changes are expressed in our statistical design through significant site by year and site by stand type by year interactions. As of the 1989 measurements air temperature (2m), soil moisture (5 cm), soil water potential (5 cm), 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 1985-1989 no site by stand by year interactions were significant (Table 1.13-1.14).

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. As of the 1989 measurements the significant interactions for soil moisture (5 cm) soil water potential (5 cm), and relative humidity have not appeared to be related to ELF antenna operation or changes in vegetation productivity among the sites.

Another approach used this year to quantify the relationships between ELF antenna operation and ambient measurements was to determine 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 incidental relationship exists between a specific climatic factor and antenna operation. Table 1.15 presents the results from this approach. Ambient measurements used for the correlations were plot or site averages for each year during 1985-1989. Field strengths were determined by integrating the field equations from EW leg operation given in Appendix A over the entire plot. The fields from EW leg equations were chosen due to the stronger fields associated with EW leg operation.

Longitudinal and magnetic fields were more consistently correlated to climatic factors than were the transverse fields. Longitudinal and magnetic fields were more highly correlated with air temperature and soil moisture (10 cm) than other ambient variables. Longitudinal fields travel through the soil and can be affected by the soil conditions at the time of measurement. Significant correlations between soil variables and longitudinal field strengths may be due to the effect of the soil conditions on the intensity of the fields. Figures 1.23 and 1.24 grahpically show the relationship between the longitudinal fields with air temperature and soil moisture (10 cm). As can be seen in these graphs the relationships are not strong. Observations from the control and preoperational years are located on the y-axis. Increased field strengths at the test sites show a slight trend with increasing air temperatures or soil moisture.

All three types of field strengths were negatively and significantly correlated to 1985-1988 global solar

Table 1.15. Correlation coefficients and significance levels (-.+,*, or **) associated with annual ambient variables and transverse, longitudinal, and magnetic EW leg antenna operation 76 hz field strengths (1985-1989).

	Transverse	Longitudinal	Magnetic
Air Temperature 2 m	-.218[1] +	-.248 *	-.272 *
Soil Temperature 5 cm	.052 -	.008 -	-.124 -
Soil Moisture 5 cm	.138 -	.154 -	.017 -
Soil Temperature 10 cm	.095 -	.038 -	-.104 -
Soil Moisture 10 cm	.215 +	.221 +	.069 -
Average Weekly Precipitation	-.095 -	-.123 -	-.175 -
Global Solar Radiation	.116 -	.130 -	.290 -
Relative Humidity	.142 -	-.053 -	.014 -
Solar Radiation Par	-.449 -	.417 -	.410 -
Air Temperature 30 cm	-.201 -	-.232 -	-.236 -

[1]/- .10<p
+ .10≥p>.05
* .05≥p>.01
** .01≥p

radiation. Correlations coefficients (Table 1.15) this year were not significant ($p \leq 0.05$). The global solar radiation sensor is located 4 m above the soil surface at the ground site and should not be affected by any possible changes in

Figure 1.23

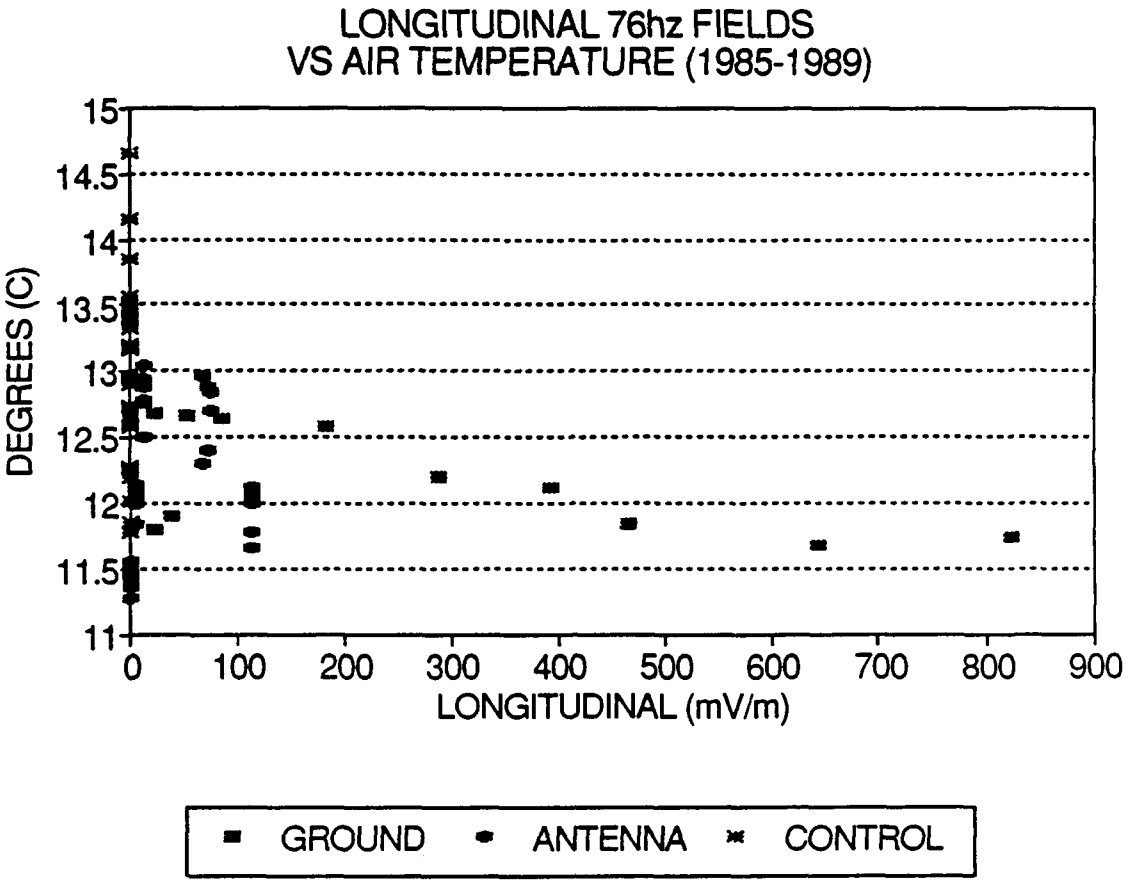
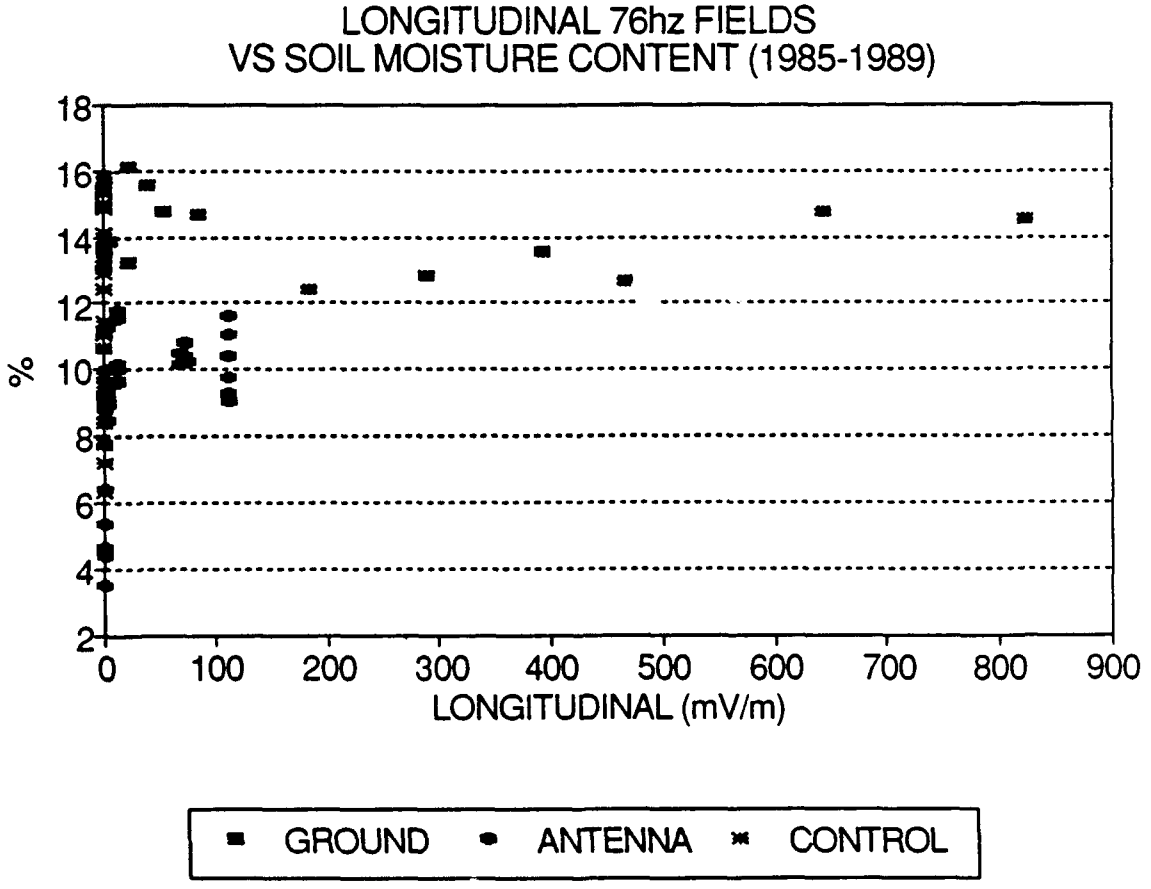


Figure 1.24



vegetation induced by ELF fields. Significant correlations found using the 1985-1988 measurements and the lack of any significant correlations this year confirm the coincidental and not the mechanistic relationship between the fields and global solar radiation.

Nutrient Monitoring

Soil Nutrients

Tree productivity analysis completed during the past years have indicated that soil nutrients are valuable covariates in explaining site and year differences (see Element 2). In addition, analysis of northern red oak foliar nutrients and litter production have also included soil nutrient information. Thus the objective of the soil nutrient study is to document spatial and temporal variability of soil nutrients within the study area and determine if soil nutrients are independent of ELF field exposure, thereby determining the suitability of soil nutrients for inclusion in covariate analysis and modeling.

Sampling and Data Collection

Soil nutrient samples are collected monthly during the growing season. During the 1987 through 1989 growing season, sampling began in May and concluded in October at each site. In 1986, sampling began in June and concluded in September. However, in 1985 the hardwoods were sampled monthly, while the plantations were sampled only once in July. After initial success in using soil nutrients in the hardwood growth models, it was decided that sampling in the plantations would also be conducted monthly in successive years to provide soil nutrient data for the red pine growth analysis. Soils are sampled using a 2.54 cm diameter push probe inserted to a depth of 15 cm in the mineral soil. Five composite samples made up of 4 randomly selected probes each are collected from each plot. These are dried in a convection oven at $60^{o}C$, sieved and mixed, and analyzed for Kjeldahl N, total P, and exchangeable Ca, Mg, and K.

Progress

Project reviews beginning in 1987 have noted the wide variability among soil nutrient values. This prompted an extensive review of data and methodology which began with a graduate project in late 1987 and continued through 1989. This has resulted in several changes.

After careful review of laboratory quality control data (standards and replicates) for sample analyses, we have determined that samples taken in 1985 are inaccurate and will no longer be used. This is not a significant loss to the project since the data set was incomplete with only one sample date on the plantations in what was the first year of soil sampling. This data set had only marginal value because it could not be easily compared to subsequent years when all

months and sites were sampled.

This same review for subsequent years showed that while laboratory quality control data were acceptable, there were some nutrient values for a given site, treatment, plot and date that differred from the mean by an order of magnitude. Since several analyses are performed on a single soil extraction, (N and P are done on one extract while Ca, K, and Mg are done on another) we cross-checked among nutrients done on a particular extract. Thus for example, if all nutrient levels were high for a particular sample extract, the value was likely to be high because of the field sample itself. Such field variability is real and is common in soil because of concentration aggregations associated with organic matter and clay (Usher 1970, Mollitor 1980, Mroz and Reed 1991). If a value of only one nutrient for a particular extraction was high, it is likely due to a laboratory error. To quickly screen data for laboratory errors, nutrient values greater or less than 50 percent of the mean for a given site, treatment, plot and month were flagged for inspection. About seven percent of the nutrient values exceeded these bounds and have been eliminated from the data set until they can be reanalyzed. If these cannot be reanalyzed, we will examine other statistically based screening procedures.

Finally, preliminary analysis of 1989 soil P data indicated an error in laboratory analysis. These samples will not be discussed in this report and will be reanalyzed.

Analysis

Analysis of variance was conducted to test differences in soil nutrient content (Kg/ha) for site and year for the hardwood stands (Table 1.20). Results varied depending upon the nutrient, but in general, there were few significant differences in values for sites, greater numbers of differences among years and no significant site by year interactions.

Table 1.20. Significance levels from the analysis of soil nutrient content, 1986-1989.

HARDWOODS	Ca	Mg	K	P	N
Site	.149	.088	.143	--	.848
Year	.001	.000	.635	--	.006
Site by year	.072	.136	.394	--	.337

PLANTATIONS	Ca	Mg	K	P	N
Site	.028	.112	.268	--	.972
Year	.073	.000	.057	--	.005
Site by year	.120	.246	.118	--	.262

There were no significant differences between the antenna and control hardwood stands for any nutrient over the four year 1986 to 1989 period but there were year differences (Table 1.20). Exchangeable soil Ca levels decreased (p=.001) at both sites by as much as 38% in 1987 and 1988 but returned to 1986 levels in 1989 (Table 1.21). Similarly soil Mg decreased (p=.000) on the antenna site by as much as 30% but returned to the same level as 1986 in 1989. Total N also showed year differences (p=.006) but was less variable than the cations with 1988 being about 15% lower than the four year average on both sites.

Plantation results were similar to those of the hardwood stands (Table 1.20). Only Ca levels were significantly different (p=.028) among sites with with the control site having the highest levels, the ground intermediate and the antenna the lowest for each year tested (Table 1.22). Greater Ca levels at the control site are consistant with slightly greater soil development and productivity at that site. Plantation soil Mg exhibited the same decrease (p=..000) in 1988 as in the hardwood stand and then returned to 1986 levels in 1989. Plantation soil N levels exhibited the same pattern as the hardwoods with decreased (p=.005) levels in 1988.

While it is possible for exchangeable nutrient levels to show yearly changes, total N should show little change, especially under undisturbed conditions. Since the data have been edited for obvious erroneous values, we will be examining several other possibilities including continued investigation of climatic effects on nutrient levels. Other studies have shown amounts of climate related leaching losses

of NO_3, NH_4 and organic N to be similar the the losses of total soil N detected in this study (Timmons et al. 1977, Lewis 1986, Foster 1989). With the coarse soil texture, rapid water drainage, low soil pH and frigid temperature regime of the ELF study sites, it is possible that leaching could account for losses of the magnitude found but this would have to be dominated by organic forms of N (Timmons et al. 1977). However, it is unlikely that such a loss would be followed by a gain of an equal amount over a one year period. Such a gain over a short period of time could only come from symbiotic N fixation; non-symbiotic N fixation could not account for such a large increase. While there is a substantial presence of the N fixing shrub *Comptonia peregrina* on the plantations, there are few N fixing plants on the hardwood sites that could account for such a gain.

While there were yearly differences for all nutrients except K, there were no significant site by year interactions on either the hardwoods or plantation (Table 1.20). This indicates that even though the nutrient values may fluctuate yearly, the relationship among the sites remains constant over the years suggesting no change in site nutrients due to ELF fields. This may also indicate that there may be a systematic sampling or analysis error for particular years that could account for yearly nutrient level variation. The examination of the nutrient data and techniques will continue to be a prime concern through the 1991 season. If current difficulties cannot be overcome, this phase of work will be scaled back or discontinued in 1991.

Table 1.21. Soil nutrient means (Kg/ha) by site and year for the hardwood stands.

Calcium Site	1986[a]	1987[b]	1988[b]	1989[a]
Control	360	299	276	444
Antenna	261	160	202	217
Magnesium				
Site	**1986[a]**	**1987[b]**	**1988[b]**	**1989[a]**
Control	61	54	51	73
Antenna	47	33	35	40
Potassium				
Site	**1986**	**1987**	**1988**	**1989**
Control	49	47	51	49
Antenna	42	35	42	42
Phosphorous				
Site	**1986**	**1987**	**1988**	**1989**
Control	721	721	688	---
Antenna	531	606	562	---
Nitrogen				
Site	**1986[a]**	**1987[a]**	**1988[b]**	**1989[a]**
Control	1001	993	814	1086
Antenna	1018	1093	846	993

Values for a given nutrient with different lower case letters are significantly different between years at p=.05. Upper case letters show differences between sites.

Table 1.22. Soil nutrient means (Kg/ha) by site and year for the red pine plantations.

Calcium Site	1986	1987	1988	1989
Control[B]	511	607	467	627
Antenna[A]	333	280	265	374
Ground[AB]	455	318	421	412

Magnesium Site	1986[b]	1987[b]	1988[a]	1989[b]
Control	68	68	56	69
Antenna	51	39	37	52
Ground	69	53	56	65

Potassium Site	1986	1987	1988	1989
Control	64	59	64	51
Antenna	51	43	50	53
Ground	65	57	68	68

Phosphorous Site	1986	1987	1988	1989
Control	741	744	657	---
Antenna	672	642	630	---
Ground	516	461	461	---

Nitrogen Site	1986[a]	1987[a]	1988[b]	1989[a]
Control	1059	1054	940	1100
Antenna	1109	1129	891	953
Ground	1111	917	932	997

Values for a given nutrient with different lower case letters are significantly different between years at p=.05. Upper case letters show differences between sites.

Element 2. Tree Productivity

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to treaatment, 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 measurement of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1986) and the strong correlation between dbh and total biomass of the tree (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 a 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, regeneration studies involving planted red pine are being conducted on the ground, antenna, and control sites. These studies were intitiated in response to a need for a larger number of conifers in the ectomycorrhizal studies (Element 6) 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 seedlings rather than on older trees. In the red pine seedlings, 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 on 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 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 growth before and after the ELF antenna becomes operational.

This hypothesis is addressed through testing of 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 season during 1987 (15 amps) and 1988 (75 amps) with full power operation (150 amps) during 1989 and 1990. Whenever possible, differences between sites and between 1987, 1988, 1989, 1990 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 model between years or across sites. Comparisons of post-operational years with previous years are in part made by examining residuals of 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 through 1989. An analysis including the 1990 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 in 1984 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 start of the 1987 growing season, the trees which had band failures in 1985 on the antenna site, as well as all

Table 2.1. Summary of hardwood stand information for the antenna and control sites at the beginning of the 1990 growing season.

Species	Average DBH (cm)[b/]	Basal Area Per Hectare (m^2/ha)	Number Bands in 86	Number Bands in 90[c/]	Number of Stems per Hectare	Site Index	Age (yrs)
Antenna							
Northern Red Oak	24.55	8.33	44	49	156	68	51
Paper Birch	21.03	0.95	8	8	25	66	59
Aspen[a/]	26.71	2.79	15	15	48	68	54
Red Maple	15.53	9.41	129	148	470	56	46
Control							
Northern Red Oak	21.68	22.42	174	177	562	72	56
Paper Birch	16.81	2.94	38	39	124	60	58
Aspen	23.77	6.24	43	43	137	65	59
Red Maple	11.87	0.78	15	22	70	58	49

[a/] The two aspen species are combined.

[b/] Average DBH includes ingrowth trees for 1987 but not trees which died in 1988.

[c/] Includes trees which grew to larger than 10.0 cm dbh since 1985 which were banded in 1987 but not trees which died in 1988.

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

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

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 year's growth to diameter taken in 1984.
C/ The two aspen species are combined.

Table 2.3. ANOVA table used for analysis of diameter growth by species.

Source of Variation		Degree of Freedom	Sum of Squares	Mean Square	F
Covariate	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)
Covariate	Group (B)	# group B covariates	SSCY	MSCY	MSCY/MSE(SY)
Error(SY)		(#trees-2-#covariates)(#yrs-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.

trees which had become larger than 10 cm dbh since 1984, were banded on both sites (Table 2.1). In 1988, there were three trees on the control site (two paper birch and one bigtooth aspen) which died. This mortality in 1988 occurred on trees which 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 (Table 2.1).

Bands were read to the nearest 0.01 inches of circumference at both study sites beginning on April 18 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until October 3 when growth had slowed considerably and over 50 percent of leaf fall had taken place. This provided a total of 25 measurements in 1990.

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 individual tree diameter growth residuals 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, seven years (1984 through 1990) 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 were not included in the analusis 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 1990 growing season; the tree growth information from 1990 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 seven growing seasons, even though data from 1984 and 1990 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.* 1991). There have been no attempts to refine 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 field 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, water retention capacity from 5 to 10 cm for red maple, and 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. In all four species, there were significant ($p<0.05$) differences indicated in individual tree diameter growth rates among the study years (Table 2.5). There were also significant ($p<0.05$) differences between the study sites for all species except northern red oak. For red maple, there was a significant ($p<0.05$) interaction between site and year. 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 between sites for any of the four species. There were differences ($p<0.05$) among years for northern red oak and red maple but not the other two species. There were no significant ($p=0.05$) site and year interactions for any species.

These results indicate that there was no difference between the individual tree diameter growth rates on the two sites. There were significant differences in individual tree diameter growth rates among the study years which were not accounted for

Table 2.4. Average seasonal diameter growth (cm) for tree species on each site for the 1984 through 1990 growing season.[a/]

	Sample Size	1984	1985	1986	1987	1988	1989	1990
		cm						
Northern Red Oak								
Antenna	44	0.2778	0.2389	0.1991	0.2710	0.2354	0.2256	0.2258
Control	174	0.1707	0.2030	0.1508	0.1823	0.1595	0.1773	0.1561
Paper Birch								
Antenna	8	0.2000	0.2038	0.1500	0.1304	0.1132	0.0990	0.1081
Control	38	0.1050	0.0765	0.0652	0.0406	0.0419	0.0345	0.0187
Aspen								
Antenna	15	0.4133	0.3653	0.2993	0.2355	0.2576	0.2877	0.2205
Control	43	0.3386	0.2643	0.2164	0.1529	0.1713	0.1415	0.1204
Red Maple								
Antenna	129	0.2163	0.1374	0.1017	0.1130	0.0830	0.0899	0.0952
Control	16	0.2667	0.2040	0.1533	0.1768	0.0690	0.1152	0.1272

[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	.082	.000	.814
Paper Birch	.006	.016	.925
Aspen	.003	.000	.189
Red Maple	.009	.000	.023
Analysis of Covariance			
Northern Red Oak[b/]	.338	.000	.250
Paper Birch	.525	.098	.780
Aspen	.542	.056	.124
Red Maple	.215	.005	.098

[a/] A significance level less that 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.

by the covariates. The fact that there was no site and year interaction for any of the four species indicates that the relationship between the individual tree diameter growth rates on the two sites did not change over time. Based on these results, there have been no significant changes in the magnitude of annual individual tree diameter growth in the four study species which could be attributed to the activity of the ELF antenna.

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 implies that the effect of the fields is confounded with the covariates and the interpretation of the results given above is invalid. To test the validity of the analysis of covariance, the correlations between the average plot EM field exposure level and the covariates were calculated. Significant ($p<0.05$) correlations were found between July soil potassium concentration ($r = -0.46$) and the magnetic field strength and between air temperature degree days through May ($r = -0.48$) and the magnetic field strength. As discussed in Appendix A, analyses including the longitudinal (ground) fields are not included in this year's report due to the spatial complexity of the field strengths across the sites which was first detected by IITRI in the summer of 1990. In the next year, methods of incorporating the longitudinal and transverse fields into the analyses discussed here will be developed.

The fact that two variables are correlated does not imply a cause and effect relationship. In this case, there does not appear to be any reason to expect a causal relationship between the magnetic fields generated by the antenna and air temperature or soil nutrient level. If this is a spurious correlation, it would be expected to diminish over an extended study period. The correlations noted between the covariates and the magnetic field levels have decreased as compared to results through 1988. In any case, the covariates are significantly correlated with the EM field exposure levels and the analysis of covariance of individual tree diameter growth should not be considered a reliable test of the effects of EM fields. The analyses of covariance 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 level 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, Appendix C) to further account for the variability in growth between sites and

over years. The growth model also provides an annual residual for each tree which can be examined to see if the diameter growth following antenna activiation is diverging from patterns seen in previous years; no similar quantity is available by 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 observed since 1985 include differences in the timing of growth between sites, differences in the timing of growth between species, and differences in the timing of growth between years (Mroz *et al.* 1986). Since the stand conditions have not changed drastically since 1985, 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, 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 = (Total Annual Growth)(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:

TAG = (Potential Growth)(Intertree Competition)
(Site Physical, Chemical, and Climatic Properties)

The degree of intertree competition is dependent on the distances and sizes of neighboring trees. Since the original stand maps extended only to the plot boundaries, the competitors for trees near the boundaries could not be determined. For this reason, only trees in the center 15 m could be utilized for the analyses using the growth model. 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 first use of the additional trees will be in the comparisons from the 1990 growing season.

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 data.

Total Annual Diameter Growth

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

For northern red oak, the 95% studentized confidence interval for the average residual overlaps zero in all years with the exception on the antenna site in 1987 (Table 2.6). The confidence intervals from the two sites overlapped each other and zero in 1988 and 1989, indicating that there were no detectable differences in the growth patterns between the two sites. The apparent difference noted in the 1987 data would appear to be an anomaly given the results of the comparisons in 1988 and 1989. There is no evidence that ELF fields have impacted total annual northern red oak diameter growth on the study sites.

For paper birch, there was a decrease in the average residual in 1989 at both the antenna and control site (Table 2.7). At the control site, the studentized 95% confidence interval included zero while this was not true at the antenna site. At both sites, the standard error of the residuals was much less than had been observed in any previous year, implying that all paper birch trees were responding similarly to environmental conditions. A further indication that the growth relationships on the two sites were consistent between 1989 and previous years is the fact that the difference in the average residual between the two sites was 0.0183 cm, well within the range observed in previous years. The studentized 95% confidence intervals from the two sites overlap considerably. This indicates that there is no apparent affect of ELF fields on paper birch diameter growth. There is a small sample size for paper birch on both sites; in the 1990 growing season trees near the edges of the plots will be available for inclusion in these analyses due to the mapping of the buffer zones around the plots. This will result in an improved ability to evaluate paper birch total annual diameter growth.

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
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

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
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

Table 2.8. 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
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

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
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

As reported last year (Mroz *et al.* 1989), aspen annual diameter growth residuals at the antenna site had been increasing over time while those at the control site were consistent and not different from zero. In 1989, the diaameter growth residuals decreased at both the antenna and control site with the studentized 95% confidence interval at the antenna site including zero while the confidence interval at the control site was below zero (Table 2.8). As was the case with paper birch, aspen diameter growth residuals decreased in 1989 as compared to the previous years. Unlike paper birch, however, the difference in average residual between the antenna and control sites increased to it's greatest level in 1989 (0.1201 cm). This indicates that diameter growth decreased on both sites in 1989 but that the decrease was less on the antenna site than on the control site. Aspen is the other species where the availability of a greater number of trees in 1990 will result in an improved ability to evaluate total annual diameter growth. The studentized 95% confidence limit on the antenna site included zero in 1989, but there was an increase in the difference between the average residuals between the two sites. Coupled with the differences observed in previous years, this information is consistent with, but does not conclusively indicate, a positive effect of the ELF fields on aspen total annual diameter growth.

In 1988 diameter growth of red maple was lower on both the antenna and control sites than in previous years (Mroz *et al.* 1989). In 1989, the diameter growth residuals indicate greater than expected growth on both sites (Table 2.9). The studentized 95% confidence intervals did not include zero at either site but there was no difference in the average residual between the two sites. In both 1988 and 1989 there apparently were environmental factors which affected diameter growth which were not reflected in the diameter growth model but the problems were apparent on both sites. Another possible reason for the poorer model performance for red maple is the fact that there has been more ingrowth of red maple than any other species. Twenty percent of the banded individuals at each site have been banded since 1986 because they have grown larger than 10 cm dbh. In any case, there is no indication that ELF fields are the cause of these differences or that ELF fields are measurably affecting red maple diameter growth at this time.

As a further evaluation of the effects of ELF fields on individual tree total annual diameter growth, an expected level of exposure to the magnetic flux generated by the antenna was determined for all banded trees using the methods described in Appendix A. For all four species at the control site, correlations between the 76 Hz magnetic field and diameter growth model residual was less than 0.001 and clearly not significant. At the antenna site, however, the correlation between magnetic flux and aspen diameter growth model residual was significant ($r=-0.67$, $p<0.05$) as was the correlation between magnetic flux and paper birch diameter growth model residual ($r=-0.61$, $p<0.05$). Similar correlations were found for aspen in previous years (Mroz *et al.* 1989). For northern red oak and red maple, correlations between magnetic flux aand diameter growth model residual were

between 0.10 and 0.20 and nonsignificant (p=0.05). At this time, the sample sizes for aspen and paper birch are probably too low to place too much emphasis on these results. These two species will benefit most from the efforts in mapping the buffer zones around the measurement plots. These results do indicate, however, that deviations from expected patterns of total annual diameter growth of aspen and paper birch are associated with, though not necessarily caused by, the magnetic field strengths at the antenna site.

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 growth predicted by the growth model (Mroz *et al.* 1988, 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 growth patterns for northern red oak on either site in 1986, 1987, or 1988 (Mroz *et al.* 1989). In 1989, there was a significant ($p<0.05$) difference between the observed and predicted seasonal growth patterns on one plot at each site. Even though the growth model did not predict the seasonal growth pattern in 1989 as well as in past years, 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 observed and predicted seasonal growth patterns for paper birch at the control site but not at the antenna site (Mroz *et al.* 1989). In 1989, there was a significant difference ($p<0.05$) between the observed and predicted seasonal growth patterns on one plot at each site. The performance of the model was better at the control site in 1989 than in past years though the reason for this is not clear. In any case, the differences between the observed and predicted seasonal diameter growth patterns for paper birch have primarily been at the control site and there is no evidence of significant ELF effects on paper birch seasonal diameter growth pattern.

There was a significant difference between observed and predicted seasonal diameter growth patterns of aspen at the control site in 1986 (Mroz *et al.* 1989) and again in 1989. There was a difference between observed and predicted seasonal diameter growth for aspen on only one plot at the antenna site in 1988 (Mroz *et al.* 1989) and this was repeated in 1989 on the same plot. This particular plot (plot 2) has only one aspen individual included in these analyses. Since the other two plots at the antenna site showed no significant deviation from the predicted seasonal diameter growth pattern, there is no real

evidence of an effect of ELF fields on the seasonal diameter growth pattern of aspen.

There were significant 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 ($p=0.05$) differences between observed and predicted seasonal diameter growth pattern for red maple on any plot at either site in 1989. There is, therefore, no evidence of an effect of ELF fields on the seasonal diameter growth pattern of red maple.

Summary

There is no evidence in any of the comparisons conducted in the hardwood growth analyses which indicates an effect of ELf fields on the growth of northern red oak or red maple. There is some evidence which is consistent with an effect of ELF fields on the total annual growth of aspen and, to a lesser extent, paper birch at the antenna site. There is no conclusive evidence of such an effect. There is no evidence of any effect of ELF fields on the seasonal pattern of diameter growth for any of the four species at either site. In particular:

1. There were no significant differences ($p>0.05$) in total annual diameter growth for any of the four species indicated in the analysis of covariance. The covariates are significantly ($p<0.05$) correlated with ELf field exposure levels which confuses the interpretation of these results. Due to these associations between the covariates and the ELF fields, the results of the analyses of covariance should not be considered reliable in evaluating the effects of the ELF fields on total annual diameter growth.

2. The diameter growth model was developed for each species to overcome many of the limitations of the analysis of covariance. Possible ELF field effects are examined by determining if the differences between the observed and predicted diameter growth values are increasing or decreasing. In the analysis of the residuals, there is no indication that ELF fields are affecting the diameter growth of northern red oak or red maple. For both paper birch and aspen, there were significant correlations between the diameter growth model residuals and the 76 Hz magnetic flux. Such correlations were also observed for aspen in 1988. The difference in average diameter growth model residual between the antenna and control site was consistent with observed differences in previous years for paper birch. For aspen, there has been an increasing difference in average diameter growth model residual between the antenna and control sites with each year of the study.

3. There are no differences between 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, possible effects of ELF electromagnetic fields on growth may be more easily detected on seedlings 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 any 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 stand information for the three study sites can be found in Table 2.10. A summary of all average diameters and heights at each study site over the length of the study 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_o: There is no difference in the level of seasonal diameter growth of planted red pine seedlings before and after the ELF antenna becomes operational.

and

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

As discussed earlier in the hardwood stand analyses, evaluation of possible ELF electromagnetic fields 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 (15 amps) and 1988 (75 amps) growing seasons. In 1989 the system has operated at 150 amps. Each of these analyses examines possible site differences as well as any existing differences between pre-operational and post-operational years. The analysis

Table 2.10. Summary of red pine stand information for the ground, antenna, and control sites at the end of the 1990 growing season.

Site	Sample Size	Average Basal Diameter (cm)	Average Height (cm)	Average Bud Size (mm)
Ground	136	4.44	167.96	30.38
Antenna	154	5.30	187.79	32.47
Control	180	5.06	203.81	34.99

Table 2.11. Average diameter (cm) and height (cm) for each site at the end of each year of this study.

	Sample Size	Basal Diameter (cm)	Total Height (cm)
Ground			
1984	300	0.450	17.18
1985	170	0.743	22.73
1986	147	1.280	37.33
1987	141	1.880	59.19
1988	137	2.427	90.22
1989	138	3.375	131.41
1990	136	4.440	167.96
Antenna			
1984	300	0.441	16.80
1985	188	0.701	23.92
1986	184	1.262	40.34
1987	177	2.117	66.55
1988	164	2.794	100.77
1989	158	3.877	146.32
1990	154	5.300	187.79
Control			
1984	300	0.459	18.96
1985	217	0.792	28.33
1986	211	1.355	50.50
1987	199	2.116	82.37
1988	192	2.706	116.69
1989	183	3.705	159.02
1990	180	5.060	203.81

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 pre- and post-operational years and any changes due to site or climatic variables can be evaluated. The level or amount of diameter growth in a growing season will only be analyzed 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 subsequent years. Only a few seedlings died during the course of the last five 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

throught 1990 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 has been mapped on a coordinate system; this is used in calculating amounts of exposure and analyzing effects of ELF fields. In order to account for evident competition between seedlings for available resources, in 1990 additional measurements were made on neighboring seedlings. These measurements included the distance of each neighbor to the seedling, the neighbor's diameter, height, previous year's growth, and crown width. This information will be incorporated into the analyses of 1990 growth.

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 1990. Measurements began in mid-April while shoots are still dormant and continued until mid-July when shoot elongation was completed. Measurements (to the nearest 1 mm) 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 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 six years of growth measurements available (1985 through 1990). 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) and these values are unavailable for the 1990 growing season at this time. Therefore, until 1990 soil nutrient analyses are completed, all growth analyses discussed include data from 1985 through 1989 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 done;
covariate determination was completed using information collected prior to antenna operation.

Annual height growth

Earlier analyses (Mroz et al. 1988) have 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 in 1986, 1987, 1988, and 1989 coupled with 1985, 1986, 1987, and 1988 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 ia 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).

Table 2.12. Average seasonal diameter growth (cm) and height growth (cm) for each site for the 1985, 1986, 1987, 1988, and 1989 growing seasons.

	1985	1986	1987	1988	1989
Diameter Growth (cm)					
Ground	0.27	0.53	0.60	0.54	0.95
Antenna	0.23	0.55	0.86	0.65	1.09
Control	0.32	0.57	0.76	0.61	1.02
Height Growth (cm)					
Ground	5.08	14.28	23.75	28.70	41.99
Antenna	6.61	16.06	26.96	33.53	46.03
Control	8.34	22.34	31.87	35.02	42.73

Prior to 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).

The covariates identified from previous work (Mroz et al. 1988) were again used in the analysis of covariance. These covariates included average maximum air temperature for the month of June, total Kjeldahl nitrogen in the 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 treatment; in this case, each covariate selected should not be linearly correlated with the EM fields. Correlations were calculated across time between the selected covariates and average EM fields 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 and the previous growing season as well the current growing season were examined. Water holding capacity at 10 to 30 cm was the only covariate significantly correlated ($p=0.05$) with magnetic flux (mG) ($r=.4105$, $r=.4713$) for both growing seasons. This covariate is a site variable and it is constant across time. The significant correlation with water holding capacity at 10 to 30 cm may be explained by the variability in EM exposure values. The antenna runs thrugh plot one at the ground site, therefore the fields are much higher for this plot than either of the other two. Water holding capacity at 10 to 30 cm is also highest on this plot (0.38 versus 0.06 or 0.04) creating a significant correlation with the ELF fields without any true cause and effect relationship existing. No conclusive evidence indicates that this covariate is not independent of ELF fields at this time, but the statistical association violates the analysis of covariance assumptions.

These three covariates were able to explain all existing site differences ($p=0.05$) in annual height growth. Yearly differences, however, as well as a site-year interaction remained significant ($p<0.001$) (Table 2.14). This significant site-year interaction indicates that the relationship between individual tree height growth rates on the three sites has changed over time. The control site, which has always had the greatest amount of height growth, now has the second highest growth rate. The antenna site has the greatest amount of height growth for the 1989 growing season (Figure 2.1).

Lundgren and Dolid's exponential monomolecular site index curve (1970) has been found to accurately predict total height of young red pine seedlings (Jones and Reed 1991). Residuals (observed total height minus predicted total height) were calculated and introduced as additional covariates as discussed last year (Mroz et al. 1989). However, they did not account for any exising significant ($p<0.001$) effect.

The significant time factor is not surprising based on the young age of the seedlings. Considering the typical sigmoid growth curve (Figure 2.4), the seedling heights are probably still in 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/]	0.1839
Year	0.0000	0.0000
Site x Year	0.0000	0.0000
Diameter Growth (cm)		
Site	0.0000	0.0472
Year	0.0000	0.0000
Site x Year	0.0000	0.0000

[a/] A significance level smaller than 0.05 would indicatd significance (p=0.05).

exponential portion of the curve. One could not expect to see similar amounts of growth from year to year until later in time when growth is slowing and more linear in shape. The change in ranking of sites in terms of amount of height growth may be due to the fact that maximum height growth has been achieved at the control site, but not at the other two sites (Figure 2.1). Analyses with future growth data will determine if this is in fact true. Another course of analysis to explain this time dependence would be to use a residual total height growth (calculated from the difference between the observed and the predicted total height) as the dependent variable rather than the observed total height growth. We could then examine expected height growth in relationship to observed height growth and determine if the trends over time remain constant.

Correlations between EM field strengtns (magnetic flux (mG)) for each seedling's location and the total seasonal height growth for each seedling were calculated. There was a significant correlation ($p=0.05$) between the magnetic flux (mG) and the seedling's height growth at all three sites. As mentioned last year (Mroz et al. 1989), the seedlings are young and, for the most part, still have increasing height growth each year. This corresponds to increasing EM field strengths over the study years. As the level of height growth levels off, these correlations need to be examined further.

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

Annual diameter growth

In diameter growth analyses, the current season's site physical, chemical and climatic data explained more site and yearly variation than the information from the previous season. This is consistent with the physiological nature of the seedlings. Thus, in diameter growth analyses, average annual growth from 1985 through 1989 were used in the analyses.

Initial analysis of variance (without the use of covariates) found strong significant differences among sites a d 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).

The four 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, minimum air temperature in May, 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 nly 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.

As discussed elsewhere, the covariates selected must be independent of EM fields. Correlations were calculated across time between exposure levels (magnetic flux (mG)) and each year's current covariate values. No significant correlations ($p=0.05$) were found, thus indicating no violation of the assumption of independence at this time.

With these covariates, site differences ($p=0.0472$), year differences ($p<0.001$) and a site-year interaction ($p<.001$) all remained (Table 2.14). Because of the existing differences, multiple range tests were employed to look at diameter growth on each site during each study year. Table 2.14 depicts the significant differences ($p=0.05$) among the sites and among the study years. In 1989 all three sites are significantly different from each other ($p=0.05$) and the diameter growth at each site in 1989 is significantly different from that found on the respective sites for every other year. The large difference in total diameter growth in 1989 compared to all other study years may be attributed to the fact that the amount of height growth seems to be leveling off. These large differences in diameter growth are not found in 1986 through 1988. There are some nonsignificant differences ($p>0.05$) in diameter growth among the sites and between the study years on a given site. The soil, site, and climatological data are obviously not sufficient in explaining existing differences among site and years by themselves. There does appear to be some "noise" in the data; the trends of diameter growth across time on any given site are not consistent nor are the rankings of diameter growth among the three sites in any given year (Figure 2.2). Diameter growth tends to be affected by competition from other seedlings for resources. A measure of competition was made in 1990 and will be incorporated into the 1990 analyses in an attempt to explain existing differences.

Correlations between EM field strengths (magnetic flux (mG)) for each seedling and the total seasonal diameter growth for each seedling were calculated. There was only a significant correlation ($p=0.05$) between seedling diameter growth and the magnetic flux at the antenna site ($r=.4577$). No significant correlations were found at the ground or the control sites. This correlation suggests that some relationship between the ELF fields and seasonal diameter growth exists. At this point, diameter growth differences do exist and these differences can not be assumed to be independent of the ELF fields. The antenna became fully operational in 1989, but has operated at lower levels in 1987 and 1988. Significant differences among sites and between years have been evident since 1985. Because of this fact, and until the variation in the system can be further examined, differences in seasonal diameter growth can not be attributed solely to the ELF field exposures.

Table 2.14. Significant relationships [a/] in the analysis of covariances on both sites and years for mean diameter growths (cm) which have been adjusted by the covariates.

	Ground	Antenna	Control
1989	0.9993[e]	1.1326[g]	1.0484[f]
1988	0.5962[b]	0.6796[c]	0.6497[c]
1987	0.5630[b]	0.8399[d]	0.6852[c]
1986	0.5600[b]	0.5661[b]	0.5542[b]
1985	0.2362[a]	0.2110[a]	0.2829[a]

[a/] Different letters of the alphabet indicate significant differences in adjusted diameter growths at the alpha=0.05 level.

Seasonal Pattern of Height Growth

Height growth models based on incremental seasonal growth of the leading shoot were developed to 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 second component was added to the model. A negative exponential component modifies the expected growth based on soil water tension (Zahner 1963). The model form is as follows:

$$g_t = \left[\left(1 - e^{-b_1 * ATDD_2}\right)^{b_3} - \left(1 - e^{-b_1 * ATDD_1}\right)^{b_3}\right] * (TGRO) * \left(e^{b_4 * (MT - .101)}\right)$$

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
$ATDD_2$	=	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 that .101 -MPa, mt was set to .101 -MPa for model development)
b_1, b_2, b_3	=	estimated coefficients for air temperature degree days component
b_4	=	estimated coefficient for moisture stress component

Table 2.15 contains the values for the estimated coefficients. The component

$$b_2 * TGRO^{b_3}$$

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 ELF in the height growth pattern which was established from previous years, the residual will either increase or decrease. Figures 2.3 to 2.5 illustrate the observed and predicted cumulative growths for 1989 on the three study sites. Although the cumulative curves may mask any possible absolute differences, the advantage in standardizing is that established patterns in growth may be examined. Examination of the residuals from 1986 through 1989 at each study site found no significant differences ($p=0.05$) between the observed and predicted seasonal height growth patterns (Table 2.16 and Figure 2.6).

Possible changes in height growth patterns may also be evaluated through correlation analysis with ELF field exposure variables. Each seedling's position was mapped and EM field strengths (magnetic flux (mG)) were calculated for individual seedlings. Correlations were calculated between the residuals from the height growth model and the strengths of EM exposures to each seedling across the four years of study. No significant correlations between the residual and the ELF fields ($p=0.05$) were found at the ground site, but significant correlations ($p=0.05$) were found at the antenna and control sites. To determine if these significant correlations were distance related correlations were run on 1989 individually and no significant correlations ($p=0.05$) were found as was also true with the 1988 data (Mroz et al. 1989). Based on both of these analyses, there appears to be no apparent ELF field effects on seasonal height growth patterns of red pine seedlings at this time.

Table 2.15. Coefficient estimates for the red pine height growth model.

	Coefficient Estimate	Asymptotic 95% Confidence Interval
b_1	0.0069	(0.0068, 0.0070)
b_2	1.7595	(1.5262, 1.9928)
b_3	0.4024	(0.3633, 0.4413)
b_4	-1.7601	(-2.1119, -1.4083)

Figure 2.3

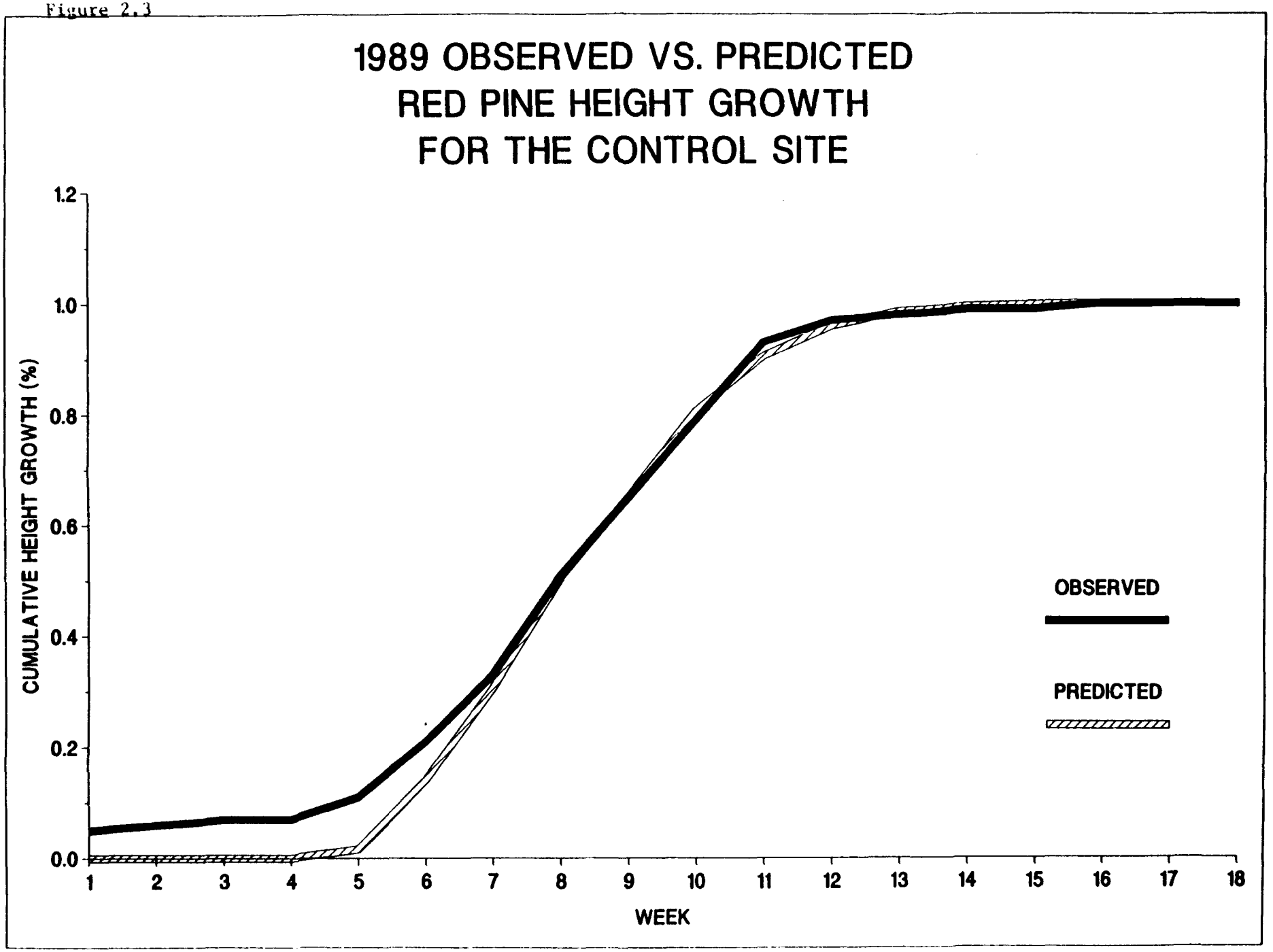

1989 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH
FOR THE CONTROL SITE
CUMULATIVE HEIGHT GROWTH (%)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
WEEK
OBSERVED
PREDICTED

Figure 2.5

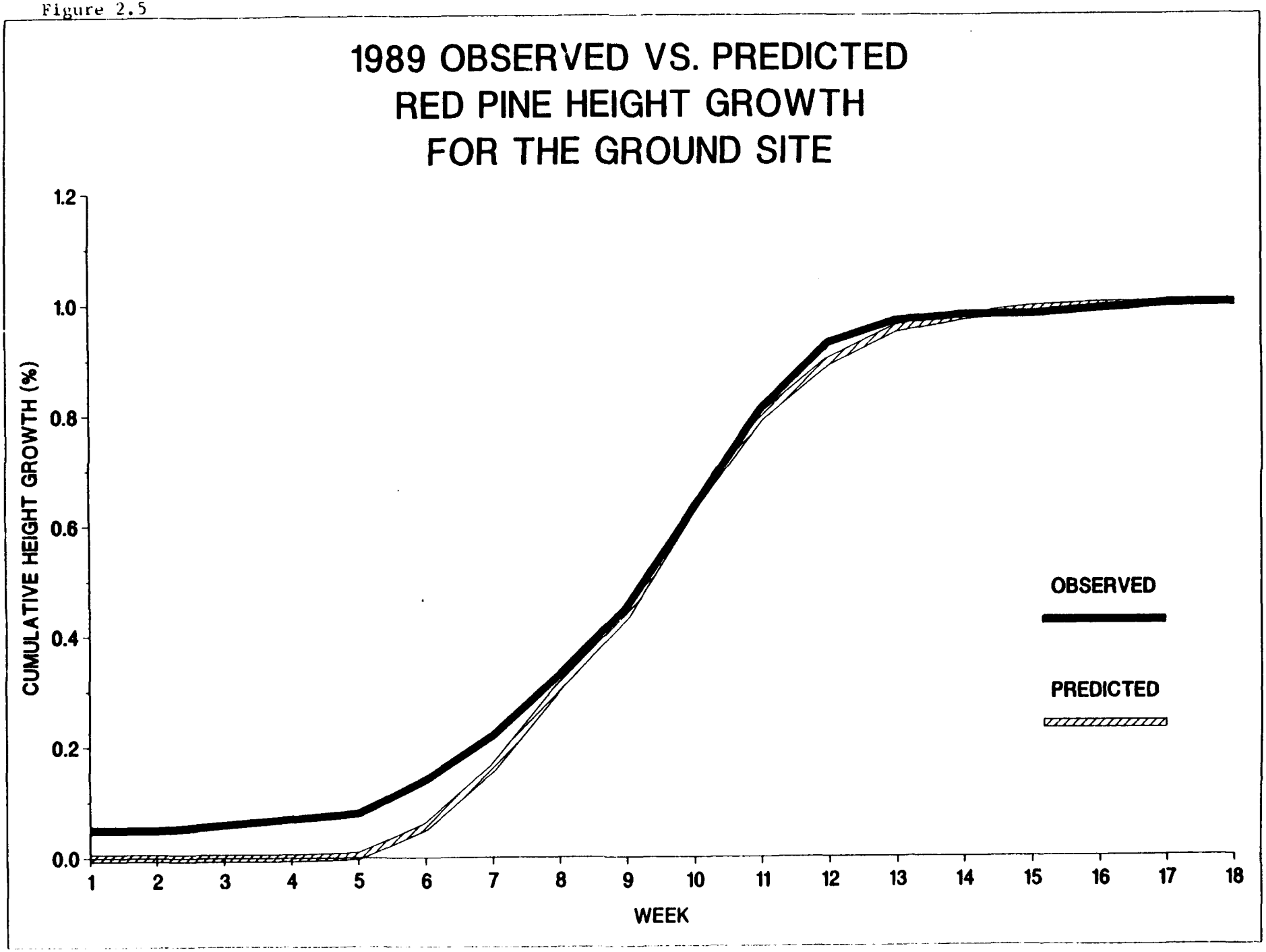

1989 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH
FOR THE GROUND SITE
CUMULATIVE HEIGHT GROWTH (%)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
WEEK
OBSERVED
PREDICTED

Table 2.16. Residual analysis from the height growth model for the ground, antenna, and control sites in 1986 through 1989.

	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)
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)
Control		
1986	-0.0687	(-0.2600, 0.1226)
1987	-0.0562	(-0.2723, 0.1597)
1988	-0.0600	(-0.3238, 0.2038)
1989	-0.1091	(-0.3555, 0.1373)

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.

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

Sampling and Data Collection

Sampling

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 in October of the 1985 through the 1990 field seasons. 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 fascicles are then randomly selected for foliar analysis. The fascicles are then dried at 60^{o} C, ground, and analyzed for concentrations of N, P, K, Ca and Mg.

Data Analysis

Comparisons of differences in 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 2.17). Covariates such as soil nutrient content, individual sample tree physiological characteristics, and climatic factors are considered as potential covariates. Individual covariates are included in the analysis if they increase the sensitivity of the analysis or reduce the variation associated with the independent factors in the analysis while maintaining the statistical assumptions inherent to analysis of covariate procedures.

Table 2.17 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

Since growth of red pine is determinate, nutrient concentrations of the one year needles may not have acclimated to

the individual site conditions by the time of sampling in 1985. To test this assumption correlations between the 1985 and 1986-1989 nutrient concentrations were performed. The 1985 nutrient concentrations were not significantly ($p \leq 0.05$) and/or positively correlated with the 1986-1989 nutrient concentrations. The lack of significant correlations between nutrient concentrations for the two different sampling periods supported the assumption that the 1985 nutrient concentrations were still acclimating and did not reflect site conditions. Thus only the 1986-1989 samples were included in ELF hypothesis testing.

Given that red pine growth is determinate, site and tree conditions at the time of bud set and foliage expansion should influence foliar nutrient concentrations. 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. Nutrient concentrations of these samples would also reflect the amount and extent of translocation of nutrients from and to the needle during the year of sampling (R. Van Den Driessche 1984). Thus potential covariates for the analysis should include factors measured two and one years prior to sampling as well as the year during sampling. At this time work has only focused on using soil, climate, and tree characteristics of the year of sampling. Future work will focus on including information collected in years prior to the individual year of sampling.

Progress

At this time, foliage nutrient analysis has been completed for samples taken at planting through 1989 (Table 2.18). 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. Nutrient concentrations are ranked in the order: N > K > Ca > P > Mg for all years sampled.

Standard deviations of individual nutrient concentrations are generally within 10 to 20% of the mean for all sites and years (Table 2.18). Standard deviations during 1984 after planting and 1985 are generally higher than the other years due to the initial acclimation of red pines to the site. The small variation after 1985 reflects the relatively uniform conditions within a site and the lack of genetic variation in red pine.

Table 2.18. Mean and standard deviation of foliage nutrient concentrations for red pine seedlings at ELF study sites at the time of planting and five years afterwards.

Site	N%	P%	K%	Ca%	Mg%
AT PLANTING					
Ground	1.12(.15)	0.14(.02)	0.40(.07)	0.22(.06)	0.12(.01)
Antenna	1.16(.11)	0.14(.02)	0.39(.06)	0.20(.06)	0.12(.02)
Control	1.15(.15)	0.14(.01)	0.39(.07)	0.22(.06)	0.12(.02)
1984					
Ground	1.42(.36)	0.15(.03)	0.49(.08)	0.30(.05)	0.13(.01)
Antenna	1.50(.35)	0.16(.03)	0.50(.13)	0.31(.06)	0.14(.06)
Control	1.33(.37)	0.15(.03)	0.46(.13)	0.30(.05)	0.13(.05)
1985					
Ground	1.43(.40)	0.16(.04)	0.51(.04)	0.20(.05)	0.09(.01)
Antenna	1.09(.35)	0.13(.03)	0.55(.07)	0.18(.03)	0.08(.01)
Control	1.61(.29)	0.18(.04)	0.55(.05)	0.23(.03)	0.10(.01)
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)

Analyses to examine site and year differences show year differences for all nutrients and site differences for only Mg and N (Table 2.19). Year by site interactions were only significant for Mg and K. The antenna site had significantly ($p \leq 0.05$) higher foliar N concentrations (1.27%) than either the control site (1.14%) or the ground site (1.16%) while having significantly lower concentrations of Mg (0.090%) compared to the control site (0.094%) or the ground site (0.095%). Differences among sites were much more consistent for N concentrations than for Mg concentrations (Figure 2.13 Figure 2.9). Concentrations of calcium increased while concentrations of nitrogen decreased during the four year study period (1986-1989) at all sites (Figure 2.7 Figure 2.13). These consistent changes reflect the changes of foliar nutrient concentrations with plant maturity (Walworth and Sumner 1987,Lambert 1984, Miller 1981).

Detection limits associated with the analysis of variance (without covariates) were generally below 10% (Table 2.19). 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 covariates into the analysis primarily decreased detection limits associated with the various factors and interactions. The covariates also explained differences in N and Mg concentration among sites. Inherent site differences due to differences in the physical nature of the sites are readily explained by using factors such as soil nutrient concentrations and/or climatic variables. Thus mean soil Mg concentration during June through September and soil moisture content in June were important covariates for explaining site differences in Mg and N respectively.

Addition of the covariates had little effect on explaining year or year by site differences. This can be attributed to the relatively small effect of current year soil, climate, or tree physiological factors on nutrient concentrations. For a number of nutrients foliar concentration of the nutrient increased as soil nutrient concentration and/or as the soil moisture content increased. This indicates that nutrient translocation from the one year old foliage was minimal with increasing soil nutrient concentration and moisture content. The number of mycorrhizal root tips was also an important covariate for N and K. N concentration decreased with increasing numbers of mycorrhizal tips per gram of roots. This may either reflect a partitioning of N to the mycorrhizae or an increase occupancy of mycorrhizae with tree maturity and nitrogen reductions. Until climatic and soil information collected during bud set and needle expansion is included as possible covariates, the covariates used to date can not be regarded as the best or final choices as covariates for the analyses.

Regardless of whether the covariate adjusted or unadjusted means are compared (Figures 2.7-Figure 2.16) there appears to be no evidence that ELF antenna operation has affected the nutrient concentrations in the red pine foliage. There has been no

Table 2.19. Results of red pine foliage nutrient analyses of variance (p value) and computed detection limits (%) with and without covariates

	P Value				
	Ca	Mg	K	N	P
Without Covariates					
Site	.139	.016	.356	.042	.145
Year	.000	.000	.000	.000	.004
Year x Site	.410	.008	.002	.249	.078
	%				
Without Covariates					
Site	9.5	3.4	7.5	8.8	10.8
Year	10.4	4.8	5.3	5.0	12.2
Year x Site	18.0	8.4	9.2	8.6	21.2
	P Value				
	Ca[1]	Mg[2]	K[3]	N[4]	P[5]
With Covariates					
Site	.193	.180	.472	.478	.113
Year	.000	.000	.000	.000	.000
Year x Site	.044	.000	.000	.255	.297
	%				
With Covariates					
Site	9.9	3.8	8.4	4.6	6.5
Year	8.7	3.6	4.2	5.2	8.6
Year x Site	15.0	6.2	7.3	9.0	15.0

[1]Covariate=Average soil moisture content 10 cm (June-September)

[2]Covariate=Mean soil Mg concentration & air temperature (June-September)

[3]Covariate=Soil water potential (September), soil potassium content (July), and mycorrhizal tips per gram of root

[4]Covariate= Mycorrhizal tips per gram of root & soil moisture content 5cm (June)

[5]Covariate= Soil moisture content 5 cm (June) and average soil phosphorus concentration (June-September)

Figure 2.9

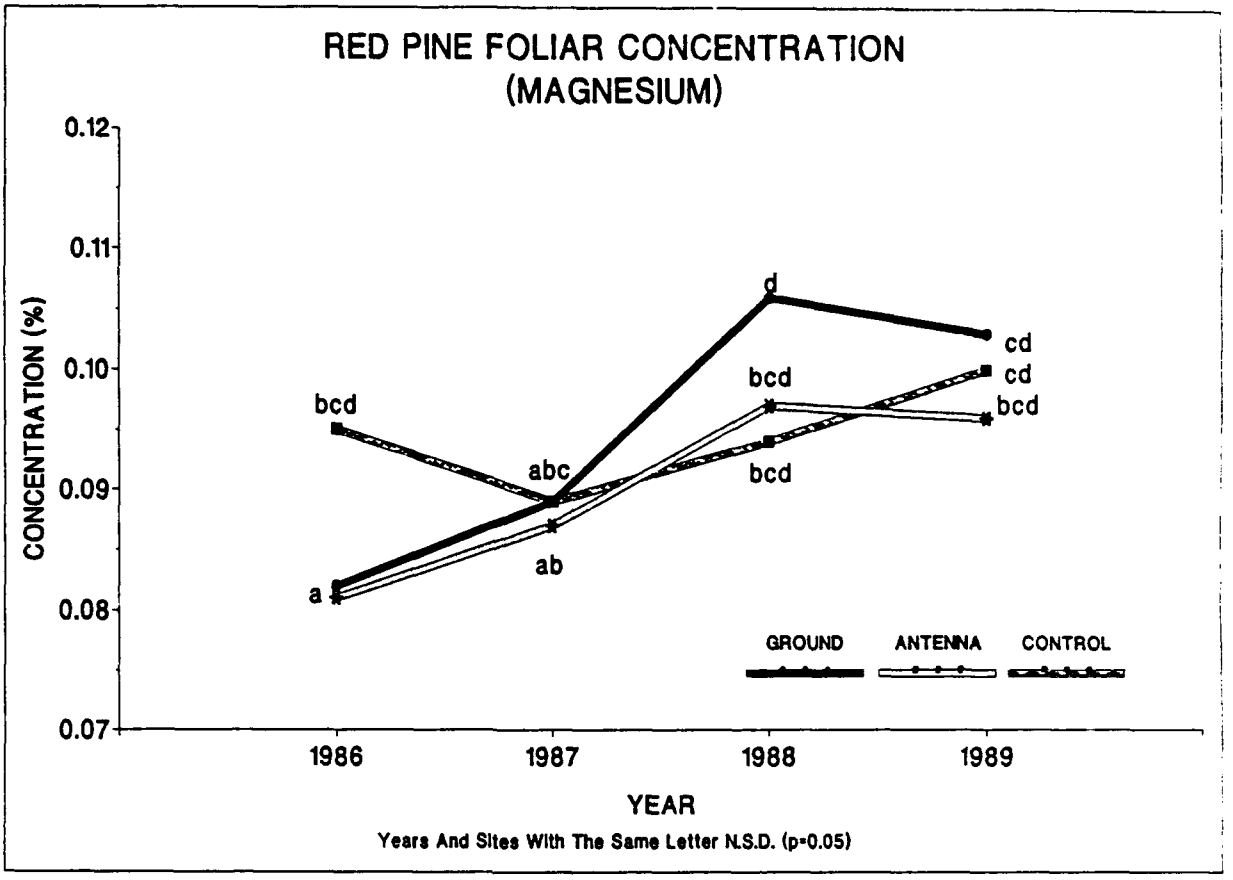


Figure 2.10

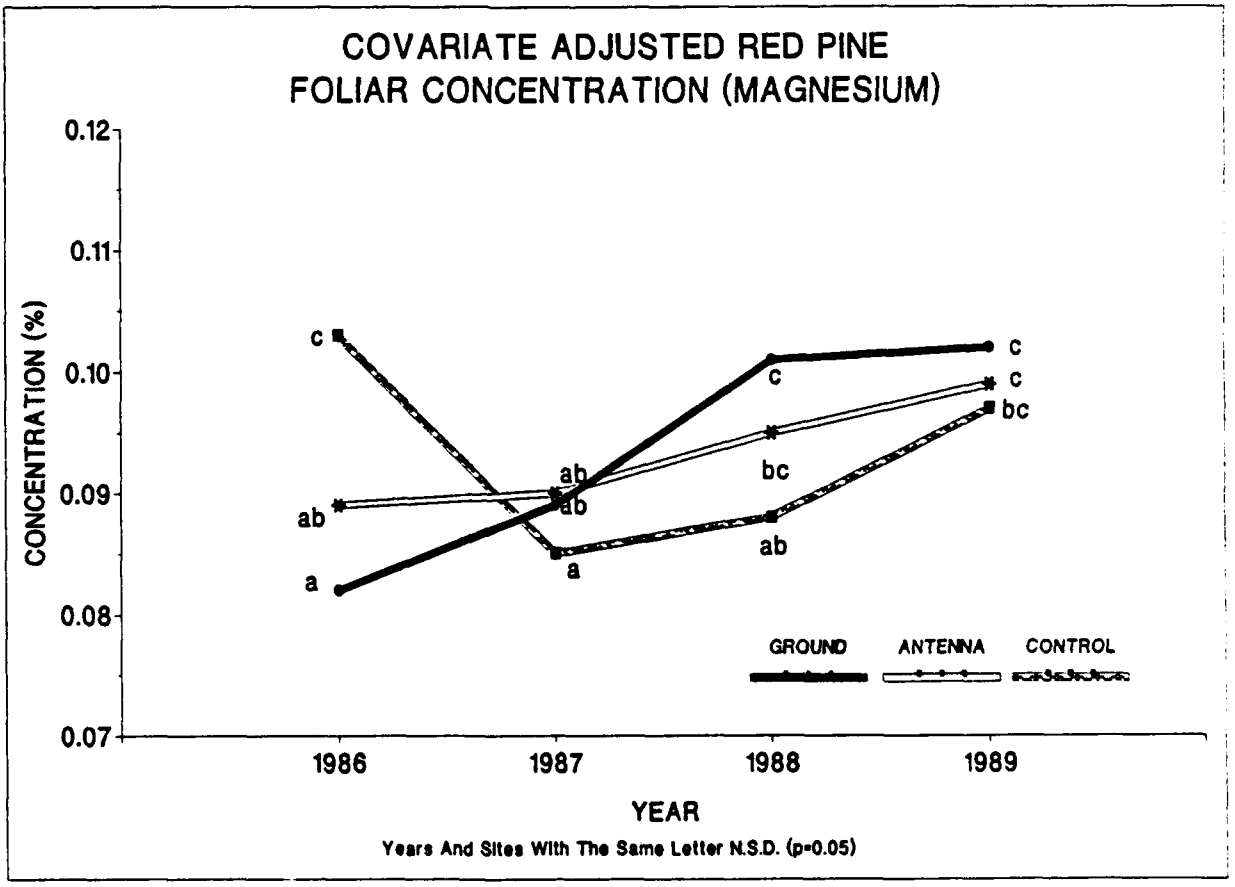


Figure 2.11

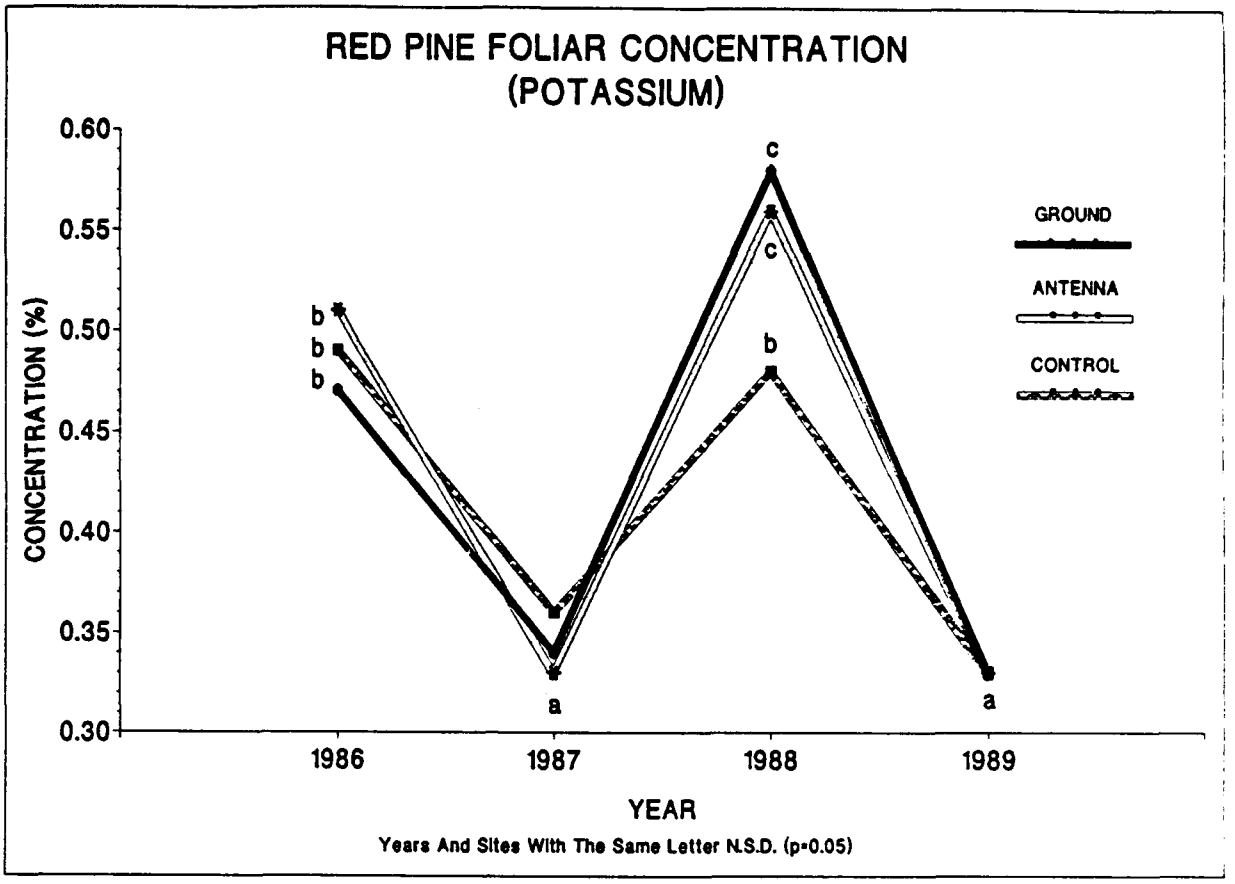


Figure 2.12

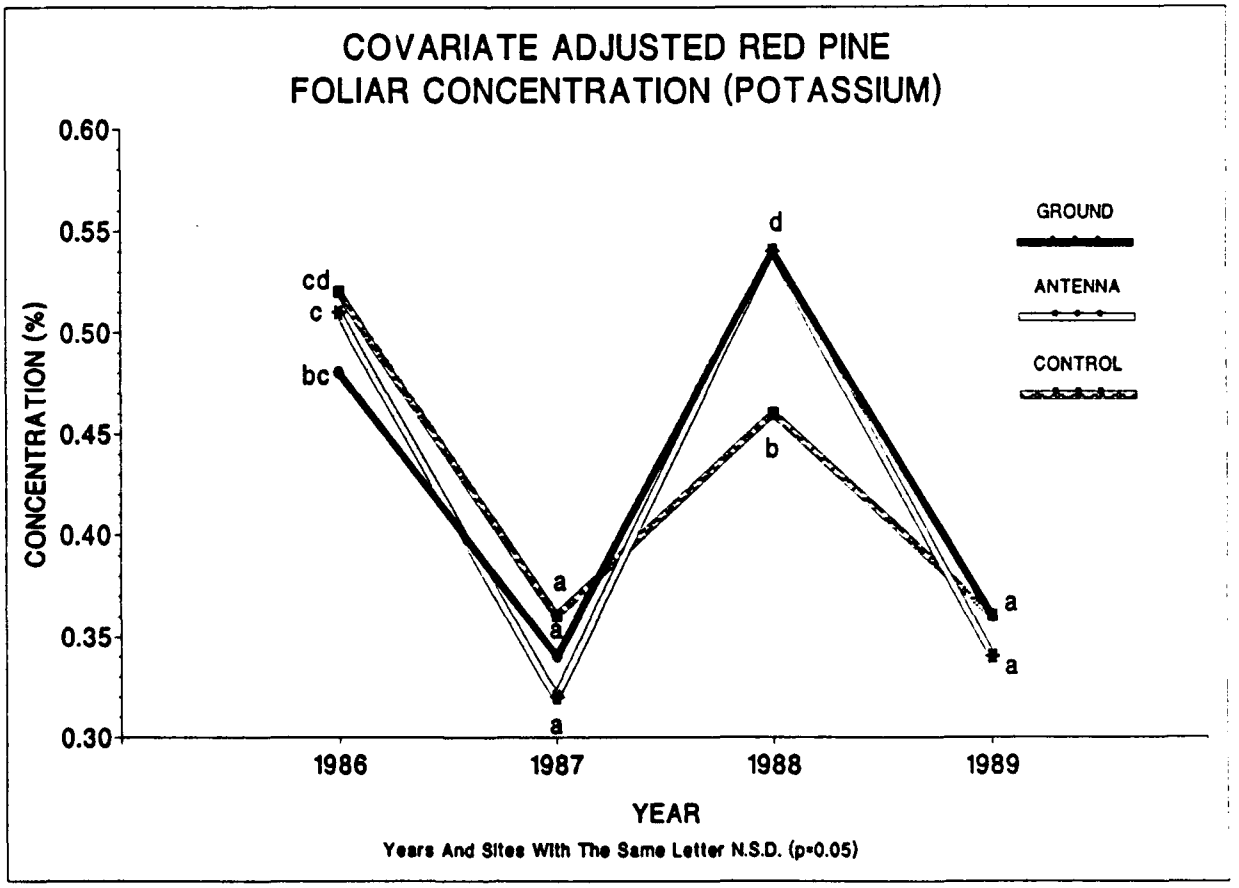


Figure 2.15

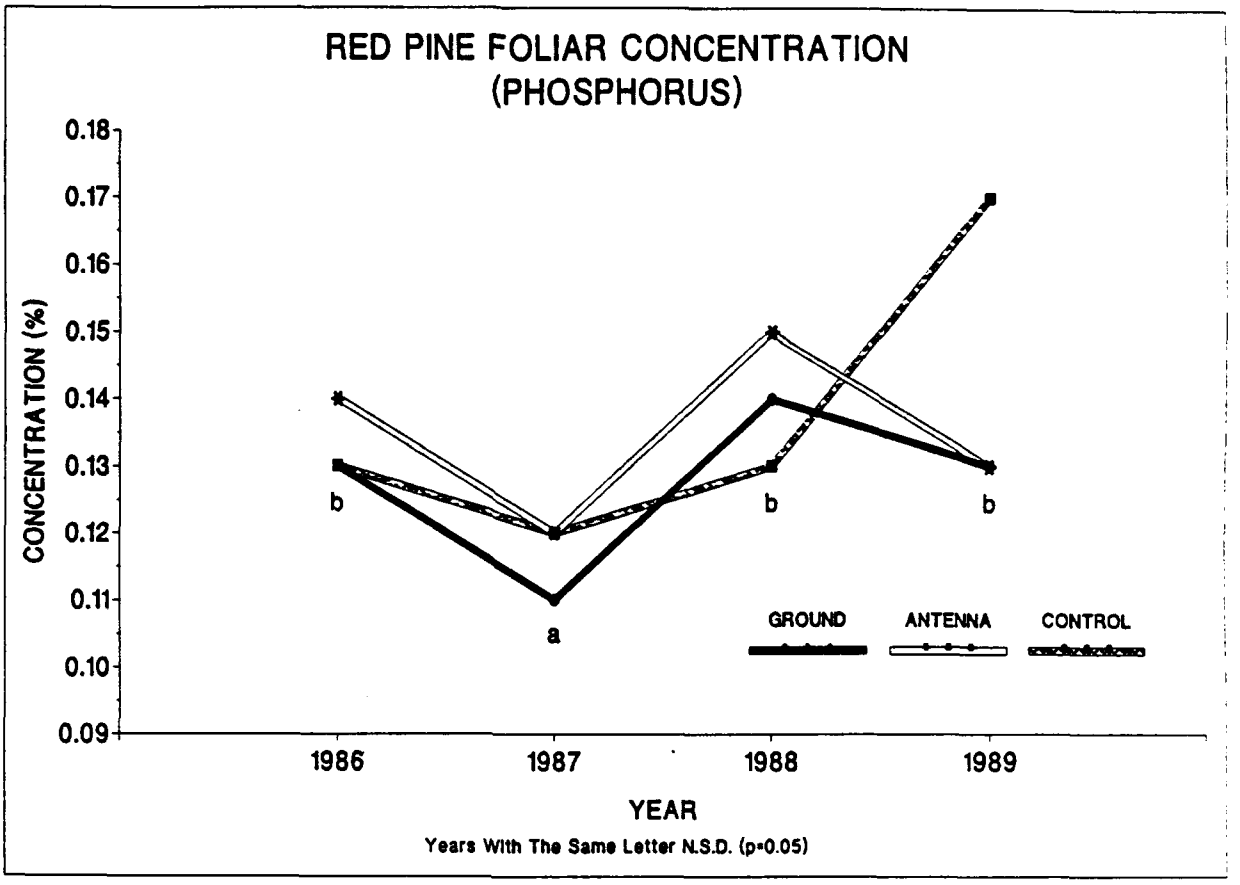
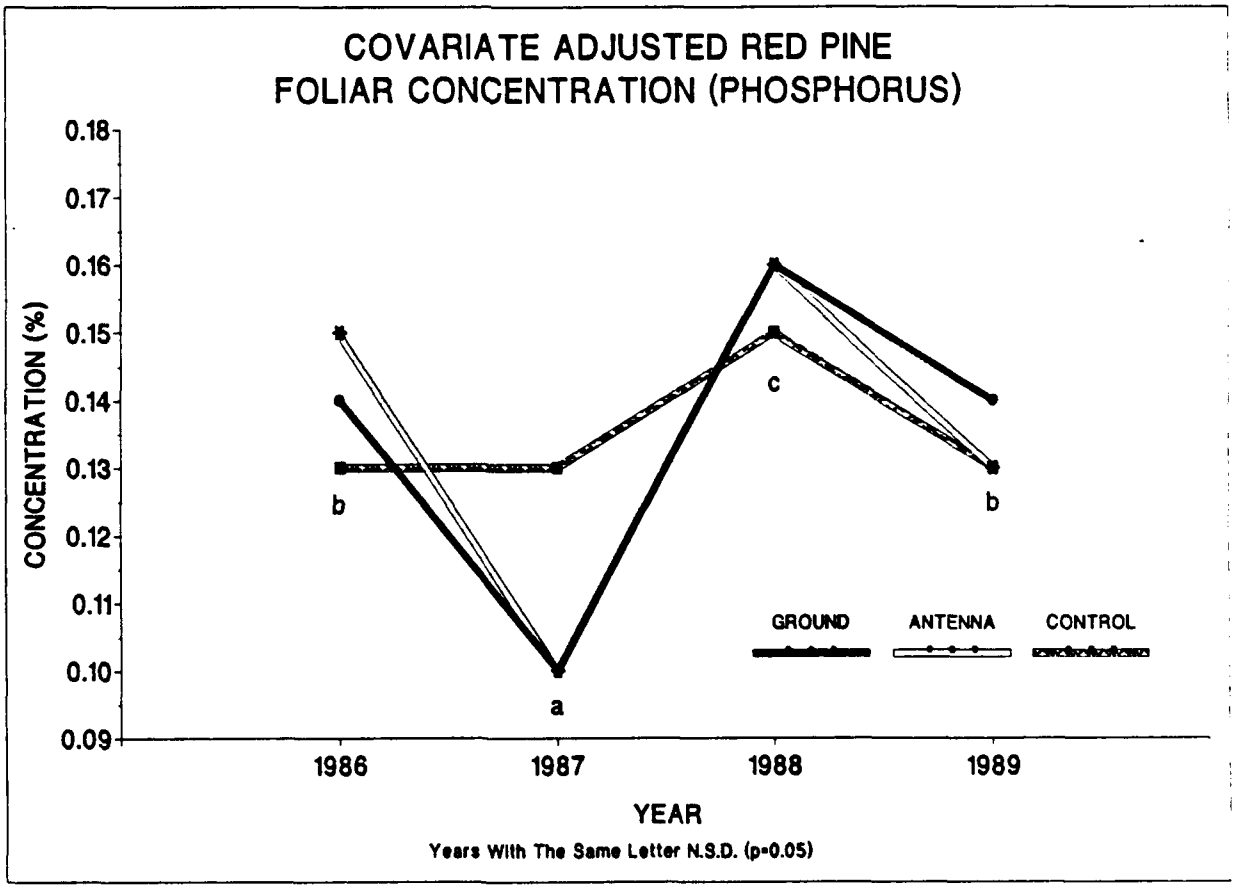


Figure 2.16



consistent increases or decreases in nutrient concentrations of the ground and antenna sites compared to the control site after antenna operation in 1988.

Summary

At this time there has been no indication that the ELF antenna operation as altered the nutrient status of the red pine. However, these analyses have been performed before any of the possible covariates measured during bud formation and leaf expansion have been included. Furthermore, the leaf primordia of one year old needles sampled in 1988 and 1989 were formed before antenna operation. The needles sampled in 1988 expanded in 1987 before full antenna operation. Thus it is not known whether foliage sampled during 1988 or 1989 would show any possible effects of ELF electromagnetic radiation. Future work will focus on the inclusion of soil and climatic information collected during bud set and leaf expansion into the analyses. Statistical techniques proposed by Bicklehaupt et al. (1979) for normalizing foliar nutrient concentrations for annual variations in climate will also be employed.

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 dependant 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 was conducted in years 1984 - 1990. 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 are not available for 1984 for use in covariate analysis.

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* This section has been renamed from 'Plant Moisture Stress' to 'Leaf Water Potential' to more accurately describe the internal moisture process and be consistent with current literature terminology as suggested by reviewers.

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 bi-weekly as in 1986 - 1990. The 1985 data could not be easily compared to subsequent years when measurements were made bi-weekly. Therefore, the analysis of LWP presented here will include years 1986-1990.

Sampling in 1990 was conducted biweekly beginning on May 25 and continuing until August 28 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 subsequent 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 each sample tree and a portion of the root system were removed from the site the afternoon following LWP determination to obtain aboveground biomass and mycorrhizae counts.

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 1988-1990.

Progress

Leaf water potential values varied between -.27 and -1.23 MPa in 1990 (Figure 2.17 and Table 2.20). Becker *et al.*

Figure 2.17

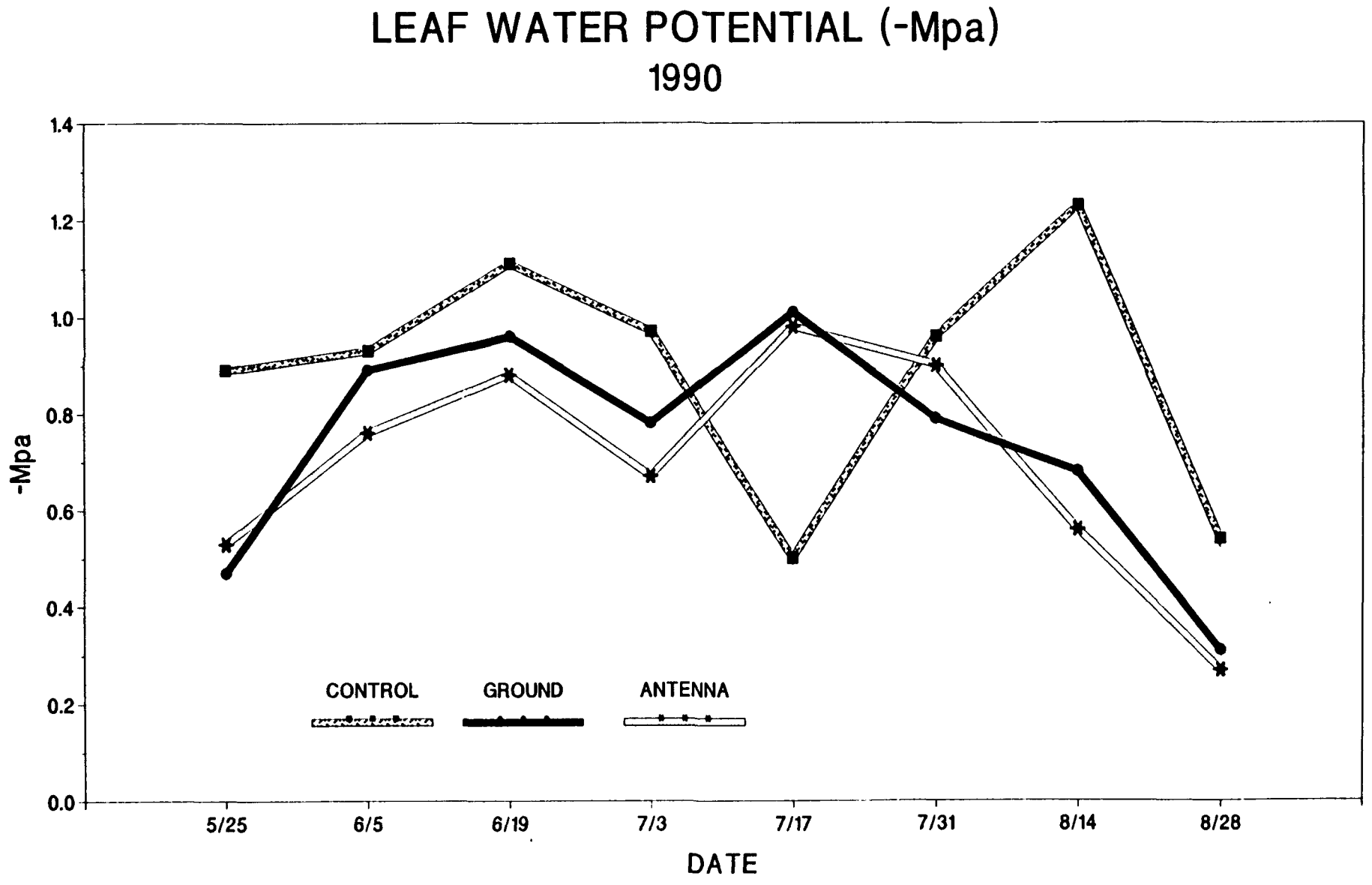

LEAF WATER POTENTIAL (-Mpa)
1990
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-Mpa
CONTROL
GROUND
ANTENNA
5/25
6/5
6/19
7/3
7/17
7/31
8/14
8/28
DATE

Table 2.20. Average leaf water potential, 1990 (-MPa) N=15.

Date	Ground		Antenna		Control		Overall
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std Dev.	
	---------- -MPa ----------						
5/25	.47	.19	.53	.36	.89	.41	.62[b]
6/5	.89	.38	.76	.35	.93	.50	.86[c]
6/19	.96	.28	.88	.39	1.11	.54	.98[c]
7/3	.78	.31	.67	.35	.97	.45	.81[c]
7/17	1.01	.48	.98	.41	.50	.18	.83[c]
7/31	.79	.28	.90	.29	.96	.34	.88[c]
8/14	.68	.24	.56	.32	1.23	.50	.83[c]
8/28	.31	.16	.27	.16	.54	.23	.37[a]
Overall	.73[x]		.69[x]		.89[y]		

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

(1987) reported that LWP values ranging from -.80 to -1.1 MPa did not produce measurable reductions in red pine seedling growth. LWP means for most measurement dates were within or above this range. Exceptions occured at the control site on June 19 (-1.11 MPa) and August 14 (-1.23 MPa). These dates represent the first occurence since the study began where LWP means exceeded published growth reduction limits. However, these periods of low LWP occured 8 weeks apart and were no longer than 2 weeks in duration. Red pine growth data for 1990 will be analyzed to determine if growth reductions occurred during these periods of low LWP at the control site. Analysis of the red pine data will be conducted during 1991. (See Element 2, Red Pine Studies).

The pattern of LWP within 1990 was similar at the ground and antenna sites while a somewhat different pattern was observed at the control site (Fig. 2.17). A similar pattern for the sites was also observed in 1989 (Mroz, *et. al.* 1990)

The lowest LWP (most stress) at the antenna and ground sites occurred on July 17 during a period of decreasing temperature and decreasing soil moisture at 10 cm (Table 2.21). At the control site the lowest LWP occured on August 14. The highest LWP (least stress) at the antenna and ground sites occured on August 14 following a period of increasing temperature and increasing soil moisture while at the control site the higest LWP occured on July 17 (Table 2.21). Although relationships between LWP and climate variables can be observed on some dates for the antenna and ground sites, they

Table 2.21. Ambient Conditions for 1990 LWP measurements dates.
(All sites combined)

Date	Air*[a] Temp.	Air Temp. Minimum	Air Temp. Maximum	Relative* Humidity %	Relative Humidity % Minimum	Soil* Temp. 10 cm	Soil* Moisture 10 cm	Rainfall[b] (in.)	Overall LWP (-MPa)
5/25	12.4	3.6	19.5	71.7	43.3	11.3	14.9	1.95	.62
6/5	7.4	1.6	16.3	77.7	35.3	11.3	15.4	1.30	.86
6/19	11.8	2.8	21.1	68.0	27.0	14.1	16.8	2.14	.98
7/3	23.0	16.2	31.5	80.0	68.9	18.8	12.9	.43	.81
7/17	17.8	10.9	28.0	86.0	58.7	16.1	12.1	1.20	.83
7/31	14.5	5.1	24.3	65.0	33.0	15.8	11.7	1.24	.88
8/14	15.8	8.4	26.2	70.3	48.0	15.1	12.7	1.17	.83
8/28	20.3	16.0	25.0	75.7	33.3	17.7	16.6	.92	.37

* Daily Average
a Temperature ^{o}C
b Total precipitation between sampling dates or prior 14 day period.

are not so obvious at the control. The LWP values at the control on July 17 and August 14, do not appear to be related to the climatic variables in the same manner as for the antenna and ground sites. In some situations, climatic variables may operate in combination to initiate a response in LWP. Additional work in defining these relationships and a modeling approach may be helpful to further explain variation between LWP and sampling dates.

Analysis of variance was conducted in order to test differences between LWP and measurement dates and sites in 1990. Significant differences ($p=0.05$) were found in 1990 between sites, measurement dates and in the date by site interaction. Significantly lower LWP (more stress) occured at the control site compared to the antenna and ground sites. Similar differences between sites were also reported for 1986 (Mroz, *et. al.*, 1987).

The combined data for years 1986-1990 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 2.2`.

Table 2.22 Anova table for the analysis of 1986 - 1990 leaf water potential data.

Source of Variation	df	SS	MS	F-Ratio
Year	4	SS(Y)	MS(Y)	MS(Y)/MS(E1)
Date w Year (E1)	35	SS(E1)	MS(E1)	MS(E1)/MS(WR)
Site	2	SS(S)	MS(S)	MS(S)/MS(E2)
Site by Year	8	SS(SY)	MS(SY)	MS(SY)/MS(E2)
Date w Year by Site (E2)	95	SS(E2)	MS(E2)	MS(E2)/MS(WR)
Within + Residual (WR)	1533	SS(WR)	MS(WR)	

w = within

LWP is being considered as a possible covariate in the red pine growth analysis. Therefore, we must determine whether LWP is independent of ELF fields. This can be accomplished by analysis of covariance using climatic variables as covariates. We have assumed if covariates can explain these differences, LWP is independent of ELF fields. As discussed earlier, 1985 LWP data was not included in the analysis reported here. Therefore, it was necessary to re-evaluate ambient and site variables as potential covariates for years 1986-1990. Regression analysis was conducted to select variables that explained significant variation in LWP. Climatic variables selected by the regression analysis were average daily minimum air temperature, total precipitation between measurement dates, and average daily relative

humidity. Linear correlation coefficients between each of these variables and LWP are found in Table 2.23.

Table 2.23. Correlations between LWP and ambient variables selected by regression analysis.

Variable	Correlation
Average daily minimum air temperature (^{o}C)	.31*
Precipitation between measurement dates	-.25*
Average daily relative humidity	-.10*

* Significant at p=0.05

LWP was weakly but significantly correlated to each ambient variable. These variables were then used as covariates in the ANCOVA for LWP (Table 2.24).

Table 2.24. Significance levels from analysis of covariance for *LWP, 1896 - 1990.*

Factor	P-value
Site	.086
Year	.956
Site by Year	.090

No significant differences (p=0.05) remained among sites, years, or in the site by year interaction by including the selected covariates. This indicates that ELF electromagnetic fields had no detectable effect on LWP for these factors. Our work with climatic data, site data, and the EM fields will continue in the coming year to determine whether the ELF system is effecting LWP.

Red Pine Seedling Mortality - Armillaria Root Disease

Armillaria root disease mortality among the planted red pine seedlings was first noted in 1986, the third year following stand conversion. In 1990, Armillaria root disease was still the only fatal infectious disease found in the plantations. We are evaluating epidemiological factors controlling the rate of seedling mortality caused by this disease, for several reasons. First, certain Armillaria spp. are well known for their ability to kill host plants subjected to various forms of stress. Wherever clones of pathogenic Armillaria spp. are active, root disease may serve as a sensitive biological indicator of the extent to which red pine seedlings, Armillaria itself, or both, are stressed by any agent, including ELF electromagnetic fields. Second, there is excellent reason to expect that additional mortality due to this disease will occur with increasing plantation age. Adequate woody foodbases (stumps and their root systems) occur on the sites, clones of the highly pathogenic Armillaria ostoyae (NABS I, North American Biological Species I) have been identified, and documented epidemics in the Lake States have peaked after 10 years of activity (Pronos and Patton 1977). Finally, the rates of mortality on the three ELF plantations showed no signs of abatement in 1990.

The causal agent of this disease is at least one member of the Armillaria species complex (Wargo and Shaw III 1985). These fungi cause a white rot type of decay in woody debris, stumps and moribund root systems which are colonized by means of airborne spores and/or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize the next. Conifer seedlings may be colonized and killed by Armillaria spp., either through infection by rhizomorphs or by seedling root growth into contact with decaying foodbases.

Seedling vulnerability depends upon several site and biological factors. First, distribution of mortality has been related to the spacing and size of hardwood stump foodbases (Pronos and Patton 1977). Seedling vulnerability increases with proximity to infested foodbases. Second, rhizomorph growth is most efficient in well-aerated light-textured soils with low rock content (Rishbeth 1978, Singh 1981). Third, seedling vulnerability is increased by the addition of physiological stresses, such as severe drought or competition. Because ELF fields represent a possible additional source of stress, the underlying factors governing Armillaria root disease development on the three plantation plots will be evaluated, and the rate of spread of Armillaria clones in the study plantations will be estimated. In this way, the role played by ELF fields in determining rates of root disease mortality can be determined.

The evaluation of Armillaria root disease development

in the plantation plots is divided into three areas: 1) identification and mapping of clones of pathogenic (and non-pathogenic) Armillaria species occurring in each plantation plot quarter-replicate, based on cultures obtained from mortality and basidiome (mushroom) collections, 2) estimation of rates of Armillaria clone extension in each quarter-replicate, with respect to seedling and ELF field distributions, and 3) evaluation of the influences of site factors (e.g., soil rock content, foodbase distribution, seedling size, and parameters of ELF field exposure) on development of disease. The null hypotheses tested in this study are:

1. H_o: There are no differences in rates of mortality accumulation among the plantation plot quarter-replicates which cannot be explained by site factors other than parameters of ELF field exposure.

2. H_o: There is no difference in the rate of spread of Armillaria root disease in the directions of higher versus lower ELF field strengths.

3. H_o: There is no difference in size (total height) of seedlings killed by Armillaria spp. versus those randomly selected healthy seedlings on which estimates of plantation seedling growth are based.

4. H_o: There is no difference between ELF field strengths experienced by seedlings killed by Armillaria spp. versus the healthy seedlings on which estimates of plantation seedling growth are based.

Sampling and Data Collection

Armillaria root disease mortality has been monitored closely since it first began to develop during the 1986 field season. The position of each seedling killed by Armillaria root disease has been marked in the field and mapped for permanent reference. As soon as seedlings develop the gray-green foliage color symptomatic of fatal decline, they are checked for the presence of characteristic mycelial fans under the bark at the root collar. Infected seedlings are then returned to the laboratory for cultural isolation of the pathogen onto potato dextrose agar in Petri dishes. Armillaria isolates are maintained indefinitely for reference.

Because of the primary importance of stumps and their associated root systems as foodbases for Armillaria, it was necessary to quantify the stump populations on the ELF plantations in order to explain the distribution of root disease on red pine seedlings. Each plantation plot was therefore represented as 12 quarter-replicates for purposes of mapping and analysis. In 1987, the location of each

stump or dead seedling was mapped on a Cartesian coordinate system using right angle prisms.

Because seedling distribution in the 3 plantations is somewhat uneven, it is necessary to map the live seedling populations in order to properly calculate percent mortality for each quarter-replicate. Seedlings are being mapped by compass and chain from nearby previously mapped stumps and mortality seedlings. Maps of live seedlings will also serve as the basis for calculating Armillaria spread rates. It is important to know the positions of potential root disease targets for spread rate calculations.

Multiple regression analysis is being used to identify factors which help to explain differences in Armillaria root disease mortality across space and time. Regression models are being derived, which relate seedling mortality percent on the quarter-replicates to characteristics of foodbase, host, site, and ambient conditions. The overall significance of each tested model is evaluated using the F test for the associated analysis of variance, and the contributions of individual independent variables in each model are evaluated using the corresponding t statistic. The predictive capability of each model is indicated by its associated r^2 value. Differences among years will be evaluated by incorporating a set of classification (dummy) variables (Searle, 1971) into the regression model. This produces a model identical in structure to the analysis of covariance model. The interpretation can be quite different because we are concerned with both the classification and continuous (analogous to covariates) variables, while the classical analysis of covariance model uses the covariates only to produce more homogeneous experimental material, thereby to reduce error.

Calculation of disease spread rates requires knowledge of the distributions of the individual vegetative colonies (called clones) of Armillaria spp., which are spreading within each plantation. Clones spread by growing along hardwood root systems, and extend themselves from one foodbase to the next in the form of cord-like rhizomorphs. Armillaria clones overlap one another commonly in the ELF plantations, making knowledge of their limits essential to the calculation of spread rates.

Sorting the Armillaria isolates obtained from 1) dying seedlings and 2) associated decaying foodbases into clones (and these clones into species) is necessary, in order to explain the distribution of mortality on the plots. Identification of clones to species is imperative in light of differences in rate of root disease development among the 12 quarter-replicates comprising each plantation plot. Armillaria spp. differ in pathogenicity to conifers and hardwoods (Korhonen 1978, Rishbeth 1985) to such an extent that differences in root disease observed among the plantation plots might be explained if the quarter-replicates are dominated by different Armillaria

spp. For example, Rishbeth (1985) found that the host ranges of A. mellea isolates were more likely to encompass hardwoods as well as conifers than were the host ranges of A. ostoyae isolates. Though both species are considered to be highly pathogenic toward pines, Rishbeth found that his isolates of A. mellea were slightly more virulent toward Scots pine than were his isolates of A. ostoyae. Also, it has been reported that A. bulbosa (common at the control site) can stimulate rhizomorph production by A. ostoyae when both species co-inhabit a foodbase (Mohammed and Guillaumin 1989). We intend to test this hypothesis independently, using isolates from the ELF study sites. Nevertheless, we have yet to find evidence from the field of more than one Armillaria clone (of the same or different species) occupying a single foodbase.

Clones are distinguished in the laboratory through cultural confrontations (on 3% malt extract agar in Petri dishes) of isolates derived from dead seedlings, decaying stumps, or Armillaria basidiomes. Isolates from the same clone grow together and intermingle freely, whereas isolates representing different clones form lines of demarcation where they grow into contact with one another (Kile 1986, Korhonen 1978, Mallett and Hiratsuka 1986, Siepmann 1985).

Armillaria clones may be identified to North American Biological Species (Anderson and Ullrich 1978) in the laboratory, by matings (on 1.5% malt extract agar in Petri dishes) of single-basidiospore tester strains (of known species identity) with representatives of each clone (Siepmann 1987). The normally fluffy white tester strains begin to grow dark and crusty when confronted with compatible isolates of the same species. More reliably, reference tester strains should be confronted in culture with haploid tester strains representing clones from the field (Anderson and Ullrich 1978). The latter can be derived either as single spore isolates from basidiomes collected in the field or from basidiomes obtained by fruiting diploid isolates in the laboratory on autoclaved orange sections. Basidiospore collections can be frozen in water for single-sporing at a later date. Success at fruiting Armillaria clones in the laboratory has been poor so far; only 1 out of 12 clones has fruited in culture so far. This appears to be a typical success rate (J.B. Anderson, personal communication).

In December 1990, aspen bait stakes (Mallett and Hiratsuka 1987) were placed at 1m intervals in one transect across each of the 3 study plantations. At the antenna and control sites, these transects continue across the buffer strip and through the hardwood study plots. Scheduled for sampling late in 1991, these bait stakes will provide Armillaria isolates which will serve as a check against clone maps based solely on seedling and basidiome isolates. It is also likely that fruiting will take place on some of these stakes, providing useful single-basidiospore isolates.

We also hope to learn the extent to which the conifer pathogen A. ostoyae also occurs in the hardwood stands as well as in the plantations. This information will help us to determine the origin of the present epidemics. We have obtained some evidence suggesting that A. ostoyae has entered the control site plantation since its creation (Smith et al. 1990).

Total heights of seedlings killed by Armillaria have been measured since early 1988. Total heights are also available on an annual basis for the seedlings selected for repeated measurement over the duration of the study. The t-statistic will be used to compare heights of seedlings killed by Armillaria each year with corresponding heights of permanent measurement seedlings on each quarter-replicate.

Longitudinal, transverse, and magnetic 76 Hz field strengths and exposures have been estimated for the locations of each seedling killed by Armillaria, and for each of the healthy seedlings reserved for repeated measurement, for each year from which 76 Hz field data are available. The t-statistic will be utilized here, in order to determine whether 76 Hz field strengths and/or durations affect seedling vulnerability to Armillaria root disease, on an annual basis for each quarter-replicate.

Progress

Monitoring Armillaria Root Disease

Table 2.25 presents mortality data for 1986 through 1990 on the 36 plantation plot quarter-replicates. Mortality for each year is expressed as the number of seedlings killed. Once the seedlings on all three plantations have been mapped, these data will be expressed as the percentage killed of the number of seedlings alive at the beginning of each year. So far, the seedling population in the antenna plantation has been completely mapped, and mapping of the control plantation is nearly complete.

Since root disease mortality was first noted in 1986, the only other cause of seedling loss has been the routine collection of seedlings for PMS and growth analysis. Striking differences in Armillaria mortality among plots and plot quarter-replicates are apparent. Statistical analyses concerning these differences are being deferred until percent mortality can be properly calculated. Numbers of seedlings killed are somewhat misleading, because seedling numbers within quarter-replicates varies widely. In general, mortality increased between 1986 and 1987 (especially in quarter-replicates 25 - 33 of the Control site), and again between 1987 and 1988 (most notably in quarter-replicates 21 - 24 of the Antenna site). In 1989, mortality declined slightly on about two-thirds of the quarter-replicates, probably due to the cool, moist spring experienced in 1989. Mortality picked up again in 1990,

Table 2.25 Red pine seedling mortality due to Armillaria root disease on each of the 36 plantation plot quarter-replicates, from 1986 through 1990, presented as the number of seedlings killed each year.

Plot	Qtr Rep.	Year 1986	1987	1988	1989	1990	Total
Ground	1	0	1	3	2	2	8
	2	0	1	1	1	1	4
	3	0	2	2	1	3	8
	4	0	0	1	2	2	5
	5	0	2	4	0	1	7
	6	0	0	3	2	2	7
	7	0	5	3	5	3	16
	8	1	2	6	3	6	18
	9	0	11	12	6	2	31
	10	1	6	9	4	1	21
	11	0	1	0	0	2	3
	12	0	1	0	3	0	4
Antenna	13	2	4	5	4	1	16
	14	1	2	7	3	3	16
	15	3	1	4	1	1	10
	16	2	1	9	0	1	13
	17	0	1	0	4	1	6
	18	0	3	6	3	2	14
	19	0	0	1	9	1	11
	20	2	5	6	13	4	30
	21	0	3	10	4	3	20
	22	0	3	24	13	11	51
	23	0	5	10	11	5	31
	24	1	14	18	9	7	49
Control	25	5	15	16	11	16	63
	26	2	11	9	10	9	41
	27	0	6	17	7	13	43
	28	2	12	17	5	12	48
	29	0	8	7	10	12	37
	30	0	19	12	9	11	51
	31	3	11	5	10	16	45
	32	3	13	12	10	11	49
	33	1	10	11	10	12	44
	34	1	1	12	8	12	34
	35	1	4	6	4	11	26
	36	0	3	5	8	15	31

especially at the control site.

Figure 2.18 is a map of quarter-replicate 24 (antenna plantation), depicting the locations of live seedlings and the historical locations of destructively sampled seedlings and seedlings killed by Armillaria root disease. Figure 2.19 presents only the locations of seedlings killed by Armillaria. Figure 2.20 portrays the distribution of hardwood stumps in the same quarter-replicate. Unfortunately, stump size is not indicated. Knowledge of the proximity of live seedlings to those killed by root disease will help greatly in making reasonable calculations of disease spread rate. It is evident from Figure 2.19 that identification of archived isolates to clone must be a high priority in 1991, because clones overlap in the field and spread rate should be determined on an individual clone basis.

Some of the Armillaria clones active in the study plantations are not associated with red pine mortality. All of these clones which have been identified belong to the species A. bulbosa (NABS VII). On the other hand, all identified clones which have killed seedlings belong to the species A. ostoyae (NABS I). NABS VII is recognized to be a common saprobic species in northern hardwood stands, whereas NABS I is a widely distributed species, well known as an aggressive parasite of northern conifers. Other Armillaria spp. may be represented in the antenna site and ground site plantations. Another high priority for 1991 is the identification of Armillaria clones to species.

A systematic approach to regression model development is being taken. The relative importance of numbers of stumps vs. basal area as predictors of Armillaria root disease, by stump species and overall, on each plantation plot and overall, is being evaluated. Stump species may be presumed to differ qualitatively in their ability to support the activity of Armillaria spp., and aspen, birch, maple, oak and pine stumps occur in various mixtures on the 36 quarter-replicates. Numbers and basal areas of stumps by species have been further categorized as sprouting or non-sprouting, in all three plantations in 1988. Sprouting will be evaluated again early in 1991, in all three plantations. Categorization of stumps as either sprouting or non-sprouting may be useful, because it seems likely that non-sprouting stumps support greater Armillaria activity.

Birch stump distribution was the most useful single variable tested in 1987, for predicting red pine seedling mortality (Bruhn et al. 1989). The explanation for this focused on the relative sprouting vigor of the hardwood species involved. Birch root systems might be expected to decline more quickly following clearcutting than those of aspen, maple and oak, which are more vigorous sprouters than birch. As the most rapidly declining stumps on the plantation plots, birch stumps would represent the majority of the available foodbases for Armillaria at the time. We

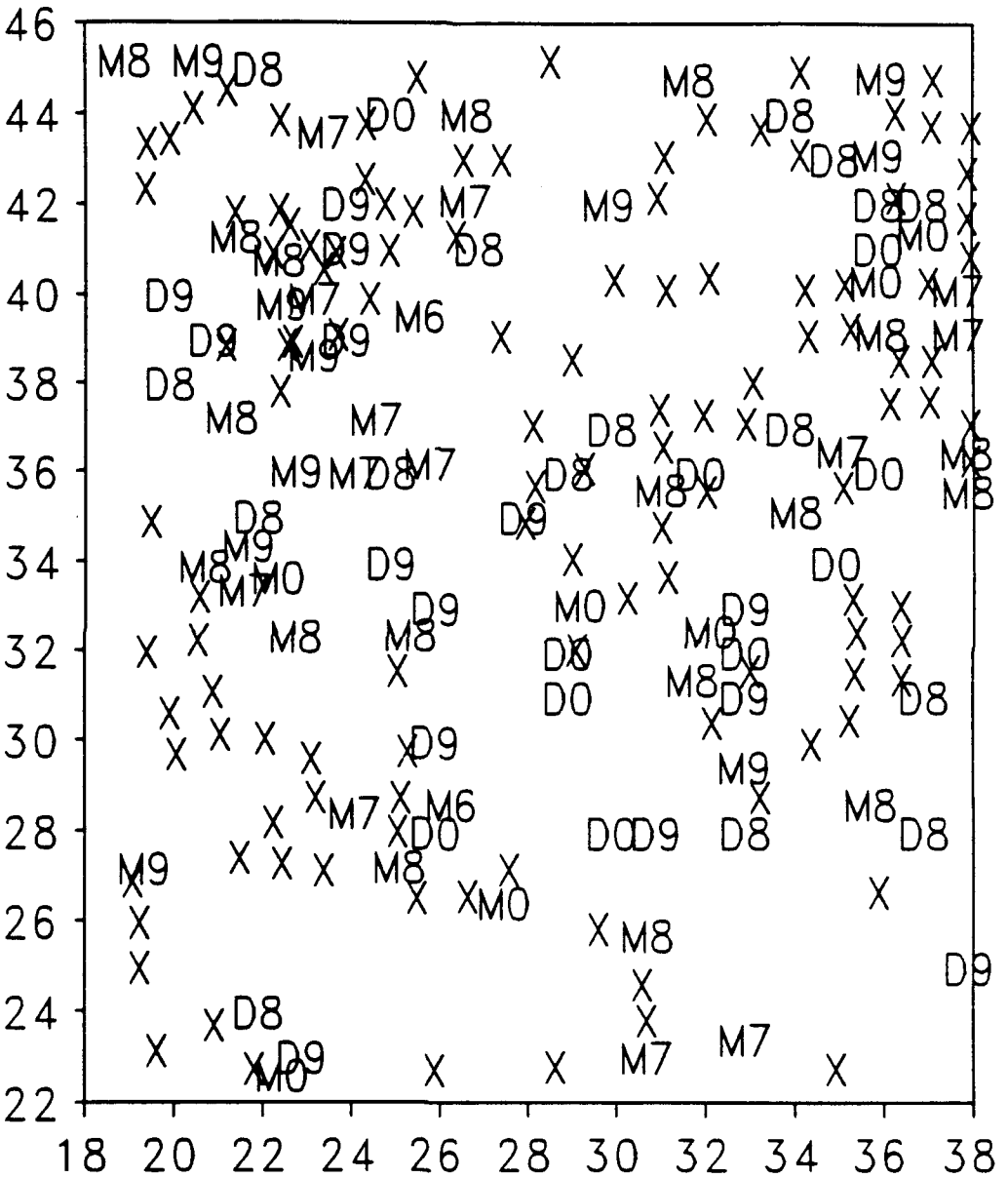


Figure 2.18. Historical map of seedlings on quarter-replicate 24 (antenna site). Legend: X, seedling alive November 1990; D#, seedling destructively sampled for PMS/mycorrhizae studies (# is the last digit of year sampled); M#, seedlings killed by Armillaria root disease (# is the last digit of the year killed).

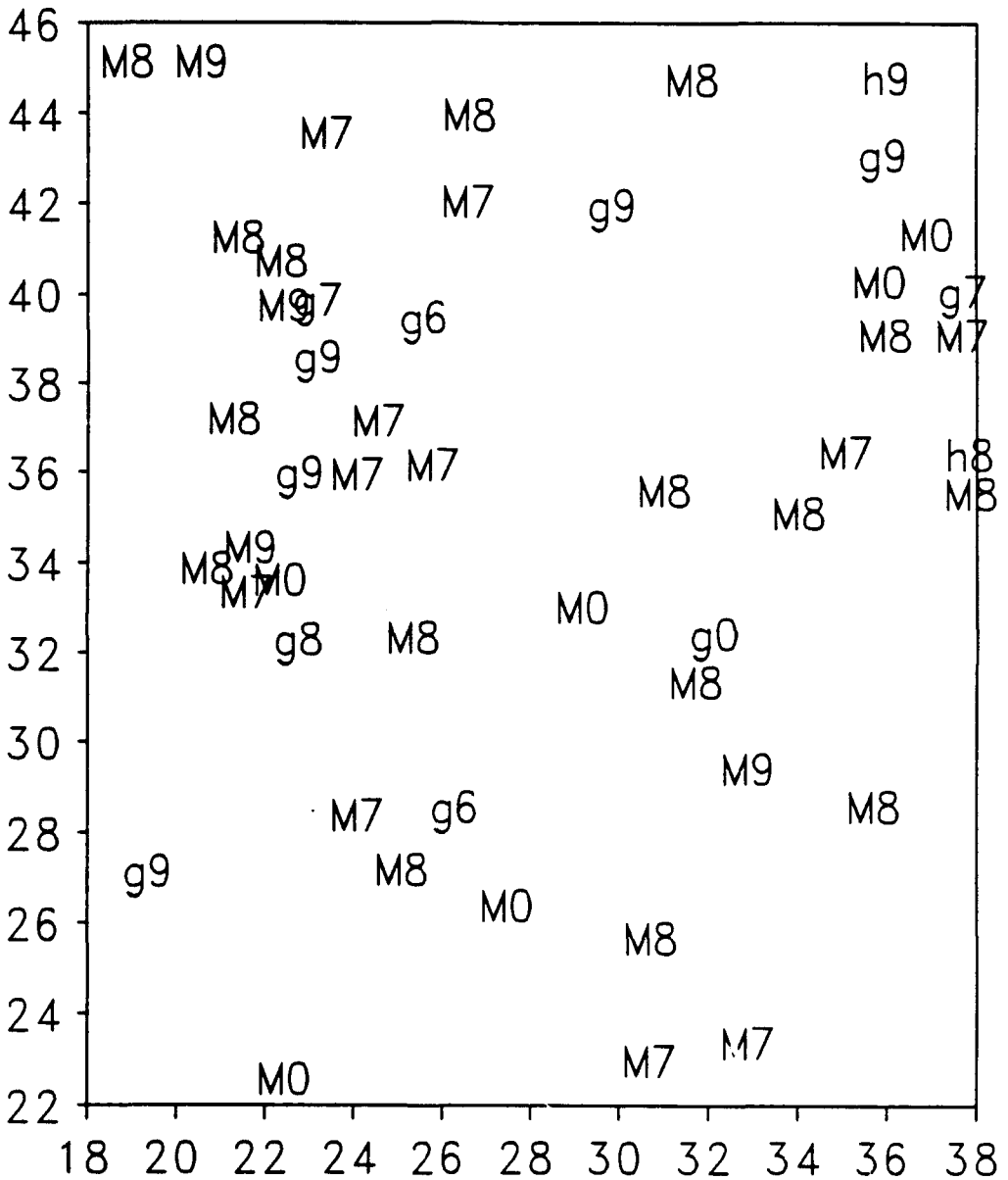


Figure 2.19. Historical map of seedlings killed by Armillaria root disease on quarter-replicate 24 (antenna plantation). Isolates designated M# (# is the last digit of year killed) have yet to be identified to clone; isolates designated by the same lower-case letter belong to the same Armillaria clone (# is the last digit of the year killed).

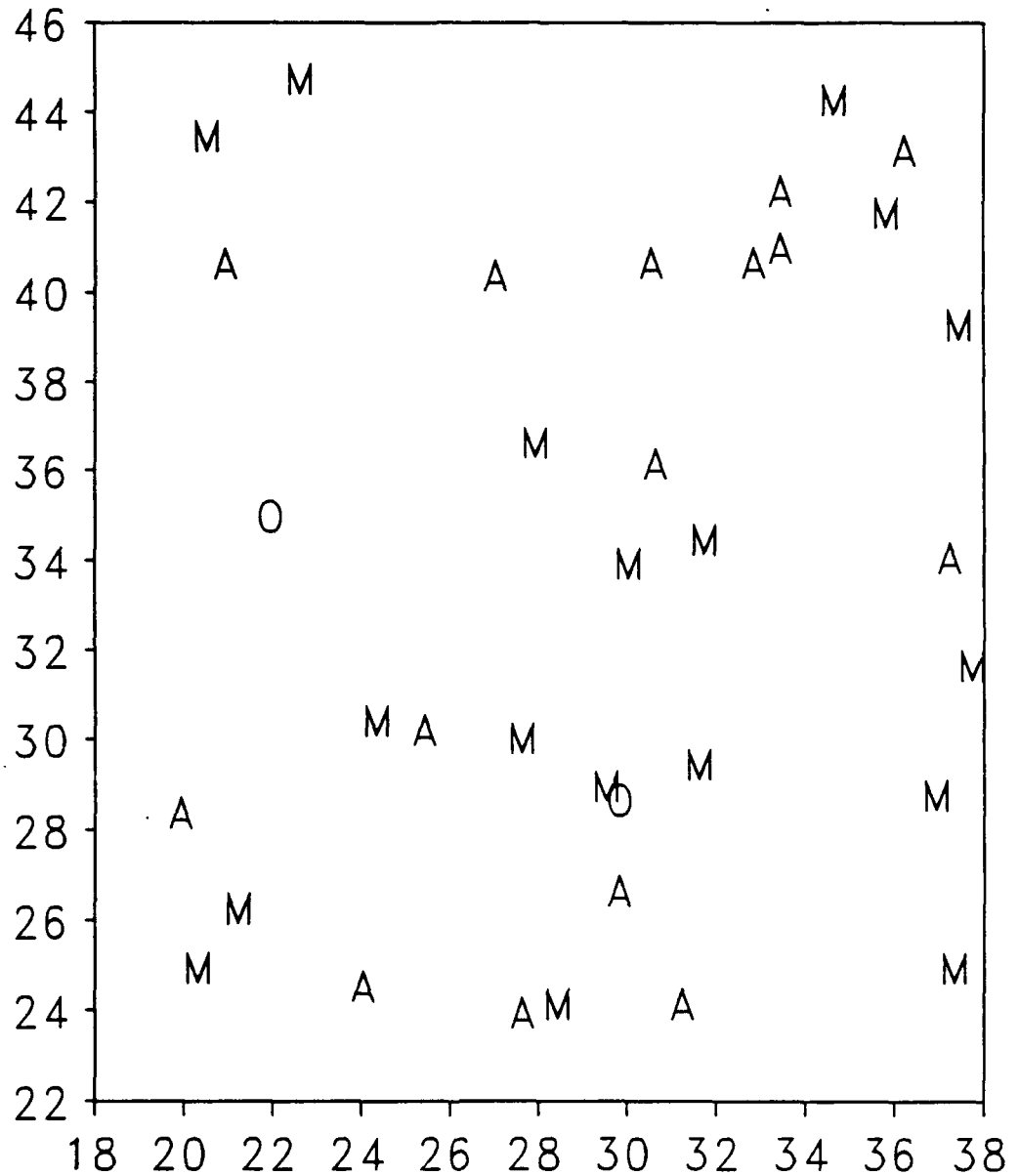


Figure 2.20. Map of stump population on quarter-replicate 24 (antenna plantation). Stumps are designated by the first letter of their generic common name (A = aspen, B = birch, M = maple, O = oak, P = pine).

expected the relationship between mortality level and birch stump distribution to change in the future, as other species of stumps have declined to the point of becoming important Armillaria foodbases.

Other independent variables to be included in the analysis are 1) percent rock content by volume, for three strata (0-10 cm, 10-30 cm, and 30-50 cm), with a single sample value representing each plot replicate (four quarter-replicates), 2) bulk density of the soil fraction <2 mm, for the same three strata and samples, 3) mean seedling height at the end of each year on each quarter-replicate, for surviving "permanent" measurement seedlings, and 4) mean seedling terminal bud length at the end of each year on each quarter-replicate, for the same seedling sample. Analysis will be conducted in 1991, as soon as accurate seedling counts are available for proper calculation of percent mortality.

ELEMENT 3: PHENOPHASE DESCRIPTION AND DOCUMENTATION

Starflower, Trientalis borealis Raf., is an important herbaceous species in a Northern Hardwood ecosystem. It is also an important species on both the control site and the ELF antenna site. Phenophases of starflower have been well documented by Anderson and Loucks (1973) in northern Wisconsin by Helenurm and Barrett (1987) in Canada. Phenological events, such as timing of stem elongation, bud break, leaf expansion, flowering, fruiting and leaf senescence have been used to monitor and assess a plant's response to climatic and edaphic factors. 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 changes in climatic and edaphic factors. This information can then be used to assess the overall vigor of a plant in response to "major" perturbations. Because there is some information on the phenophases of starflower and on its morphological characteristics and because we consider starflower to be a sensitive species to stand disturbances, we have chosen it to be an indicator of ecosystem responses to extremely low frequency (ELF) fields.

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 null hypothesis to be tested each year is: H_0: 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: H_0: 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 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 among years and sites and site by year interactions.

Sampling and Data Collection

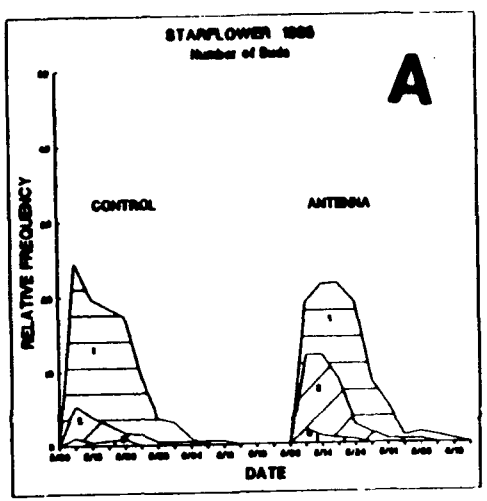
During the 1990 field season, data were collected at the antenna and control sites between April 26 and August 25. Each site was sampled twice a week from April 26 until June 22 to delineate flowering periods and leaf expansion with greater precision. After full leaf expansion and flower development, each site was sampled once a week until August 25. Parameters measured per plant for each observation period included stem length, length and width of the largest leaf, number of leaves, number of buds, number of flowers, number of fruit, number of yellow leaves (leaves senescing), and number of brown leaves. To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained for each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 m^2 subplots. Individual plants within each subplot were then numbered and tagged until a normal distribution of mean stem length was attained. Stem length was used as the response variable for this determination because it is a prime indicator of a herbaceous plant's potential sexual productivity. A normal distribution of stem length insures 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, 1987, 1988, 1989, and 1990 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.

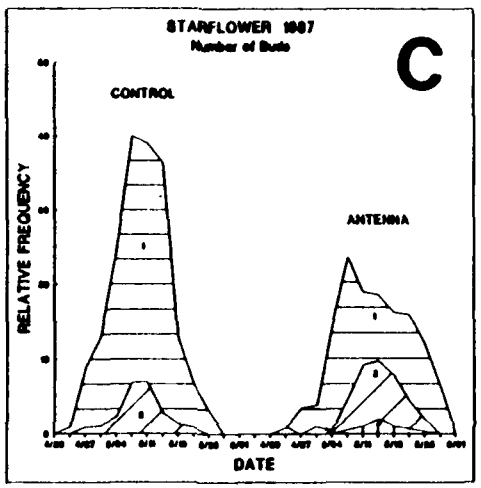
Progress

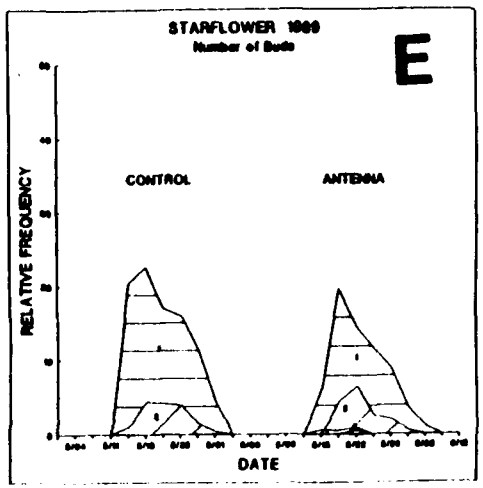
Phenological characteristics

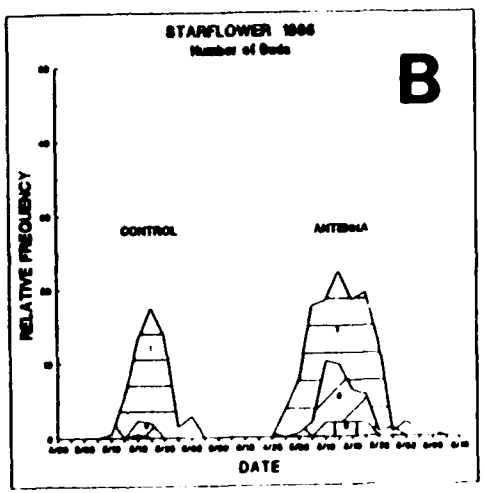
In 1990, stem expansion on the antenna site began one week earlier than stem expansion on the control site, while leaf expansion occurred at similar times on both sites. Bud formation on the control site began at the same time (April 26) as bud formation on the antenna site (Figure 3.1F). Flowering on the antenna site began 14 days earlier (May 3) than flowering on the control site (May 21) (Figure 3.2F). As with bud formation, fruiting occurred at the same time on the

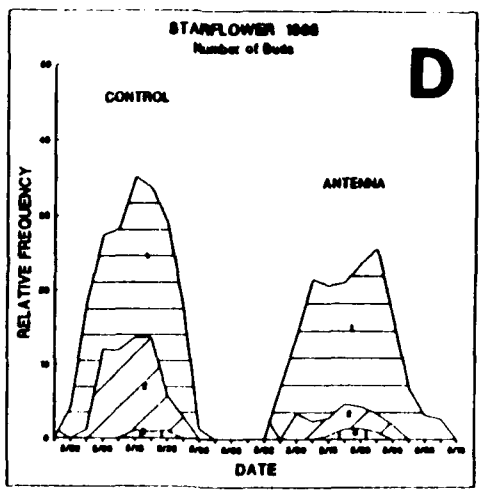
Figure 3.1: Relative frequency for number of plants with one or more buds by sampling date on the control and the antenna sites for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), and 1990 (F).











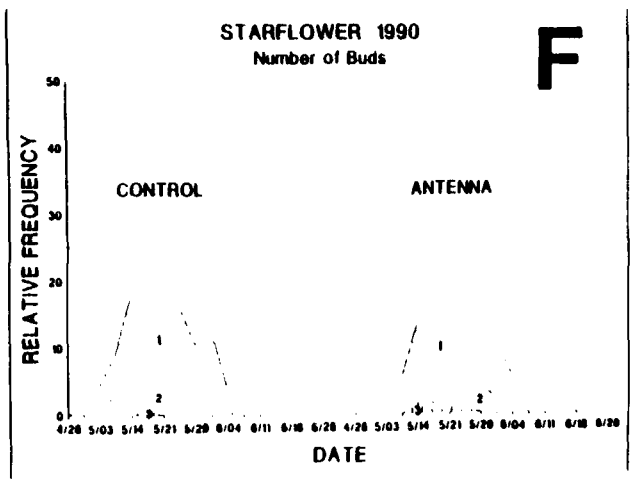
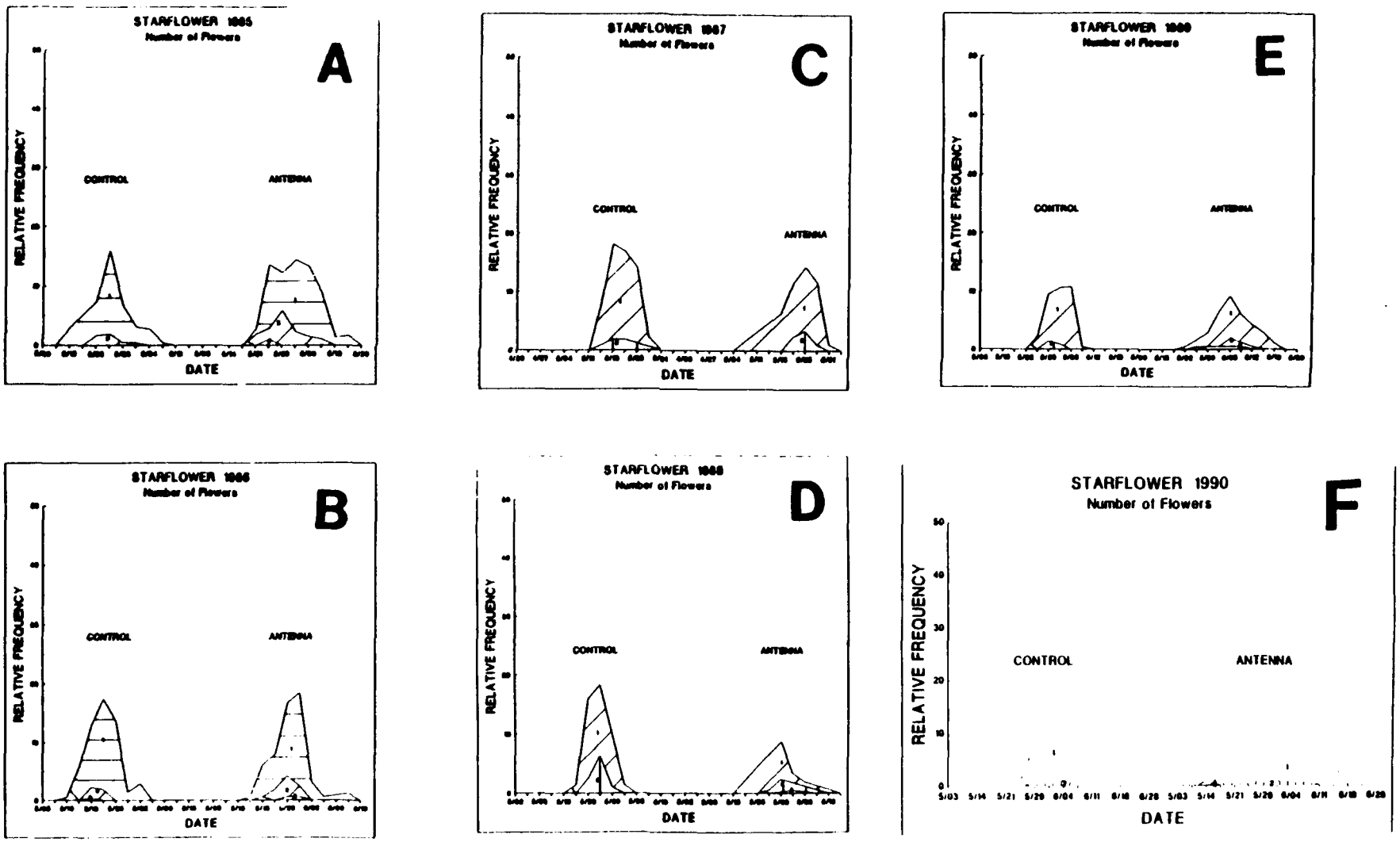


Figure 3.2: Relative frequency for number of plants with one or more flowers by sampling date on the antenna site and the control site for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), and 1990 (F).

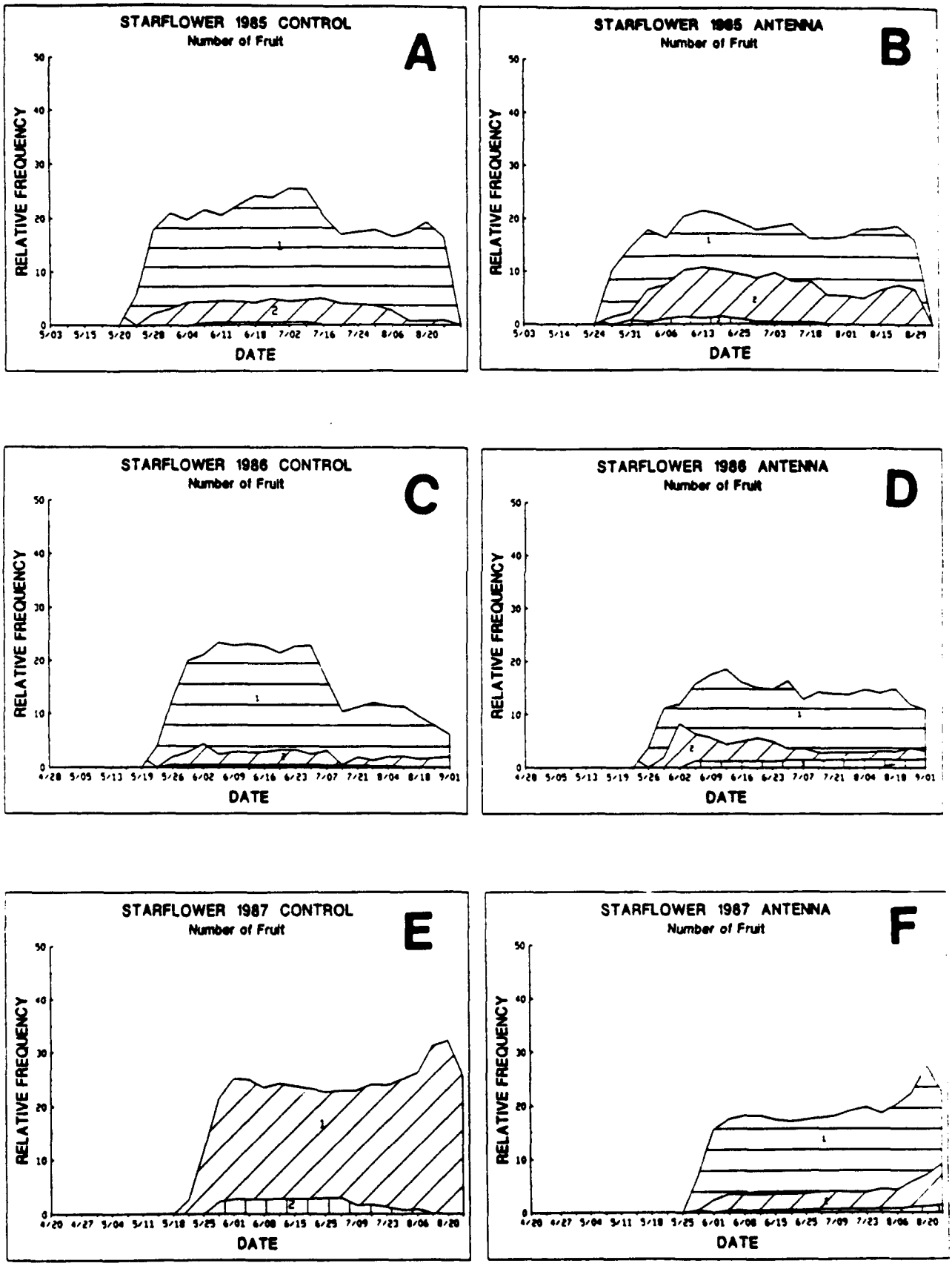


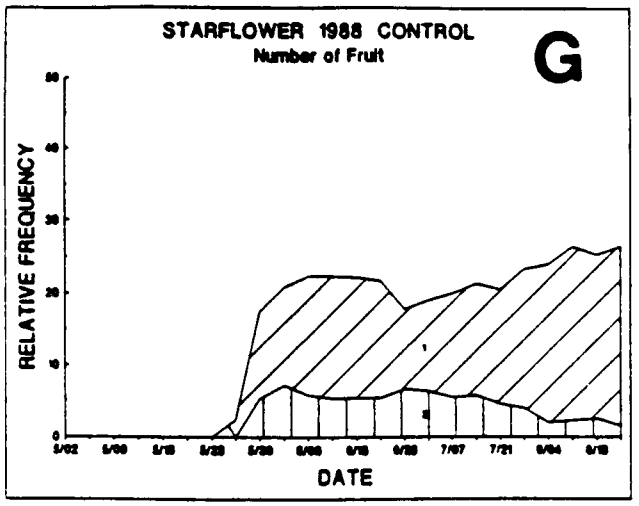
control site as fruiting on the antenna site (Figures 3.3K and 3.3L). Leaf senescence (yellowing leaves) began earlier on the antenna site (June 4) compared with the control site (June 7) (Figures 3.4K and 3.4L) while the occurrence of dead leaves (brown leaves) began at the same time (June 7) on both sites (Figures 3.5K and 3.5L). Similar relationships occurred in the 1989, 1988, 1987, 1986, or 1985 growing seasons indicating that the ELF fields present during the 1990 growing season had no distinguishable effect on the timing of starflower's phenological events.

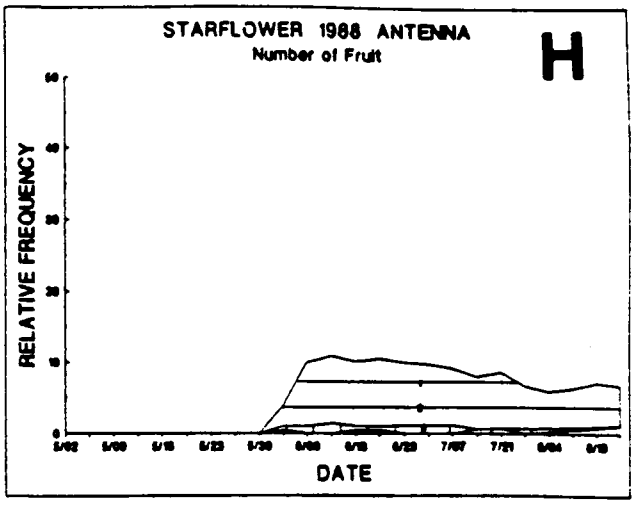
In the past 5 years, flowering and fruiting on both sites began when the previous event was at its maximum except for flowering on the antenna site (Figure 3.6A-3.6J). However this year, flowering and fruiting on the antenna site seemed to be quite different from previous years. The initiation of flowers and fruits began before the peak in number of plants with buds and number of plants with flowers. The proportion of plants flowering was significantly lower on the control site (<12%) than in years 1988, 1987, 1986, and 1985 (>20%) indicating that there is some phenological and morphological change occurring on this site. This change may be due to climate, handling, or to interactions among these factors. Significant differences in the number of plants flowering were not detected. Reasons for this are unclear since the amount of plants flowering was not different from last year. 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.

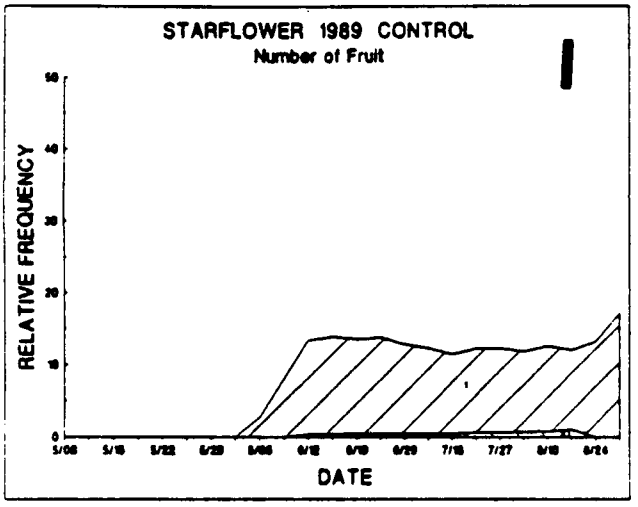
Analysis of covariance (ANCOVA) was used to determine if climatic and microsite characteristics could be used to explain differences in stem expansion (cm/time period), leaf expansion (cm/time period), and leaf area expansion (cm^2/time period) between sites (antenna vs control), years, and site by years (Table 3.2). The same ANCOVA was used in 1990 as in 1989,1988, and 1987. Error terms (1 and 2) for this year included sampling period (P) as in 1989 and 1987. Because of the evident subplot variation along the sampling transect, additional information on the basal area and canopy coverage associated with each subplot was taken in 1989. Basal area by major tree species and total basal area were measured 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 analysis.

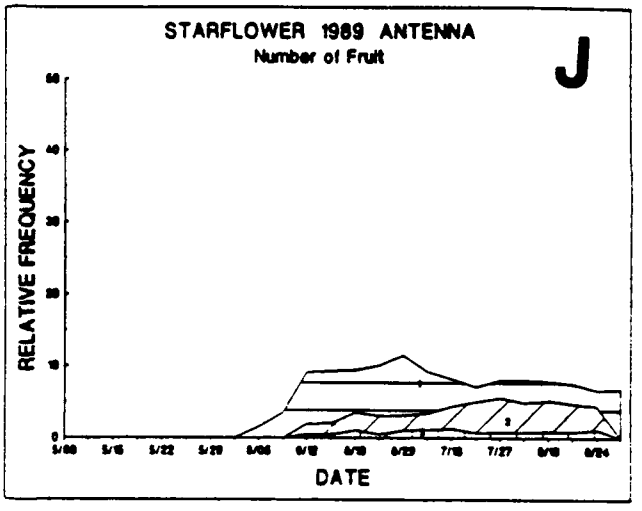
Figure 3.3: Relative frequency for number of plants with one or more fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I) and 1990 (K) (and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), and 1989 (J) and 1990 (L).

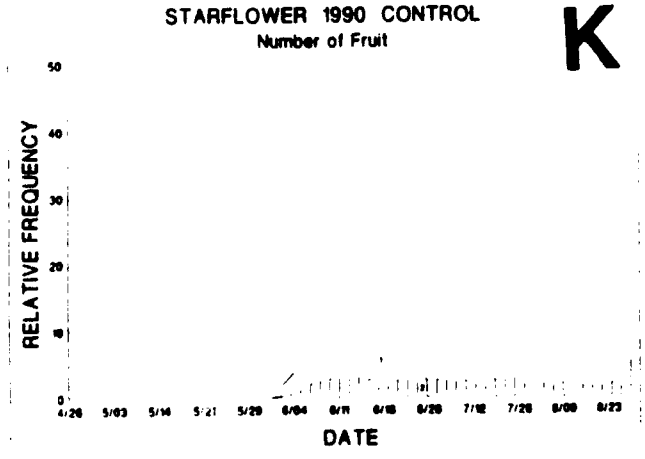



STARFLOWER 1988 CONTROL
Number of Fruit
G
RELATIVE FREQUENCY
DATE


STARFLOWER 1988 ANTENNA
Number of Fruit
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
Number of Fruit
I
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 ANTENNA
Number of Fruit
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
Number of Fruit
K
RELATIVE FREQUENCY
DATE

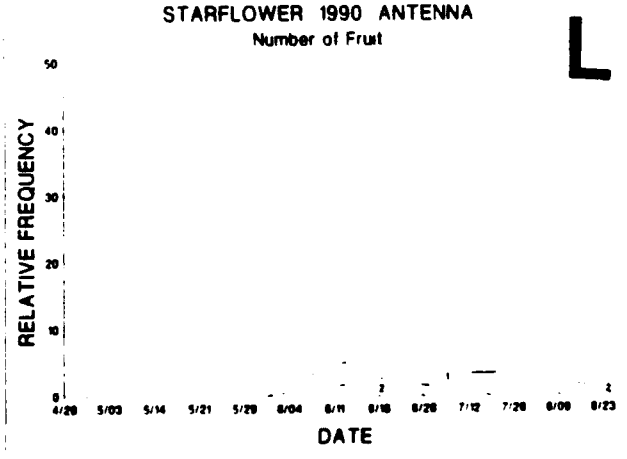
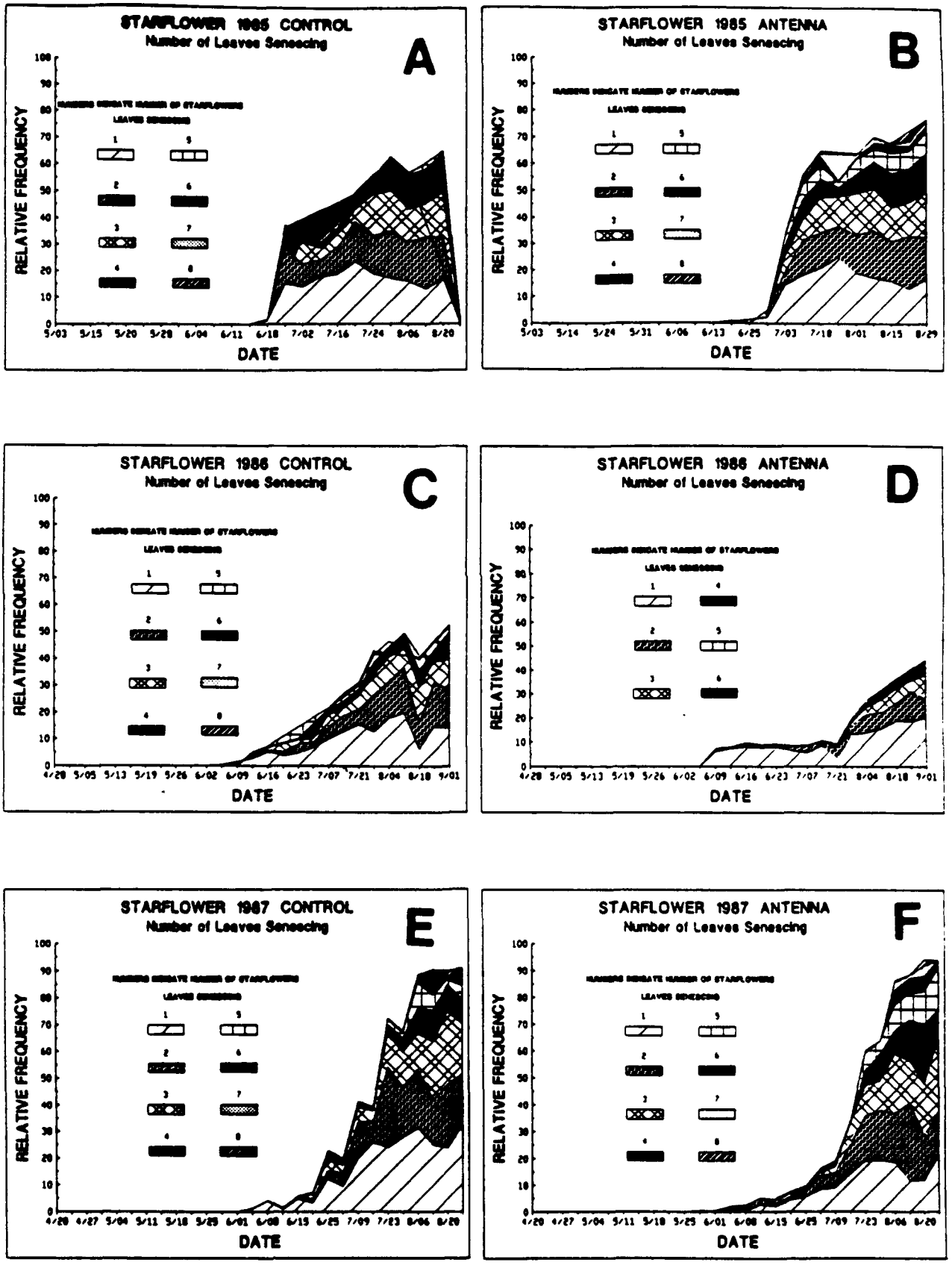
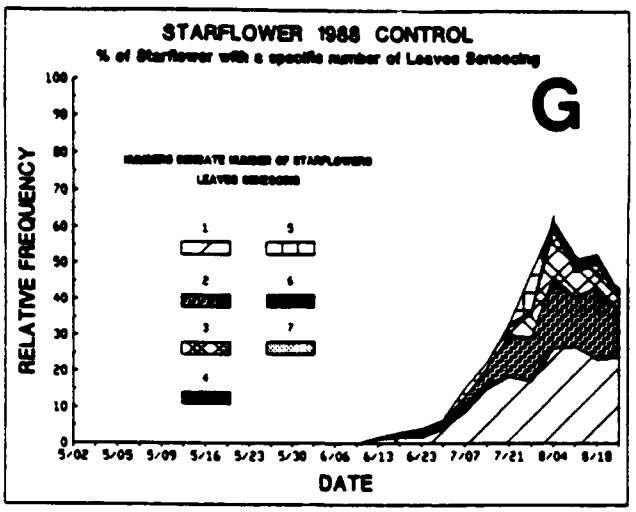
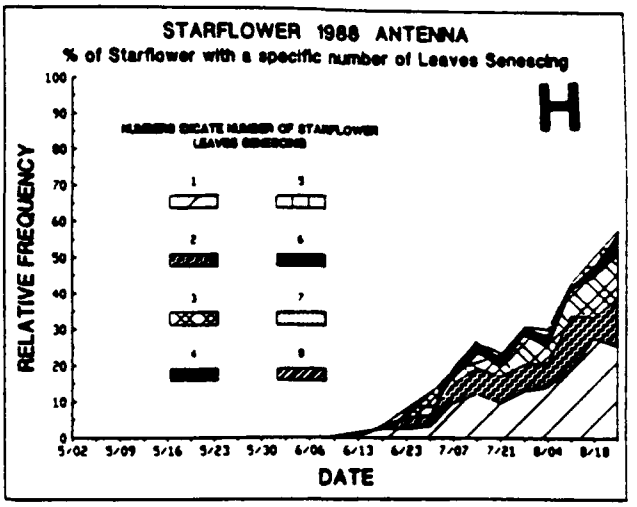
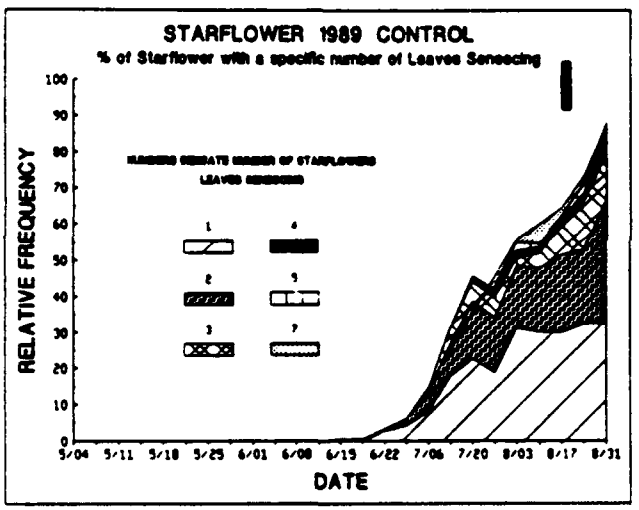

STARFLOWER 1990 ANTENNA
Number of Fruit
L
RELATIVE FREQUENCY
DATE

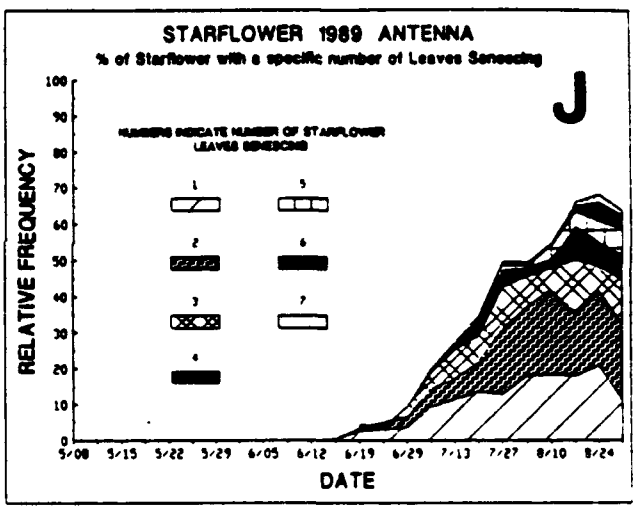
Figure 3.4: Relative frequency for number of plants with one or more leaves senescing by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), and 1990 (K) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), and 1990 (L)

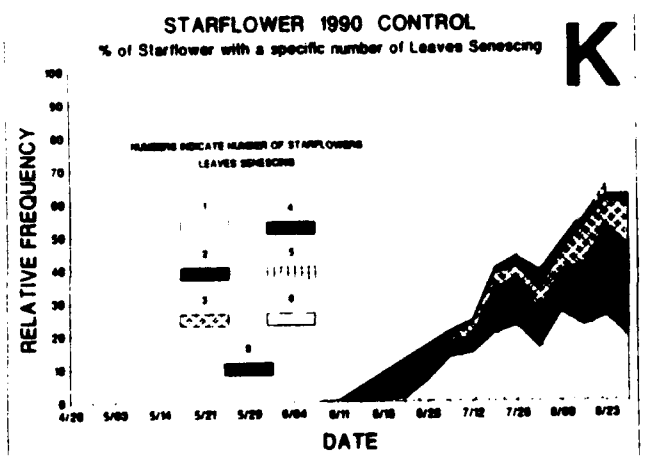



STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Leaves Senescing
G
RELATIVE FREQUENCY
DATE


STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Leaves Senescing
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Leaves Senescing
I
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Leaves Senescing
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
% of Starflower with a specific number of Leaves Senescing
K
RELATIVE FREQUENCY
DATE

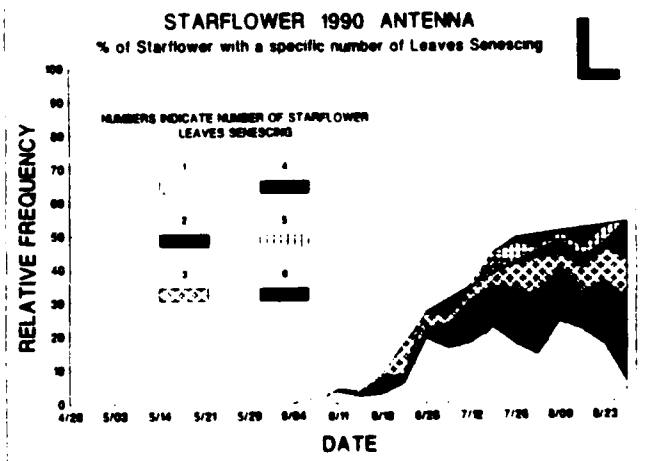
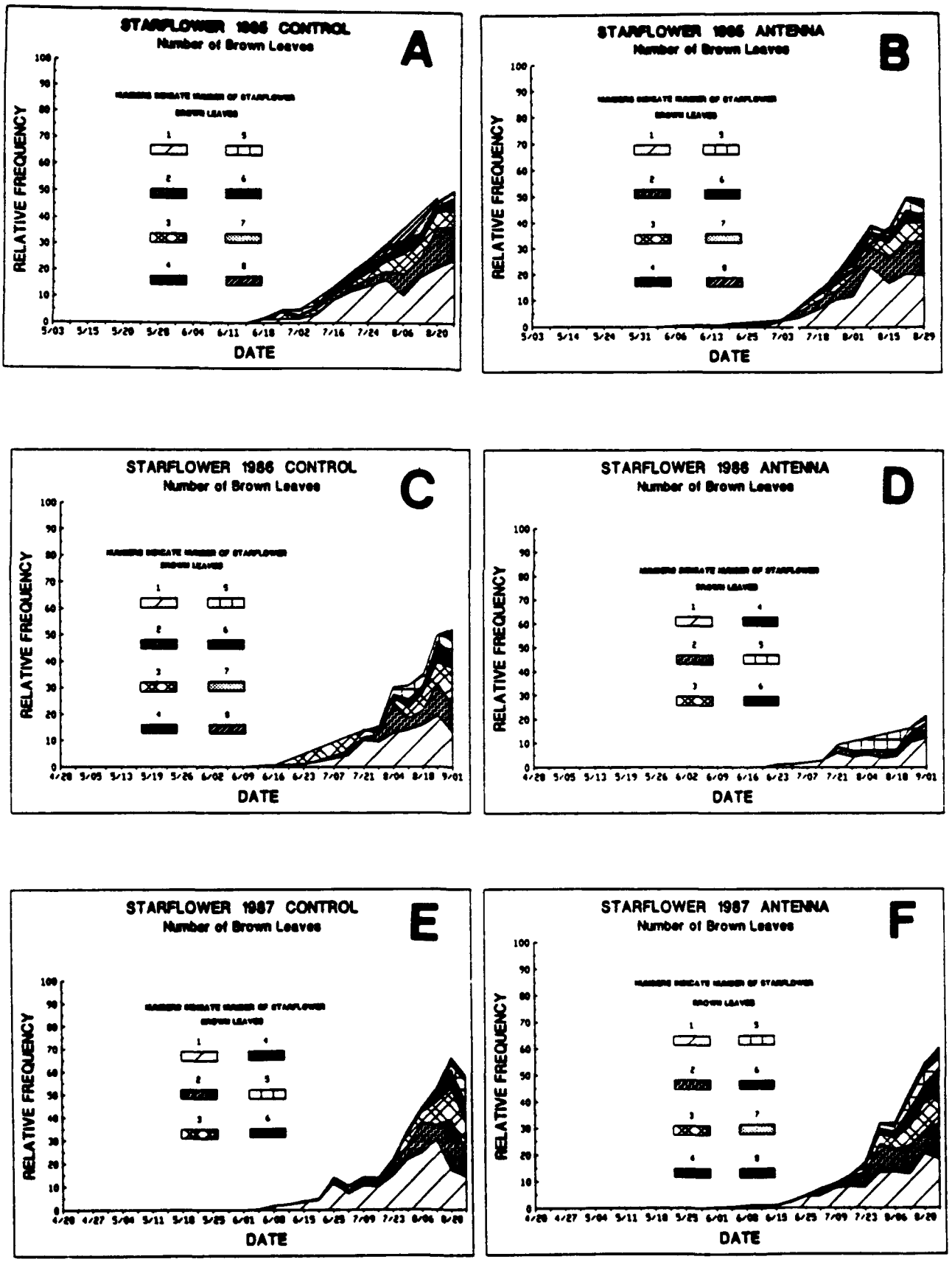
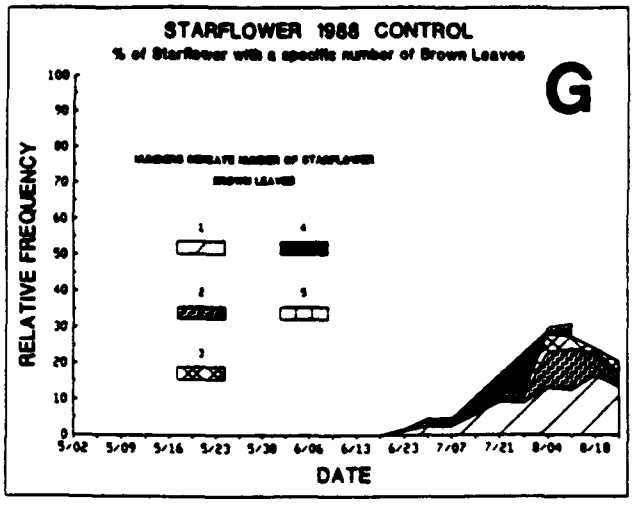
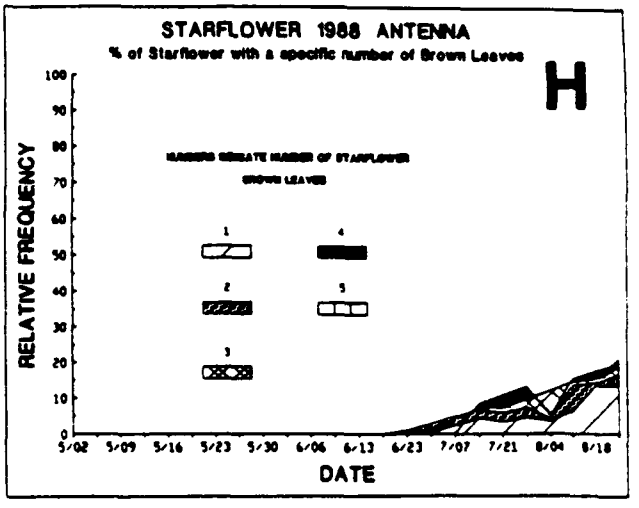
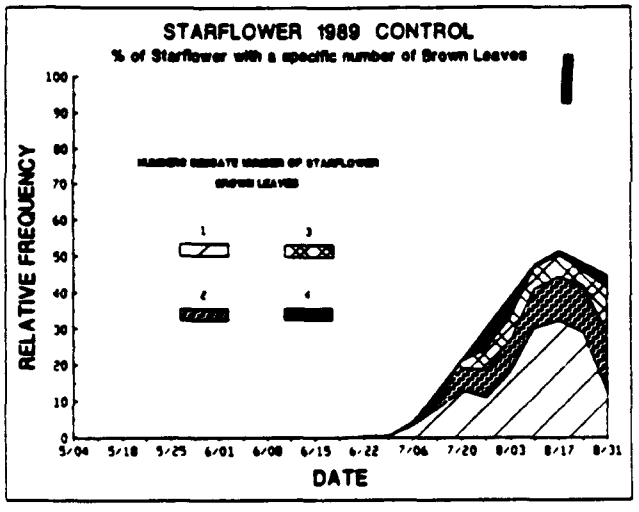

STARFLOWER 1990 ANTENNA
% of Starflower with a specific number of Leaves Senescing
L
RELATIVE FREQUENCY
DATE

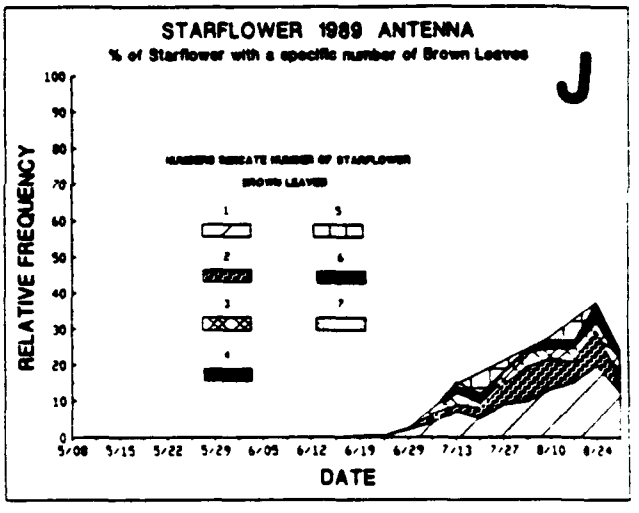
Figure 3.5: Relative frequency for number of plants with one or more brown leaves by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J).and 1990 (L)

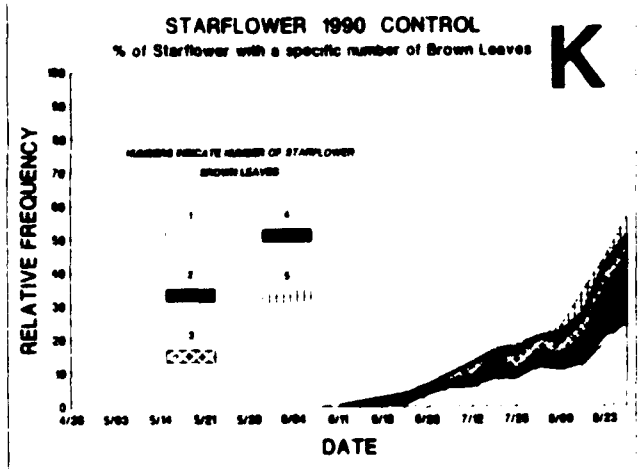



STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Brown Leaves
G
RELATIVE FREQUENCY
DATE


STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Brown Leaves
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Brown Leaves
I
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Brown Leaves
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
% of Starflower with a specific number of Brown Leaves
K
RELATIVE FREQUENCY
DATE

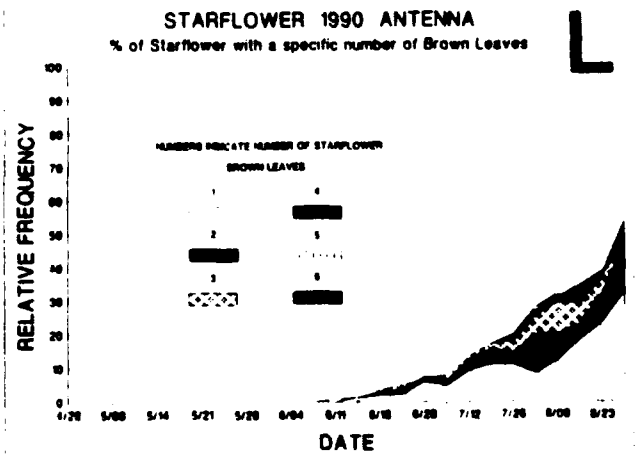
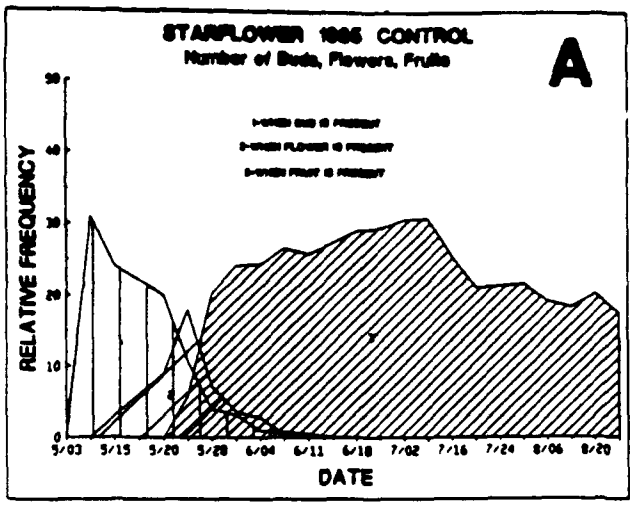
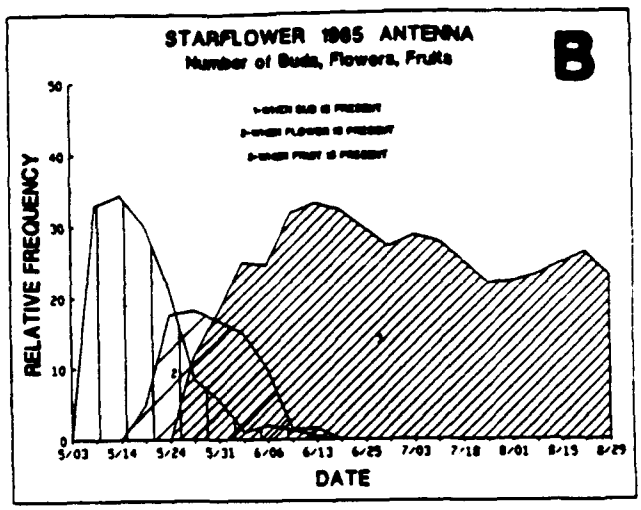
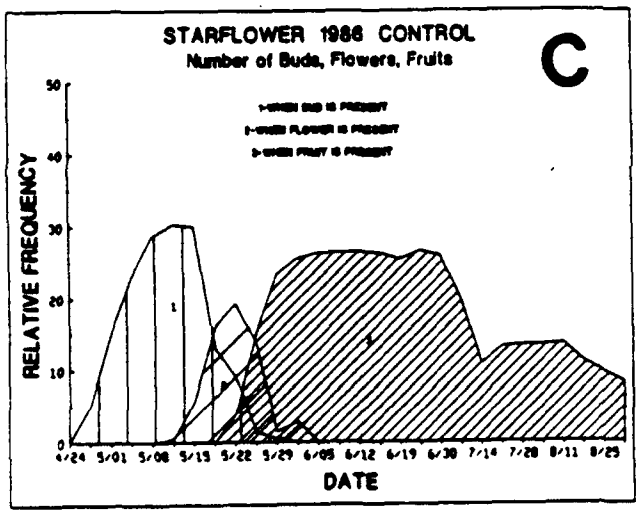
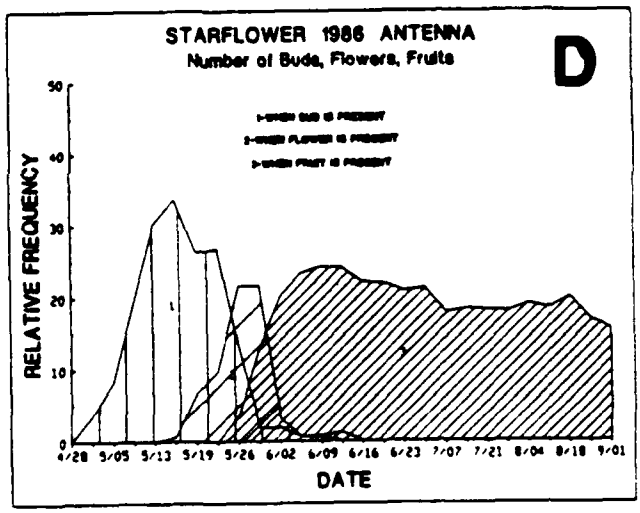

STARFLOWER 1990 ANTENNA
% of Starflower with a specific number of Brown Leaves
L
RELATIVE FREQUENCY
DATE

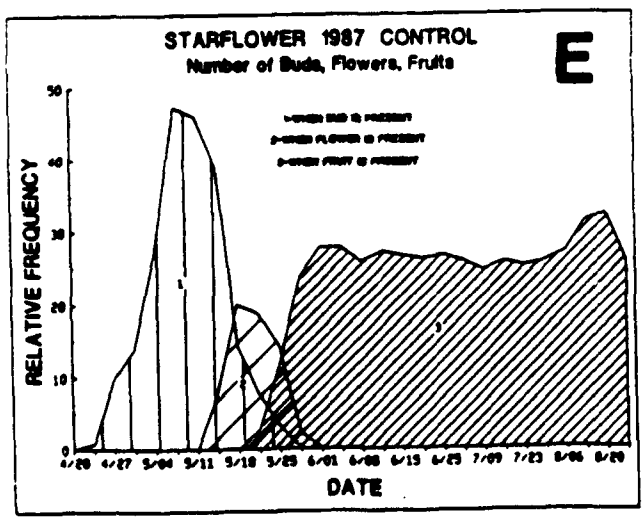
Figure 3.6: Comparison of the relative frequency and proportion of plants with one or more buds, flowers, and fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), and 1990 (K) and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), and 1990 (L).

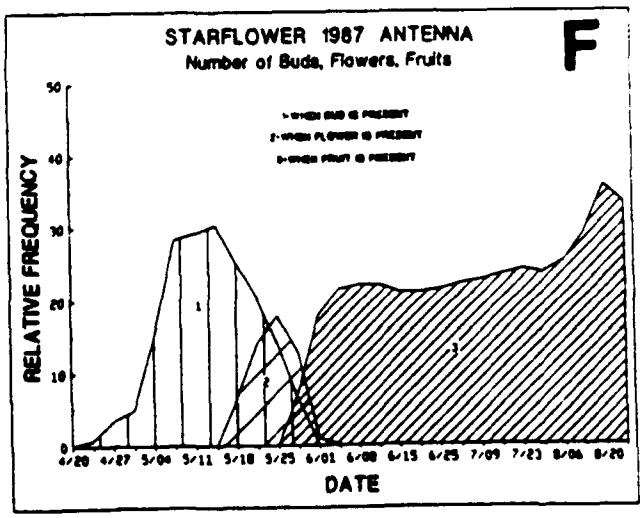


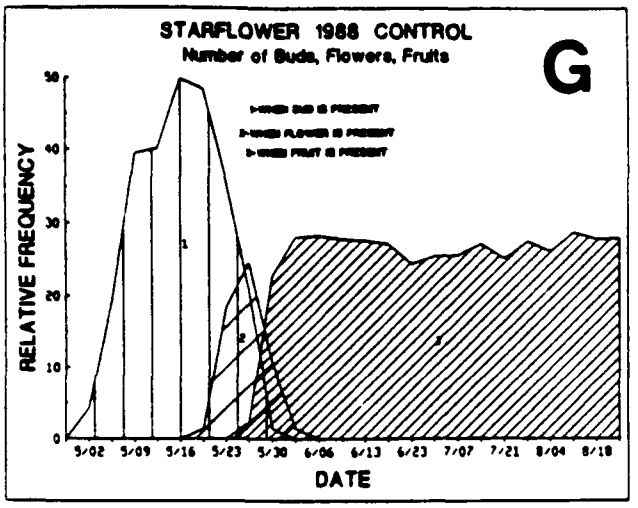


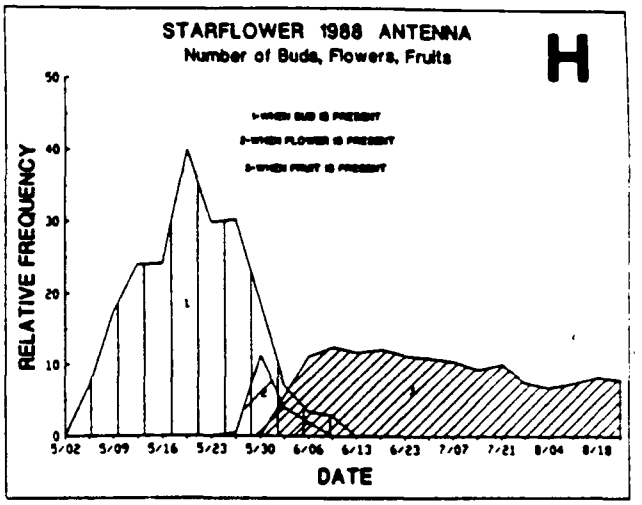


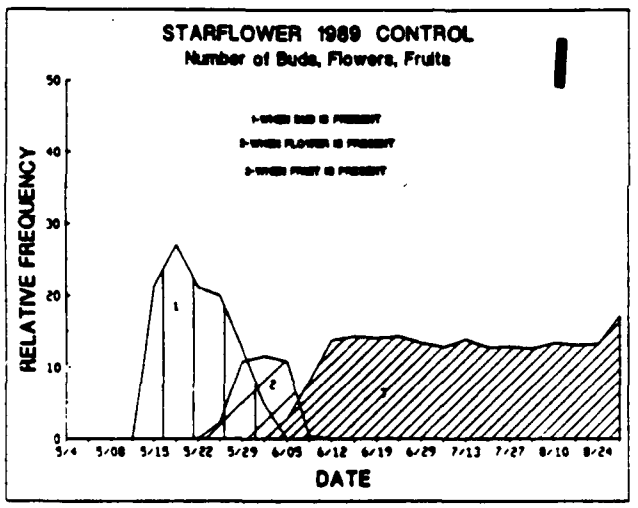


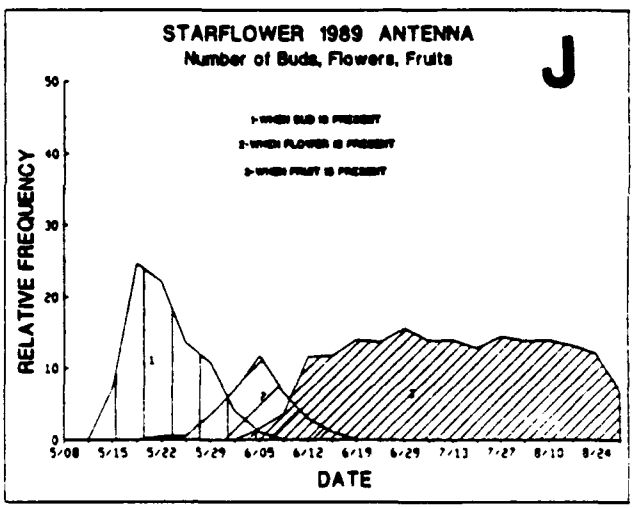


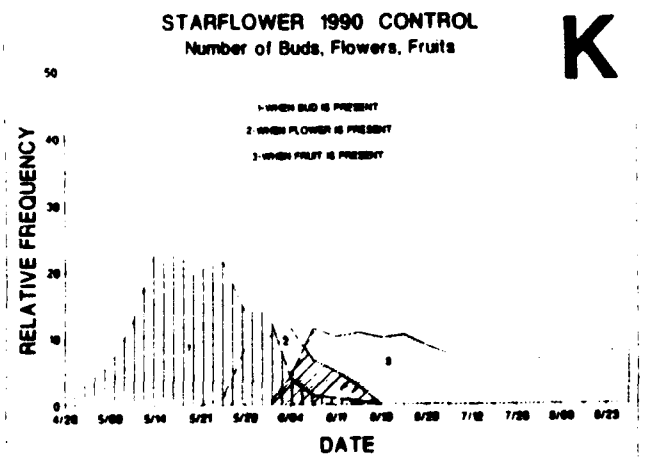



STARFLOWER 1988 CONTROL
Number of Buds, Flowers, Fruits
G
RELATIVE FREQUENCY
DATE


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


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


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


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

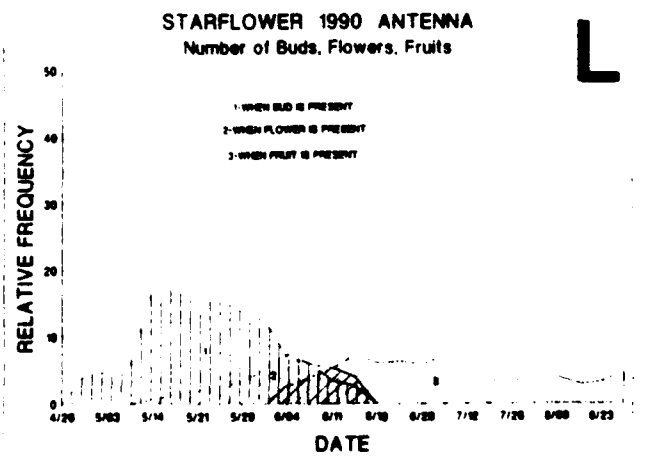

STARFLOWER 1990 ANTENNA
Number of Buds, Flowers, Fruits
L
RELATIVE FREQUENCY
DATE

Table 3.2. Analysis of Covariance table for stem expansion, leaf expansion, and leaf area expansion.

Source of Variation	df	SS	MS	F
Year	4	SS_y	MS_y	MS_y/MS_{e1}
Covariates	#	SS_{cy}	MS_c	MS_c/MS_{e1}
Error 1 (P/Y)	40-#	SS_{e1}	MS_{e1}	
Site	1	SS_s	MS_s	MS_s/MS_{e2}
Site by Year	4	SS_{sy}	MS_{sy}	MS_{sy}/MS_{e2}
Covariates	#	SS_{cs}	MS_{cs}	MS_{cs}/Ms_{e2}
Error 3 (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 3.3A) Year and site/year interactions were also determined to be significantly different (Table 3.3A). 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 were most highly correlated to leaf area expansion and leaf length expansion were 1) maximum solar radiation (SOLMX) (r=-0.44, -0.44, respectively), 2) natural log of soil temperature degree days running total at 10 cm (LST10DRT) (r=0.60, 0.65, respectively), 3) bigtooth aspen basal area (BTABA) (r=0.32, 0.31, respectively), and 4) northern red oak basal area (NROBA) (r=-0.32, -0.30, respectively). Interactions between the climate variables and microsite variables were also highly correlated to leaf area expansion and leaf length expansion (ie., LST10DRT/BTABA (r= -0.22, -0.19, respectively), and LST10DRT/NROBA (r=0.30, 0.31, respectively) SOLMX/BTABA (r= -0.31, -0.33, respectively)). Although not highly correlated to leaf area and leaf length expansion, the interaction SOLMX/NROBA (r= -0.02, 0.03, respectively) was used as a covariate to explain the high component of northern red oak trees on the control site. Due to multicollinearity among these variables only BTABA, NROBA, and their corresponding interactions were used in the analysis. The use of these covariates explained significant amounts of variation in leaf area expansion and leaf length expansion between sites and among site by years but not among years (Table 3.3B).

Table 3.3. Results of ANCOVA (p values) to determine significant differences in stem expansion (STEM), leaf expansion (LGTH), and leaf area expansion (LAREA) between sites, years, and years by site.

A) No Covariates

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

B) Covariates for Leaf Length (LGTH) and Leaf Area (LAREA). Natural log (Soil Temperature Degree Days Running Total) + 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/BTABA + Maximum Solar Radiation/NROBA.

Source of Variation	LGTH	LAREA
Year	0.00	0.00
Site	0.98	0.95
Site by Year	0.16	0.67

C) Covariates for Stem Length (STEM). - Natural log (Soil Temperature Degree Days) + Bigtooth Aspen Basal Area (BTABA) + Northern Red Oak Basal Area (NROBA) + Maximum Solar Radiation/BTABA + Maximum Solar Radiation/NROBA.

Source of Variation	STEM
Year	0.00
Site	0.98
Site by Year	0.00

The same covariates used for leaf length and area expansion could not be used for stem expansion. The reason for this is unknown, however, stem expansion may be related to the amount of carbon stored in the roots from the previous year and to initial seasonal conditions. The variables most highly correlated to stem expansion were 1) maximum solar radiation (SOLMX) (r=-0.17), 2) natural log of soil

temperature degree days running total at 10 cm (LST10DRT) (r=0.24), 3) bigtooth aspen basal area (BTABA) (r=0.24), and northern red oak basal area (NROBA) (r= -0.23). Interactions between the climate variables and microsite variables were highly correlated to stem expansion SOLMX/BTABA (r=-0.21) and SOLMX/NROBA (r=0.05). All these variables were used in the covariate analysis. These covariates explained significant amounts of variation in stem expansion between sites only (Table 3.3C). Yearly differences and site by year interactions could not be explained. The addition of other climatic and microsite factors as covariates did not yield better results. Information on the strength of the ELF field was not available for the analysis. Once this information becomes available it will be used to determine if the field strengths can explain the site by year interactions and the year differences. Monitoring the effects of ELF fields on stem, leaf, and area expansion will continue.

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. then measured in early September to determine if there were morphological differences between the two sites. This 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. At this time, there is no explanation for these results. Work will continue to evaluate the effects of ELF on these plants.

Three buds per plant were observed on both the antenna site and the control site this year (Figure 3.1F). The amount of plants that produced flowers were lower on the antenna site versus the control site (Figure 3.2F). Plants on the antenna site produced the same number of fruit but during the period of July 19 to August 9 the number of plants with two fruit were not observed. Reasons for this are unclear. The antenna and control sites exhibited the same percent plants that produced yellow (Figures 3.4K and 3.4L). The percent of plants with brown leaves were also similar between the antenna and the control site (Figures 3.5K and 3.5L). Except for the proportion of plants flowering, similar relationships were seen in the 1985, 1986, and 1987 growing seasons. The effects of ELF fields 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, 1987, 1988, 1989, 1990) on each site (Table 3.5). The independent variable of leaf width x leaf length explained 99 percent of the variation in leaf area for both sites in 1986, 1987, and 1989. 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, respectively, in 1988. Higher standard errors occurred with the development of the 1988 curves (Table

Table 3.5. 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
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

[1] Standard error of regression

3.5). In 1989, the standard error of the regression was similar to 1986 and 1987. Possible causes of increased error in 1988 were attributed to inaccuracies in leaf length and leaf width measurements and/or leaf sampling in the field. These problems seem to be corrected for the 1989 data.

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. Significant yearly

differences ($p < 0.001$) in both the slopes and the intercepts were determined. Intercepts for the antenna and control sites in 1988 were again significantly greater than for 1986, 1987, 1989, and 1990 and 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, and 1990. These differences may be due to the increase in the amount of solar radiation in 1988 compared to other years (Element 1, this report). There were no differences in coefficients between sites or among site/year interactions. Leaf areas will continue to be measured and prediction equations developed using leaf length and leaf width.

Summary

At this time, significant variation in stem expansion, leaf 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, maximum solar radiation, and interactions between these variables. Significant site by year interactions indicate that ELF fields in 1990 may be having an affect on stem length. Timing of flowering and fruiting has also been observed to be before maximum bud break and flowering which may also be an indication of some ELF effects. Once information on ELF fields are available it will be used to determine if these observations can be explained by the ELF fields in 1990.

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 are affected by ozone and air pollution (Kowalski 1987, Reich *et al.* 1985, Mejstrik and Cudlin 1987) and heavy metal buildup in soils (Jones and Hutchinson 1986). Extremely low frequency fields could detectably alter the more discriminating mycorrhizal fungus component. Data regarding mycorrhizae may also be used to substantiate responses seen in other measures of tree productivity.

Populations of mycorrhizae on each red pine plantation site are compared at monthly intervals during the growing season (May-October)and with corresponding monthly intervals during the growing season from previous years. The basic experimental units are individual red pine seedlings. Mycorrhizae are categorized into morphological types produced by different fungal associations on red pine seedlings. Changes in both the frequency of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling are quantified for analysis both within and among years as well as among sites. Data for analysis are expressed as the total number of mycorrhizae per gram of seedling root mass (oven dry weight (o.d.w.) 60^{o}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 1990 growing season, as was done the previous five 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 22 cm in diameter and 22 cm deep. 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^{o}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, but was not always necessary, to distinguish the mycorrhizal types. Morphology types are tallied separately and then totaled for each seedling. Non-mycorrhizal root tips are easily distinguishable as white root tips composed entirely of plant tissue, obviously lacking a fungal component.

Descriptions of Red Pine Mycorrhizal Morphology Types

Type 3 Mycorrhiza

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

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

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

Type 5 Mycorrhiza

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

Microscopic: Surface hyphae dark-brown to black, 3-6

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

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

Type 6 Mycorrhiza

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

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

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

Statistical Analysis

Though red pine seedlings were outplanted on the study sites in June 1984, data from that year are not being compared with subsequent years for two reasons. First, 1984 was the year of plantation establishment; nursery seedlings are small and planting shock is known to have a significant effect on seedling root systems. Second, ambient weather and soil data was not available for 1984. For all years following 1984, total mycorrhizae per gram of dry root (o.d.w.) has been used to compare sites and sites within and among years. 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 1990 season. Since 1985 non-mycorrhizal root tips have continued to decline, 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 future years, in case (hypothetically) seedlings undergo a reversion in maturity due to ELF field effects.

Type 3 mycorrhizae in 1990 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 more like numbers on the antenna site. This result was similar to results in 1989 but not to results in 1988. The reason for this is unclear except that, over all sites, the mean air temperature was cooler in 1990 and 1989 than in 1988. Perhaps the dry, hot weather of 1988 had a greater impact on monthly fluctuations of mycorrhizal numbers. This is evidenced by the lack of distinct peaks in mycorrhizal numbers during the growing season in 1988. During the 1990 growing season there was a distinct increase in mycorrhizal numbers in June and July (Figures 4.1 and 4.2). This did not correspond to increases in precipitation as it did in 1989. Even with the increases in Type 3 mycorrhizae in 1990, numbers of mycorrhizae per gram dry root in 1990 were not significantly different than numbers in 1989, 1988, 1987, and 1986 (Figure 4.1).

Type 5 mycorrhizae increased in May, June, and July in 1990 (Figure 4.3). This year was comparable to 1989 and 1987. Statistical comparisons from year to year for any

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

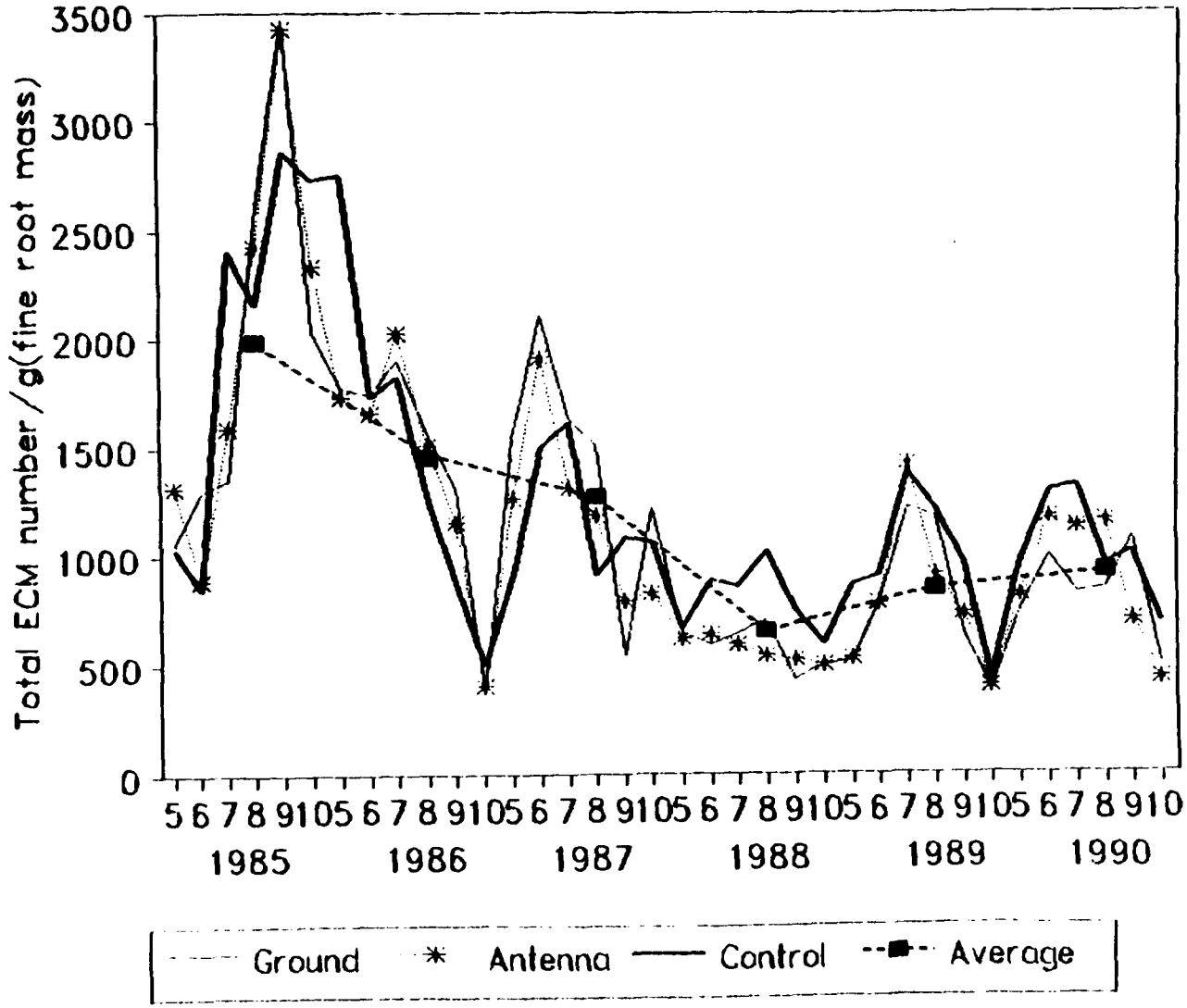


Figure 4.2: Yearly and monthly comparisons of the number of Type 3 mycorrhizal root tips per gram of dry root.

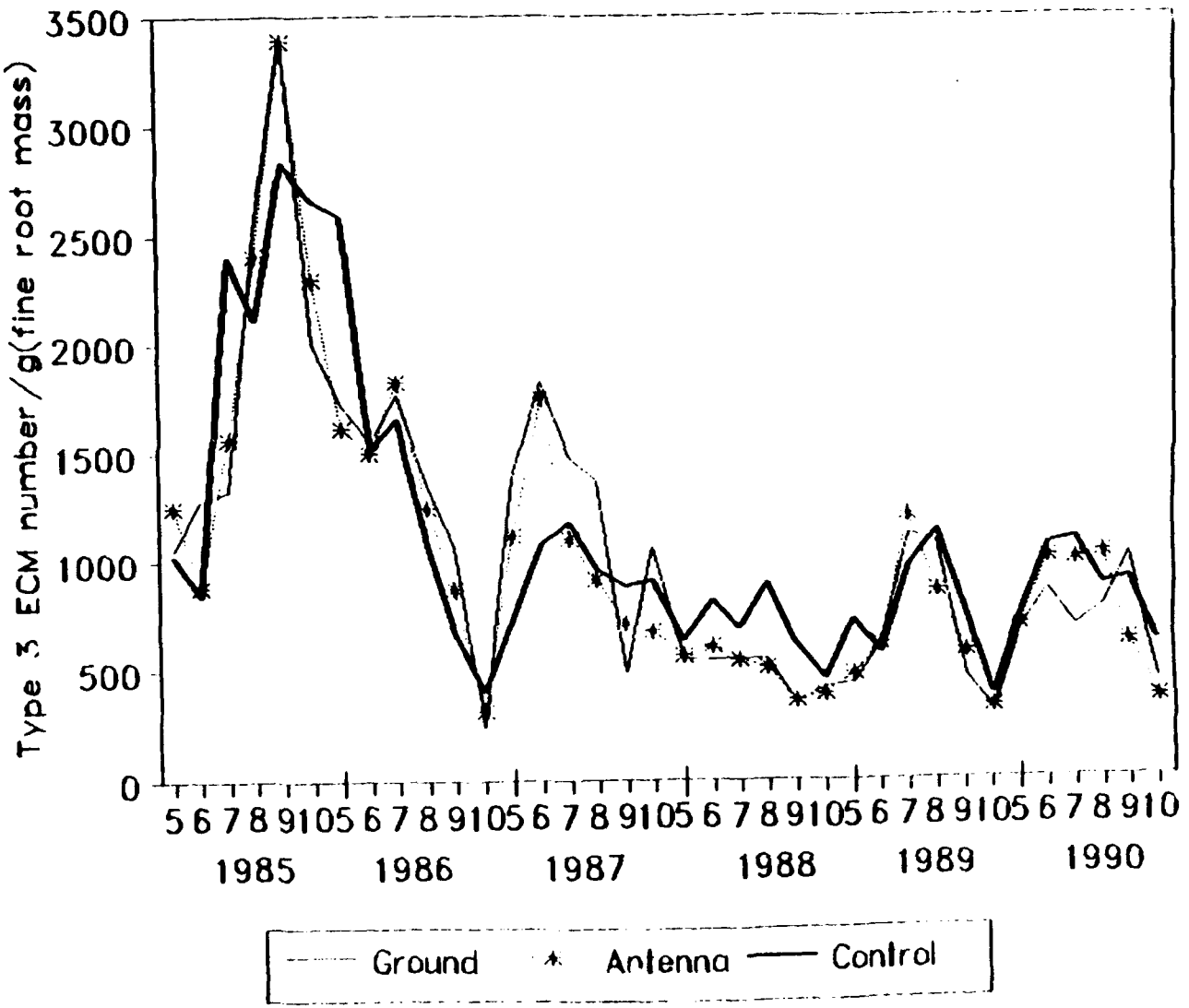
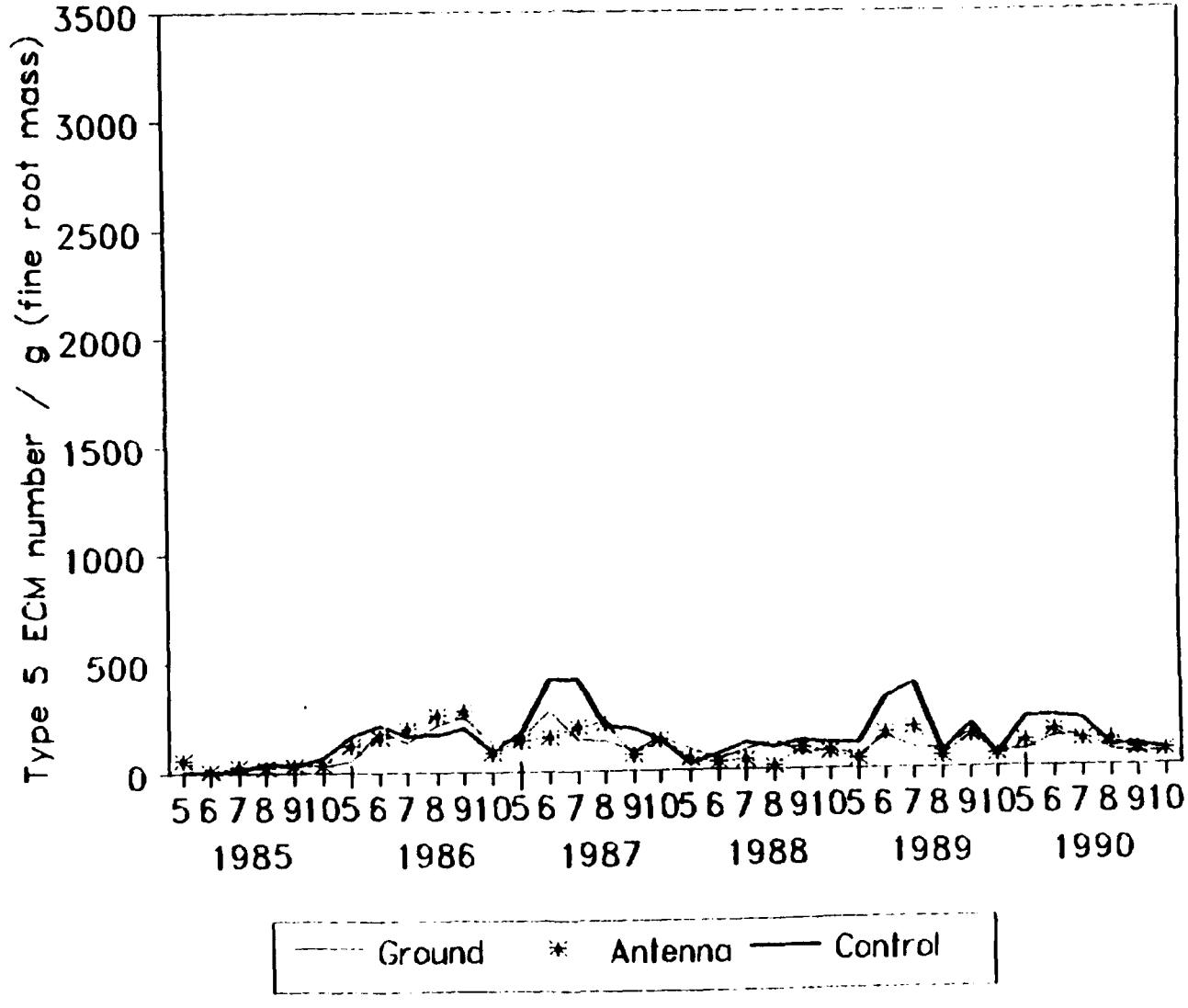


Figure 4.3: Yearly and monthly comparisons of the number of Type 5 mycorrhizal root tips per gram of dry root.



site and month demonstrate that numbers in 1990 were most like numbers in 1989 and 1987. The control site had significantly higher numbers of Type 5 mycorrhizae in May, June and July months than the antenna and ground sites. These same fluctuations were observed in 1987 and in 1989 but not in 1988. As with Type 3 mycorrhizae these differences may be due to fluctuations in mean air temperatures in the preceeding months.

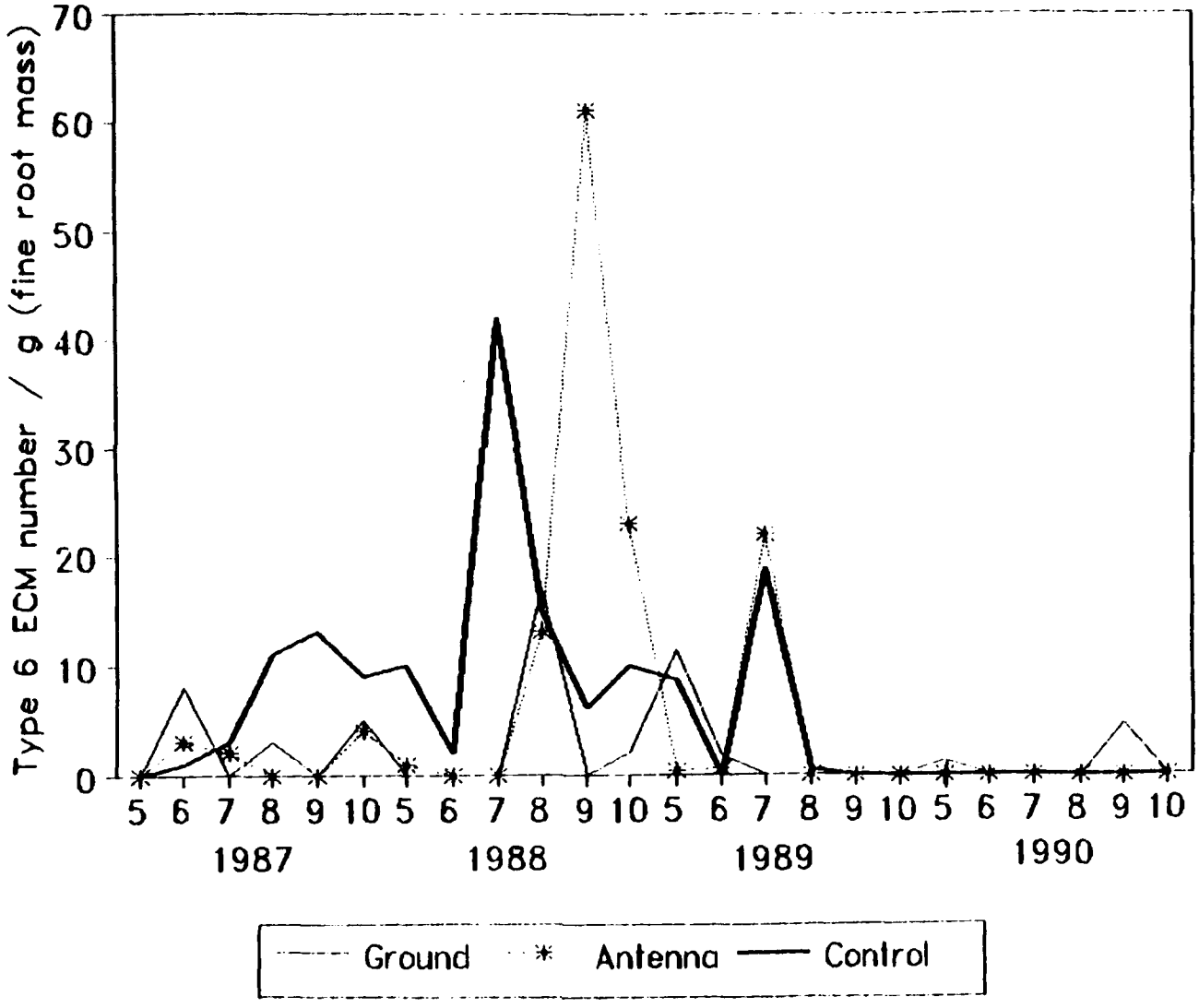
Type 6 mycorrhizae are the least common type encountered on red pine seedlings for all study sites (Figure 4.4; note different scale of the Y axis compared with Figures 4.1, 4.2, and 4.3). They were first observed in late 1984 on very few seedlings. In 1985, Type 6 mycorrhizae were recorded only in July and August on the Control site. In 1986, no seedlings were found with Type 6 mycorrhizae. In 1987 the occurrence of Type 6 mycorrhizae was still infrequent and sporadic (Figure 4.4), but they were found often enough on all sites (but not all months) to make comparisons among sites for the year. 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 site having similar numbers in May and the control and antenna site having similar numbers in July (Figure 4.4). In 1990, numbers of Type 6 mycorrhizae were similar to 1989 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 sites, the Control site, where tree growth had been advancing more quickly (see Element 2). Differences among months may be due to individual soil properties associated with each seedling sampled and not to climatic characteristics.

At this time, there does not appear to be any affect of ELF fields on the number of mycorrhizal root tips per gram of dry root. In 1989, site differences were the least distinct of all years. If there are changes in mycorrhizal numbers due to ELF fields this should become evident within the next few years since the ELF antenna became fully operational in September, 1989.

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

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



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 also shown in Table 4.1. Lower correlation coefficients were observed this year than in previous years. Reasons for this result are unknown at this time. A wider variation in weather patterns may be needed to predict major changes in mycorrhizal numbers or some other methodology to model daily changes in weather over the samppling period.

Analysis of variance (ANOVA) was performed with six years of data (1985-1990) to detect differences between the various factors, and their interactions, on total mycorrhizae per gram of dry root. Mycorrhizal numbers were not significantly different ($p<0.05$) among sites and among site by year interactions (Table 4.2). Significant differences among years were detected. Significantly fewer numbers of mycorrhizae occurred in years 1988, 1989, and 1990 compared with year 1985. Numbers of mycorrhizae in 1986 and 1987 were not significantly different from numbers in 1985 nor were numbers of mycorrhizae in 1988, 1989, and 1990 significantly different from numbers in 1987 and 1986. 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 five years of collected data. Table 4.2 lists probability (p) values (significance of the F statistic) after analysis of covariance using five significantly correlated ($p<.001$) 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. In all cases, although p values for site factors and site and year interactions changed, yearly differences could not be explained.

Of the five ambient parameters used as covariates the one decreasing the site differences and the site and year interaction differences the most was total precipitation (PRCTOT). This ambient parameter is most likely to affect 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 climate. 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 4.1. Pearson correlation coefficients (r) calculated for total mycorrhizae per gram of seedling root with ambient parameters for the six years 1985 through 1990.

Ambient Parameter	Correlation Coefficient
AT=mean daily air temperature	.0889***
ATMN=mean minimum daily air temperature	.1266***
ATMX=mean maximum daily air temperature	.0477 .1
ATDD=mean air temperature degree days	.0862**
ATDDRT=air temperature degree days running total	-.0283NS
ST5=mean soil temperature at 5 cm	.1143***
ST5MN=mean minimum soil temperature at 5 cm	.1057***
ST5MX=mean maximum soil temperature at 5 cm	.1207***
ST5DD=mean soil temperature at 5 cm degree days	.1138***
ST5DDRT=soil temperature at 5 cm degree days running total	.0018
ST10=mean soil temperature at 10 cm	.1171***
ST10MN=mean minimum soil temperature at 10 cm	.1129***
ST10MX=mean maximum soil temperature at 10 cm	.1204***
ST10DD=mean soil temperature at 10 cm degree days	.1167***
ST10DDRT=soil temperature at 10 cm degree days running total	.0055NS
PRCDAV=mean daily precipitation	.0720**
PRCMNDAV=mean minimum daily precipitation	.0777**
PRCMXDAV=mean maximum daily precipitation	.0724**
PRCTOT=total precipitation	.1551***
PRC.01=number of days precipitation events > 0.01 cm	.1220***
PRC.10=number of days precipitation events > 0.10 cm	.1598***
SM5=mean soil moisture at 5 cm	-.0459NS
SM5MN=mean minimum soil moisture at 5 cm	-.0703*
SM5MX=mean maximum soil moisture at 5 cm	-.0183NS
SM10=mean soil moisture at 10 cm	-.0296NS
SM10MN=mean minimum soil moisture at 10 cm	-.0868**
SM10MX=mean maximum soil moisture at 10 cm	.0464 .1
Seedling AGE	-.3994***

*** Indicates significant correlation ($p<0.001$)
** Indicates significant correlation ($0.001<p<0.01$)
* Indicates significant correlation ($0.01<p<0.05$)
.10 Indicate significant correlation ($0.05<p<0.10$)
NS Indicates non-significant correlation ($p > 0.10$)

Table 4.2. Comparison of p values (significance of F) for total mycorrhizae per gram of seedling root data (1985 through 1990) after multiple analysis of covariance (ANCOVA) using some of the highly correlated (p<.001) ambient parameters.

COVARIATE	SITE	YEAR	YEAR x SITE
No Covariate	.159	.000	.236
AGE	.205	.000	.236
PRC.01[1/]	.496	.002	.161
PRC.10	.149	.003	.068
PRCTOT	.874	.002	.284
ATMN	.316	.000	.279
ST5MX	.267	.000	.267

[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 1990, 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 nor analysis of covariance. The use of individual ambient parameters as covariates in the analysis reduces the differences among sites and site by year interactions. The use of covariates does 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.

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; numbers of mycorrhizae from year 1990 on the antenna and/or ground site(s) would be determined to be significantly different than the numbers on the control site or from prior years information. The ELF antenna system has been operational since the fall of 1989. 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.

Additional years information is needed to fully assess the long term effects of ELF fields on mycorrhizal root production. With refinements in the ambient parameters, as mentioned above, and their application to the analysis, detection limits will probably decrease. Findings, thus far, support the proposal that mycorrhizal symbiosis between tree roots and fungi can indeed be used as a sensitive indicator of subtle environmental changes.

Element 5. LITTER PRODUCTION

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

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

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

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

Each year prior to an operational antenna (1984-1986), baseline measurements of the antenna and control site were taken to.determine whether there were any differences in the total weight of litter fall, and foliar nutrient concentrations of northern red oak trees. The resulting ANOVA table for these analyses are given below (Table 5.1). Previous ELF annual reports have shown that no appreciable differences in these stand components were evident between these two sites prior to the onset of antenna operation.

Sampling and Data Collection

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

Table 5.1. ANOVA table for the analysis of litter components and foliar nutrients

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

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

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

Progress

Litter weight

In 1990, the major litter fall in the ELF study area started between September 26 and October 3, and was completed by November 1 on both the antenna and control sites (Figure 5.1). Based on the previous 6-year average, this litter fall period began at a later date and continued longer into October (Figure 5.2a&b). As in past years, periodic litterfall amounts varied considerably between the antenna site and the control site at all collection times in the fall. These differences in weekly leaf fall are 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 trees longer than either maple or aspen, and account for much of the litter fall variations between locations.

Figure 5.1

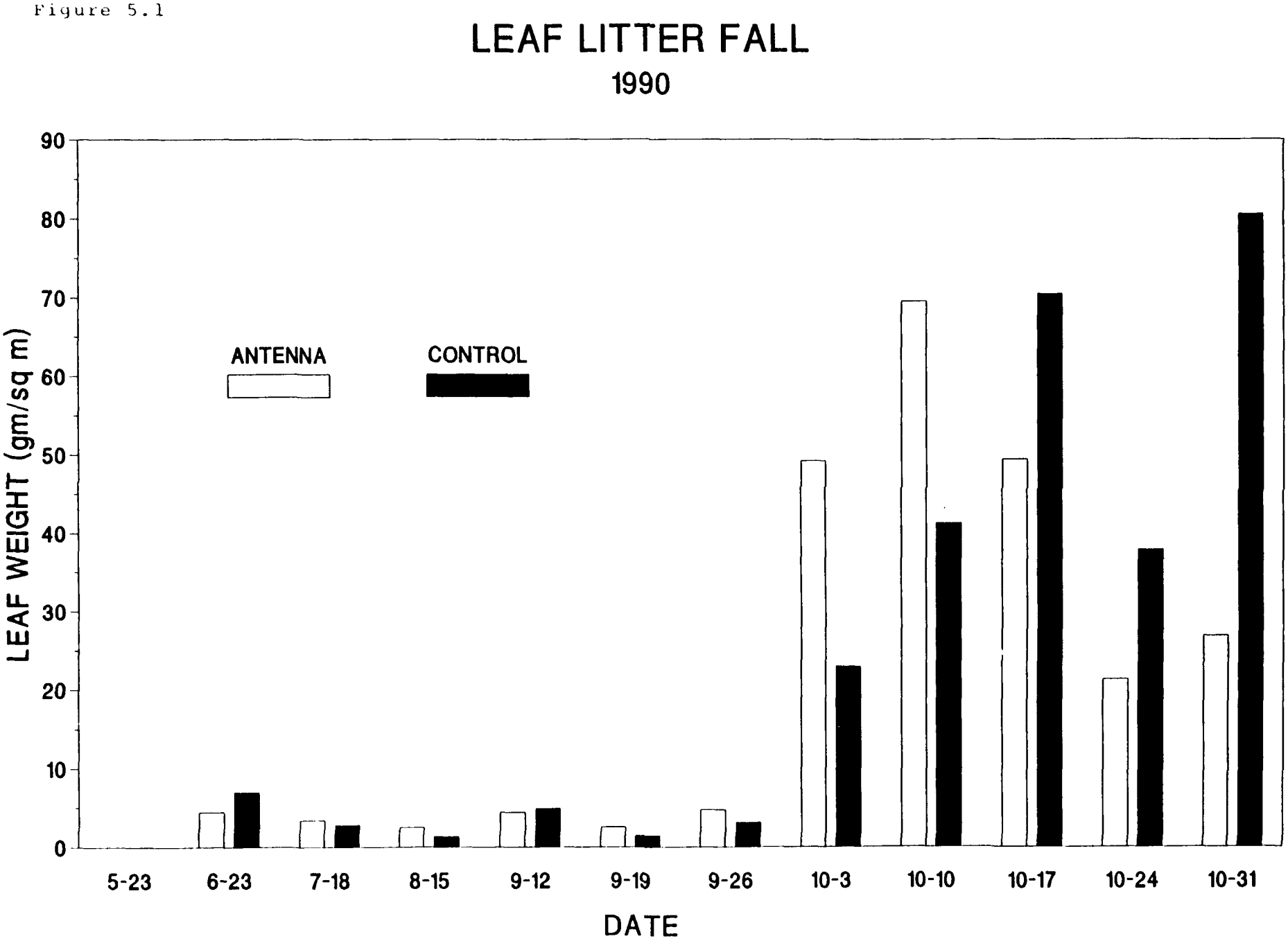

LEAF LITTER FALL
1990
LEAF WEIGHT (gm/sq m)
90
80
70
60
50
40
30
20
10
0
ANTENNA
CONTROL
5-23
6-23
7-18
8-15
9-12
9-19
9-26
10-3
10-10
10-17
10-24
10-31
DATE

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

Tree Species	Leaf Weight (g/m^2) 1985	1986	1987	1988	1989	1990	% of Total 1985	1986	1987	1988	1989	1990
Antenna												
Red Maple	135	147	142	143	127	103	45	43	44	41	41	44
Red Oak	93	120	105	116	95	71	31	35	33	33	32	31
B. Aspen	45	52	46	56	18	32	15	15	14	17	6	15
Q. Aspen	1	1	2	3	2	1	<1	<1	<1	1	<1	1
Paper Birch	25	21	25	28	28	24	9	6	8	8	9	10
Red Pine	1	1	2	2	2	1	<1	<1	<1	<1	<1	1
Control												
Red Maple	42	55	47	41	48	41	14	17	16	13	15	16
Red Oak	227	266	208	230	223	184	73	69	69	71	70	71
B. Aspen	14	17	13	12	16	17	4	5	4	4	5	7
Q. Aspen	11	9	8	13	10	3	3	3	3	4	3	1
Paper Birch	19	22	26	26	20	13	6	6	8	8	7	5
Red Pine	0	0	0	0	0	0	0	0	0	0	0	0

The weight of the litterfall leaf component on both the antenna and control site in 1990 was the lowest of the seven years measured (Table 5.3). While strong annual litterfall fluctuations are evident on these sites, analysis of variance (ANOVA) using the seven 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 litterfall 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 study 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 detection 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 1990 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 years 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) 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 the antenna operation.

Table 5.3. Total litter fall at the antenna and control sites: 1984-1990.

	Antenna	Control
	g/m^2	
Leaves		
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)
Average	315	344
Wood		
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)
Average	51	64
Miscellaneous		
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)
Average	57	46

Collection Period:

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

Numbers in parentheses are standard deviations.

Table 5.4. Correlations between litter component weight and the covariates selected for inclusion in the analysis of covariance: 1985-1990.

Covariate	Litter Component		
	Foliage	Wood	Miscellaneous
Air Temperature Degree Days (through Sept. 15)	-.50	---	---
Soil Temperature at 10 cm (April 1 - June 15)	---	---	-.36
Air Temperature (August 16-September 15)	---	.19	---
Air Temperature Degree Days (through June 15)	---	.16	---

Table 5.5 Significance levels from the split plot analysis of covariance for litter components - 1985 to 1990

Factor	Foliage	Wood	Miscellaneous
	p values		
Site	0.940	0.292	0.166
Years	0.700	0.753	0.000
Site x Years	0.141	0.731	0.144

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

Litter Component	Sites		Years	
	g/m^2	%	g/m^2	%
Foliage	58.4	17.7	26.7	8.1
Wood	30.4	51.9	21.5	36.7
Miscellaneous	23.9	42.1	18.4	32.5

*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 and 1990 (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 all leaf litter nutrient concentration detection levels are well below fifteen 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 can not be attributed to the low level ELF fields generated since 1987.

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 significant site x year interactions for foliar N and K that could not be explained using the covariates tested (Table 5.16). Similar results were found for site x month interactions. Multiple range tests (SKN) were used to evaluate these site differences. Similar to the litterfall results, these analyses showed that significant site x year and site x month differences occurred prior to the beginning of antenna operation in 1987.

Table 5.7. Average nutrient content of litterfall at the antenna and control sites: 1985-1989.

	Antenna					Control				
	1985	1986	1987	1988	1989	1985	1986	1987	1988	1989
	(kg/ha)									
Foliage										
N	26.4	26.4	26.2	19.9	16.5	28.1	19.9	24.9	21.5	20.3
P	4.6	4.2	4.4	4.6	5.5	10.0	4.6	4.0	5.3	5.8
K	9.9	10.1	9.0	12.4	13.1	13.6	10.5	13.5	18.0	17.9
Ca	36.0	33.1	40.6	38.1	27.1	35.7	37.2	44.1	40.2	31.3
Mg	5.7	5.5	6.1	5.5	6.4	5.6	5.8	6.0	6.4	6.5
Wood										
N	3.2	2.7	2.3	2.2	1.3	0.4	3.3	2.7	3.0	1.3
P	0.3	0.3	0.2	0.3	0.3	4.0	0.4	0.2	0.4	0.3
K	0.5	0.4	0.3	0.7	0.5	0.9	0.8	0.5	0.8	0.8
Ca	6.8	4.3	5.5	4.7	3.0	9.0	7.5	6.3	9.4	4.1
Mg	0.4	0.3	0.3	0.3	0.2	0.6	0.5	0.3	0.4	0.3
Miscellanous										
N	7.1	3.4	12.3	12.0	7.5	5.1	3.7	6.6	7.8	5.4
P	0.8	0.3	1.3	1.4	1.1	0.9	0.3	0.7	1.0	0.8
K	2.8	1.0	1.9	5.7	4.9	1.6	0.7	1.4	6.3	3.5
Ca	3.0	2.0	8.8	5.0	2.9	5.6	3.1	9.9	4.0	2.6
Mg	0.5	0.3	1.0	0.8	0.8	0.4	0.2	0.7	0.7	0.6
Total										
N	36.7	32.5	40.8	34.1	25.3	37.2	26.9	24.2	32.3	27.0
P	5.7	4.8	5.9	6.3	6.9	11.3	5.3	4.9	6.7	6.9
K	13.2	11.5	11.2	18.8	18.5	16.1	12.0	15.4	22.8	22.2
Ca	45.8	39.4	54.9	47.8	33.0	50.3	47.8	60.3	53.6	38.0
Mg	6.6	6.1	7.4	6.6	7.4	6.6	6.5	7.0	7.5	7.4

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: 1985-1989.

	Antenna	Control
	(%)	
Foliage		
N	0.71 (0.15)*	0.67 (0.09)
P	0.14 (0.02)	0.17 (0.06)
K	0.33 (0.09)	0.42 (0.08)
Ca	1.07 (0.17)	1.10 (0.14)
Mg	0.18 (0.03)	0.18 (0.01)
Wood		
N	0.46 (0.14)	0.48 (0.14)
P	0.05 (0.01)	0.06 (0.01)
K	0.11 (0.04)	0.15 (0.05)
Ca	0.96 (0.24)	1.24 (0.30)
Mg	0.06 (0.01)	0.07 (0.01)
Miscellaneous		
N	1.15 (0.29)	1.02 (0.22)
P	0.13 (0.03)	0.13 (0.04)
K	0.43 (0.17)	0.40 (0.20)
Ca	0.60 (0.22)	0.90 (0.44)
Mg	0.09 (0.02)	0.09 (0.01)

*Numbers in parentheses are standard deviations.

Table 5.9. Average nutrient concentrations of tree litter on the antenna and control sites: 1985-1989.

	Antenna	Control
	(%)	
Northern Red Oak		
N	0.72 (0.18)*	0.64 (0.09)
P	0.13 (0.02)	0.19 (0.10)
K	0.33 (0.08)	0.40 (0.07)
Ca	0.96 (0.10)	1.02 (0.12)
Mg	0.12 (0.01)	0.15 (0.02)
Paper Birch		
N	0.78 (0.14)	0.78 (0.09)
P	0.17 (0.06)	0.18 (0.03)
K	0.42 (0.08)	0.58 (0.14)
Ca	1.38 (0.23)	1.16 (0.21)
Mg	0.27 (0.03)	0.28 (0.02)
Big Toothed Aspen		
N	0.79 (0.10)	0.66 (0.11)
P	0.12 (0.06)	0.15 (0.04)
K	0.36 (0.13)	0.50 (0.12)
Ca	1.28 (0.20)	1.46 (0.19)
Mg	0.26 (0.03)	0.28 (0.02)
Red Maple		
N	0.45 (0.06)	0.47 (0.11)
P	0.16 (0.03)	0.18 (0.03)
K	0.24 (0.09)	0.34 (0.10)
Ca	1.04 (0.10)	1.16 (0.10)
Mg	0.18 (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.

	N	P	K	Ca	Mg
	p value				
Leaf	--	(c)*	--	(f)	(e)
Site	.217	.093	.094	.097	.276
Year	.024	.000	.000	.001	.001
Year x Site	.471	.000	.368	.472	.205
Wood	(ps)	(s)	(c)	(d)	(c)
Site	.590	.394	.068	.213	.014
Year	.000	.199	.000	.007	.007
Year x Site	.814	.724	.591	.251	.183
Miscellaneous	(cq)	(bc)	(h)	(dn)	(am)
Site	.575	.936	.672	.946	.699
Year	.009	.000	.000	.000	.284
Year x Site	.016	.014	.077	.011	.183

*Variables used in COANOVA (see Table 5.10).

Table 5.12. Results of covariate analyses of site and year differences in leaflitter nutrient concentrations by species.

	N	P	K	Ca	Mg
	p value				
Northern Red Oak	--	(cf)	(cf)	(bh)	(ei)
Site	.175	.623	.081	.828	.188
Year	.007	.000	.000	.000	.000 .00
Year&Site	.854	.005	.853	.014	.013
Hazelnut and Paper Birch	(ab)	(cf)	(ah)	(kh)	(ah)
Site	.335	.363	.431	.692	.168
Year	.000	.014	.000	.000	.133
Year x Site	.649	.039	.008	.052	.053
Big Toothed Aspen	(bq)	(cde)	(dg)	(der)	(cdg)
Site	.064	.431	.160	.506	.530
Year	.051	.000	.151	.000	.015
Year x Site	.001	.001	.524	.105	.081
Red Maple	(cgh)	(l)	(ci)	(hit)	--
Site	.660	.764	.886	.885	.207
Year	.006	.000	.000	.226	.000
Year x Site	.034	.194	.221	.073	.510

*Variables used in COANOVA (see Table 6.10.).

Table 5.13. Detection limits for litter nutrient concentrations by component.*

Component	Site		Year	
	ppm	% of mean	ppm	% of mean
Leaf				
Ca	962	8.6	275	2.5
Mg	171	9.9	59	3.4
K	480	14.7	280	8.6
N	480	6.4	878	11.7
P	167	10.7	76	4.9
Wood				
Ca	650	4.8	330	2.8
Mg	75	10.8	91	13.2
K	161	13.7	278	23.7
N	656	12.1	77	14.3
P	79	14.0	89	15.8
Misc.				
Ca	2025	21.4	1183	12.5
Mg	80	8.6	56	6.0
K	400	13.1	512	16.8
N	871	7.5	1319	11.4
P	173	13.0	104	7.8

*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.*

Species	Site		Year	
	ppm	% of mean	ppm	% of mean
Northern Red Oak				
N	1076	14.6	795	10.1
P	116	11.3	68	4.8
K	306	9.3	228	6.9
Ca	326	3.3	206	2.1
Mg	135	10.5	39	3.0
Hazelnut and Birch				
Ca	1574	11.6	352	2.6
Mg	245	8.9	107	3.9
K	403	9.4	307	7.1
N	831	10.0	341	4.1
P	193	11.9	116	7.2
Big Tooth Aspen				
Ca	1409	9.7	368	2.5
Mg	234	10.0	68	2.9
K	901	22.8	343	8.7
N	354	4.9	365	5.1
P	295	25.0	136	11.5
Red Maple				
Mg	118	6.5	73	4.0
Ca	414	3.7	454	4.1
K	220	9.6	269	11.8
N	435	8.8	298	6.0
P	130	8.3	119	7.6

*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 1989.

	Antenna					Control				
	1985	1986	1987	1988	1989	1985	1986	1987	1988	1989
	(%)									
N	2.04	1.88	1.89	1.73	2.21	1.80	1.98	1.78	2.09	2.22
P	0.18	0.20	0.19	0.16	0.33	0.17	0.20	0.18	0.19	0.32
K	0.87	0.82	0.75	1.01	0.83	0.95	1.02	0.18	1.02	0.99
Ca	0.71	0.73	0.65	0.76	0.69	0.68	0.80	0.64	0.79	0.69
Mg	0.13	0.14	0.15	0.16	0.16	0.13	0.15	0.15	0.16	0.17

A factor in evaluating foliage nutrient concentrations is the weight of individual leaves. Consequently, an analysis of variance was conducted on average yearly leaf weights on the antenna and the control sites (Table 5.17) No significant site, month, year, and diameter interactions were found.

Since good covariates are presently lacking for the covariate analysis of foliage nutrient content, detection limits are relatively high (Table 5.18). Detection limits are generally under ten percent for yearly differences, but over twenty percent between sites. Thus, changes in tree nutrient translocation and cycling as affected by the ELF electromagnetic fields need to be relatively large to be detected by these analyses.

Table 5.16. Results of covariate analyses for differences in foliage nutrient concentration: 1985-1989.

	N (1)*	P (2)	K (3)	Ca (4)	Mg (5)
	p values				
Site	.671	.655	.001	.724	.576
Tree Diameter	.278	.056	.046	.241	.047
Site x Diameter	.800	.034	.461	.076	.092
Year	.000	.000	.000	.000	.000
Year x Site	.000	.216	.001	.069	.087
Year x Diameter	.319	.829	.020	.280	.119
Year x Site x Diameter	.116	.015	.216	.807	.418
Month	.000	.000	.000	.000	.000
Month x Site	.031	.007	.192	.039	.869
Month x Year	.000	.000	.000	.003	.002
Month x Year x Site	.049	.000	.000	.022	.002

* Covariates used

[1] Maximum air temperature, maximum soil moisture at 10 cm, maximum soil temperature at 5 cm, minimum soil temperature at 10 cm.

[2] Soil P and N, soil temperature at 10 cm degree days - running total, maximum soil moisture at 10 cm, minimum soil moisture at 5 cm.

[3] Soil Ca, minimum soil temperature at 5 cm, maximum air temperature, soil moisture at 10 cm, minimum soil moisture at 10 cm.

[4] Soil N, soil Ca, soil Mg, maximum air temperature, maximum soil temperature at 10 cm.

[5] Maximum air temperature, minimum soil moisture at 10 cm, soil temperature at 10 cm degree days.

Table 5.17. Analysis of variance results testing for differences in the average weight of ten leaf samples by site, tree diameter and sampling time (1985-90).

	p value
Site	.960
Diameter	.526
Site x Diameter	.265
Year	.000
Year x Site	.455
Year x Diameter	.216
Year x Diameter x Site	.274
Month	.003
Month x Site	.129
Month x Year	.155
Month x Year x Site	.288

Table 5.18. Detection limits for northern red oak foliage nutrient concentrations: 1985-1989*

	Site		Year	
	ppm	% of mean	ppm	% of mean
N	5488	28.2	1086	5.6
P	454	21.5	290	21.4
K	2688	29.9	617	6.9
Ca	3582	49.9	501	7.0
Mg	726	48.6	83	5.6

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

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APPENDIX A

Electromagnetic Field Measures

and

Correspondence

Interpolation equations were developed for the 1989 EM field exposure levels as in past years (Mroz et al. 1989). These equations allow the interpolation of EM field strength across the measurement plots based on the measurements made by IITRI in the summer of 1989 (see attached memo dated 26 January 1990). For all three sites and fields (transverse, longitudinal, and magnetic), the equations provided very good fits to the measurements, with values of R^2 exceeding 85.0 in all cases (see attached memo dated July 11, 1990). These equations are used to estimate average 76 Hz field strengths on each measurement plot in each year of the study (Table 1). In the summer of 1990, IITRI intensified the measurements of longitudinal field and determined that the spatial pattern of longitudinal field strength was complex and could not really be dealt with using equations of the type described above (see attached letter and maps of 6 September 1990). Based on this information, efforts are currently underway to improve our ability to interpolate longitudinal fields across the study sites utilizing the maps provided by IITRI. In the analyses discussed in the main body of this report, only the interpolated values of magnetic flux are used in making comparisons with response variables; exposure to longitudinal and transverse fields will be further quantified in next year's report.

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

312/567-4000

26 January 1990

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

Dear Dr. Mroz:

The purpose of this letter is to provide you with documentation of the annual ELF electromagnetic (EM) field measurements made by IITRI at your study sites on 19 September and 11 and 12 October 1989. EM measurement data from previous years and a brief summary of the Michigan Transmitter Facility (MTF) operations for 1989 are also included.

Study Sites

This year, EM measurements were made at 45 locations at the study sites listed in Table 1. Measurement positions within each study site are diagrammed in Figures 1 through 5. Please check these figures for accuracy. All measurement points characterized from 1985 through 1988 were remeasured in 1989. In addition, five measurement locations were added at the antenna test site and eight locations were added at the ground test site in order to characterize the EM field profiles across these study areas.

MTF Operations - 1989

A brief summary of MTF operations for 1989 is provided in Table 2. It is intended to provide an overview of the average and cumulative periods of ELF EM exposure at your study sites during 1989. As day-to-day variations in the MTF schedule were extensive, this summary can not be used to define the antenna operating conditions for specific points in time.

For the first four months of 1989 the MTF operated intermittently during the weekday hours of 8am to 4pm EST, and was OFF at other times. Only single antenna operation (either north/south or east/west) at 75 amperes was employed, with unmodulated signals at 44 Hz or 76 Hz.

During the first two weeks of May, the MTF conducted testing and tuning activities at 150 amperes using one or both antennas. Operation was between 8am and 5pm EDT and totaled one to eight hours/day. Various frequencies from 40 Hz to 80 Hz were employed with both unmodulated and modulated signals.

The MTF began standard 150 ampere operation with both antennas on 14 May, operating continuously from 4pm to 8am EDT weekdays and all day on weekends. During these periods the operating frequency was typically 76 Hz, either modulated or unmodulated. On weekdays beginning the same date, the MTF usually operated intermittently from 8am to 4pm EDT. During these working hours one or both antennas were operated at 150 amperes and frequencies of 44 Hz or 76 Hz. Intermittent operation ranged from near zero up to eight hours/day.

The MTF became an operational Navy communications facility on 7 Oct. Since that time it has operated continuously, with the exception of normally scheduled maintenance periods from 9am to 2pm EDT on Tuesdays and Thursdays. Normal operating parameters are 150 amperes on both antennas and a modulated signal centered at 76 Hz.

At this time, a computer database of MTF operating times and conditions for 1989 is still in preparation. A monthly and an annual summary of the hours of MTF operation by antenna condition will be included in the 1989 EM Field Measurements and Engineering Support report. In the meantime, if you require more detailed operating times data for a specific period, we can send you a copy of the monthly operating summaries as provided to IITRI by the Navy.

EM Measurement Protocol

Measurements of 76 Hz EM fields were conducted in 1989 at all study sites with antenna currents of 150 amperes. This is the first year that EM measurements were made under full-power MTF operation. Ambient 60 Hz EM fields were also measured at the control and leaf sampling sites. Ambient fields could not be measured at either test site because the 60 Hz fields were masked by the EM fields generated by the east/west antenna under modulated signal operation.

Three types of EM fields were characterized at each measurement point: transverse (or air) electric field, longitudinal (or earth) electric field, and magnetic flux density. For each of the fields, a set of orthogonal measurements were made and reduced to a single magnitude by vector addition. EM field intensities were determined under the following conditions:

1) The ambient 60 Hz fields were measured with both antennas operating at 150 amperes, standard phasing, and an unmodulated signal.

2) The 76 Hz fields from the MTF were measured with both antennas operating at 150 amperes, standard phasing, and either a modulated or an unmodulated signal.

Measurement locations within your study sites were initially chosen to be at plot corners and along plot boundaries, based on the intermediate size and rectangular shape of the site plots. This served to bracket the range of EM field intensities over the study ares. However, because the test plots cross either an antenna or ground element, they experience ranges of EM field exposures that typically span one to two orders of magnitude. To better characterize the test sites in 1989, EM field profiles were measured along transects perpendicular to the rights-of-way. Meaqsurement points were typically evenly-spaced on the profiles, but extra points were added at locations of localized field nulls and maxima near the overhead and buried wires.

60 Hz EM Fields

60 Hz EM field measurement data for 1983 through 1989 are presented in Tables 3-5. As previously stated, ambient field intensities could not be measured at your test sites in 1989 because of modulated signal operation of the MTF. The 60 Hz ambient field intensities measured at your control and leaf collection sites are consistant with values measured in previous years.

76 Hz EM Exposures - 1989

The 76 Hz EM field measurement data taken during the 1989 annual EM survey, along with data from earlier years, are presented in Tables 6-8. All field measurements were made and are presented as vector sum magnitudes. The antenna currents at which measurements were made in each year are given in the column headings of the tables. The 1989 measurements were made with 150 ampere antenna currents, the predominent MTF operating current since 4 May. The EM exposures at your study sites for the period prior to 4 May can be estimated either by using the 75 ampere antenna current measurement data from 1988, or by taking one-half of the value of the 1989 150 ampere data.

Plots of the 76 Hz EM field profiles for the antenna and ground test sites are presented in Figures 6 through 9. The EM field intensities at any point in the test plots can be estimated from the appropriate EM field profiles, given the straight-line distance of the point to the antenna or ground wire. However, the accuracy of such estimates may be limited by several factors, as discussed below.

At the ground site, both the magnetic field (Figure 9) and the transverse (air) electric field (Figure 8) gradients conform well to theoretical prediction. The slight dip in the magnetic field contour over the buried ground wire is likely the result of partial cancellation between the field generated by the overhead feed wire and that from the buried ground wire. The longitudinal (earth) electric field contour (Figure 9) shows the expected deep null directly over the buried ground wire and the field maxima nearby on either side. The symmetrical and consistant roll-off of the longitudinal electric field contour indicates that the bulk soil conductivity at this site is fairly uniform over a large area. Thus, the accuracy of estimates of the EM fields at the ground test site will be primarily limited by the accuracy of locating the points of interest with respect to the buried ground wire. This will be especially true for points close to the wire where the field magnitudes change rapidly over small distances.

At the antenna site, the magnetic field (Figure 7) also conforms well to theory. Magnetic field estimates based on the measured profile should be very good for distances of 10 m or greater from the overhead wire. Along the southeastern edge of the pine plantation some variation from the measured profile may occur because changes in terrain elevation close to the wire will affect the absolute distance to the wire, and therefore the field magnitude. The air electric field (Figure 6) behaves predictably in the pine plantation and air field estimates there should be as accurate as those for the magnetic field. Within the hardwood stands, however, the vertical component of the air electric field produced by the overhead wire is greatly attenuated. Here the air field is primarily horizontal and is generated by the earth electric field. As a result, the air electric field in the stands is less predictable and the accuracy of field estimates is markedly reduced.

The profile of the longitudinal (earth) electric field intensity across the antenna site is quite irregular (see Figure 7). Indeed, the field's intensity does not decrease with distance from the antenna as anticipated, but generally increases across the site. The most plausible explanation for this unusual profile is that the bulk conductivity of the soil is highly variable over both the pine plantation and pole stand. One would, therefore, have low confidence in any estimates of the earth electric field intensities. Should estimates of

the longitudinal electric field intensities be required at this site, it is recommended that they be derived by linear interpolation between the nearest measured points and not from the measured profile provided with this letter.

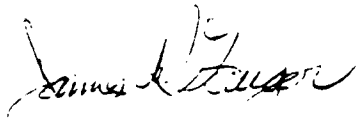
We have forwarded estimated field intensities for 150 ampere antenna operation in previous letters and reports. With these 1989 data, you now have measured values for the 76 Hz EM exposures at your study sites for full power MTF operation. EM exposure ratios have not been calculated by IITRI for 1989 or the past two years because the primary function of the ratios was to serve as guidelines for site selection. However, we suggest that you compute the exposure ratios using the measured 150 ampere data to verify that the EM ratios between paired study sites, as well as EM variations and gradients across sites, are consistent with the goals of your study. We would appreciate information on your plans for incorporating the EM exposure measurements into your analyses, and will be happy to assist with the calculation of EM exposure ratios. Software copies of the EM data tables will be made available for use in analyses or inclusion in your annual report.

1990 Schedule

As an operational communications system, the MTF is expected to continue full-time 150 ampere operation except for scheduled maintenance. The annual EM measurements for 1990 have not been scheduled, but will likely be in the August-October period. 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. Please contact me or Jack Zapotosky regarding the questions and concerns raised in this letter.

Sincerely,

IIT RESEARCH INSTITUTE



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cc: Dr. J. Bruhn, MTU
JEZapotosky
RDCarlson/File
DPHarademe
RGDrexler

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

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

TABLE 2. MTF 1989 OPERATIONS SUMMARY

Period	Operating Times And Conditions
1 Jan. thru 17 Mar.	Intermittent weekday operation, 8am - 4pm EST. Single antenna operation at 75 amperes. 44 Hz or 76 Hz, unmodulated.
18 Mar. thru 3 May	Both antennas OFF except for 12 hours of operation at 75 amperes.
4 May thru 13 May	Began 150 ampere tuning and testing. Intermittent operation 8am - 5pm EDT. Single antenna operation at 150 amperes. 44 Hz or 76 Hz, modulated and unmodulated.
14 May thru 6 Oct.	Began continuous 150 ampere Operation, 4pm - 8am EDT (16 hrs/day) on weekdays and all-day on weekends. Both antennas at 150 amperes. 76 Hz, modulated and unmodulated. Intermittent operation 8am - 4pm EDT weekdays. One or both antennas at 150 amperes. 44 Hz or 76 Hz, modulated and unmodulated.
7 Oct. to present	MTF is an on-line Navy communications facility. Continuous operation except for scheduled maintenance from 9am -2pm EDT on Tuesdays and Thursdays. Both antennas at 150 amperes, 76 Hz, modulated.

TABLE 3. 60 Hz TRANSVERSE 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 [d]
4C1-6	-	0.003	<	<	<	<	<
4C1-7	-	0.006	<	<	<	<	<
4C1-8	-	0.004	<	<	<	<	<
4C1-9	-	0.002	<	<	<	<	<
4C1-10	-	-	<	<	<	<	<
4C1-11	-	-	<	<	<	<	<
4C1-12	-	-	<	<	<	<	<
4C1-13	-	-	<	<	<	<	<
4T2-3	-	0.001	<	<	<	0.002	#
4T2-4	-	-	<	<	<	0.001	#
4T2-5	-	-	<	<	<	0.011	#
4T2-6	-	-	<	<	<	<0.001	#
4T2-7	-	-	<	<	<	<0.001	#
4T2-8	-	-	<	<	<	/	#
4T2-9	-	-	<	<	<	<	#
4T2-10	-	-	<	<	<	<	#
4T2-11	-	-	<	<	<	<	#
4T2-12	-	-	<	<	<	/	#
4T2-13	-	-	<	<	<	<0.001	#
4T2-14	-	-	<	<	<	0.011	#
4T2-15	-	-	-	-	-	-	#
4T2-16	-	-	-	-	-	-	#
4T2-17	-	-	-	-	-	-	#
4T2-18	-	-	-	-	-	-	#
4T2-19	-	-	-	-	-	-	#

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
< = estimated <0.001 V/m based on E in ground.

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

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

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
< = estimated <0.001 V/m based on E in ground.

TABLE 4. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITES (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 [d]
4C1-6	-	0.022	0.016	0.005	0.043	0.023	0.016
4C1-7	-	0.143	0.123	0.077	0.178	0.118	0.030
4C1-8	-	0.104	0.117	0.077	0.131	0.078	0.018
4C1-9	-	0.011	0.019	0.024	0.034	0.032	0.023
4C1-10	-	-	0.090	0.068	0.118	0.106	0.054
4C1-11	-	-	0.160	0.107	0.132	0.146	0.066
4C1-12	-	-	0.104	0.101	0.075	0.093	0.042
4C1-13	-	-	0.040	0.030	0.046	0.065	0.025
4T2-3	-	0.51	0.39	0.194	0.27	0.28	#
4T2-4	-	-	0.27	0.24	0.30	0.25	#
4T2-5	-	-	0.43	0.32	0.20	0.20	#
4T2-6	-	-	0.66	0.46	0.192	0.22	#
4T2-7	-	-	0.42	0.52	0.197	0.28	#
4T2-8	-	-	0.47	0.190	0.22	/	#
4T2-9	-	-	0.49	0.31	0.183	0.25	#
4T2-10	-	-	0.44	0.32	0.155	0.166	#
4T2-11	-	-	0.51	0.40	0.31	0.43	#
4T2-12	-	-	0.47	0.38	0.24	/	#
4T2-13	-	-	0.76	0.31	0.31	0.25	#
4T2-14	-	-	0.61	0.29	0.35	0.21	#
4T2-15	-	-	-	-	-	-	#
4T2-16	-	-	-	-	-	-	#
4T2-17	-	-	-	-	-	-	#
4T2-18	-	-	-	-	-	-	#
4T2-19	-	-	-	-	-	-	#

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.

TABLE 4. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]	1989[d]
4T4-4	-	0.72	0.42	0.185	0.56	0.079	#
4T4-5	-	-	0.58	0.58	4.3	1.12	#
4T4-6	-	-	0.22	0.16	0.61	0.188	#
4T4-7	-	-	0.44	0.29	0.64	0.22	#
4T4-8	-	-	0.42	0.193	0.40	0.23	#
4T4-9	-	-	0.50	0.21	0.27	0.073	#
4T4-10	-	-	0.42	0.22	0.29	0.063	#
4T4-11	-	-	0.40	0.60	2.7	1.27	#
4T4-12	-	-	-	0.75	3.4	1.35	#
4T4-13	-	-	-	-	-	-	#
4T4-14	-	-	-	-	-	-	#
4T4-15	-	-	-	-	-	-	#
4T4-16	-	-	-	-	-	-	#
4T4-17	-	-	-	-	-	-	#
4T4-18	-	-	-	-	-	-	#
4T4-19	-	-	-	-	-	-	#
4T4-20	-	-	-	-	-	-	#
4S1-1	-	-	-	-	8.5	12.2	11.6
4S2-1	-	-	-	-	0.155	0.109	0.032
4S3-1	-	-	-	-	0.65	1.73	0.73

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.

TABLE 5. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988	d 1989
4C1-6	-	0.003	0.003	0.003	0.002	0.003	0.002
4C1-7	-	0.003	0.002	0.001	0.003	0.002	0.001
4C1-8	-	0.003	0.003	0.002	0.003	0.002	0.001
4C1-9	-	0.003	0.003	0.002	0.001	0.002	0.002
4C1-10	-	-	0.002	0.002	0.002	0.002	0.002
4C1-11	-	-	0.002	0.002	0.002	0.002	0.001
4C1-12	-	-	0.002	0.003	0.001	0.002	0.001
4C1-13	-	-	0.002	0.003	0.001	0.003	0.002
4T2-3	-	0.002	0.001	0.001	0.003	0.005	#
4T2-4	-	-	0.001	0.001	0.003	0.006	#
4T2-5	-	-	0.001	0.007	0.017	0.030	#
4T2-6	-	-	0.001	0.006	0.006	0.014	#
4T2-7	-	-	0.001	0.004	0.004	0.007	#
4T2-8	-	-	0.001	0.002	0.004	/	#
4T2-9	-	-	0.001	0.003	0.003	0.005	#
4T2-10	-	-	0.001	0.003	0.003	0.005	#
4T2-11	-	-	0.001	0.004	0.005	0.007	#
4T2-12	-	-	0.002	0.004	0.005	/	#
4T2-13	-	-	0.001	0.005	0.008	0.013	#
4T2-14	-	-	0.002	0.011	0.018	0.029	#
4T2-15	-	-	-	-	-	-	#
4T2-16	-	-	-	-	-	-	#
4T2-17	-	-	-	-	-	-	#
4T2-18	-	-	-	-	-	-	#
4T2-19	-	-	-	-	-	-	#

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.

TABLE 5. 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 [d]
4T4-4	-	0.004	0.002	0.001	0.003	0.003	#
4T4-5	-	-	0.002	0.006	0.010	0.017	#
4T4-6	-	.	0.002	0.001	0.004	0.007	#
4T4-7	-	-	0.001	0.001	0.004	0.005	#
4T4-8	-	-	0.002	0.001	0.004	0.005	#
4T4-9	-	-	0.002	0.001	0.002	0.003	#
4T4-10	-	-	0.001	0.001	0.002	0.002	#
4T4-11	-	-	0.002	0.002	0.012	0.019	#
4T4-12	-	-	-	0.002	0.010	0.016	#
4T4-13	-	-	-	-	-	-	#
4T4-14	-	-	-	-	-	-	#
4T4-15	-	-	-	-	-	-	#
4T4-16	-	-	-	-	-	-	#
4T4-17	-	-	-	-	-	-	#
4T4-18	-	-	-	-	-	-	#
4T4-19	-	-	-	-	-	-	#
4T4-20	-	-	-	-	-	-	#
4S1-1	-	-	-	-	0.035	0.043	0.052
4S2-1	-	-	-	-	0.003	0.002	0.002
4S3-1	-	-	-	-	0.036	0.095	0.028

a = prior to antenna construction.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = both antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.

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

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
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
4T2-4	<	<	0.005	0.008	0.001	0.014	0.017	0.113	0.149
4T2-5	0.018	<	0.092	0.153	0.003	0.23	0.033	2.6	1.31
4T2-6	<	<	0.005	0.008	0.003	0.013	0.014	0.142	0.138
4T2-7	<	<	0.007	0.012	0.001	0.018	0.020	0.165	0.173
4T2-8	<	<	0.004	0.007	0.002	0.012	/	/	0.124
4T2-9	<	<	0.005	0.008	0.002	0.010	0.019	0.137	0.12
4T2-10	<	<	0.004	0.007	0.002	0.011	0.020	0.112	0.113
4T2-11	<	<	0.003	0.005	0.002	0.012	0.010	0.130	0.22
4T2-12	<	<	0.002	0.003	0.002	0.014	/	/	0.095
4T2-13	<	<	0.005	0.008	0.002	0.012	0.010	0.121	0.125
4T2-14	0.030	<	0.155	0.26	0.003	0.186	0.026	2.5	1.66
4T2-15	-	-	-	-	-	-	-	-	2.3
4T2-16	-	-	-	-	-	-	-	-	1.92
4T2-17	-	-	-	-	-	-	-	-	0.69
4T2-18	-	-	-	-	-	-	-	-	0.28
4T2-19	-	-	-	-	-	-	-	-	0.107

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.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.
< = estimated <0.001 V/m based on E in ground.

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

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4T4-4	<	<	0.006	0.010	0.002	0.005	0.008	0.028	0.067
4T4-5	0.033	0.008	0.20	0.33	0.019	0.27	0.089	1.31	4.8
4T4-6	0.005	<	0.023	0.038	0.002	0.021	0.011	0.064	0.175
4T4-7	<	<	0.006	0.010	0.002	0.015	0.008	0.090	0.133
4T4-8	<	<	0.008	0.013	0.002	0.016	0.007	0.083	0.145
4T4-9	<	<	0.009	0.015	0.001	0.008	0.009	0.047	0.095
4T4-10	<	<	0.007	0.012	0.001	0.001	0.011	0.057	0.112
4T4-11	<	0.005	0.38	0.63	0.025	0.43	0.20	4.4	5.0
4T4-12	0.055	0.005	0.43	0.72	0.017	0.30	0.150	2.1	4.5
4T4-13	-	-	-	-	-	-	-	-	0.26
4T4-14	-	-	-	-	-	-	-	-	0.88
4T4-15	-	-	-	-	-	-	-	-	2.7
4T4-16	-	-	-	-	-	-	-	-	5.9
4T4-17	-	-	-	-	-	-	-	-	4.5
4T4-18	-	-	-	-	-	-	-	-	4.8
4T4-19	-	-	-	-	-	-	-	-	1.16
4T4-20	-	-	-	-	-	-	-	-	0.32
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.

- = measurement point not established.
/ = measurement not taken.
= measurement not possible.
* = data cannot be extrapolated.
< = estimated <0.001 V/m based on E in ground.

TABLE 7. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4C1-6	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.005	0.030
4C1-7	<0.001	<0.001	<0.001	*	0.005	0.006	0.024	0.023	0.091
4C1-8	<0.001	<0.001	<0.001	*	0.004	0.004	0.017	0.016	0.076
4C1-9	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.006	0.030
4C1-10	<0.001	<0.001	<0.001	*	0.005	0.004	0.026	0.023	0.087
4C1-11	<0.001	<0.001	<0.001	*	0.006	0.005	0.028	0.028	0.113
4C1-12	<0.001	<0.001	<0.001	*	0.004	0.003	0.016	0.016	0.068
4C1-13	<0.001	<0.001	<0.001	*	0.002	0.002	0.012	0.011	0.051
4T2-3	1.31	0.22	6.3	10.5	1.36	15.2	7.7	76	131
4T2-4	1.05	0.22	5.0	8.3	1.70	10.7	6.2	68	135
4T2-5	1.18	0.24	5.3	8.8	1.46	12.7	8.2	62	86
4T2-6	1.11	0.27	4.4	7.3	2.2	12.4	10.4	56	105
4T2-7	1.13	0.23	5.3	8.8	1.31	9.7	8.8	71	90
4T2-8	1.32	0.25	5.7	9.5	1.81	15.8	/	/	141
4T2-9	1.17	0.21	5.1	8.5	1.46	13.7	7.1	63	119
4T2-10	0.97	0.22	4.1	6.8	1.84	10.5	8.1	50	96
4T2-11	1.14	0.21	5.0	8.3	2.2	10.7	9.6	122	182
4T2-12	1.06	0.21	4.3	7.2	1.93	13.5	/	/	99
4T2-13	1.12	0.64	5.4	9.0	1.74	14.9	8.2	71	138
4T2-14	1.07	0.175	5.1	8.5	1.66	14.3	6.6	56	124
4T2-15	-	-	-	-	-	-	-	-	73
4T2-16	-	-	-	-	-	-	-	-	88
4T2-17	-	-	-	-	-	-	-	-	104
4T2-18	-	-	-	-	-	-	-	-	95
4T2-19	-	-	-	-	-	-	-	-	107

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.

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

TABLE 7. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO.. MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4T4-4	0.33	0.181	1.46	2.4	1.63	3.7	7.2	16.5	42
4T4-5	13.8	2.0	81.	135.	14.0	194.	68	910	2100
4T4-6	1.22	0.22	6.2	10.3	2.2	12.9	10.3	62	140
4T4-7	0.94	0.175	5.5	9.2	2.0	14.1	9.1	62	119
4T4-8	0.91	0.188	5.3	8.8	1.36	10.7	6.8	65	106
4T4-9	0.29	0.130	1.32	2.2	1.08	3.0	7.5	18.1	47
4T4-10	0.29	0.169	1.63	2.7	1.35	3.9	5.1	16.0	39
4T4-11	0.59	1.82	89.	148.	10.7	178.	50	850	1870
4T4-12	21.	2.2	118.	197.	13.8	260.	40	760	1950
4T4-13	-	-	-	-	-	-	-	-	64
4T4-14	-	-	-	-	-	-	-	-	220
4T4-15	-	-	-	-	-	-	-	-	760
4T4-16	-	-	-	-	-	-	-	-	3000
4T4-17	-	-	-	-	-	-	-	-	130
4T4-18	-	-	-	-	-	-	-	-	3200
4T4-19	-	-	-	-	-	-	-	-	750
4T4-20	-	-	-	-	-	-	-	-	200
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#
4S2-1	-	-	-	-	0.005	0.005	0.026	0.026	0.126
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#

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

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

TABLE 8. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4C1-6	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003
4C1-7	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-8	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-9	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003
4C1-10	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-11	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-12	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002
4C1-13	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003
4T2-3	0.047	0.001	0.22	0.37	0.008	0.55	0.040	2.8	5.7
4T2-4	0.049	0.001	0.24	0.40	0.008	0.57	0.041	2.9	5.8
4T2-5	0.197	<0.001	1.00	1.67	0.011	2.4	0.061	12.4	24
4T2-6	0.058	0.001	0.44	0.73	0.006	1.16	0.020	5.0	10.3
4T2-7	0.046	0.001	0.22	0.37	0.006	0.59	0.024	2.6	5.4
4T2-8	0.045	0.001	0.22	0.37	0.006	0.59	/	/	5.6
4T2-9	0.029	0.001	0.138	0.23	0.007	0.38	0.027	1.72	3.4
4T2-10	0.033	0.001	0.149	0.25	0.006	0.39	0.027	1.78	3.5
4T2-11	0.043	0.001	0.21	0.35	0.006	0.56	0.025	2.6	5.0
4T2-12	0.047	0.001	0.23	0.38	0.006	0.61	/	/	5.6
4T2-13	0.086	<0.001	0.43	0.72	0.005	1.14	0.020	5.1	10.1
4T2-14	0.21	<0.001	1.03	1.72	0.012	2.5	0.061	11.9	25
4T2-15	-	-	-	-	-	-	-	-	33
4T2-16	-	-	-	-	-	-	-	-	28
4T2-17	-	-	-	-	-	-	-	-	13.6
4T2-18	-	-	-	-		-	-	-	8.6
4T2-19	-	-	-	-	-	-	-	-	5.9

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.

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

TABLE 8. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amp	1986 NEW 6 amp	1986 SEW 6 amp	1986 SEW 10 amp (EX)	1987 NS 15 amp	1987 EW 15 amp	1988 NS 75 amp	1988 EW 75 amp	1989 B 150 amp
4T4-4	0.019	<0.001	0.096	0.160	0.005	0.24	0.027	1.15	2.5
4T4-5	0.114	0.001	0.57	0.95	0.008	1.40	0.033	6.9	13.9
4T4-6	0.045	0.001	0.22	0.37	0.008	0.53	0.034	2.7	5.3
4T4-7	0.038	0.001	0.186	0.31	0.008	0.45	0.033	2.3	4.4
4T4-8	0.035	0.001	0.179	0.30	0.007	0.43	0.033	2.1	4.2
4T4-9	0.025	0.21	0.118	0.197	0.005	0.29	0.027	1.41	2.8
4T4-10	0.022	<0.001	0.116	0.193	0.005	0.27	0.027	1.33	2.7
4T4-11	0.161	0.001	0.80	1.33	0.011	1.89	0.042	8.9	18.7
4T4-12	0.115	0.001	0.58	0.97	0.010	1.37	0.041	7.1	14.5
4T4-13	-	-	-	-	-	-	-	-	2.7
4T4-14	-	-	-	-	-	-	-	-	7.0
4T4-15	-	-	-	-	-	-	-	-	11.9
4T4-16	-	-	-	-	-	-	-	-	18
4T4-17	-	-	-	-	-	-	-	-	14.3
4T4-18	-	-	-	-	-	-	-	-	16.8
4T4-19	-	-	-	-	-	-	-	-	9.8
4T4-20	-	-	-	-	-	-	-	-	5.9
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#
4S2-1	-	-	-	-	<0.001	<0.001	0.001	<0.001	0.002
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	#

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

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

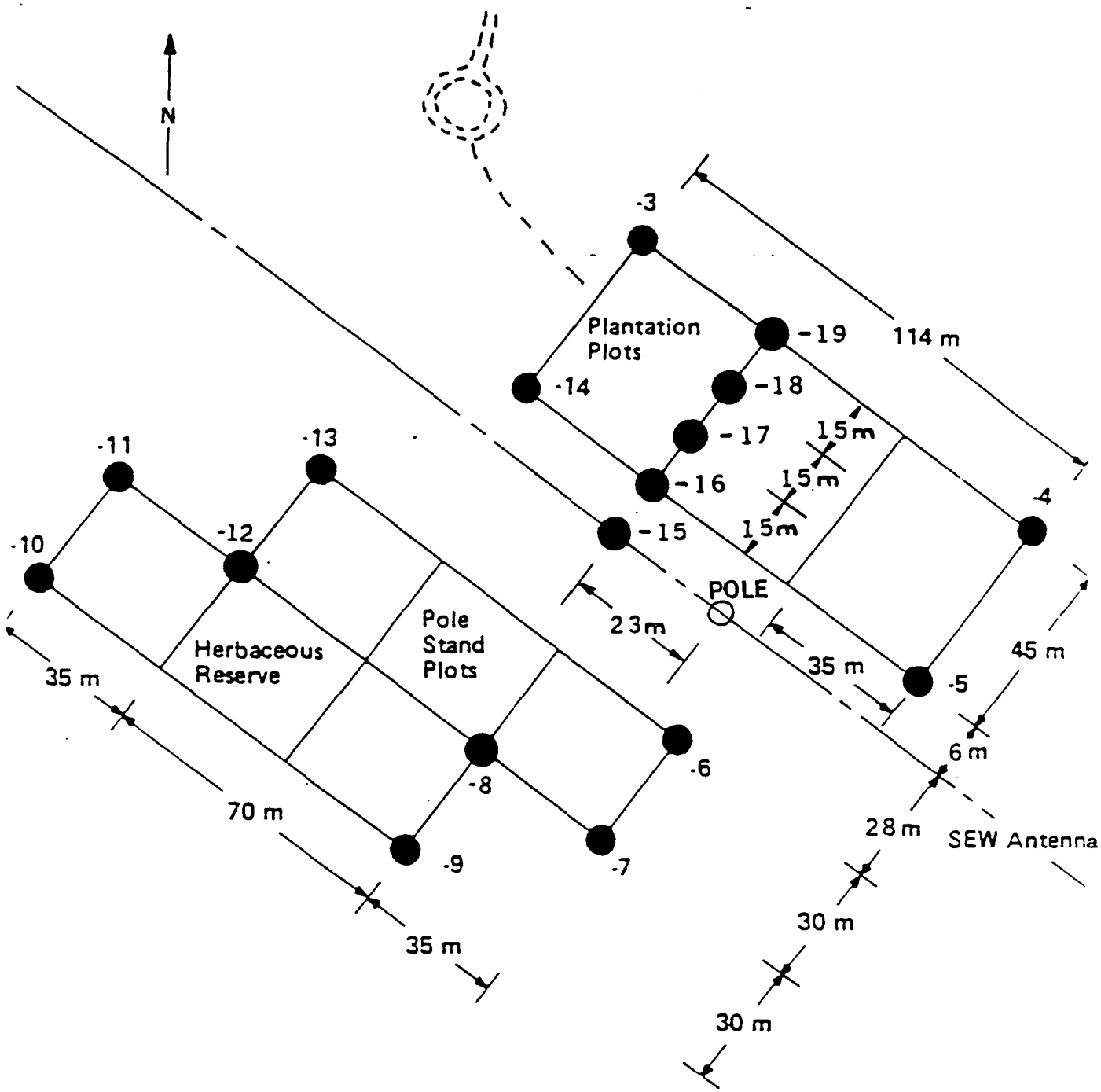


FIGURE 1. MARTELL'S LAKE (OVERHEAD): ML; 4T2-3 THRU -19

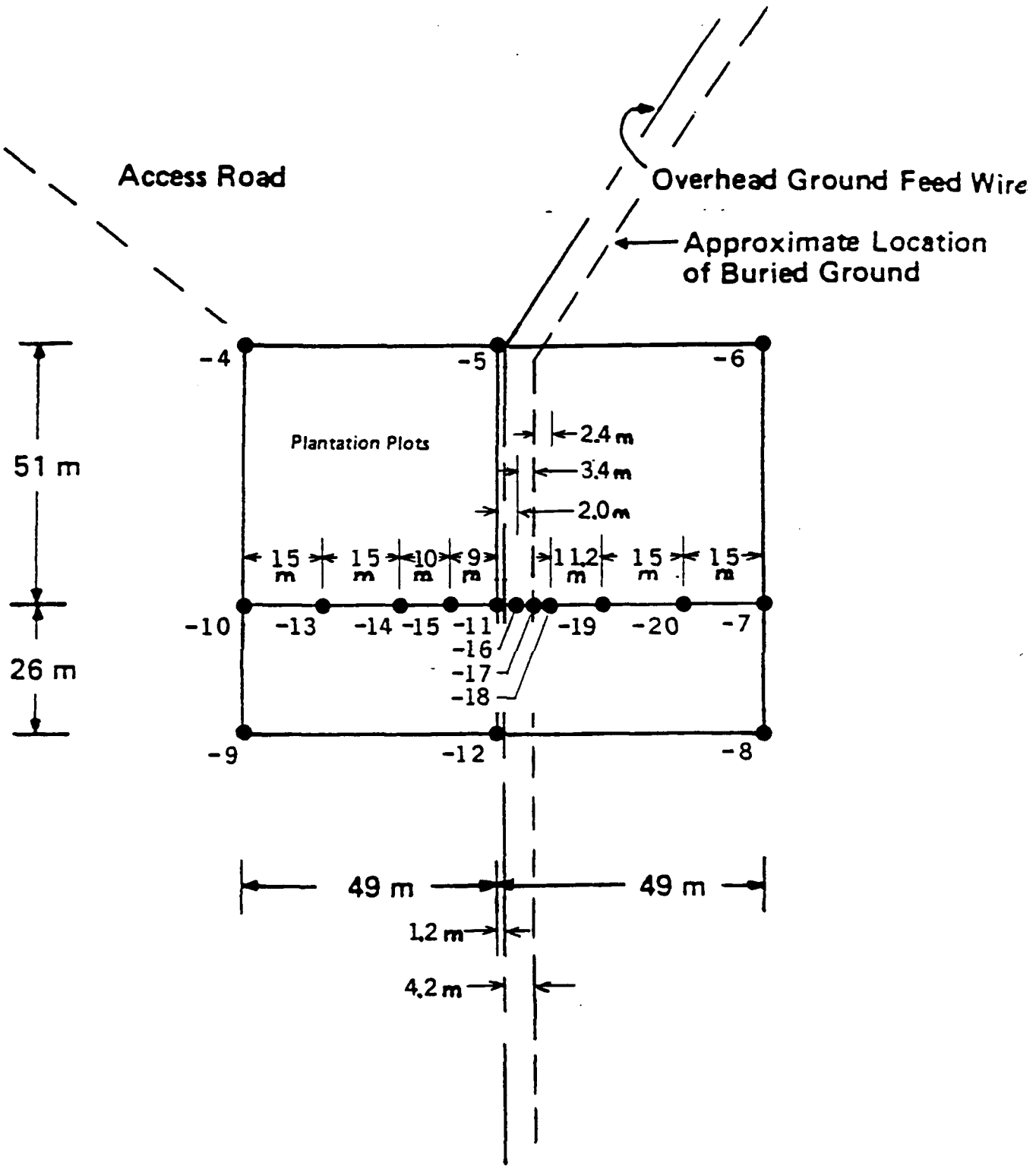


FIGURE 2. MARTELL'S LAKE (BURIED): EP; 4T4-4 THROUGH 12.

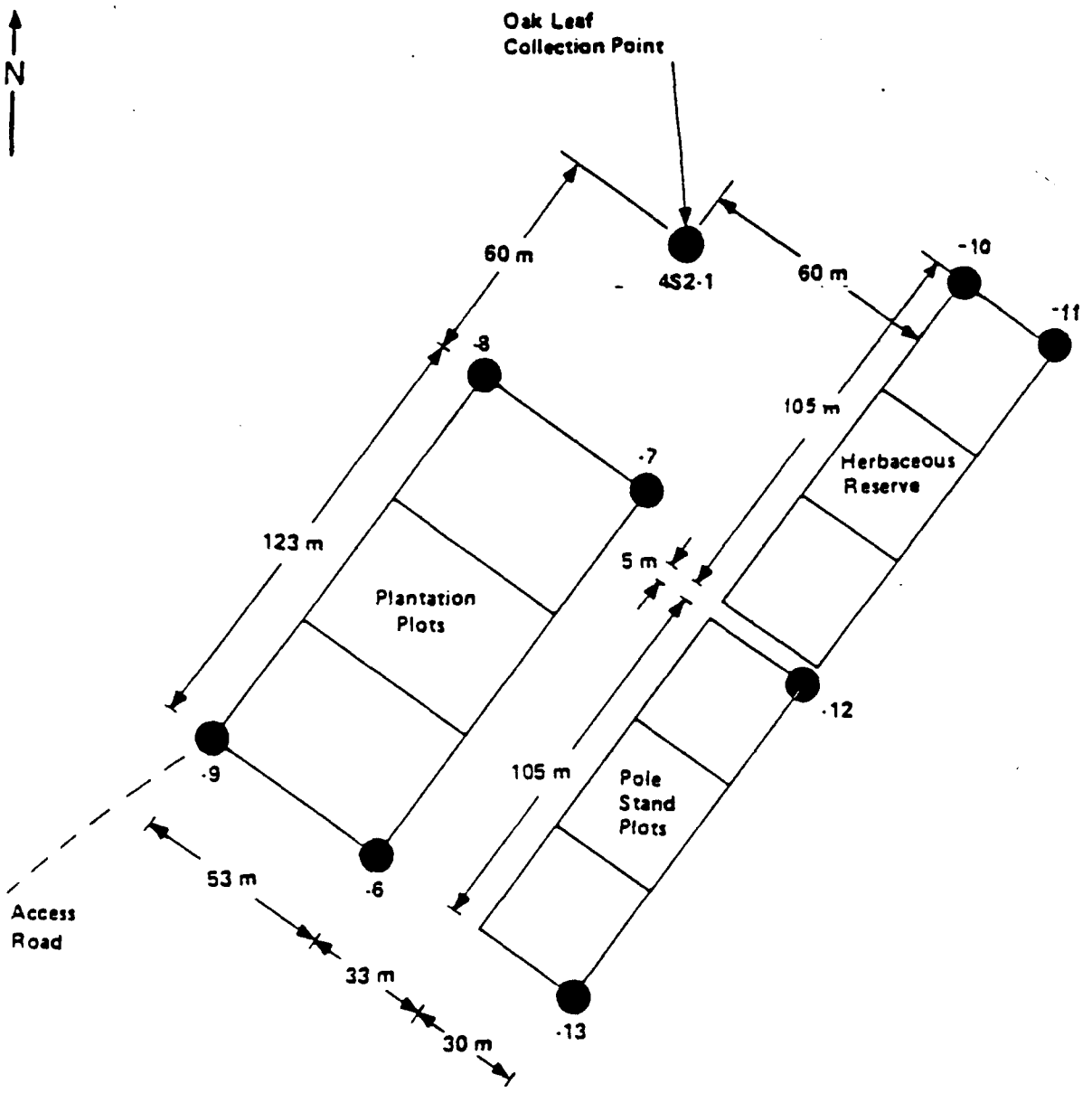


FIGURE 3. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

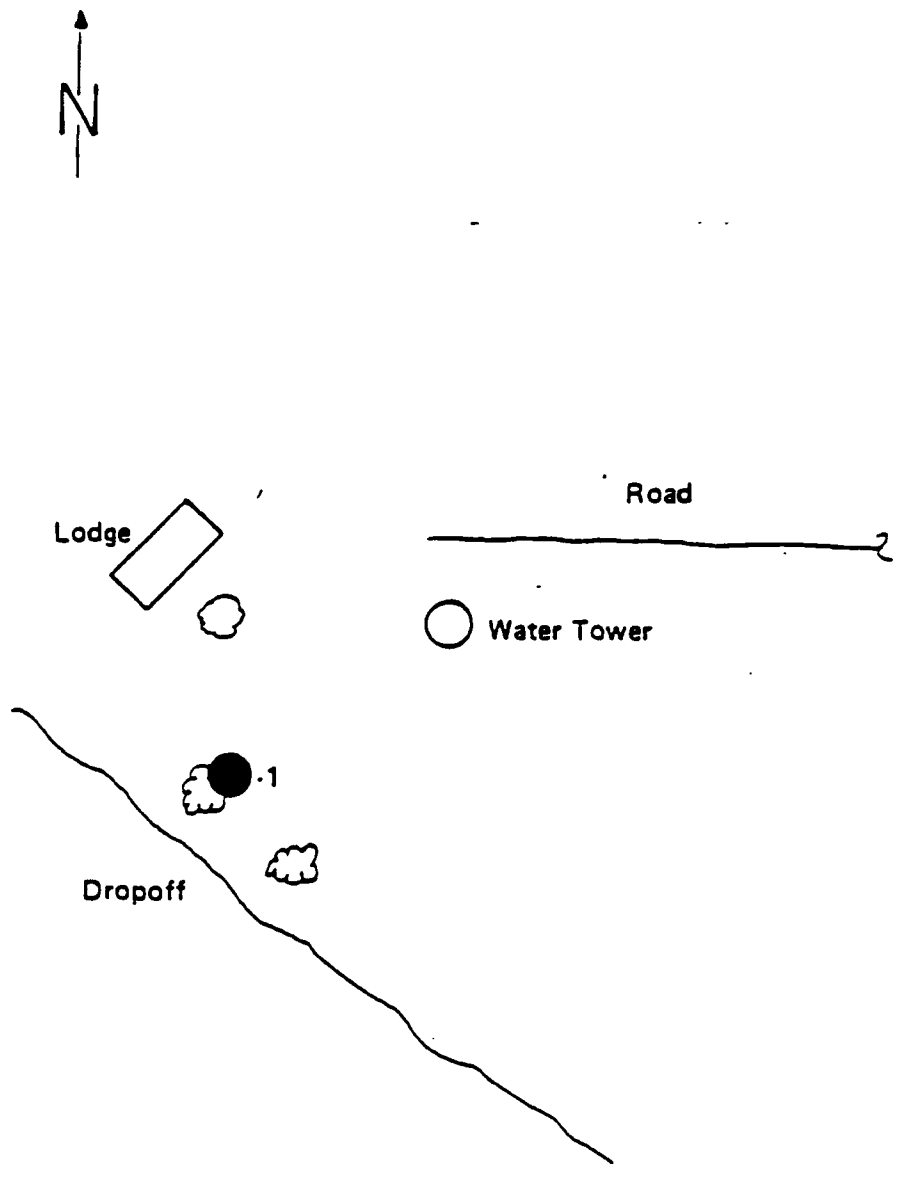


FIGURE 4. MEASUREMENT POINT AT RED MAPLE LEAF SAMPLE COLLECTION SITE; 4S1-1.

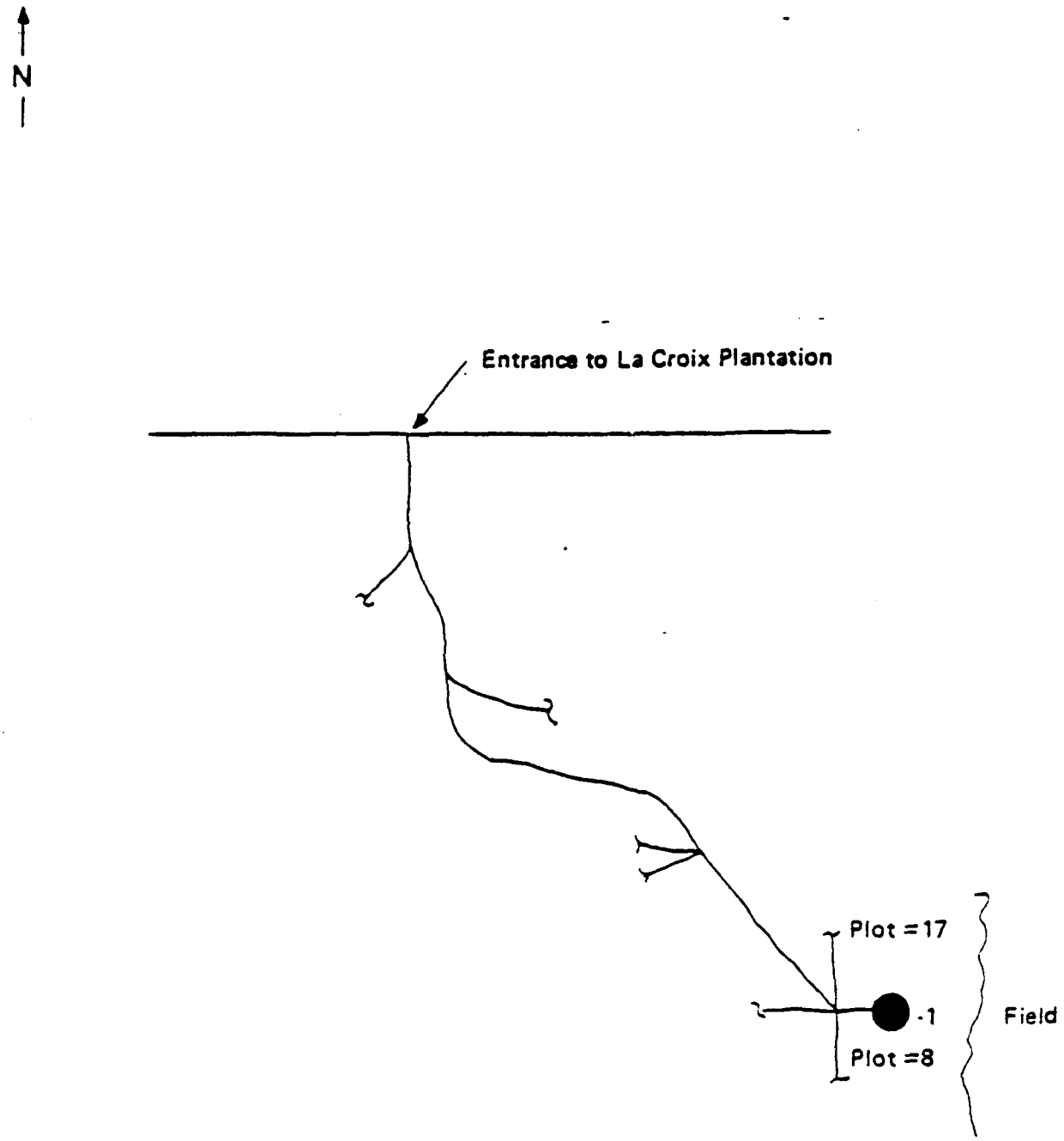


FIGURE 5. MEASUREMENT POINT AT THE PINE NEEDLE SAMPLE COLLECTION SITE; 4S3-1.

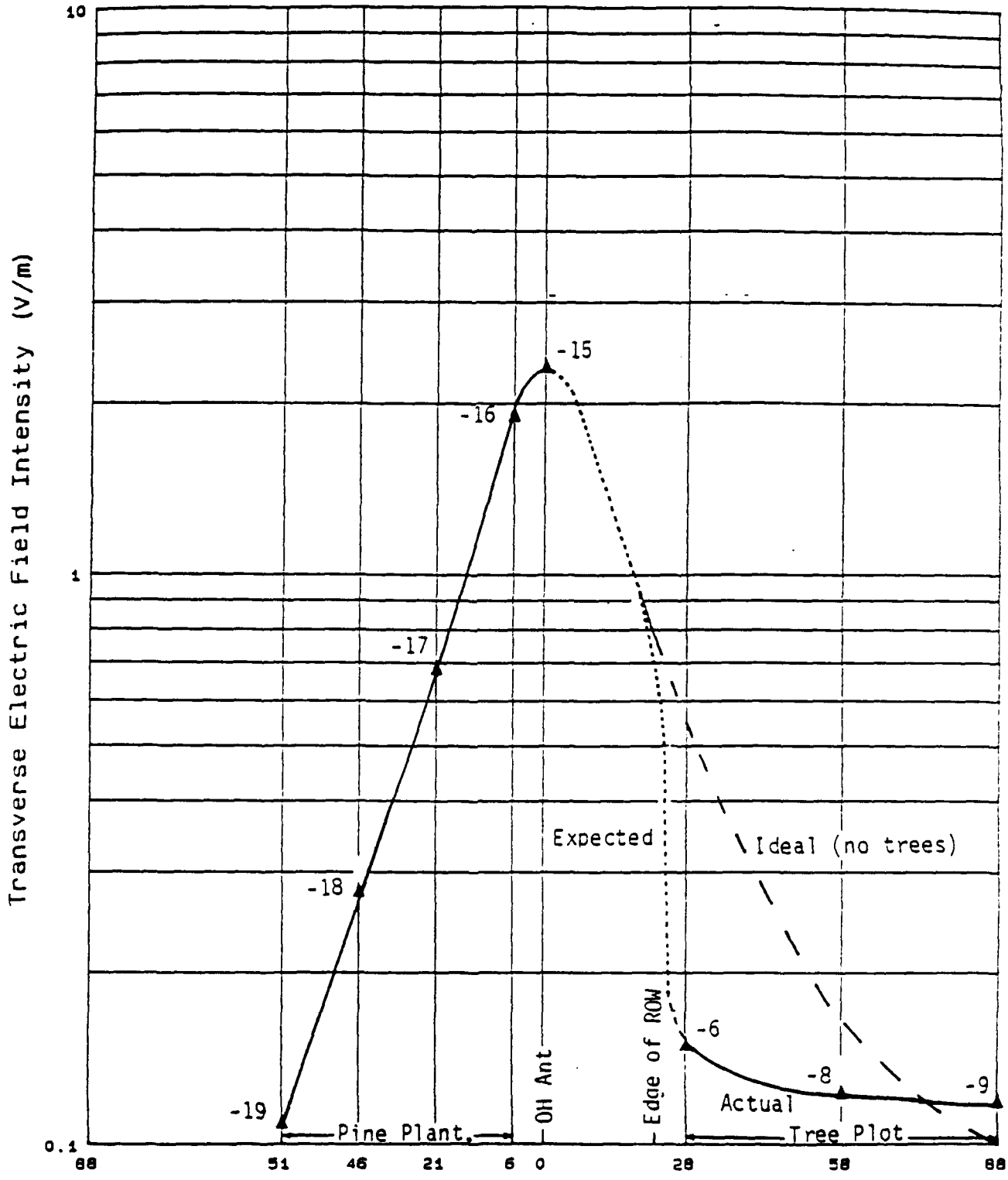


FIGURE 6. 76 Hz TRANSVERSE ELECTRIC FIELD PROFILES, MARTELL'S LAKE (OVERHEAD): ML: 4T2-8, 9, 15-19.

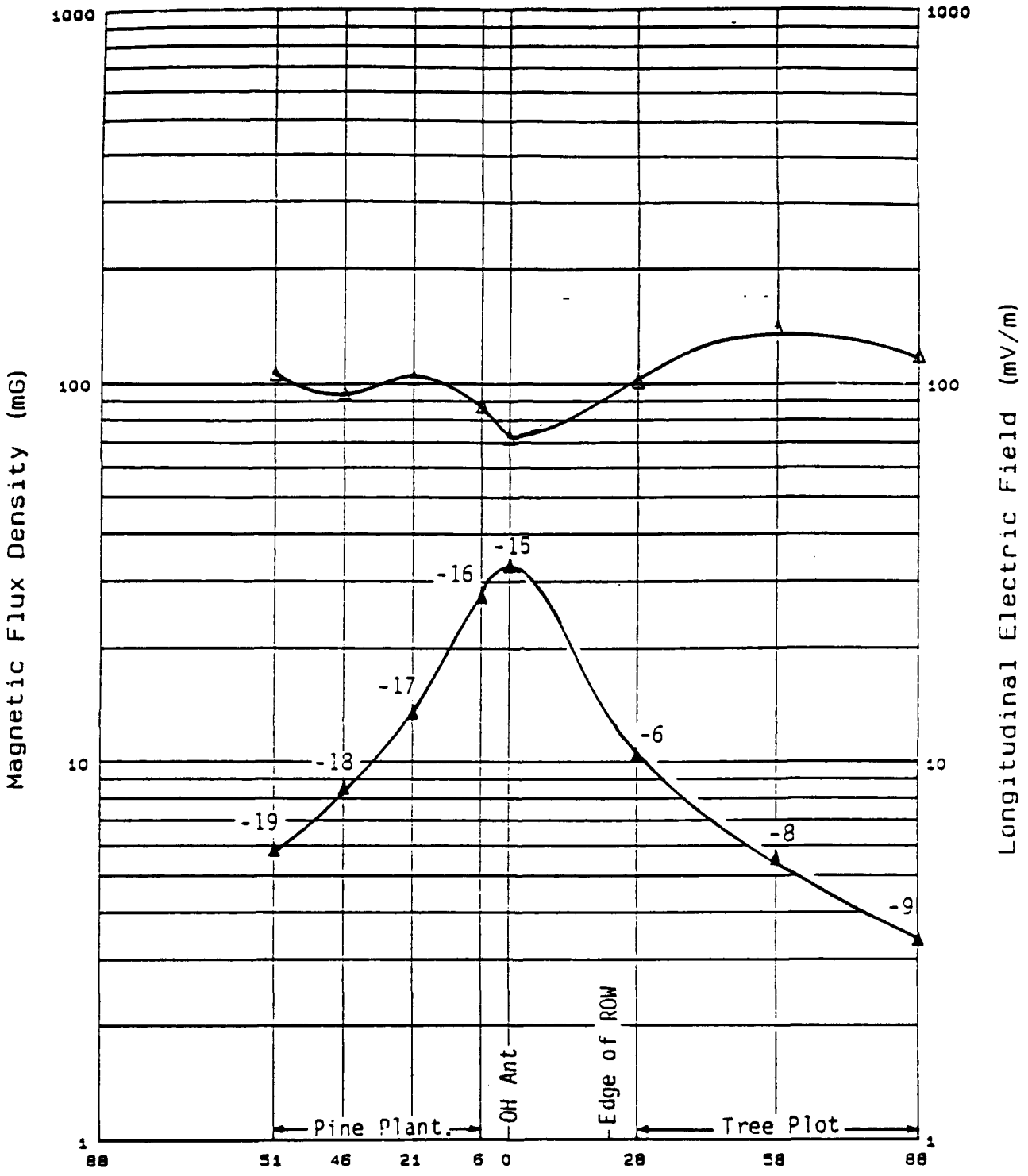


FIGURE 7. 76 Hz MAGNETIC & LONGITUDINAL ELECTRIC FIELD PROFILES, MARTELL'S LAKE (OVERHEAD): ML: 4T2-8, 9, 15-19.

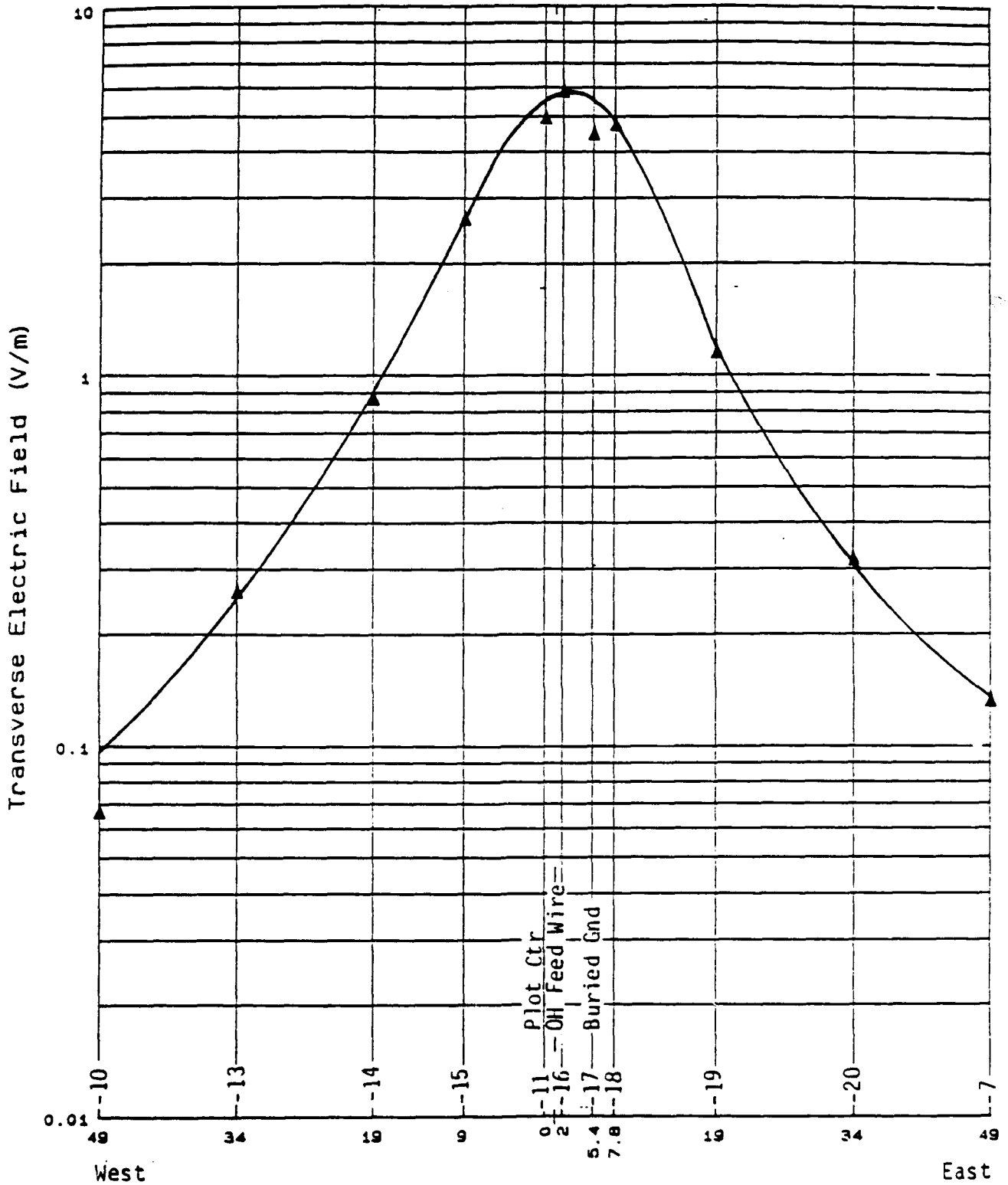


FIGURE 8. TRANSVERSE ELECTRIC FIELD PROFILE, MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

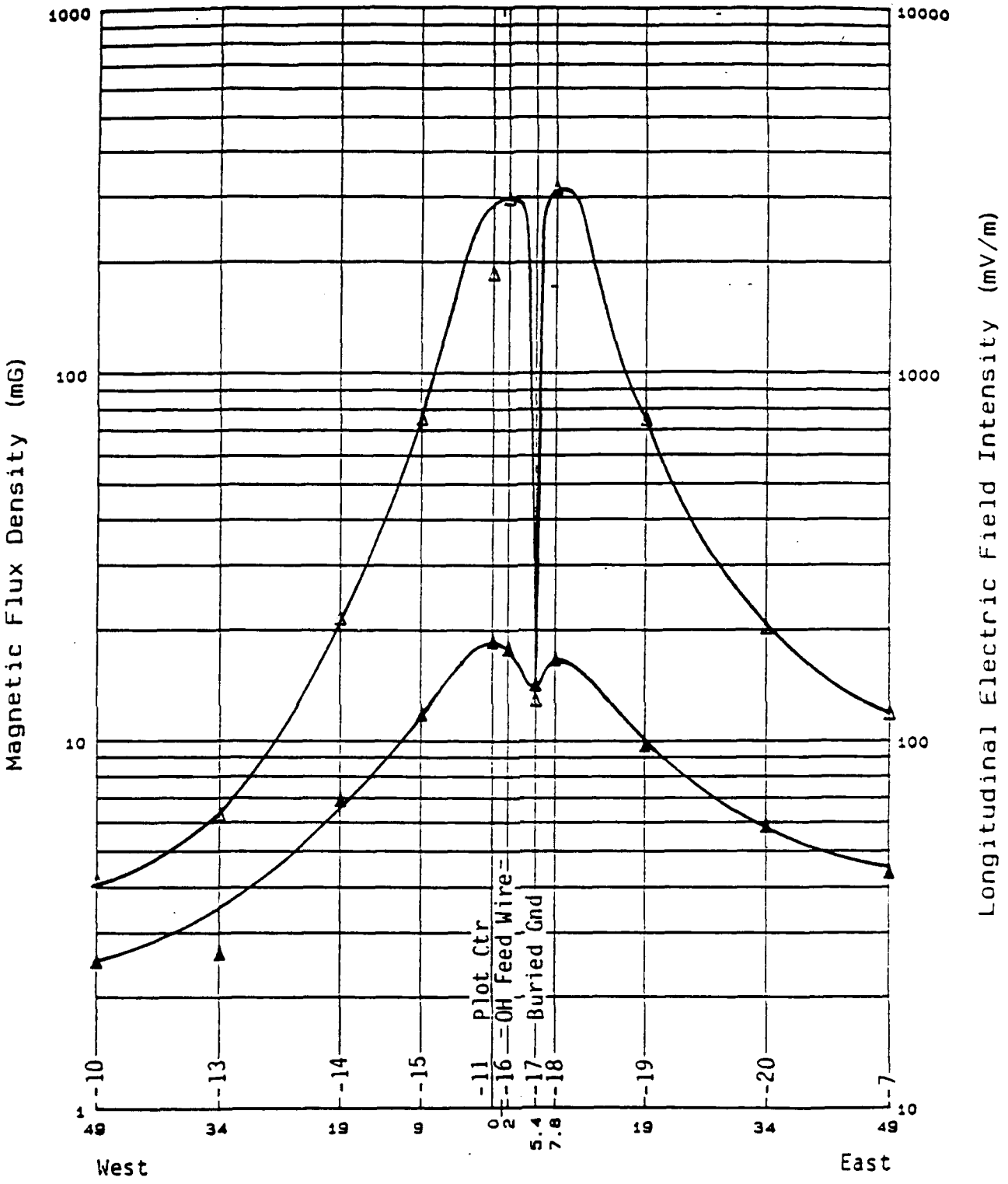


FIGURE 9. 76 Hz MAGNETIC & LONGITUDINAL ELECTRIC FIELD PROFILES, MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

Table 1A. Estimated average yearly exposure levels by plot for control hardwood site for 1985,1986, 1987, 1988 and 1989.

	1985	1986	1987	1988	1989
60 H					
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 H					
TRANSVERSE EW (V/m)					
PLOT 1	0.0000	0.0000	0.0000	0.0000	0.0010
PLOT 2	0.0000	0.0000	0.0000	0.0000	0.0010
PLOT 3	0.0000	0.0000	0.0000	0.0000	0.0010
LONGITUDINAL EW (mV/m)					
PLOT 1	0.0000	0.0000	0.0025	0.0100	0.0440
PLOT 2	0.0000	0.0000	0.0029	0.0126	0.0546
PLOT 3	0.0000	0.0000	0.0034	0.0152	0.0651
MAGNETIC FLUX EW (mG)					
PLOT 1	0.0000	0.0000	0.0000	0.0000	0.0025
PLOT 2	0.0000	0.0000	0.0000	0.0000	0.0025
PLOT 3	0.0000	0.0000	0.0000	0.0000	0.0025

Table 1B. Estimated average yearly exposure levels by plot for control plantation site for 1985, 1986, 1987, 1988 and 1989.

	1985	1986	1987	1988	1989
60 H					
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	0.0500	0.0500	0.0500	0.0500	
PLOT 2	0.0646	0.0646	0.0646	0.0646	
PLOT 3	0.0791	0.0791	0.0791	0.0791	
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 H					
TRANSVERSE EW (V/m)					
PLOT 1	0.0000	0.0000	0.0000	0.0000	0.0010
PLOT 2	0.0000	0.0000	0.0000	0.0000	0.0010
PLOT 3	0.0000	0.0000	0.0000	0.0000	0.0010
LONGITUDINAL EW (mV/m)					
PLOT 1	0.0000	0.0000	0.0025	0.0102	0.0449
PLOT 2	0.0000	0.0000	0.0031	0.0132	0.0573
PLOT 3	0.0000	0.0000	0.0036	0.0163	0.0697
MAGNETIC FLUX EW (mG)					
PLOT 1	0.0000	0.0000	0.0000	0.0000	0.0025
PLOT 2	0.0000	0.0000	0.0000	0.0000	0.0025
PLOT 3	0.0000	0.0000	0.0000	0.0000	0.0025

Table 1C. Estimated average yearly exposure levels by plot for antenna hardwood site for 1985, 1986, 1987, 1988 and 1989.

	1985	1986	1987	1988	1989
60 H					
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 H					
TRANSVERSE EW (V/m)					
PLOT 1	0.0000	0.0130	0.0356	0.0711	0.2238
PLOT 2	0.0000	0.0130	0.0356	0.0711	0.2238
PLOT 3	0.0000	0.0130	0.0356	0.0711	0.2238
LONGITUDINAL EW (mV/m)					
PLOT 1	0.0000	5.0830	12.8410	82.2323	112.3500
PLOT 2	0.000	5.0830	12.8410	78.0708	112.3500
PLOT 3	0.0000	5.0830	12.8410	73.9093	112.3500
MAGNETIC FLUX EW (mG)					
PLOT 1	0.0000	0.3076	0.8092	3.4658	6.8361
PLOT 2	0.0000	0.3076	0.8092	3.4658	6.8361
PLOT 3	0.0000	0.3076	0.8092	3.4658	6.8361

Table 1D. Estimated average yearly exposure levels by plot for antenna plantation site for 1985, 1986, 1987, 1988 and 1989.

	1985	1986	1987	1988	1989
60 H					
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 H					
TRANSVERSE EW (V/m)					
PLOT 1	0.0000	0.0311	0.0614	0.4362	0.2983
PLOT 2	0.0000	0.0311	0.0614	0.4362	0.2983
PLOT 3	0.0000	0.0311	0.0614	0.4362	0.2983
LONGITUDINAL EW (mV/m)					
PLOT 1	0.0000	5.0830	12.8410	77.0920	112.3500
PLOT 2	0.0000	5.0830	12.8410	72.5738	112.3500
PLOT 3	0.0000	5.0830	12.8410	68.0556	112.3500
MAGNETIC FLUX EW (mG)					
PLOT 1	0.0000	0.4289	1.0977	4.9401	8.2701
PLOT 2	0.0000	0.4289	1.0977	4.9401	8.2701
PLOT 3	0.0000	0.4289	1.0977	4.9401	8.2701

Table 1E. Estimated average yearly exposure levels by plot for ground plantation site for 1985, 1986, 1987, 1988 and 1989.

	1985	1986	1987	1988	1989
60 H					
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 H					
TRANSVERSE EW (V/m)					
PLOT 1	0.0000	0.2506	0.2506	1.9393	2.0561
PLOT 2	0.0000	0.0727	0.0727	0.5531	0.8357
PLOT 3	0.0000	0.1616	0.1616	1.2462	1.4459
LONGITUDINAL EW (mV/m)					
PLOT 1	0.0000	38.1698	86.0053	393.2960	823.9260
PLOT 2	0.0000	6.5540	23.4046	184.5830	465.5572
PLOT 3	0.0000	22.3619	54.7049	288.9393	644.7413
MAGNETIC FLUX EW (mG)					
PLOT 1	0.0000	0.3430	0.8179	4.0315	13.7774
PLOT 2	0.0000	0.2231	0.5958	2.8562	12.8773
PLOT 3	0.0000	0.2831	0.7068	3.4439	13.3273

To: Glenn Mroz

Date: July 11, 1990

From: Dave Reed

cc: M. Jurgensen
M. Gale
J. Bruhn
H. Liechty
B. Reed
P. Cattelino

Subject: 1989 ELF Field Exposure Information

Now that we have all the samples for 1989 analyzed, we can begin to look at the effects of 1989 fields on the study sites. The attached equations can be used to interpolate field exposure levels to any point within the study sites. Like last year, the X coordinate is distance from the antenna (using IITRI's measurement data) while Y is the distance along the antenna. Examples are given on the attached maps. In 1989, operation during the growing season was at 130 amps with both antennas operating simultaneously (indicating no need for NS or EW equations like we used last year).

While IITRI provided more measurements in the plantations in 1989, there were no statistically significant differences in the interpolation equaitons between the hardwood stands and the plantations (in other words, variables indicating plantation measurements were not significant in the regression analyses). I expect they will not be happy with this but that is the way it came out. They probably will be happy that there were no significant trends across the plots in the longitudinal fields at the antenna site, hence I recommend using the average value from all the measurement points.

There were no detailed information on hours of operation by month or number of on-off cycles in the 1989 memo from IITRI (included as an Appendix in our last annual report). The hours of operation could be inferred from what they gave for the growing season months but I would prefer to see if we could get a table of operational hours and number of on-off cycles from IITRI like they provided in past years.

Like last year, there is no set way of incorporating these data into our analyses. What has been attempted was included in last year's report. If anyone has spectacular success they should share the methods with the group. Likewise, if anyone has any problems using the interpolation equations, please let me know as soon as possible so I can correct and distribute the corrected information to the group.

1989 ELF Exposure Interpolation Equations

	Equation	R2	MSE
Control Site			
Transverse (76 Hz)	V/m=.001		
Long. (76 Hz)	mV/m=.0387 + .0003022Y	85.3	.00015
Magnetic (76 Hz)	mG =.0025		
Antenna Site			
Transverse (76 Hz)	V/m=3.6842/X	96.1	.02341
Long. (76 Hz)	mV/m=112.35		
Magnetic (76 Hz)	mG =7.752 + 110.913/X - .0773*X	98.5	1.225
Ground Site			
Transverse (76 Hz)	V/m=17.728/X	87.8	1.105
Long. (76 Hz)	mV/m=466.795 + 7586.943/X - 12.061*X	97.1	42131
Magnetic (76 Hz)	mG =12.736 + 15.872/X - 0.203*X	92.6	3.0171

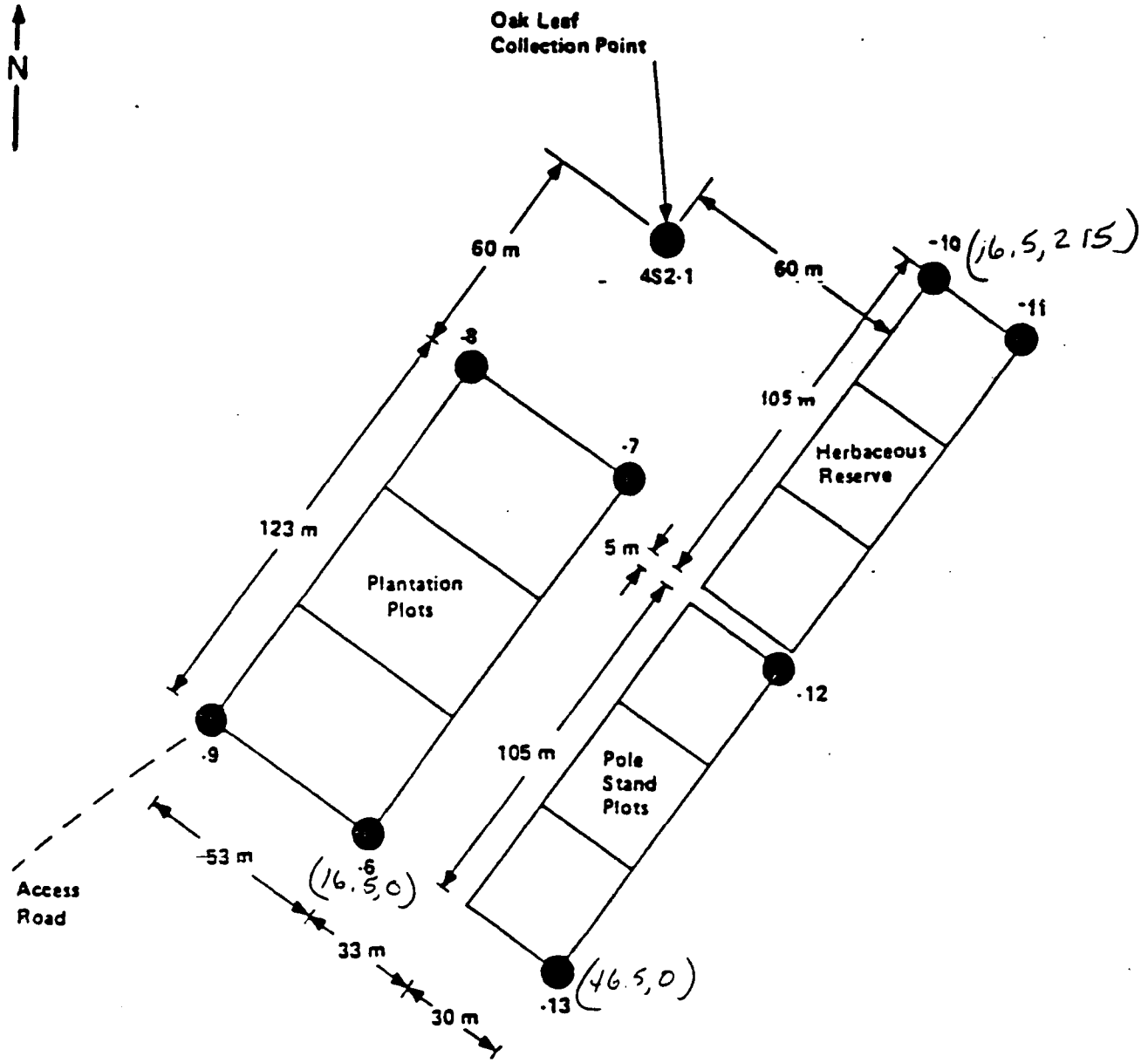


FIGURE 3. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

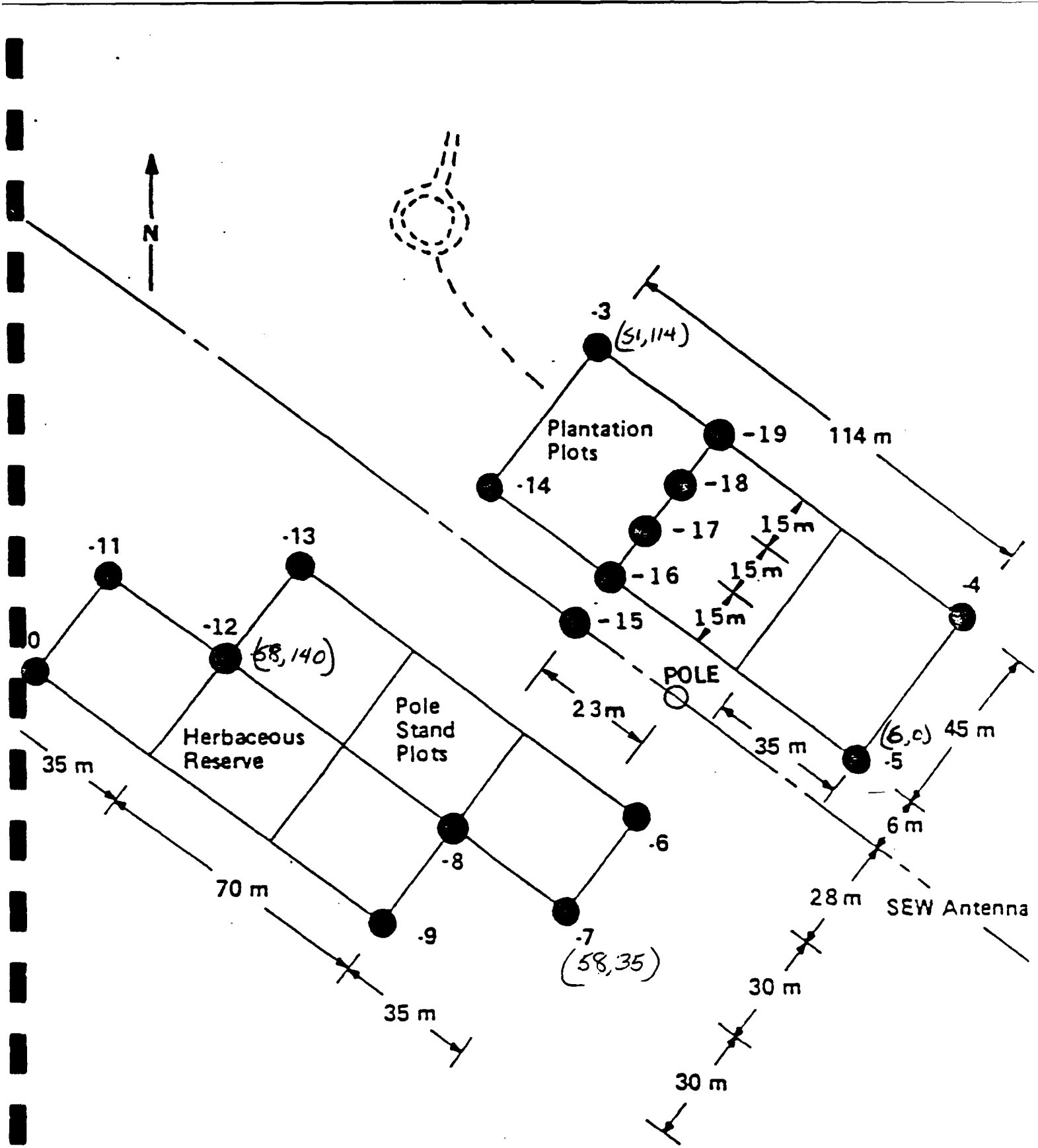


FIGURE 1. MARTELL'S LAKE (OVERHEAD): ML; 4T2-3 THRU -19

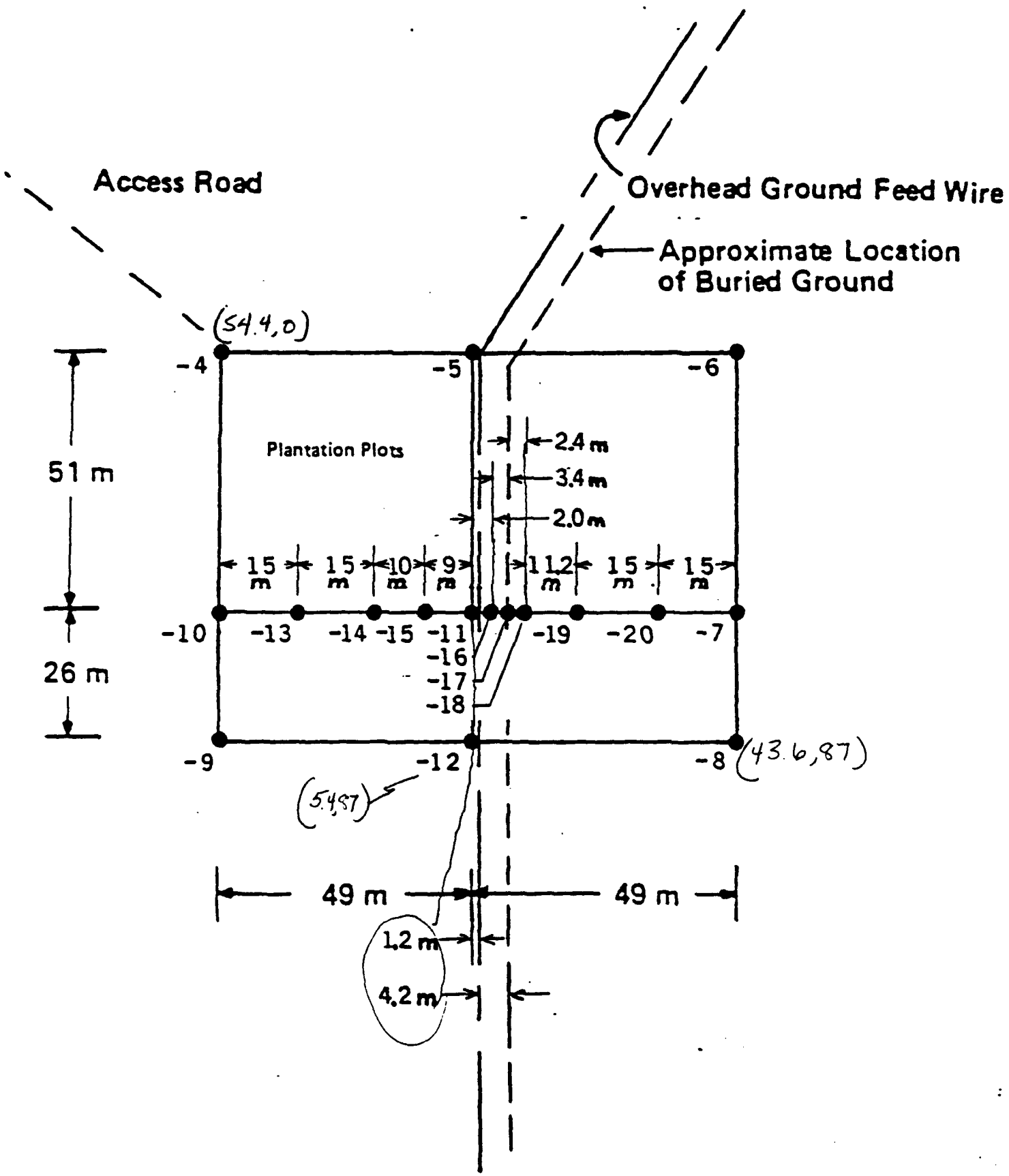


FIGURE 2. MARTELL'S LAKE (BURIED): EP; 4T4-4 THROUGH 12.

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799
312/567-4000

since 1936

6 September 1990

Glenn D. Mroz, PhD
School of Forestry and Wood Products
Michigan Technological University
Houghton, MI 49931

Subject: ELF Longitudinal Electric Field Data

Dear Glenn:

As agreed in our 20 March meeting in Houghton, Michigan, IITRI has performed an extensive survey of the subject fields at MTU ecological monitoring treatment sites at the Naval Radio Transmitting Facility - Republic. In addition to the survey, fixed measurement points have been established to determine the temporal variation of the subject field. Preliminary data are enclosed and include:

Antenna Site, 4T2

- o E-field survey values and measurement locations
- o survey values, locations, and contours (2)
- o survey values, color coded contours (2)
- o location of fixed measurement points
- o table of E-field values at fixed points (6/28 - 8/21)

Ground Site, 4T4

- o E-field survey values and measurement locations
- o survey values, locations, and contours
- o survey values, color coded contours
- o location of fixed measurement points
- o table of E-field values at fixed points (6/28 - 8/21).

Other EM values (transverse E-field intensity and magnetic flux density) were determined at historical measurement points on these sites at about the same time, but not on as extensive a grid, as the longitudinal E-field survey. In addition to historical points, several new measurement points were added to more accurately assess transverse E-field and magnetic gradients across your hardwood stand at the antenna site. All EM fields at historical points on the control site were measured within a day of characterizing the fields at the treatment sites. These other EM data will be forwarded to you at a later date.

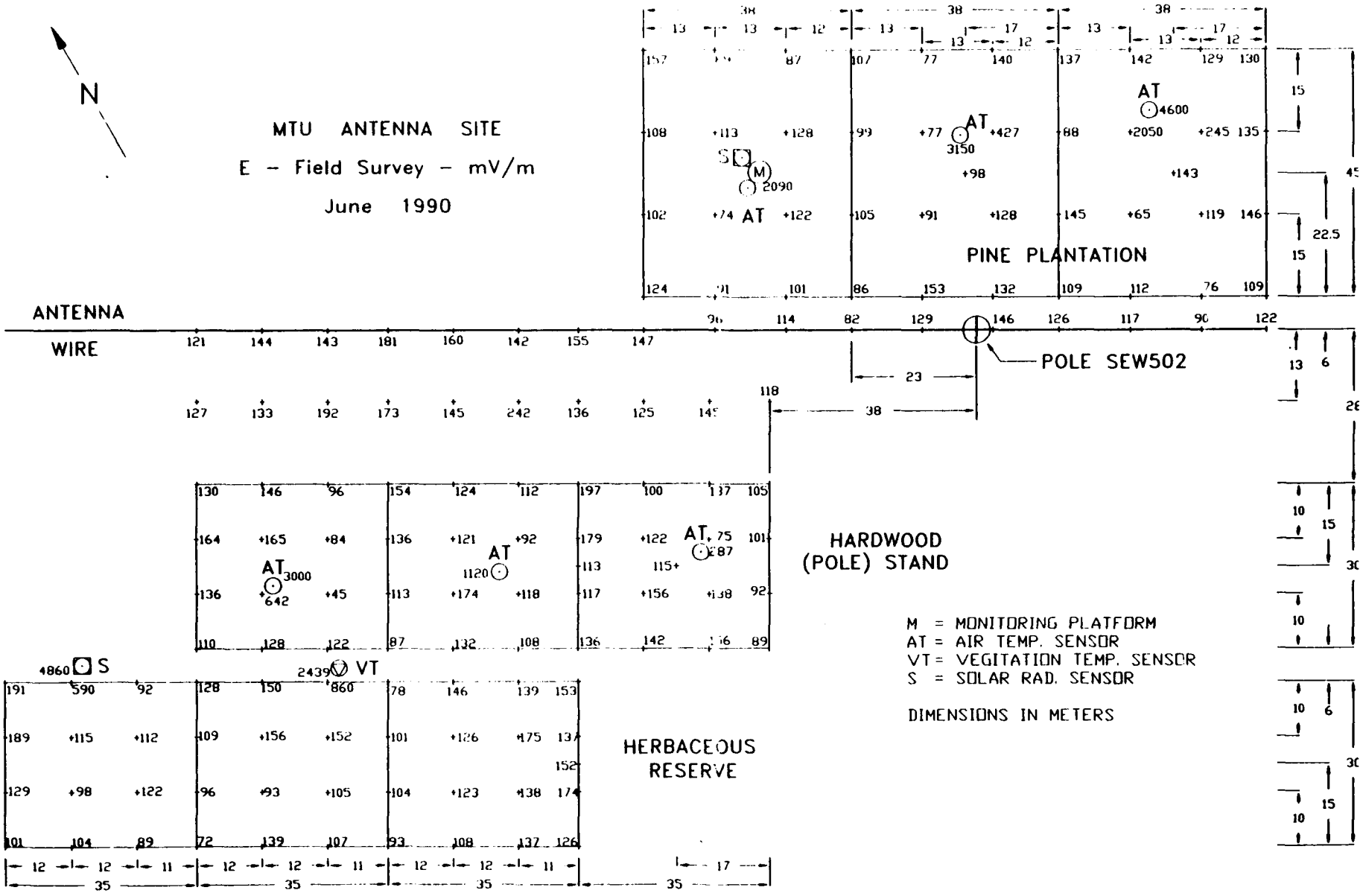
As planned, Jim Gauger and I will meet with you and your staff during the first week in October to discuss the enclosed data. I will call you in a few weeks to arrange a mutually convenient time and date for the meeting.

Sincerely,
IIT RESEARCH INSTITUTE

John E. Zapotosky

Enclosures (12)

cc: w/o encls.
JNBruhn
JRGauger
RDCarlson/File

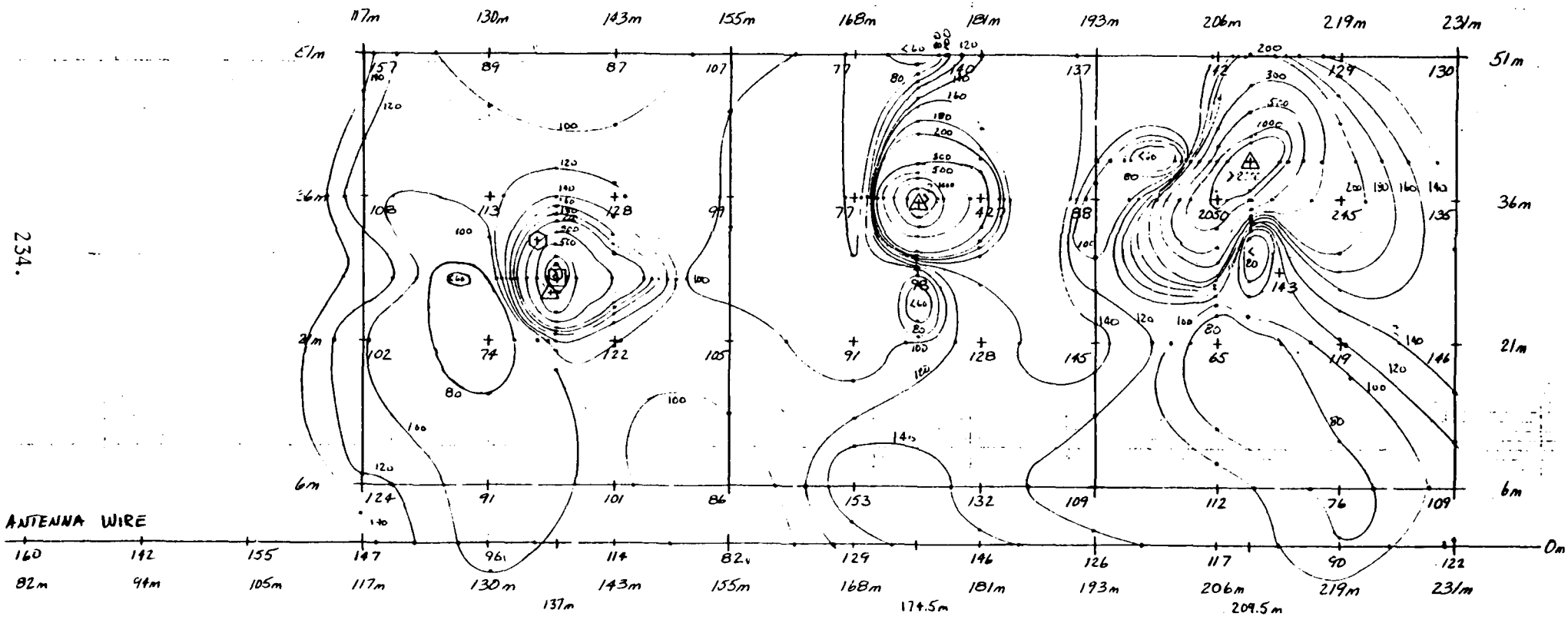

N
MTU ANTENNA SITE
E - Field Survey - mV/m
June 1990
PINE PLANTATION
HARDWOOD
(POLE) STAND
HERBACEOUS
RESERVE
ANTENNA
WIRE
POLE SEW502
M = MONITORING PLATFORM
AT = AIR TEMP. SENSOR
VT = VEGITATION TEMP. SENSOR
S = SOLAR RAD. SENSOR
DIMENSIONS IN METERS

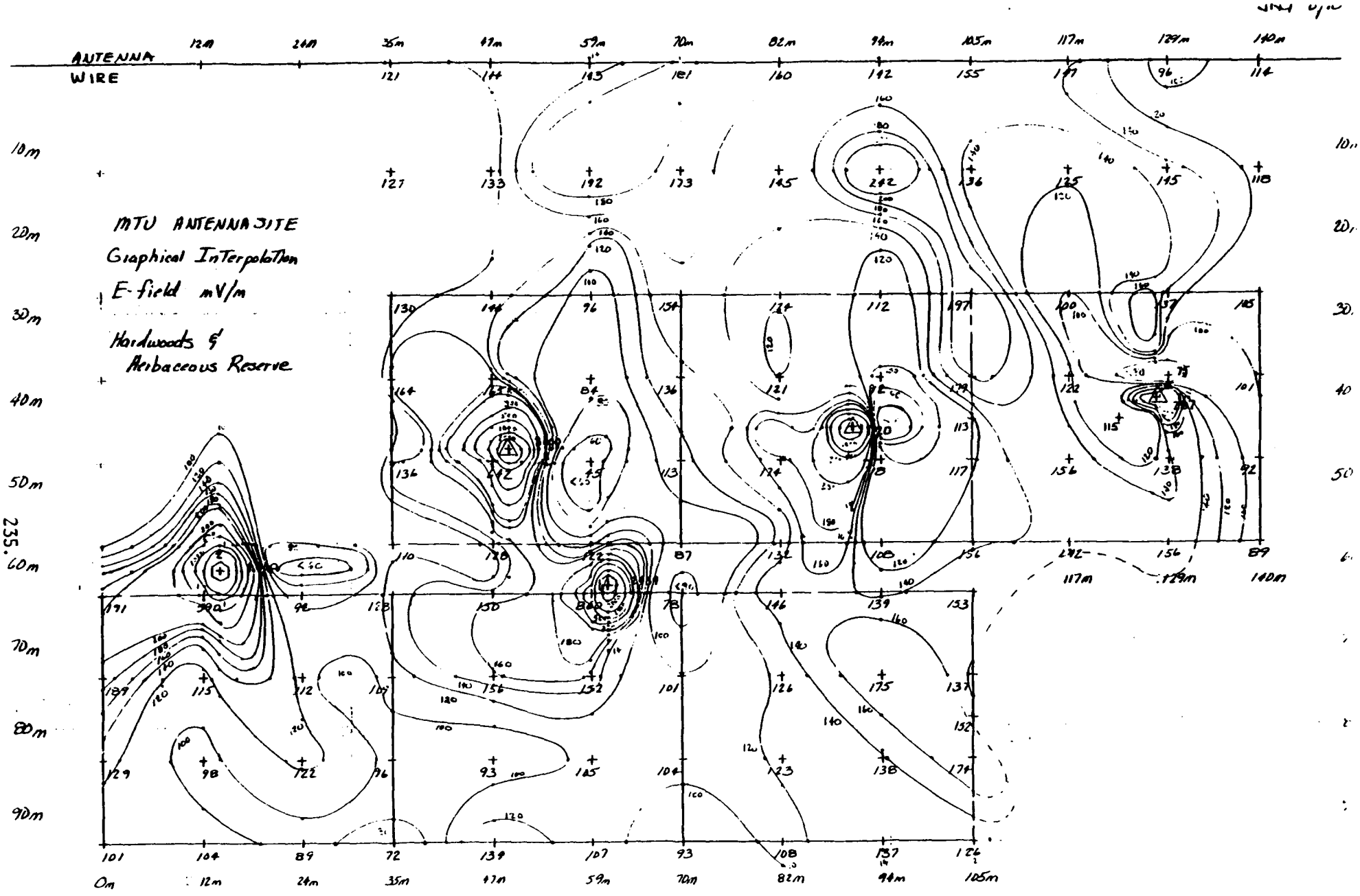
MTU ANTENNA SITE

Graphical Interpolation

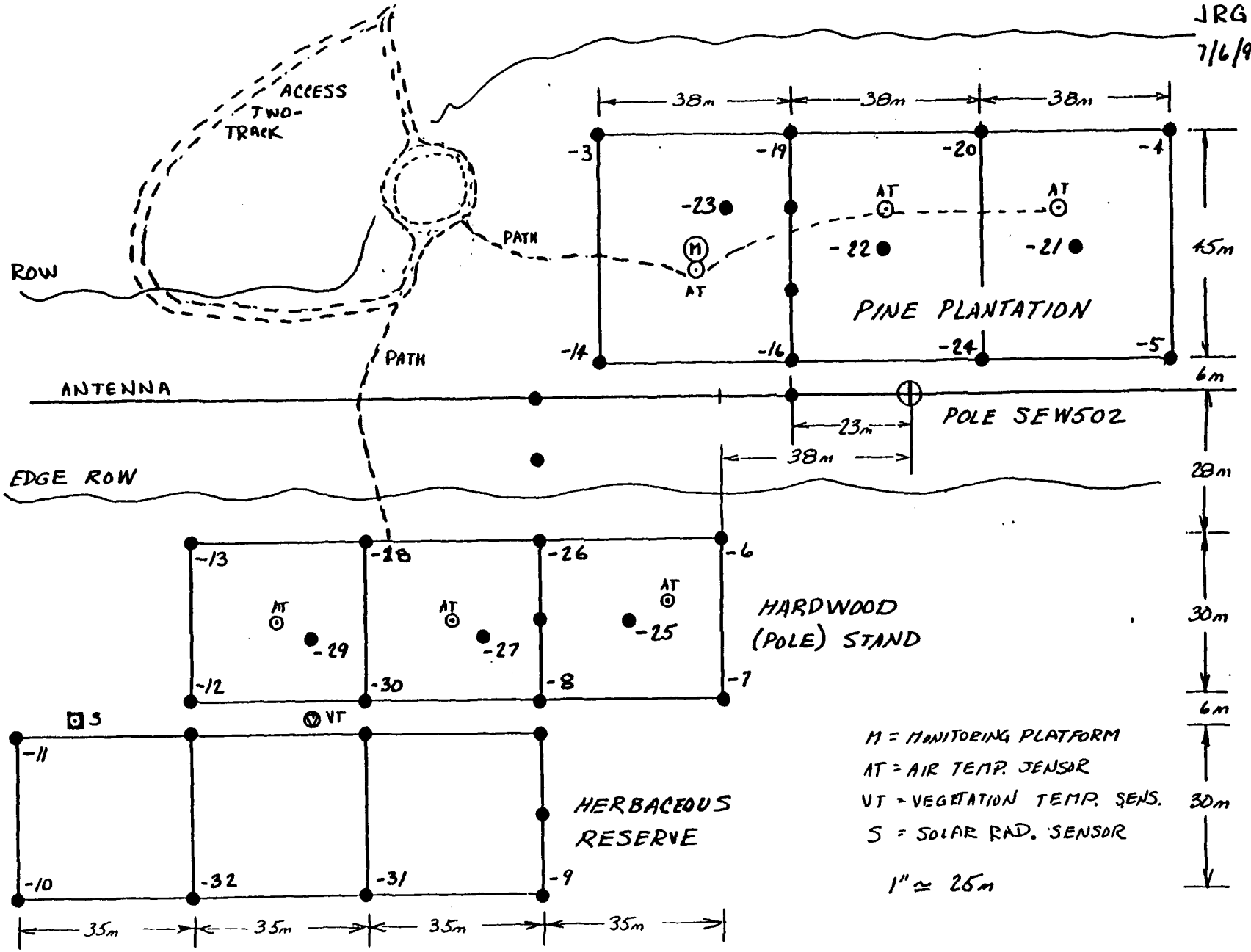
E-field mV/m

Pine Plantation




MTU ANTENNA SITE
Graphical Interpolation
E-field mV/m
Hardwoods & Arbaceous Reserve
ANTENNA WIRE
12m
24m
35m
47m
59m
70m
82m
94m
105m
117m
129m
140m
10m
20m
30m
40m
50m
60m
70m
80m
90m
0m
235.

JRG
7/6/90



MARTELL'S LAKE (Overhead) 4T2

MTU ANTENNA SITE - FIXED TEST POINTS 3-14 16 19-32

MTU ANTENNA SITE
FIXED TEST POINTS 3-14, 16, 19-32.
E-FIELD (mV/m).

TEST POINT	DATE						
	28 June	10 July	24 JULY	7 Augt.	21 Augt.		
3	140	135	139	145	142		
4	129	128	124	125	126		
5	105	99	~~98~~ 97	94	102		
6	101	100	96	97	100		
7	89	86	84	82	80		
8	135	130	142	143	132		
9	125	122	119	116	120		
10	91	87	88	88	87		
11	170	168	160	158	168		
12	114	114	113	114	110		
13	144	142	144	145	144		
14	121	115	117	113	118		
16	91	88	85	81	90		
19	107	106	106	103	106		
20	107	107	102	108	107		
21	143	139	122	132	139		
22	98	92	91	85	93		
23	114	108	109	107	112		
24	120	121	114	112	117		
25	115	60 *	117	131	116		
26	210	204	203	213	206		
27	118	112	124	130	119		
28	151	151	153	157	152		
29	55	55	61	63	53		
30	106	105	113	122	110		
31	94	96	98	99	99		
32	75	73	73	72	74		

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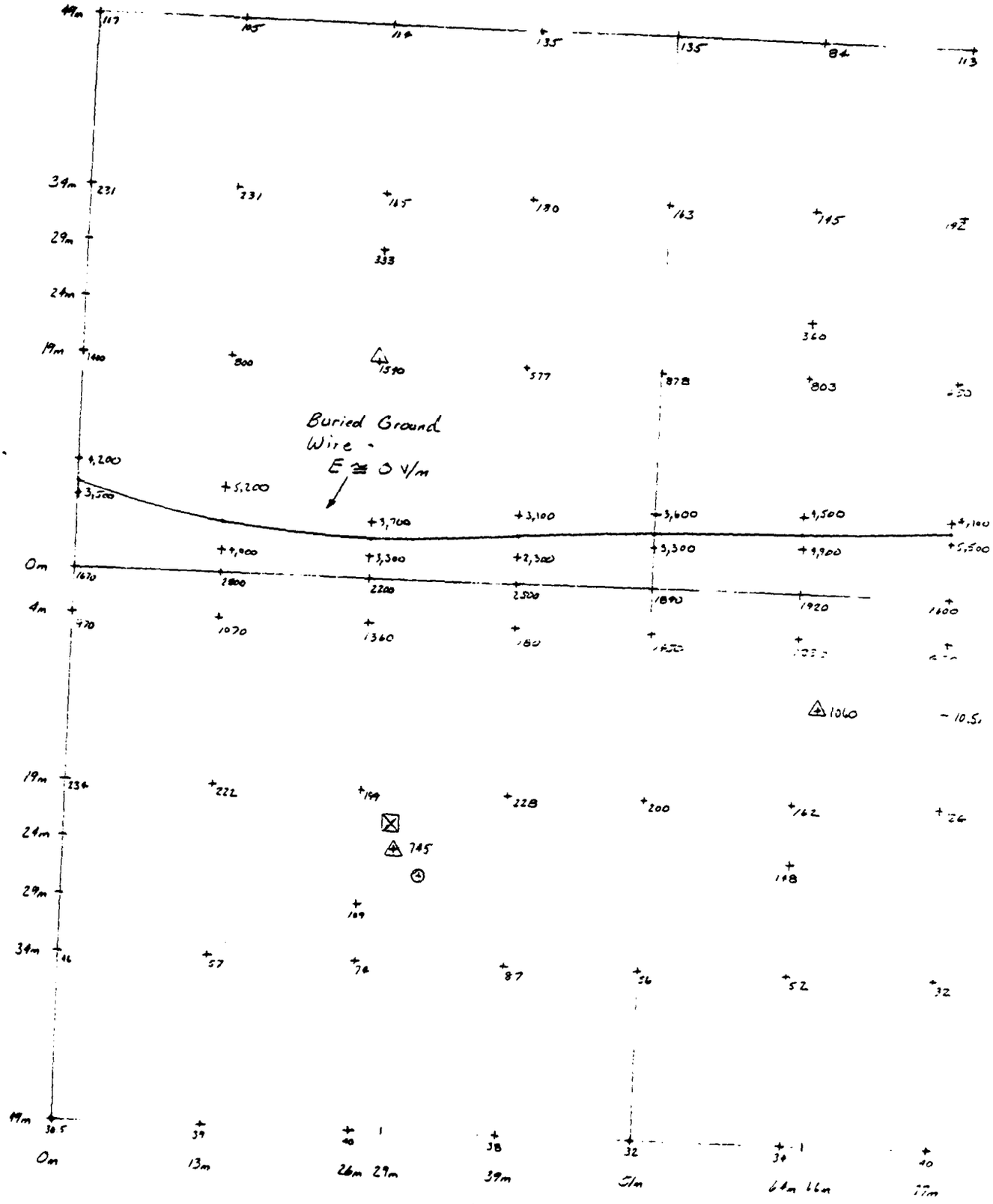
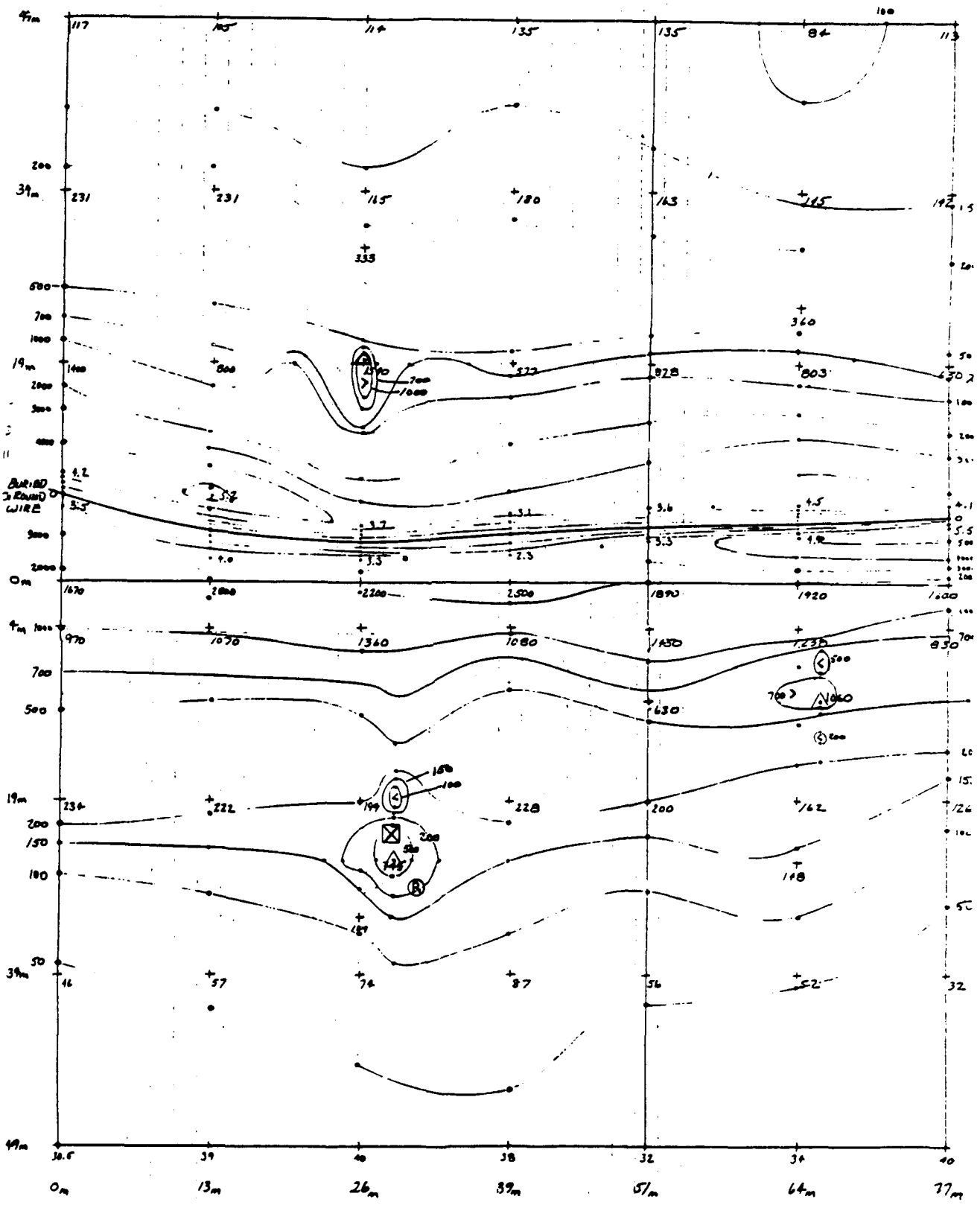
To	From
Jim Gauger	Lance Smith
Co.	Co.
Dept.	Phone #



MTU GROUND SITE

E-field Survey - mV/m

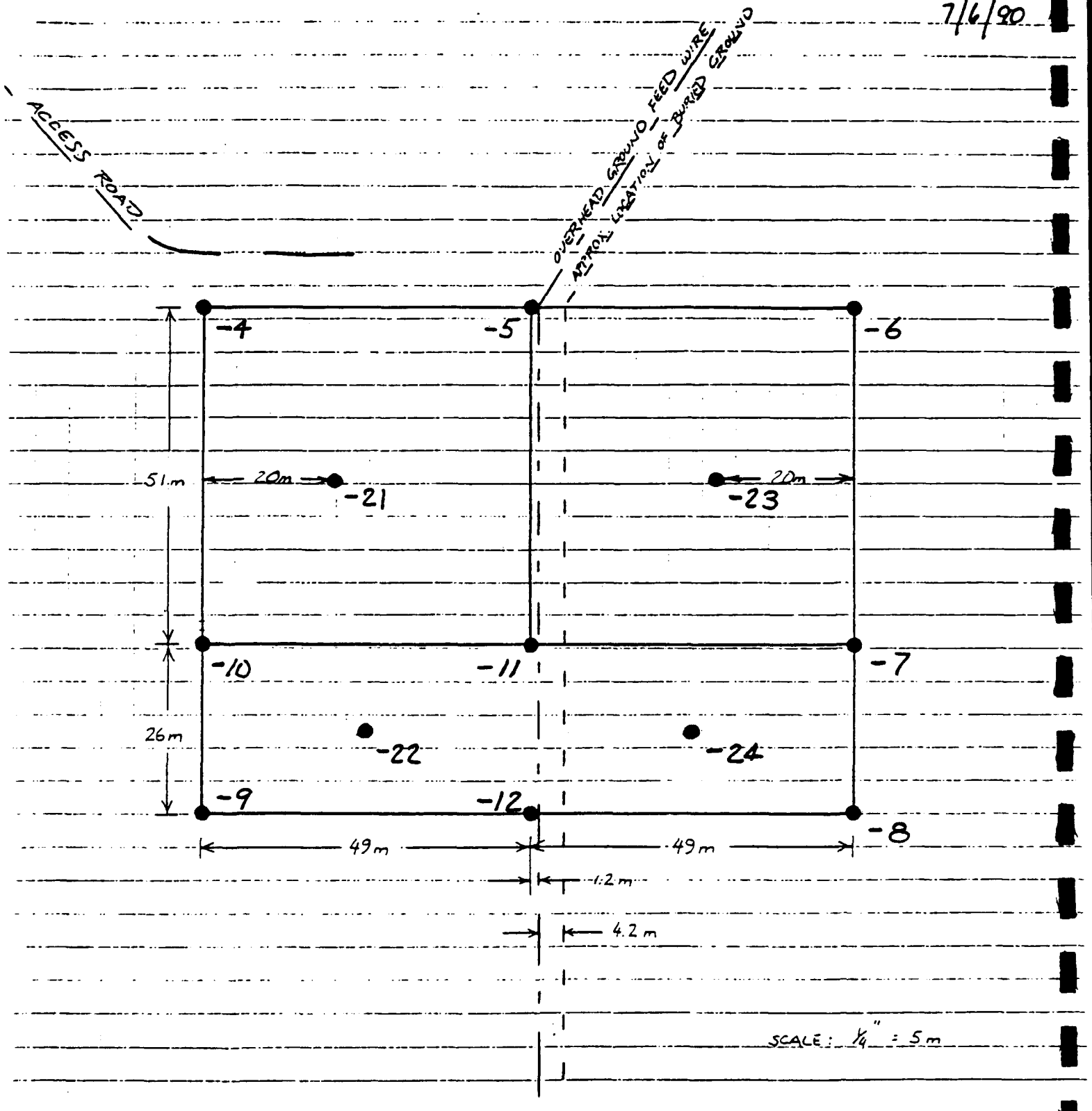
□ - Platform
△ - Air Temp
○ - Rain Gauge
+ * - Data Point & E-field Magnitude



MTU GROUND SITE - GRAPHICAL INTERPOLATION

E-Field mV/m

JRG
7/6/90



PINE PLANTATION

MARTELL'S LAKE (BURIED) ; 4T4

MTU GROUND SITE - FIXED TEST POINTS 4-12, 21-24

MTU GROUND SITE
FIXED TEST POINTS 4-12, 21-24

DATA SHEET
E-Field (mV/m)

TEST POINT	Date								
	28 June	10 July	24 JULY	7 Augt.	21 Augt.				
4	30.5	29.0	27.0	28	31				
5	1670	1796	1830	1954	2100				
6	117	115	115	125	136				
7	135	132	130	132	137				
8	113	108	105	106	109				
9	42	42	42	43	41				
10	32	30	30	30	30				
11	1990	1941	2191	2304	2030				
12	1600	1611	1698	1815	1850				
21	109	107	91	97	122				
22	148	137	139	148	153				
23	333 *	337	329	351	380				
24	360	360	344	344	393				

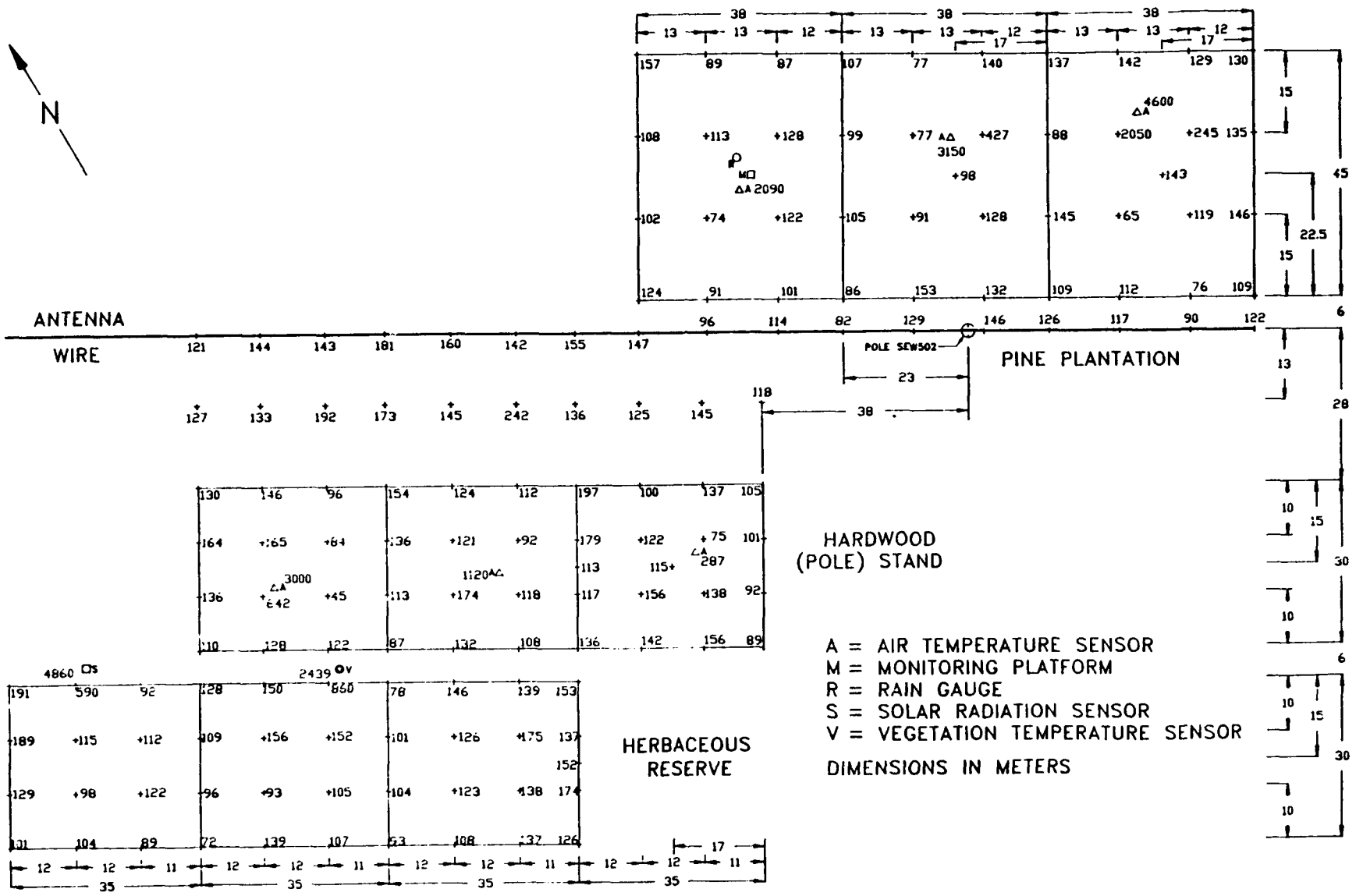


FIGURE 10. MTU ANTENNA SITE-MARTELL'S LAKE (OVERHEAD):ML
LONGITUDINAL E-FIELD SURVEY. 6/90 (mV/m)

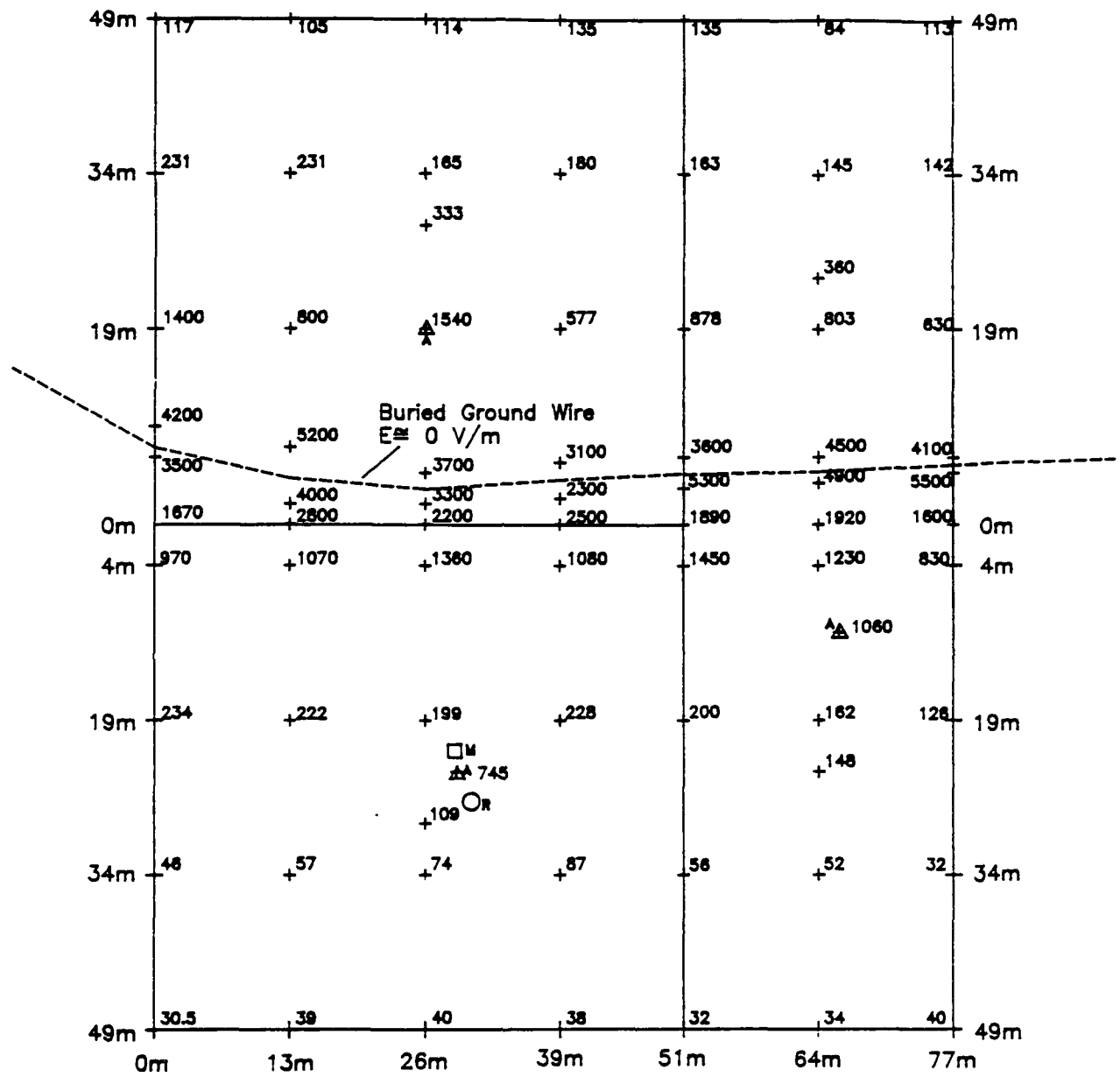


FIGURE 11. MTU GROUND SITE MARTELL'S LAKE (BURIED):EP LONGITUDINAL E-FIELD SURVEY, 6/90 (mV/m)

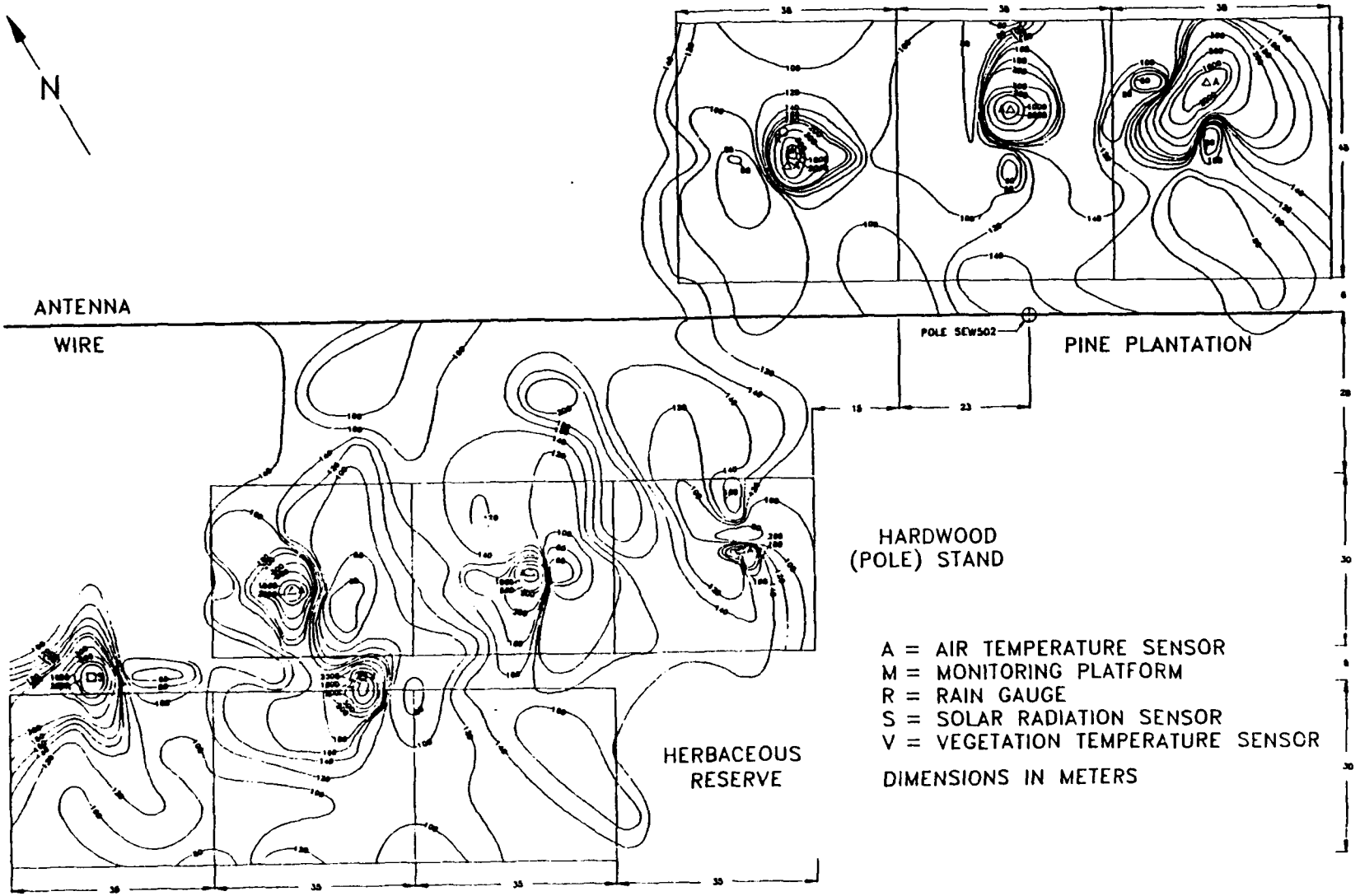


FIGURE 12. MTU ANTENNA SITE-MARTELL'S LAKE (OVERHEAD):ML LONGITUDINAL E-FIELD CONTOURS. 6/90 (mV/m)

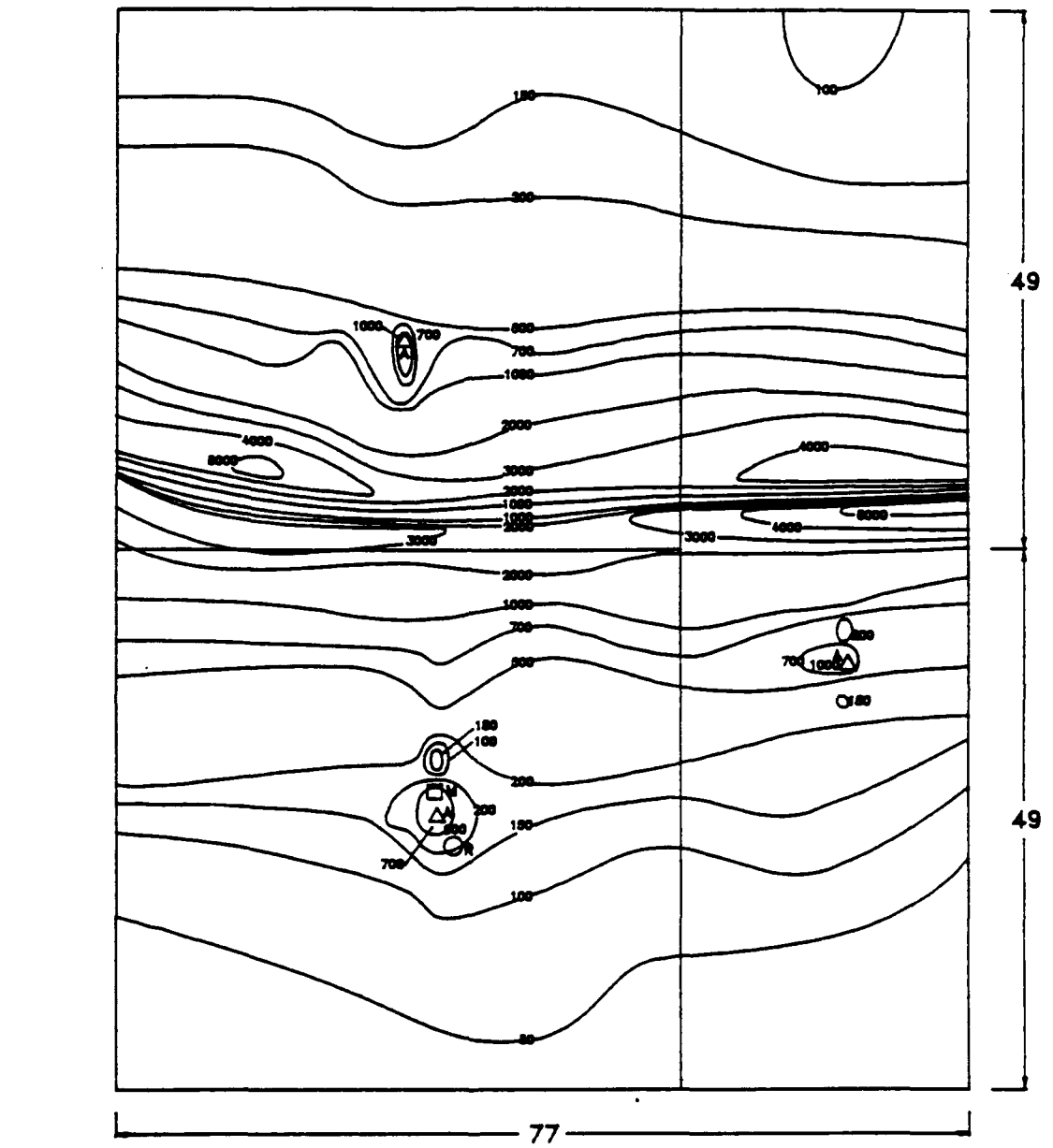


FIGURE 13. MTU GROUND SITE MARTELL'S LAKE (BURIED):EP LONGITUDINAL E-FIELD CONTOURS, 6/90 (mV/m)

APPENDIX B

Ambient Monitoring

Missing Data Equations

Table 1. Missing data equations 1990.

1990 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	Air Temperature Ground Plantation Plots				
1	$Y = .967(X_1)+.006$	6.9	.082	.992	$Y\pm.16$
2	$Y = .977(X_1)+.048$	7.0	.065	.995	$Y\pm.13$
3	$Y = .972(X_1)+.021$	7.0	.066	.995	$Y\pm.13$

X_1 = average daily air temperature at antenna site
Y = average daily air temperature at ground site

	Soil Temperature Ground Plantation Plots (5 cm)				
1	$Y =-1.147(X_1)+.988(X_2)+5.493$	9.3	.088	.978	$Y\pm.18$
2	$Y =-1.105(X_1)+.941(X_2)+5.582$	9.1	.092	.974	$Y\pm.18$
3	$Y =-.825(X_1)+.942(X_2)+4.517$	9.4	.089	.976	$Y\pm.18$

X_1 = month of year (i.e...4,5)
X_2 = average daily soil temperature 5 cm at antenna site
Y = average daily soil temperature 5 cm at ground site

	Soil Temperature Ground Plantation Plots (10 cm)				
1	$Y =-.719(X_1)+.939(X_2)+3.687$	8.6	.080	.978	$Y\pm.16$
2	$Y =-.853(X_1)+.928(X_2)+4.276$	8.5	.086	.974	$Y\pm.17$
3	$Y =-.243(X_1)+.901(X_2)+2.044$	8.8	.094	.968	$Y\pm.19$

X_1 = month of year (i.e...4,5)
X_2 = average daily soil temperature 10 cm at antenna site
Y = average daily soil temperature 10 cm at ground site

Table 2. Missing data equations 1990.

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	1990 Missing Data Equations				
	Air Temperature Antenna Plantation Plots				
1	$Y = .962(X_1)+1.142$	17.4	.089	.949	$Y \pm .18$
2	$Y = .950(X_1)+1.130$	17.1	.075	.961	$Y \pm .15$
3	$Y = .965(X_1)+.914$	17.2	.086	.952	$Y \pm .17$
	X_1 = average daily air temperature at ground site Y = average daily air temperature at antenna site				
	Air Temperature Antenna Hardwood Plots				
1	$Y = .953(X_1)+1.013$	17.1	.112	.920	$Y \pm .22$
2	$Y = .957(X_1)+.570$	16.7	.106	.928	$Y \pm .21$
3	$Y = .962(X_1)+.365$	16.6	.100	.930	$Y \pm .20$
	X_1 = average daily air temperature at ground site Y = average daily air temperature at antenna site				
	Soil Temperature Antenna Plantation Plots (5 cm)				
1	$Y = -.450(X_1)+.832(X_2)+6.402$	17.2	.048	.927	$Y \pm .10$
2	$Y = -.245(X_1)+.938(X_2)+3.194$	17.3	.046	.946	$Y \pm .09$
3	$Y = .026(X_1)+.943(X_2)+.919$	17.1	.046	.945	$Y \pm .09$
	X_1 = month of year (i.e...6,7,8) X_2 = average daily soil temperature 5 cm at ground site Y = average daily soil temperature 5 cm at antenna plantation plots				

Table 3. Missing data equations 1990.

1990 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	Soil Temperature Antenna Hardwood Plots (5 cm)				
1	$Y = .052(X_1)+.894(X_2)-.330$	15.3	.063	.891	$Y\pm.13$
2	$Y = .075(X_1)+.878(X_2)-.109$	15.4	.067	.877	$Y\pm.13$
3	$Y =-.235(X_1)+.942(X_2)+1.156$	15.4	.070	.885	$Y\pm.14$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = average daily soil temperature 5 cm on antenna hardwood plots

	Soil Temperature Antenna Plantation Plots (10 cm)				
1	$Y =-.359(X_1)+1.007(X_2)+3.464$	17.1	.027	.972	$Y\pm.05$
2	$Y =-.129(X_1)+1.115(X_2)-.029$	17.1	.030	.970	$Y\pm.06$
3	$Y = .367(X_1)+1.122(X_2)-4.283$	16.7	.038	.951	$Y\pm.08$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm at ground site
Y = average daily soil temperature 10 cm at antenna plantation plots

	Soil Temperature Antenna Hardwood Plots (10 cm)				
1	$Y = .248(X_1)+1.003(X_2)-3.196$	14.9	.056	.880	$Y\pm.11$
2	$Y = .279(X_1)+1.023(X_2)-3.731$	14.9	.060	.867	$Y\pm.12$
3	$Y =-.187(X_1+1.130(X_2)-4.686$	15.0	.071	.888	$Y\pm.14$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm at ground site
Y = average daily soil temperature 10 cm at antenna hardwood plots

Table 4. Missing data equations 1990.

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	1990 Missing Data Equations				
	Soil Moisture Antenna Plantation Plots (5 cm)				
1	$Y = 1.033(X_1)+.500(X_2)-1.808$	12.9	.262	.719	$Y\pm.52$
2	$Y = 3.734(X_1)+.406(X_2)-21.453$	11.7	.231	.834	$Y\pm.46$
3	$Y = 1.979(X_1)+.276(X_2)-5.817$	12.6	.162	.792	$Y\pm.32$
	X_1 = month of year (i.e...6,7,8) X_2 = average daily soil moisture 5 cm on ground site Y = average daily soil moisture 5 cm on antenna plantation site				
	Soil Moisture Antenna Hardwood Plots (5 cm)				
1	$Y = 2.107(X_1)+.243(X_2)-6.359$	12.6	.098	.904	$Y\pm.20$
2	$Y = 1.114(X_1)+.312(X_2)-1.159$	11.4	.136	.817	$Y\pm.27$
3	$Y = 3.432(X_1)+.127(X_2)-14.403$	12.6	.219	.683	$Y\pm.44$
	X_1 = month of year (i.e...6,7,8) X_2 = average daily soil moisture 5 cm on ground site Y = average daily soil moisture 5 cm on antenna hardwood site				
	Soil Moisture Antenna Plantation Plots (10 cm)				
1	$Y = 1.863(X_1)+.420(X_2)-7.259$	11.6	.137	.806	$Y\pm.27$
2	$Y = 1.999(X_1)+.486(X_2)-8.947$	11.7	.108	.892	$Y\pm.22$
3	$Y = 2.135(X_1)+.552(X_2)-10.634$	11.9	.095	.931	$Y\pm.19$
	X_1 = month of year (i.e...6,7,8) X_2 = average daily soil moisture 10 cm on ground site Y = average daily soil moisture 10 cm on antenna plantation site				

Table 5. Missing data equations 1990.

1990 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	Soil Moisture Antenna Hardwood Plots (10 cm)				
1	$Y = 2.066(X_1)+.331(X_2)-7.535$	11.5	.160	.730	$Y\pm.33$
2	$Y = 2.063(X_1)+.330(X_2)-7.492$	11.5	.160	.727	$Y\pm.33$
3	$Y = 2.059(X_1)+.329(X_2)-7.450$	11.5	.165	.714	$Y\pm.33$
	X_1 = month of year (i.e...6,7,8) X_2 = average daily soil moisture 10 cm on ground site Y = average daily soil moisture 10 cm on antenna hardwood site				
	Antenna Average Vegetation Temperature (30 cm)				
	$Y = .940(X_1)-.091$	15.7	.090	.935	$Y\pm.18$
	X_1 = average daily air temperature at ground site Y = average vegetation temperature at antenna site				
	Relative Humidity Antenna Site				
	$Y = 5.447(X_1)+.325(X_2)+29.924$	86.7	1.000	.271	$Y\pm2.00$
	X_1 = month of year (i.e...6,7,8) X_2 = daily relative humidity at ground site Y = daily relative humidity at antenna site				
	Air Temperature Control Plantation Plots				
1	$Y = .938(X_1)$	16.4	.262	.989	$Y\pm.52$
2	$Y = .975(X_1)$	17.4	.202	.990	$Y\pm.40$
3	$Y = .962(X_1)$	17.1	.196	.990	$Y\pm.40$
	X_1 = average daily air temperature at Crystal Fall DNR station Y = average daily air temperature at control plantation site				

Table 6. Missing data equations 1990.

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	1990 Missing Data Equations				
	Air Temperature Control Hardwood Plots				
1	$Y = .958(X_1)$	17.1	.176	.992	$Y \pm .35$
2	$Y = .939(X_1)$	16.7	.184	.991	$Y \pm .37$
3	$Y = .966(X_1)$ $Y \pm \pm .35$	17.2	.176	.992	
	Soil Temperature Control Plantation Plots (10 cm)				
1	$Y = .171(X_1) + .352(X_2) + 8.003$	15.5	.114	.548	$Y \pm .22$
2	$Y = .686(X_1) + .415(X_2) + 4.403$	16.6	.112	.690	$Y \pm .22$
3	$Y = 1.242(X_1) + .274(X_2) + 2.811$	16.3	.125	.633	$Y \pm .25$
	Soil Temperature Control Hardwood Plots (10 cm)				
1	$Y = 1.278(X_1) + .377(X_2) - .226$	15.4	.104	.776	$Y \pm .20$
2	$Y = 1.204(X_1) + .447(X_2) - 1.628$	14.7	.102	.803	$Y \pm .20$
3	$Y = 1.445(X_1) + .303(X_2) - .723$	14.7	.108	.750	$Y \pm .22$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily air temperature at Crystal Fall DNR station
Y = average daily soil temperature (10 cm) at control plantation site

X_1 = month of year (i.e...6,7,8)
X_2 = average daily air temperature at Crystal Fall DNR station
Y = average daily soil temperature (10 cm) at control hardwood site

Table 7. Missing data equations 1990.

1990 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R^2	Confidence Interval at X_1, X_2
	Soil Temperature Control Plantation Plots (5 cm)				
1	$Y = .376(X_1)+.418(X_2)+6.014$	16.1	.097	.717	$Y\pm.19$
2	$Y = .522(X_1)+.484(X_2)+4.422$	16.7	.110	.732	$Y\pm.22$
3	$Y = .664(X_1)+.401(X_2)+5.618$	17.4	.112	.676	$Y\pm.22$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily air temperature at Crystal Fall DNR station
Y = average daily soil temperature (5 cm) at control plantation site

	Soil Temperature Control Hardwood Plots (5 cm)				
1	$Y = .763(X_1)+.513(X_2)+1.050$	15.5	.131	.702	$Y\pm.26$
2	$Y = 1.016(X_1)+.475(X_2)-.284$	15.3	.111	.772	$Y\pm.22$
3	$Y = 1.202(X_1)+.425(X_2)-.866$	15.1	.106	.782	$Y\pm.21$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily air temperature at Crystal Fall DNR station
Y = average daily soil temperature (5 cm) at control hardwood site

	Control Average Vegetation Temperature (30 cm)				
	$Y = .954(X_1)$	17.0	.018	.992	$Y\pm.36$

X_1 = average daily air temperature at Crystal Fall DNR station
Y = average vegetation temperature at control site

	Relative Humidity Control Site				
	$Y = 2.679(X_1)+.387(X_2)+29.093$	75.8	1.131	.194	$Y\pm2.26$

X_1 = month of year (i.e...6,7,8)
X_2 = daily relative humidity at Crystal Fall DNR station
Y = daily relative humidity at control site

APPENDIX C

Hardwood Diameter Growth Model Manuscript

MODELING DIAMETER GROWTH AS A FUNCTION OF CLIMATE: A CASE STUDY INVOLVING FOUR NORTH AMERICAN DECIDUOUS SPECIES

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MODELING DIAMETER GROWTH AS A FUNCTION OF CLIMATE:
A CASE STUDY INVOLVING FOUR NORTH AMERICAN DECIDUOUS SPECIES

ABSTRACT

Existing models representing the growth of forest species as a function of environmental conditions make a number of assumptions which are inappropriate when applied to local populations. Physiological growth functions can often be localized by utilizing information in the forest growth and yield literature to make site-specific estimates of such things as maximum tree diameter and height for a given species. Most existing models also use an annual timestep which may not be appropriate when attempting to model growth of individual trees and their response to environmental conditions. A model utilizing a weekly timestep is described and applied to four widespread North American deciduous tree species. Since response to environmental conditions can vary regionally due to genetic heterogeneity, the resulting model should not be considered as universally appropriate for these species. This study illustrates some of the problems encountered in attempting to model tree growth in response to environmental conditions and a description of methods which can be utilized when developing models for application to local populations.

MODELING DIAMETER GROWTH AS A FUNCTION OF CLIMATE: A CASE STUDY INVOLVING FOUR NORTH AMERICAN DECIDUOUS SPECIES

A model was developed to quantify differences in productivity of mixed-species northern hardwood forests due to natural factors: site physical and chemical properties, climate, and competition. This study is part of a larger project attempting to determine the effects of an imposed factor, in this case electromagnetic fields, against a background of natural variability in climate and other factors (Mroz et al. 1988). Ultimately, the emphasis is on the response of the natural ecosystem; this includes the need to quantify the effects of natural factors on individual trees in order to detect changes in system productivity which may be due to imposed environmental stresses.

Productivity here will be defined as the annual increase in overstory biomass. 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 (Smith 1986, Spurr and Barnes 1980). While monitoring of actual biomass production over time is difficult in field situations, it is relatively easy to accurately and precisely measure cambial development. For

these reasons, diameter increment was chosen as the response variable representing biomass productivity.

There are several 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 (1982) are examples. These models are based on certain species-specific life history 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). The diameter growth functions from the JABOWA and FORET models were tested on the two study sites described below by Fuller et al. (1987) 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.

There are several reasons for the poor performance of these models. An annual timestep might 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 recover from a pertubation in the nutrient status of the rooting environment to be on the order of 10^5 seconds (a few days) and the recovery time of a natural system to be on the order of 10^9 seconds (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 counter-productive to use a timestep that is many orders of magnitude less than the recovery time of the system of interest. This study quantifies diameter growth of individual trees while accounting for the effects of neighboring trees as well as soil and climatic conditions in a biologically rational fashion. Since this involves individual plant as well as community responses to the environment, a timestep of one week was utilized in developing a diameter growth model of the type described by Reed (1980).

Models of the type described above may perform poorly on specific sites because the life history characteristics they utilize might not be universally applicable for a species. The maximum expected diameter and height for a species is dependent on site characteristics and is not constant over the entire range of the species. There is much information in the forest growth and yield literature relating tree growth and development to site quality class or site index. Taking advantage of this existing knowledge, information relating tree growth and development to site

quality was extracted from the literature and used to modify expected maximum tree sizes in existing growth models on a site specific basis.

A diameter growth model using site specific life history characteristics and observed relationships between diameter growth, competition, and site physical, chemical, and climatic properties was developed for two study sites in Upper Michigan. Methods of localizing the life history characteristics presented here can be used to refine existing models for use on specific sites. The relationships given here between diameter growth, competition, and site physical, chemical, and climatic properties reflect the genotypes on the study sites and will probably not extend across the range of the species. The methodology for identifying and quantifying these relationships should be applicable to other study sites and species.

METHODS

Data from two intensively measured field sites are used to verify assumptions concerning plant level processes that are incorporated into the growth model. The field measurements are also used to calibrate the model for the four species in the study area. The mathematical forms representing the relationships between tree, stand, and

environmental factors and diameter growth are consistent with the results of previous field studies and controlled experiments. These relationships were verified by the field data prior to incorporation into the diameter growth model.

Site Description

The two study sites are located in the central Upper Peninsula of Michigan. Site One is at 46°10'N, 88°30'W and Site Two is at 46°20'N, 88°10'W. Both sites have relatively undisturbed second growth deciduous vegetation consisting principally of red maple (Acer rubrum) and northern red oak (Quercus rubra) with minor components of quaking aspen (Populus tremuloides), bigtooth aspen (Populus grandidentata), and paper birch (Betula papyrifera). The sites are both characterized as the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983).

Field Measurements

Measurement of radial increment was accomplished using a band dendrometer as described by Cattelino et al. (1986). The dendrometer bands were read weekly to the nearest 0.008 cm of diameter. Readings began in early April and continued through the growing season until over 50 percent of leaf fall had taken place. There were 274 trees banded on site one and 197 trees banded on site two prior to the 1985

growing season. Weekly measurements have been made over the 1985, 1986, 1987, and 1988 growing seasons. Locations of the individual trees are 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 of the study sites is equipped with a remote data collection platform located in a cleared area adjacent to the sites. The main data collection platform contains sensors measuring precipitation, air temperature, relative humidity, and solar radiation; each of three 30 m X 35 m plots at each site contain sensors measuring air temperature, soil temperature, and soil moisture content at 5 and 10 cm depths. Data are retrieved eight times daily via NOAA satellite transmissions. Sensors are queried every 30 minutes and computed into three-hour mean values by the platform microprocessor. Precipitation data are logged once every three hours. These daily climatological and soil data are 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 are sampled monthly during the growing season for determination of nutrient levels.

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 amount of growth during a given week, d_t, is represented as a function of tree, stand, climate, and site physical and chemical factors. These factors are incorporated in four model components:

1) Annual potential growth (PG)

2) The reduction of annual potential growth due to intertree competition (IC)

3) The reduction of annual potential growth due to site physical, chemical, and annual climatic properties (SPC)

4) The seasonal growth pattern and further reduction of annual potential growth due to weekly climatic factors (SGP_t)

Each of the last three components is expressed as a proportion of the annual potential growth and the weekly diameter growth is expressed as the product of the four components:

d_t = (Annual Potential Growth) *
(Effect of Intertree Competition) *
(Effect of Site Physical, Chemical, and Climatic Properties) *
(Seasonal Growth Pattern and Effect of Weekly Climatic Conditions)

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) found that the model form given by Botkin et al. (1972) showed the most promise on these study sites. A slightly modified form of this model is used to represent potential growth (PG) on the study sites:

$$PG = \frac{G\ D\ (1 - D/D_{MAX})}{274 + 3\ b_2\ D - 4\ b_3\ D^2}$$

where D is tree DBH (cm), D_{MAX} is the maximum observed tree diamter 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 cm) in their model formulation; due to the difficulty in precisely measuring height and annual height growth in mature deciduous species,

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:

$$b_2 = 2\,(H_{MAX} - 137)/D_{MAX}$$

$$b_3 = (H_{MAX} - 137)/D_{MAX}^2$$

These constraints were imposed on b_2 and b_3 in this study as well to retain logical behavior of PG.

Fuller (1986) found that the model with the values of the coefficients given by Botkin et al. (1972) performed poorly on the study sites and required reestimation. As discussed by Botkin et al. (1972) and Reed et al. (1988), this is at least partly due to the fact that that H_{MAX} and D_{MAX} are site specific within a species rather than constant across all sites. 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 manipulated to estimate D_{MAX} and H_{MAX} for the study plots. An asymptotic basal area of 32 m^2/ha was chosen. Basal areas exceeding this in mixed species stands of this type are possible on small plots, but

very rare on a stand level. Numerical procedures were used to solve the equations to find the diameter which would lead to insignificant (< 0.01 m) height growth; that diameter was taken as D_{MAX} for the site and the corresponding height was taken as H_{MAX}. The resulting estimates of D_{MAX} and H_{MAX} were used to fix b_2 and b_3 in the model as defined in the limiting relationships given above (Table 2).

Botkin et al. (1972) set G to produce approximately 2/3 of the maximum diameter at 1/2 of the maximum age. In this study, G was statistically estimated from the observed data (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 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. These relationships may vary due to stand conditions as well as genetic makeup of the local population.

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.

In this study, 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 insufficient, especially since the study plots here ar 30 X 35 m and contain many more trees than the 10 X 10 m simulated plots in JABOWA and FORET.

Holmes and Reed (1989) used map information from the study plots to evaluate the performance of numerous individual tree competition indices for each of the four species. They found that a simple competition index given by Lorimer (1983) performed best for northern red oak, paper birch, and red maple. This index is given by:

$$CI_i = \sum \frac{DBH_j}{DBH_i}$$

where CI_i is the value of the competition index for the ith (subject) tree, DBH_K is the diameter of the respective tree, and the summation is over all trees within 7.62 m of the subject tree.

Holmes and Reed (1989) found that there were no significant differences in the relationship between Lorimer's competition index and diameter growth over sites and years (1985-1987) for northern red oak, paper birch, and red maple. A correlation of -0.64 was observed between the competition index and northern red oak diameter growth; similar correlations of -0.75 for paper birch and -0.56 for red maple were also observed.

For aspen, the most shade intolerant of the four species in this study, the competition index given by Bella (1971) proved to be the most highly related to observed diameter growth. This index includes additional information regarding the distance to neighboring trees:

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

where CI_i is the value of the competition index for the ith (subject) tree, DBH_K is the diameter of the respective tree, A_i is the area of the influence zone (as defined by the open grown crown radius given by Ek (1974)) of the ith tree, and a_{ij} is the area of the overlap of the influence zone of the ith tree and the jth competitor. The correlation between

aspen diameter growth and the value of this competition index was -0.50.

A negative exponential relationship was assumed between diameter growth and increasing competition. In the diameter growth model, this is represented by:

$$IC = e^{-(a*CI)}$$

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. 1988). Reed et al. (1990) describe an intensive variable screening procedure which was used to identify a set of environmental variables

for each species which were correlated, either positively or negatively, with productivity 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 are accounted for in the model by a linear function which is constrained to produce the proportion of potential growth which might be expected:

$$SPC = \frac{(DBH + b_0 + b_1X_1 + b_2X_2 + b_3X_3)}{DBH}$$

where SPC is the effect of site physical, chemical, and climatic factors on diameter growth and DBH is tree diameter. The particular environmental factors (X_k) and the associated constants (b_k) are species specific. The factors identified in this study were total seasonal air temperature growing degree days (April - September) on a 4.4^{o} C basis for northern red oak, paper birch, and aspen and air temperature degree days through May for red maple, July potassium concentration 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 to 10 cm for red maple and at a depth of 10 to 30 cm for paper birch. The intercept (b_0) was not significant ($p > 0.05$) for northern red oak and paper birch and was removed from the model (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^{o} C basis) was the most significant environmental factor impacting the timing of diameter growth for all four species on both sites. Reed et al. (1988) 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 increasing evaporation and plant respiration 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 .101 -MPa (1 atm), water is freely available to plants and is not assumed to be limiting. At potentials greater than .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 .101 -MPa, a value of .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):

$$SGP_t = (e^{-(ATD_{t1}/b)^c} - e^{-(ATD_{t2}/b)^c})(e^{-d\,(SWP_t - .101)})$$

where SGP_t is the proportion of potential total annual growth expected in week t. The coefficients b, c, and d are species specific coefficients and are estimated statistically (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 using the 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 to the observed growth values. A studentized test on the average residual found no evidence of bias in the combined model for any species except 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 is probably due to a number of factors which include the small sample size for aspen, the extreme genetic diversity found in aspen in the Lake States, and the fact that large differences in growth can be found between individuals of a shade intolerant species growing in a mixed stand with tolerant species due to the differences in light availability to individuals.

The standard error of the residuals in the estimation data is analogous to 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) is analogous to R^2 in linear regression and, for all four species, is in the range found by other studies in deciduous species (Harrison et al. 1986 for example). Further improvement in these values may not be possible at the study sites due to 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 to 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 definitely 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 can be seen in Table 4, for northern red oak and paper birch, the studentized 95% confidence limits for each of the three 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 overlap zero, indicated adequate model performance 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 the two sites. This indicates that the model did not adequately represent the growing conditions in 1988 and that some factor or combination of factors lead 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 compared to previous 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 (Harlow and Harrar 1969, Fowells 1965). There is the possibility that the reduced moisture availability on the study sites in 1988, as indicated by soil water potential at 5 cm, could be the cause of the reduced growth compared to previous years. This emphasizes the necessity of data collection over a longer time period in order to truly 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 One have increased during the three year study period while they have remained relatively constant at Site Two. The reasons for this difference are not clear. Both sites are located adjacent to a cleared area. However, 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 the 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 One between 1988 and previous years. Taken together, these factors indicate that the aspen at Site One could not be responding to an increased light environment in 1988. There is a greater red maple component at Site One than Site Two and the aspen could be responding to reduced competition due to the reduced red maple growth described above. If so, this is happening at Site One and not Site Two 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 three years. For one species (red maple), the model did not perform well in 1988 at either site. It seems likely that this is due to decreased moisture availability as compared to previous years. This emphasizes the fact that each year represents a unique combination of environmental conditions and an extended sampling period is needed to truly 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 clearly obvious at this time, but there does not appear to be a simple environmental or competitive explanation.

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 is affecting seasonal growth pattern and it 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 Figure 1.

For northern red oak, there are no significant differences ($p>0.05$) between the observed and predicted seasonal diameter growth patterns at either site in any of the three years. This indicates that there is no significant deviation from the seasonal diameter growth pattern predicted by the model.

For paper birch at Site One, there were no significant differences between the observed and predicted seasonal growth pattern in any of the three years. At Site Two, there were significant differences ($p<0.05$) between the observed and predicted seasonal growth patterns on one plot in all three years and on a second plot in 1987 and 1988; there were no differences on the third plot. It is not clear that these differences are due to any seasonal difference in weather conditions between the two sites. The

overall effect was that the model predicted a lower proportion of growth early in the year compared to what was observed. As discussed earlier, the overall net affect did not include a difference in total annual diameter growth. The differences may largely be due to 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 One with the exception of one plot in 1986 and another plot in 1988. At Site Two, 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 the differences which could be attributed to inadequacies in the model. For the majority of plots and years there was no difference between the observed and predicted seasonal growth patterns.

For aspen, there was no significant difference ($p>0.05$) between the observed and predicted seasonal growth pattern for any plot in any year with the exception of one plot in 1988. This plot contains a single aspen individual and, while this difference could possibly related to the increased aspen growth at Site One, unless this difference is repeated in the future and found on other plots at Site One there is no real evidence of an inadequacy in the model's prediction of seasonal diameter growth pattern. At Site Two, there were no differences ($p>0.05$) between observed and predicted seasonal growth pattern with the

exception of one plot in 1986. In 198 , the studentized 95% confidence intervals for the total annual growth residuals did not overlap zero and this may have 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 problem with the model.

In the seasonal growth pattern evaluations, comparisons were made on a plot basis (using each of 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 Two 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 exisiting models which represent tree growth as a response to climate contain assumptions which may or may not be adequate on a regional basis but which cause poor model performance on many sites. Physiological 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 the existing growth models. Another example would be a species' response to climate. From provenance trials it is well known that genetic material from different locations within a species' geographic range respond differently to climatic conditions at a given site for many species. In many existing growth 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 climatic conditions.

For many species and localities, traditional forest growth and yield information can be utilized in localizing the physiological limits in existing models. 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 physiologically based growth models could be developed for many species in much of North America.

An annual time step may not be sufficient for modeling tree response to environmental conditions. While ecosystem level response to a shift in environmental conditions may be

on the order of several years, and 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 may be as critical as their intensity in determining their affect on tree growth. For these reasons, a weekly timestep was utilized in modeling seasonal growth pattern and, by summation, total annual diameter growth on the study sites.

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. Not only extremes of temperature and precipitation but also different timing of events can result in differential plant response. In this study, over two sites and three years, the models performed well for two of the four species, for one species there was a growth reduction at both sites in the third year, most likely due to a combination of temperature and precipitation leading to a reduction in available water during the growing season, and 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 truly understand and quantify the effects of environmental factors on forest productivity.

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Table 1. Stand Characteristics at the beginning of the study (1986).

Species	Average Diameter (cm)	Average Height (cm)	Average Basal Area (m^2/ha)	Density (stems/ha)	Site Index (m @ 50)	Age (yrs.)
Site One						
Northern Red Oak	20.82	22.24	20.00	556	22	52
Paper Birch	16.30	20.63	2.92	127	18	54
Aspen	22.82	23.51	3.33	79	20	55
Red Maple	11.85	16.31	0.52	48	18	45
Site Two						
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

Table 2. Coefficient estimates (and associated asymptotic 95% confidence limits for statistically estimated coefficients) for the four species.

Coefficient	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
Annual Potential Diameter Growth Component				
Site Index (m@50)				
Site One	22.0	19.8	18.3	17.7
Site Two	20.7	20.7	20.1	17.1
H_{Max} (cm)				
Site One	2416	2278	2204	2105
Site Two	2359	2324	2287	2077
D_{Max} (cm)				
Site One	73	60	60	52
Site Two	72	61	60	51
b_2				
Site One	62.438	71.367	68.900	75.692
Site Two	61.722	71.705	71.667	76.078
b_3				
Site One	.42766	.59472	.57417	.72781
Site Two	.42863	.58775	.59722	.74587
G	200.78 (174.45,227.10)	139.23 (69.25,209.22)	112.92 (98.08,127.76)	133.47 (117.63,149.31)
Intertree Competition Component				
a	.0557 (.0443,.0671)	.0431 (.0150,.0712)	.1206 (.0919,.1493)	.0352 (.0290,.0414)

Table 2, Continued.

Coefficient	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
Site Physical, Chemical and Climatic Factor Component				
b_o	-3.32 (-12.75,6.31)	0	-47.28 (-35.02,-59.55)	-40.35 (-33.93,-46.77)
b_1	.-0045 (-.0056,.0034)	-.0025 (-.0044,-.0007)	.0356 (-.0429,-.0283)	.0890 (.0696,.1084)
b_2	.1081 (-.0514,.2671)	0	.3456 (.1429,.5503)	.1498 (.0695,.2302)
b_3	0	-37.26 (-56.11,-18.42)	0	12.71 (6.47,18.95)
Seasonal Growth Pattern Component				
b	809.67 (762.75,856.60)	725.75 (685.83,765.68)	713.97 (693.07,734.87)	761.11 (740.06,782.16)
c	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	-.5125 (-.7882,-.2367)	-.3278 (-.5708,-.0849)	0	-.5005 (-.7133,-.2876)

Table 3. Diameter growth model performance for each species when predicting total seasonal growth (sites and years combined).

Species	Proportion of Variation Explained	Average Residual (cm)	Standard Error of Residuals (cm)	H_o:=O H_a:=0
Northern Red Oak	0.443	0.0128 (6.4%)	.0079	NS
Paper Birch	0.724	0.0037 (6.1%)	.0075	NS
Aspen	0.286	0.0328 (16.9%)	.0105	p=0.01
Red Maple	0.512	0.0010 (1.0%)	.0041	NS

Table 4. Performance of the diameter growth model in predicting total seasonal growth by site and year for each species.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Northern Red Oak					
1	1986	61	-0.0069	0.0103	-0.0275, 0.0137
	1987	62	0.0135	0.0112	-0.0089, 0.0359
	1988	62	-0.0178	0.0113	-0.0414, 0.0048
2	1986	20	0.0204	0.0251	-0.0321, 0.0776
	1987	22	0.0797	0.0323	-0.0125, 0.1469
	1988	23	0.0250	0.0202	-0.0169, 0.0669
Paper Birch					
1	1986	10	0.0047	0.0162	-0.0139, 0.0413
	1987	10	0.0007	0.0086	-0.0188, 0.0202
	1988	10	0.0270	0.0270	-0.0200, 0.0740
2	1986	3	0.0191	0.0241	-0.0846, 0.1228
	1987	3	-0.0083	0.0153	-0.0711, 0.0605
	1988	3	-0.0048	0.0207	-0.0939, 0.0843
Aspen					
1	1986	30	0.0033	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	-0.0240, 0.0304
	1988	28	0.0533	0.0184	-0.0048, 0.0411
2	1986	11	0.0282	0.0193	-0.0143, 0.0707
	1987	11	0.0599	0.0227	0.0099, 0.1099
	1988	10	0.1175	0.0175	0.0779, 0.1571

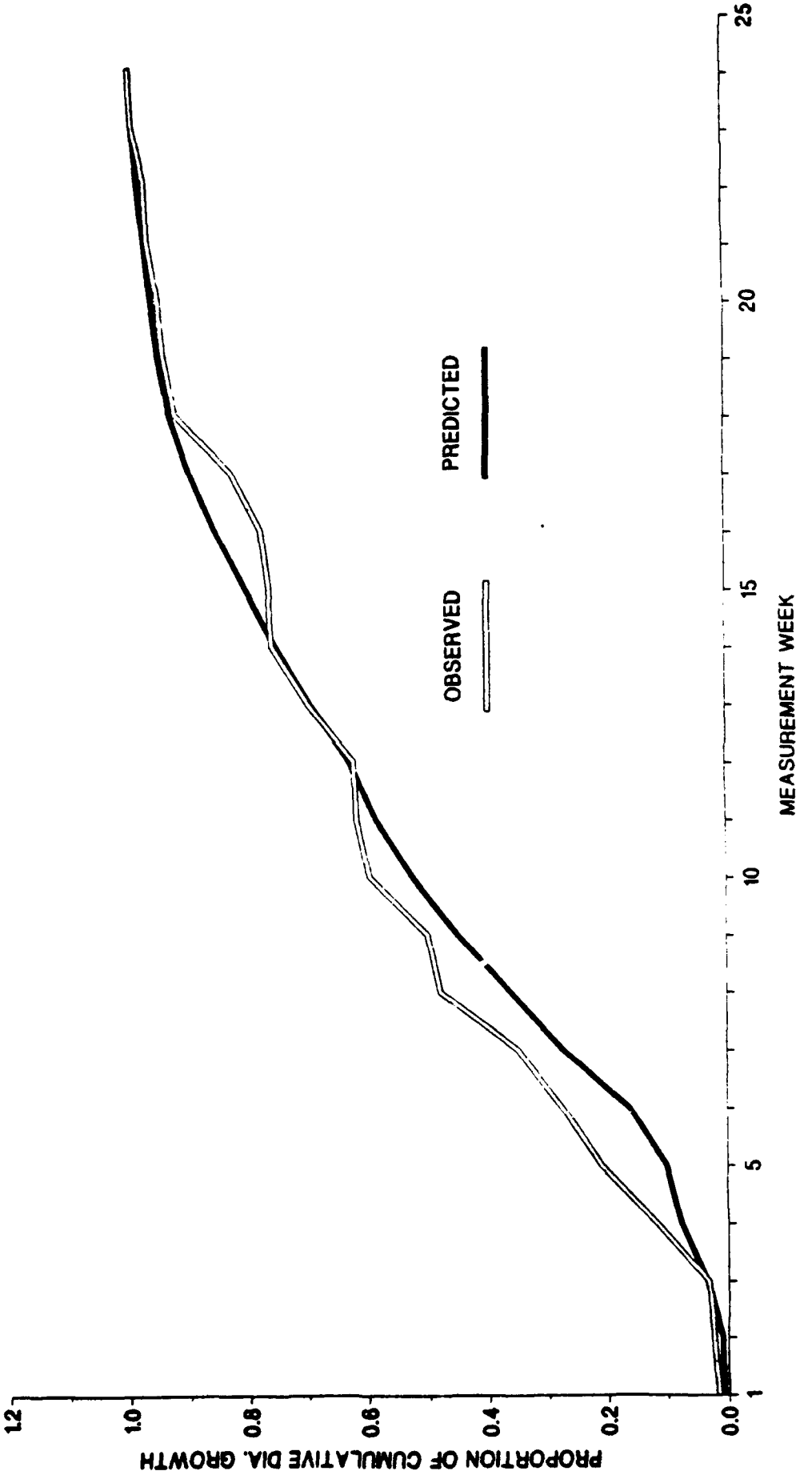
Table 4, Continued.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Red Maple					
1	1986	10	0.0307	0.0143	-0.0016, 0.0630
	1987	10	0.0095	0.0129	-0.0197, 0.0387
	1988	10	-0.0852	0.0243	-0.1402,-0.0302
2	1986	70	-0.0019	0.0059	-0.0136, 0.0098
	1987	80	0.0002	0.0064	-0.0125, 0.0129
	1988	84	-0.0771	0.0053	-0.0876,-0.0666

Table 5. Average April-October weather conditions on the two study sites.

Variable	Site	Year 1986	1987	1988
Air Temperature (°C 2m 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

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


PROPORTION OF CUMULATIVE DIA. GROWTH
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1
5
10
15
20
25
MEASUREMENT WEEK
OBSERVED
PREDICTED

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: LITTER DECOMPOSITION AND MICROFLORA
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ABSTRACT

Six full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed in the hardwood stand subunits at the control and antenna study sites, and in the red pine plantations at the control, antenna, and ground study sites. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss. The litter decomposition portion of this report focuses on analysis of the bulk litter sample data.

Precision in the annual raw data sets has generally been only slightly higher for the hardwood stand subunits than for the plantation subunits. For a variety of reasons, though, the hardwood stand subunits represent much 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 electromagnetic field exposures.

Among the three study species, pine and oak have provided the most precise data. Bulk samples of each species lose approximately 25 percent of initial dry matter mass during their first year on the forest floor. Individual pine fascicles also lose approximately 25 percent of initial mass, but provide more precise data than bulk pine samples, because fragmentation mass loss is controlled with individual fascicles by discarding broken fascicles on retrieval. On the other hand, data for individual oak leaves, which lose from 30 to 40 percent of initial mass, are less precise than bulk oak data; fragment loss from individual leaves is greater than from bulk samples, because

the multi-layered bulk samples tend to trap a higher percentage of fragments. Bulk maple leaf data are the least precise, with samples losing from 33 to 42 percent of initial mass.

We have begun to evaluate the generally significant year-by-site interactions detected by ANOVA. Two types of ANOVA model have been used in preparation of this year's report. First, the traditional effects model ANOVA examines the data set for significant differences among years, sites, months, and plot nested within site, as well as for significant year-by-site interaction. Second, the mathematically equivalent means model ANOVA looks for significant differences among "siteyears" (e.g., control1985, antenna1985, ground1985, control1986, etc.). When significant differences exist among siteyears, multiple comparisons can be used to explain site trends among years. Bulk litter samples of all three species have decomposed faster in the antenna site hardwood stand than in the control site hardwood stand, beginning in 1988. Prior to 1988, ANOVA detected no significant difference in mass loss progress between the two stands, except that oak litter decomposed faster in the control hardwood stand during 1987. ELF field exposures have increased steadily at the antenna site since 1987. The year-by-site interactions in the plantation data set are less straightforward, but the plantations are also much less homogeneous and less stable ecosystems for study than are the hardwood stands. Our principle objective is to use ANACOV to explain these year-by-site interactions, using covariates unrelated to ELF field exposures if possible.

Covariates are proving useful for explaining differences detected by ANOVA in dry matter mass loss among hardwood stands, plantations, and years. Use of covariates is also an important tool for explaining the generally significant year-by-site interactions detected by ANOVA. Useful covariates so far include actual evapotranspiration (AET), total precipitation,

precipitation event frequency, air and soil temperature degree days, initial lignin content, and initial leaf density (for individual oak leaves). Nevertheless, for several reasons, we feel certain that ANACOV will become more effective, as our understanding of the decomposition process as influenced by the ELF study area ecosystem allows us to design more appropriate covariates.

Two approaches are being taken to improve the effectiveness of covariate analysis. First, the data collected in early November will not be included in ANOVA or ANACOV models in future reports, because of an apparent shift during October in the relationship between sample decomposition and sample mass loss. Second, we are developing an additional set of covariates, based on monthly (and seasonal) contributions of energy and moisture to the decomposition system. This set of covariates (e.g., degree days, total precipitation, and frequency of precipitation for each month or season) should permit expression of the differential seasonal effects of energy inputs with respect to concurrent precipitation inputs.

For this report, we have included several ANACOV models whereby 76 Hz and/or 60 Hz electromagnetic field exposures contributed strongly with other more satisfactory covariates toward accounting for more differences among years, sites, and year-by-site interactions than did other groups of covariates without electromagnetic field exposure variables. We are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models. It seems possible that they may behave largely as categorical variables in apparently explaining differences among years and sites (and year-by-site interaction), especially considering the relatively small number of years included in the analysis so far. Also, the P values achieved by all four electromagnetic field strength variables (L60, L76, M76, and T76) are very high, raising

questions about the nature of their contributions to a real explanation of year and site differences. In this regard, however, AET, PCN and PCP also have high P values in a number of interesting models.

This year's report includes a discussion of statistical considerations concerning the use of estimated periodic daily dry matter mass loss (δx) as an alternative dependent variable. On balance, we conclude that this alternative approach is not desirable.

Emphasis in the Red Pine Rhizosphere Streptomycete work element during 1990 was again focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings in the three plantations. Counts of both streptomycete levels and numbers of streptomycete morphotypes were made. Representatives of each morphotype were again characterized for ability to degrade complex organic compounds.

Detectable differences for the 6-year data set using ANOVA were generally less than 1 percent for streptomycete levels and less than 9 percent for morphotype numbers. Significant differences in overall levels were found among years, plantations, and months, and a significant year-by-site interaction was detected. For morphotype numbers, significant differences were detected among years and months, but not among plantations, and no year-by-site interaction was detected. For levels, the 1987 and 1988 values were significantly higher than those for 1985, 1986, 1989, and 1990. Levels appear to be slightly lower in the control plantation than in the antenna and ground plantations. October levels were significantly lower than for all other months. Morphotype numbers declined annually from 1985 through 1987, but levelled off for 1988 through 1990. May morphotype numbers were greater than those for all months except June, while those in October were lower than for all other

months. Similar, relatively stable streptomycete populations appear to have become established at all three study plantations.

ANACOV for streptomycete levels, using air temperature degree days, total precipitation, precipitation frequency, and mycorrhizosphere pH as covariates, explained all differences among years and plantations, and also explained the year-by-site interaction. ANACOV for morphotype numbers, using AET, precipitation frequency, and the delay in processing samples following root excavation as covariates, explained all differences among years and months. We were not surprised to find that "delay" influences the number of morphotypes recovered, but not overall levels. Less abundant types might be expected to be lost to detection with processing delay, without affecting total streptomycete counts.

Morphotype B was again detected at each plantation on each sampling date. Morphotype F, which had a high frequency of isolation prior to 1989, was again detected with less frequency. Fungal and bacterial "contamination" of plates prepared from ground plantation samples continue to cause difficulty in recovery of morphotypes from these samples, as in previous years. In general, the overall 1990 morphotype recovery patterns were more similar to those for 1987 and 1988 than to those for 1986 or 1989. Representatives of each morphotype recovered in 1990 were again tested for their abilities to degrade calcium oxalate, cellulose, and lignocellulose. Test results were consistent with results from previous years, indicating little change in morphotype activities in the past four years.

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SUMMARY

Litter Decomposition and Nutrient Flux

Six full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study units (including 2 hardwood stand and 3 plantation subunits). Samples for the seventh complete study have been installed in the field. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and associated nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss patterns. Dry matter mass loss data sets are complete at this time.

Nutrient (N, P, K, Ca, and Mg) data sets for the 1983-84, 1984-85, and 1985-86 studies are complete. The nutrient data sets for alternate months (May, July, September, and November) are complete from the 1986-87 and 1987-88 studies. Nutrient analysis of retrieved samples has been suspended, at least temporarily, in order to divert needed resources to studies of dry matter mass loss. Nevertheless, all retrieved samples have been archived for additional future analysis. Nutrient and lignin content analyses continue for the parent litter collections from which field samples are drawn.

The level of precision obtained in our studies with bulk and individual fascicle/leaf samples of each litter species is expressed for convenience as the minimum shift in each sample mean which would be detected ($\alpha = 0.05$). As in previous annual reports, minimum detectable differences are presented in the summary tables for raw dry matter mass loss data representing each sample type collected on each sampling date in 1989 at each field subunit. Minimum detectable differences are also reported for treatment means (years, monthly sampling dates, and plantation or hardwood stand subunits) associated with analyses

of variance (ANOVA) and selected analyses of covariance (ANACOV), using transformed data. Dry matter mass loss data have been transformed to the arcsin square root of X (where X is the proportion of original mass remaining) to homogenize variances prior to ANOVA or ANACOV.

Precision in the annual raw data sets has generally been only slightly higher for the hardwood stand subunits than for the plantation subunits. For a variety of reasons, though, the hardwood stand subunits represent much 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 electromagnetic field exposures.

Among the three study species, pine and oak have provided the most precise data. Bulk samples of each species lose approximately 25 percent of initial dry matter mass during their first year on the forest floor. Individual pine fascicles also lose approximately 25 percent of initial mass, but provide more precise data than bulk pine samples, because fragmentation mass loss is controlled with individual fascicles by discarding broken fascicles on retrieval. On the other hand, data for individual oak leaves, which lose from 30 to 40 percent of initial mass, are less precise than bulk oak data; fragment loss from individual leaves is greater than from bulk samples, because the multi-layered bulk samples tend to trap a higher percentage of fragments. Bulk maple leaf data are the least precise, with samples losing from 33 to 42 percent of initial mass.

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 ANOVA model have been used in preparation of this year's report. First, the traditional effects model ANOVA examines the data set for significant differences among years, sites, months, and plot

nested within site, as well as for significant year-by-site interaction. Second, the mathematically equivalent means model ANOVA looks for significant differences among "siteyears" (e.g., control1985, antenna1985, ground1985, control1986, etc.). When significant differences exist among siteyears, multiple comparisons can be used to explain site trends among years. Bulk litter samples of all three species have decomposed faster in the antenna site hardwood stand than in the control site hardwood stand, beginning in 1988. Prior to 1988, ANOVA detected no significant difference in mass loss progress between the two stands, except that oak litter decomposed faster in the control hardwood stand during 1987. ELF field exposures have increased steadily at the antenna site since 1987. The year-by-site interactions in the plantation data set are less straightforward, but the plantations are also much less homogeneous and less stable ecosystems for study than are the hardwood stands. Our principle objective is to use ANACOV to explain these year-by-site interactions, using covariates unrelated to ELF field exposures if possible.

Explanation of all differences in decomposition rate among years for all litter sample types may be an unrealistic goal, especially for the plantations, where vegetational changes are proceeding at different rates and interacting with yearly weather differences. Effects model ANOVAs ranked years differently for each litte species. This is not surprising, in that the annual parent litter collections probably differ substantially in substrate quality, even though parent collections are made at the same locations each year. To the extent that substrate qualtiy 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.

Covariates are proving useful for explaining differences detected by ANOVA in dry matter mass loss among hardwood stands, plantations, and years. Use of covariates is also an important

tool for explaining the generally significant year-by-site interactions detected by ANOVA. Useful covariates so far include actual evapotranspiration (AET), total precipitation, precipitation frequency, air and soil temperature degree days, initial lignin content, and initial leaf density (for individual oak leaves). Nevertheless, for several reasons, we feel certain that ANACOV will become more effective, as our understanding of the decomposition process as influenced by the ELF study area ecosystem allows us to design more appropriate covariates.

Two approaches are being taken to improve the effectiveness of covariate analysis. Both approaches address in effect the basic nonlinearity of litter decomposition progress at the ELF study sites. First, the data collected in early November will not be included in ANOVA or ANACOV models in future reports, because of an apparent shift during October in the relationship between sample decomposition and sample mass loss. We have noticed that the early November mass loss data commonly demonstrate a slow-down in mass loss during October, especially at the site where mass loss through September was fastest. In some cases, sample mass gains occur during October. These mass loss slow-downs or mass gains appear to result in artificially similar estimates of the year-end state of sample decomposition, and in some cases, indicate a reversal of site ranking. We presume that decomposition is actually proceeding during October, but that sample mass loss due to decomposition is being masked by additions of inorganic mass and microbial biomass associated with an advanced state of decomposition. Presuming this to be the case, exclusion of the early November data from analysis should improve the effectiveness of both our ANOVA and ANACOV modeling efforts. ANOVA would provide clearer recognition of differences in mass loss rates among plantations and hardwood stands, and the effectiveness of our ANACOV models, which are largely based on the driving influence of weather variables on mass loss progress, should be substantially improved. Indeed, the correlations between weather variables (including AET) and mass loss are much

poorer, and frequently non-significant, for the November-only data set vs. the May through November data set. Second, we are developing an additional set of covariates, based on monthly (and seasonal) contributions of energy and moisture to the decomposition system. This set of covariates (e.g., degree days, total precipitation, and frequency of precipitation for each month or season) should permit expression of the differential seasonal effects of energy inputs with respect to concurrent precipitation inputs.

For this report, we have included ANACOV models wherein 76 Hz and/or 60 Hz electromagnetic field exposures contributed strongly with other more satisfactory covariates in accounting for more differences among years, sites, and year-by-site interactions than did other groups of covariates without electromagnetic field exposure variables. We are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models. They may behave largely as categorical variables in apparently explaining differences among years and sites (and year-by-site interaction), especially considering the relatively small number of years included in the analysis so far. Also, the P values achieved by all four electromagnetic field strength variables (L60, L76, M76, and T76) are very high, raising questions about the nature of their contributions to a real explanation of year and site differences. In this regard, however, AET, PCN and PCP also have high P values in a number of interesting models.

This year's report also includes a discussion of statistical considerations concerning the use of periodic daily dry matter mass loss (δx) as an alternative dependent variable. On balance, we conclude that this alternative approach is not desirable.

Rhizoplane Streptomycetes

As in previous years, the emphasis of this work element during 1990 was focused on the enumeration and characterization

of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings planted in 1984 in the three plantations. As a result of some suboptimal-sized samples, and contamination of a few samples in the Environmental Microbiology laboratory, fewer than the desired six samples per plantation were successfully processed for each sampling date. Pre-weighed washed mycorrhizal fine root subsamples were macerated, serially diluted, and spread-plated onto starch casein agar amended with antifungal antibiotics. After 14 days incubation, counts of streptomycete levels as well as numbers of morphotypes were made. Representatives of each morphotype were subcultured for further characterization, in particular for ability to degrade complex organic compounds. Streptomycete level and morphotype number data were transformed to $\log_{10}$ and subjected to analysis of variance (ANOVA) for detection of differences first within the 1990 sampling season data and then among all years, sampling dates, and plantations. Analysis of covariance (ANACOV) was used to explain differences detected by ANOVA among years, sampling dates and plantations, and to explain year-by-site interaction.

There was no significant difference detected by ANOVA in either overall streptomycete levels or morphotype numbers among the control, antenna, and ground plantations during the 1990 field season. A significant seasonal effect was identified on morphotype numbers, but not on overall levels. Morphotype numbers in May were higher than those of June and October, August and September levels were higher than June, July and October, and October levels were lower than all months except June and July.

When comparing the six annual streptomycete levels and morphotype numbers data sets, significant differences in overall levels were found among years, months, and plantations, and the year-by-site interaction was also significant. The 1987 and 1988 values were significantly higher than those for 1985 through 1996 and 1989 through 1990. October levels were significantly lower than for all other months. Levels in the control

plantation were lower than levels in either the greound or antenna plantations. Morphotype numbers declined annually from 1985 through 1987, but have levelled off since 1988. May morphotype numbers were greater than those in all other months, while October had fewer morphotypes than any other month. Detectable differences for the $\log^{10}$-transformed six-year data set using ANOVA were generally less than 1 percent for streptomycete levels and typically less than 9 percent for morphotype numbers, for years, months, and plantations.

ANACOV for streptomycete levels, using air temperature degree days, total precipitation, precipitation frequency, and mycorrhizosphere pH as covariates, explained all differences between years and plantations detected by ANOVA, and also explained the year-by-site interaction detected by ANOVA. ANACOV for morphotype numbers, using soil temperature degree days and processing delay (between excavation of roots and delivery of washed type 3 mycorrhizae to the lab) as covariates, explained all differences detected by ANOVA among years and months.

In 1990, as in all previous years, the streptomycete morphotype B was commonly isolated at all three plantations on all sampling dates. Morphotype F, which had a high frequency of isolation prior to 1989, was again detected with less frequency. Fungal and bacterial "contamination" of plates prepared from ground plantation samples continue to cause difficulty in recovery of morphotypes from these samples, as in previous years. In general, the overall 1990 morphotype recovery patterns were more similar to those for 1987 and 1988 than to those for 1986 or 1989. Representatives of each morphotype recovered in 1990 were again tested for their abilities to degrade calcium oxalate, cellulose, and lignocellulose. Test results were consistent with results from previous years, indicating little change in morphotype activities in the past four years.

Similar, relatively stable streptomycete populations appear to have become established on the red pine seedlings at all three study plantations.

INTRODUCTION

Forest vegetation dominates the ELF Communications System antenna area. The litter decomposition subsystem of any forest ecosystem serves to 1) pool the nutrients relinquished by primary producers, 2) transform the essential nutrients remaining in litter or trapped by it into forms available for root uptake, and 3) release these nutrients in a regulated fashion for re-use by the autotrophs. The energy provided by litter decomposition also fuels heterotrophic dinitrogen fixation and the capture of nutrients washed from the atmosphere or leached from living plants. As heterotrophic microorganisms, streptomycetes have also been implicated in the calcium and phosphorus nutrition of conifer mycorrhizae, and could influence mycorrhizosphere microbial composition through production of antibiotics, growth factors, etc. Due to the large quantities of potentially available plant nutrients found in the litter component of forest biomass, 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 electromagnetic fields merit investigation for possible effects on the litter decomposition subsystem.

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause fundamental changes in forest productivity and health. This research program includes two separate yet highly integrated projects, the Herbaceous Plant Cover and Tree Studies ("Trees") project and the Litter Decomposition and Microflora project. Work elements examining 1) rates of litter decomposition and 2) mycorrhizoplane streptomycete population dynamics were initiated simultaneously

with those of the "Trees" project and on the same study units. The two work elements comprising this project complement and extend the baseline studies of the "Trees" project. The information obtained will be used for comparison of pre-operational and operational status of the study variables to evaluate possible ELF electromagnetic field effects on the local forest ecosystem. After six years, and considerable refinement, we believe that the research studies representing the two work elements of this project are both biologically defensible and statistically rigorous. The overall objectives of these work elements are to determine the impacts of ELF electromagnetic fields on:

1) rates of litter decomposition for three important local tree species (northern red oak, red maple, and red pine), and

2) populations of streptomycete species functionally associated with mycorrhizae of planted red pine seedlings.

Ultimately, the question of whether ELF electromagnetic 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.

PROJECT DESIGN

Overview of Experimental Design

Emphasis has been placed from the beginning on development of a statistically rigorous experimental design capable of separating potentially subtle ELF 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 into those of the "Trees" 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

Table 1. Critical null hypotheses which will be tested to fulfill objectives of the ELF environmental monitoring program Litter Decomposition and Microflora project.

I.	There is no difference in the level of foliar litter decomposition (dry matter loss) achieved, or the seasonal pattern by which it proceeds, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.
II.	There is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations on the planted 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 planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

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.

Field Design

The electromagnetic fields associated with the ELF system are different at the antenna and ground locations. As a consequence,

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 and individual leaf litter samples of oak, maple, and pine**[2]; climatic and biotic variables, soil nutrients, litter nutrient and lignin content	1,(1),(6)[1]
II	2	**Monthly counts of streptomycetes associated with mycorrhizae from planted red pine seedlings;** climatic variables, soil nutrients and pH, mycorrhiza density, seedling growth and moisture stress, and processing delay	1,(2),(4)
III	2	**Monthly determinations of numbers of streptomycete strains associated with Type 3 mycorrhizae from planted red pine seedlings;** climatic variables, soil nutrients and pH, mycorrhiza density, seedling growth and moisture stress, and processing delay	1,(2),(4)

[1] Numbers in parentheses refer to work elements in the Herbaceous Plant Cover and Trees project.
[2] Bold print designates the response variable; other lists are covariates.

forest vegetation at each site could be deferentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at a ground terminal, and at a control location some distance from the antenna.

The most general experimental design for the "Trees" project is a split-plot in space and time. Each unit (control, antenna, and ground) is subjected to a regime of ELF field exposures and is subdivided into two stand types (subunits). Pole-sized hardwood stands and red pine (Pinus resinosa Ait.) plantations comprise the treatments for this level of the design (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Figure 1, page 5). Both stand type subunits at each field unit 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 rerandomization. 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 (Steel and Torrie 1980).

Each unit follows this design with one exception. There is no pole-sized hardwood stand subunit at the ground unit because the necessary buffer strips would have resulted in the hardwood subunit being too distant from the grounded antenna for meaningful exposure. Thus one treatment factor (hardwood stands) is eliminated at the ground unit. 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.

Statistical Design

Analysis of variance (ANOVA) and analysis of covariance (ANACOV) are used in our studies to determine effects of treatments (year, individual plantation or hardwood stand, monthly sampling date, and Elf field exposure) on decomposition progress and streptomycete population levels. The statistical design employed in both study elements reported here is a factorial design with blocking and covariates. The factors included in the design vary somewhat by experiment, but include year, month, unit, and blocking. Recall that unit represents the three ELF treatments, control, ground, and antenna. Separate analyses are conducted for the hardwood stand and pine plantation subunits to satisfy the assumptions required by the analysis of variance and analysis of covariance models. These experiments are not split-plot experiments across time, a design frequently used in the "Trees" project, because the experimental units are destructively sampled to obtain the required measurements. A split-plot design across time requires repeated measurements on the same experimental unit.

Blocking is employed to control variability in all experiments, but the definition of blocks varies between experiments. The unit of blocking in the streptomycete experiments and the bulk leaf litter experiments is the plot (3 plots per subunit), with 2 replicates per block. For the individual leaf samples, the location of each group of leaf bags (24 groups per subunit) is a block, from which one replicate bag is removed each month. The blocking employed produces a balanced incomplete block design (i.e., not all ELF treatments can be represented in each block). This 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 fields before they can be legitimately used to explain (with respect to ELF fields) any non-ELF-induced differences in response variables between years or units. The independence of the ambient conditions covariates will be tested by the "Trees" project.

Covariates under examination differ among the dependent variables considered (Table 2). Most analyses use climatic variables computed from weather data, such as monthly mean air temperature, monthly mean soil temperature, monthly total precipitation and the number of precipitation events each month. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the observation; for example, other covariates in the analysis of mycorrhizoplane streptomycete populations could include seedling diameter, seedling height, current season seedling shoot length, simultaneous Type 3 mycorrhiza density, plant moisture stress, mycorrhizosphere soil pH, and/or the delay between root excavation and streptomycete isolation. Analyses will be conducted to determine which of these are both biologically meaningful and statistically significant without violating the necessary assumptions required for the analysis of covariance (Cochran, 1957).

The treatment means presented for each ANOVA and the adjusted treatment means for each ANACOV model employ either the arc sin square root transformation of raw data (litter decomposition, as dry matter mass loss) or the $\log_{10}$ transformation (streptomycete levels and types). 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.

As noted above, the experimental design appropriately supports statistical data analysis by three-way ANOVA and ANACOV. Nevertheless, the sample means presented in figures throughout this report are accompanied by bars indicating the bounds of 95 percent confidence intervals. These confidence intervals are provided as a means of depicting relative sample variability, and do not represent the multiple (or pairwise) comparisons associated with ANOVA or ANACOV, respectively. The error bars in the figures are based on small samples, the number of observations for each specific treatment combination. ANOVA and ANACOV are based on much larger samples, and tend to explain much more variability - partly because n is larger, but also because factors used for statistical blocking and covariance analysis, which contribute to error when calculating the confidence intervals, are included in the ANOVA model. The error bars on the figures are therefore quite conservative when compared to ANOVA results. In other words, a significant difference may be found by ANOVA or ANACOV even if all confidence intervals overlap, if a consistent and sufficient trend exists between at least two levels of a given factor (i.e., monthly sampling dates, years, or different hardwood stand or plantation subunits). We discussed an example of ANOVAs ability to detect a systematic trend in a previous report (Annual Report 1987, page 16).

As sample size increases and/or sample variance decreases, detection of a statistically significant difference between treatments becomes increasingly likely. Yet the biological effect of the given treatments on the dependent variable remains

unchanged, and is either consequential (biologically significant) or not, regardless of the statistical significance achieved. According to Mize and Schultz (1985),

"Means can be consequentially and (or) statistically different. A consequential difference is a difference that is large enough to be important. A statistical difference is a difference that is larger than expected, given the variability of the characteristic that was studied. Sometimes, consequential differences are not statistically different. Also, statistical differences are sometimes not consequential. The researcher should be primarily interested in discussing the statistical significance of consequential differences."

Our experimental design with respect to litter decomposition is powerful enough to detect some statistical differences which, because of their small size, appear to be inconsequential. We view this situation to be highly preferable to the reverse situation. Nevertheless, we expect that careful use of ANACOV will explain additional differences (e.g., between certain years) detected by ANOVA.

Alternative Dependent Variables and New Analysis Procedures to Measure Litter Decomposition

The dependent variable used in this study to measure dry matter mass loss has been the proportion of initial dry matter mass remaining when the samples are retrieved from the study sites. This value is represented in the following discussion by x_i, where i represents the month of sample retrieval. An alternative response variable, suggested by one of the peer reviewers, is the rate of change in dry matter mass between sampling dates. This value will be represented in the following discussion by δx_i. The relative merit of using δx_i as the dependent variable was discussed in last year's report (Annual Report 1989, pages 11-15). The purpose of this section is to further discuss and demonstrate the relative merit of new analysis procedures involving the use of δx_i as the dependent variable. To familiarize the reader with the nature of δx_i as a variable, Tables 3-8, respectively, present δx_i for the 1984-85

Table 3. Mean periodic decomposition rates (δx_i), calculated as the daily change, between 1985 sampling dates, in the proportion[a] of initial dry matter mass (30°C) remaining, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.0005	0.0002	37	0.0005	0.0001	22
2 June	0.0014	0.0009	65	0.0015	0.0006	41
2 July	0.0006	0.0006	110	-0.0004	0.0005	130
31 July	0.0008	0.0013	161	0.0003	0.0005	157
27 August	0.0021	0.0007	36	0.0026	0.0010	39
12 October	0.0017	0.0012	72	0.0017	0.0012	76
2 November	-0.0020	0.0042	222	-0.0023	0.0053	240
1 December				0.0045	0.0035	82

Table 3. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.0004	0.0001	28	0.0005	0.0001	16
2 June	0.0014	0.0008	57	0.0010	0.0004	43
2 July	0.0016	0.0007	48	0.0009	0.0003	32
31 July	0.0005	0.0007	156	0.0002	0.0014	717
27 August	0.0018	0.0009	52	0.0029	0.0014	50
12 October	0.0009	0.0014	157	0.0020	0.0006	34
2 November	0.0025	0.0047	196	0.0009	0.0020	227
1 December				0.0021	0.0011	56

Table 3. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
30 April	0.0006	0.0001	24
2 June	0.0012	0.0004	37
2 July	0.0010	0.0006	60
31 July	0.0014	0.0006	44
27 August	0.0022	0.0012	60
12 October	0.0013	0.0007	58
2 November	0.0003	0.0032	1045

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 periodic decomposition rates (δx_i), calculated as the daily change, between 1986 sampling dates, in the proportion[a] of initial dry matter mass (30°C) remaining, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.0005	0.0001	28	0.0004	0.0002	41
3 June	-0.0000	0.0008	2131	-0.0004	0.0009	261
1 July	0.0011	0.0004	42	0.0005	0.0002	45
30 July	0.0009	0.0004	51	0.0009	0.0003	39
4 September	0.0027	0.0005	19	0.0016	0.0011	70
1 October	0.0020	0.0006	32	0.0016	0.0005	36
6 November	0.0010	0.0016	165	0.0021	0.0008	41
6 December				0.0015	0.0016	107

Table 4. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.0004	0.0001	16	0.0004	0.0000	10
3 June	0.0005	0.0004	80	-0.0003	0.0004	136
1 July	0.0008	0.0004	59	0.0007	0.0004	59
30 July	0.0010	0.0003	36	0.0008	0.0005	64
4 September	0.0015	0.0006	38	0.0021	0.0009	44
1 October	0.0019	0.0010	58	0.0021	0.0002	8
6 November	0.0024	0.0024	107	0.0014	0.0003	24
6 December				-0.0002	0.0001	45

Table 4. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.0005	0.0001	15
3 June	-0.0001	0.0004	395
1 July	0.0012	0.0005	46
30 July	0.0012	0.0005	45
4 September	0.0019	0.0004	23
1 October	0.0021	0.0011	57
6 November	0.0018	0.0017	110

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 periodic decomposition rates (δx_i), calculated as the daily change, between 1987 sampling dates, in the proportion[a] of initial dry matter mass (30°C) remaining, for bulk northern red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Unit: Hardwood Stand Mean	S.D.	%
29 April	0.0004	0.0002	47	0.0003	0.0001	36
27 May	0.0028	0.0023	88	-0.0001	0.0011	1197
25 June	-0.0006	0.0015	252	0.0014	0.0008	59
23 July	0.0025	0.0021	87	0.0021	0.0006	31
27 August	0.0016	0.0024	159	0.0019	0.0005	29
24 September	0.0007	0.0016	253	0.0017	0.0012	73
28 October	0.0007	0.0009	137	0.0001	0.0005	920
22 November				0.0015	0.0006	44

Table 5. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D.	%	Control Unit: Hardwood Stand Mean	S.D.	%
29 April	0.0004	0.0002	53	0.0004	0.0001	28
27 May	0.0010	0.0004	48	0.0009	0.0005	61
25 June	0.0009	0.0009	100	0.0007	0.0004	65
23 July	0.0017	0.0005	31	0.0018	0.0008	48
27 August	0.0020	0.0008	41	0.0017	0.0010	61
24 September	0.0016	0.0019	119	0.0032	0.0031	101
28 October	0.0003	0.0015	602	-0.0008	0.0009	115
25 November				0.0013	0.0008	66

Table 5. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
29 April	0.0006	0.0007	115
27 May	-0.0008	0.0020	249
25 June	0.0025	0.0036	151
23 July	0.0023	0.0056	255
27 August	0.0004	0.0022	639
24 September	0.0012	0.0013	130
28 October	0.0005	0.0010	199

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 6. Mean periodic decomposition rates (δx_i), calculated as the daily change, between 1988 sampling dates, in the proportion[a] of initial dry matter mass (30°C) remaining, for bulk northern red oak leaves disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
4 May	0.0006	0.0001	17	0.0005	0.0001	23
1 June	0.0004	0.0008	252	-0.0002	0.0007	439
29 June	0.0012	0.0008	76	0.0007	0.0010	149
28 July	0.0009	0.0008	91	0.0006	0.0005	86
31 August	0.0026	0.0012	51	0.0035	0.0003	10
28 September	0.0006	0.0014	223	0.0012	0.0006	46
2 November	0.0020	0.0016	95	0.0018	0.0009	52
1 December				-0.0006	0.0020	353

Table 6. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	0.0004	0.0001	18	0.0004	0.0001	21
1 June	0.0015	0.0007	46	0.0004	0.0005	145
29 June	0.0006	0.0017	277	0.0001	0.0007	649
28 July	0.0006	0.0012	196	0.0007	0.0003	38
31 August	0.0022	0.0004	17	0.0023	0.0008	37
28 September	0.0017	0.0004	27	0.0023	0.0006	27
2 November	0.0018	0.0008	47	0.0013	0.0006	54
1 December				-0.0010	0.0009	95

Table 6. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	0.0006	0.0001	23
1 June	0.0010	0.0005	54
29 June	0.0005	0.0013	260
28 July	0.0012	0.0011	99
31 August	0.0022	0.0004	20
28 September	0.0016	0.0007	44
2 November	0.0018	0.0018	105

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 7. Mean periodic decomposition rate (δx_i), calculated as the daily change, between 1989 sampling dates, in the proportion[a] of initial dry matter mass (30°C) remaining, for bulk red oak foliar litter samples disbursed in early December, 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
12 May	0.0005	0.0003	50	0.0005	0.0001	15
10 June	0.0012	0.0015	139	0.0012	0.0009	74
8 July	0.0014	0.0013	99	0.0016	0.0009	59
5 August	0.0019	0.0021	116	0.0020	0.0011	57
9 September	0.0018	0.0022	130	0.0016	0.0008	52
9 October	0.0003	0.0017	568	0.0007	0.0010	139
13 November	0.0009	0.0013	150	0.0009	0.0013	149

Table 7. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
12 May	0.0006	0.0001	19	0.0005	0.0001	23
10 June	0.0014	0.0006	41	0.0006	0.0006	96
8 July	0.0013	0.0009	73	0.0014	0.0007	52
5 August	0.0010	0.0012	126	0.0014	0.0014	101
9 September	0.0016	0.0009	60	0.0013	0.0009	75
9 October	0.0016	0.0011	72	0.0011	0.0017	166
13 November	0.0007	0.0008	136	0.0004	0.0010	254

Table 7. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
12 May	0.0006	0.0003	48
10 June	0.0018	0.0011	62
8 July	0.0010	0.0011	108
5 August	0.0023	0.0010	47
9 September	0.0010	0.0011	113
9 October	0.0011	0.0009	84
13 November	0.0006	0.0011	174

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 8. Mean periodic decomposition rate (δx_i), calculated as the daily change, between 1990 sampling dates, in the proportion[a] of initial dry matter mass (30°C) remaining, for bulk red oak foliar litter samples disbursed in early December, 1989.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
8 May	0.0002	0.0001	44	0.0002	0.0001	30
6 June	0.0010	0.0007	73	0.0007	0.0004	58
5 July	0.0011	0.0004	43	0.0014	0.0005	39
1 August	0.0007	0.0005	76	0.0011	0.0006	61
3 September	0.0012	0.0006	51	0.0017	0.0008	53
6 October	0.0021	0.0014	72	0.0021	0.0004	18
10 November	0.0010	0.0016	159	0.0002	0.0018	1271

Table 8. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
8 May	0.0002	0.0001	30	0.0002	0.0000	17
6 June	0.0009	0.0006	67	0.0004	0.0003	70
5 July	0.0014	0.0003	25	0.0009	0.0007	89
1 August	0.0012	0.0008	75	0.0017	0.0012	79
3 September	0.0014	0.0007	52	0.0017	0.0006	35
6 October	0.0018	0.0010	56	0.0022	0.0004	20
10 November	0.0012	0.0009	80	0.0007	0.0010	153

Table 8. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
8 May	0.0003	0.0001	24
6 June	0.0010	0.0004	38
5 July	0.0013	0.0004	34
1 August	0.0017	0.0011	64
3 September	0.0008	0.0009	130
6 October	0.0014	0.0005	42
10 November	0.0005	0.0009	223

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

through 1989-90 bulk oak litter decomposition experiments.

Demonstration of New Analysis Procedures

This section will present analytical approaches which have not previously been used in the litter decomposition and microflora studies. The new techniques are:

1. Use of the change in dry matter mass loss as the dependent variable.
2. Introduction of an alternative, but mathematically equivalent, linear statistical model representation.

New analysis approach 1: Use of change in dry matter mass as the dependent variable

Last year's annual report contained a discussion of the potential advantages and disadvantages of using change in dry matter mass as the dependent variable. Edited portions of this discussion are reproduced below. See the 1989 annual report for the complete discussion.

For this discussion, the variable x_i represents dry matter mass remaining, and the variable δx_i represents the change in dry matter mass between consecutive (i-1 and i) sample retrievals.

The possible advantages of using δx_i to model decomposition are:

1) To circumvent concern about the lack of independence between observations of mass remaining at different points in time during the sampling year.
2) Elapsed time between sample collection dates could be explicitly included in the analysis of litter decomposition by expressing δx_i as a daily rate of change.
3) Explanation of differences between sites and years using covariates may be facilitated.

The possible disadvantages of using δx_i to model decomposition are:

1) Actual loss of statistical power caused by variance inflation which occurs when two random variables are subtracted (or added).
2) Perceived loss of statistical power resulting from comparing small magnitude responses (δx_i) versus large magnitude responses (x_i).
3) Actual loss of independence of the error terms between successive measurements. This occurs because each x_i variable is used to calculate two δx_i values, which creates an autocorrelated error structure.

In last year's annual report, we argued that advantage one and disadvantage two should not be concerns. We did indicate the intent to test the use of δx_i as the independent variable. The remainder of this section discusses this effort.

The bulk sample dataset was modified to include δx_i and the rate of change of x_i (δx_i/number of days between sample collections). Weather variables for the period between sampling dates were included for analysis of covariance. The pole stands were used for this analysis because they provide a more homogeneous process over time, and therefore would be expected to be more sensitive to ELF disturbance. δx_i was calculated as $x_{i-1} - x_i$, where the x_{i-1} sample was recovered from the same "location" within a subplot during the previous month. If samples were missing for an x_{i-1} measurement, then the subplot average for the previous month was used for x_{i-1}.

The analysis of variance results for bulk samples when the rate of change of x_i was used as the dependent variable are presented in Tables 9 (pine), 11 (oak), and 13 (maple). These tables include the minimum difference between means required for significance using Tukey's honestly significant difference multiple range test. The analogous analyses using the proportion

Table 9. ANOVA results for bulk pine across all years using the rate of change in dry matter mass as the dependent variable.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	.0001264		12.31	0.0001	.35
Year	4		.00000495	2.41	0.0486	
Site	1		.00000015	0.28	0.5951	
Year*Site	4		.00000017	0.08	0.9881	
Plot(Site)	4		.00000072	0.35	0.8452	
Month	7		.00012169	33.85	0.0001	
Error	445	.0002285				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]							
Year				5	6	7	8	9	
1985	0.0007357								
1986	0.0009494								
1987	0.0009836								
1988	0.0008992								
1989	0.0008320								
Tukey's minimum significant difference = 0.000288									
Month		5	6	7	8	9	10	11	12
May	0.0005528				*	*	*		
June	0.0008508					*		*	*
July	0.0006222				*	*	*		
August	0.0010618	*		*		*		*	*
September	0.0020063	*	*	*	*		*	*	*
October	0.0011142	*		*		*		*	*
November	0.0004258		*		*	*	*		
December	0.0002954		*		*	*	*		
Tukey's minimum significant difference = 0.000405									
Pole Stand						A	C		
Antenna	0.0008977								
Control	0.0008658								
Tukey's minimum significant difference = 0.000130									

[a] $\alpha = 0.05$, Tukey's H.S.D.

Table 10. ANOVA results for bulk pine across all years using the the dry matter mass remaining as the dependent variable.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	2.7013		300.06	0.0001	.93
Year	4		0.115773	64.30	0.0001	
Site	1		0.006526	14.50	0.0002	
Year*Site	4		0.022676	12.59	0.0001	
Plot(Site)	4		0.002910	1.62	0.1691	
Month	7		2.537363	805.28	0.0000	
Error	445	0.2003				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]							
Year				5	6	7	8	9	
1985	0.7854				*	*	*	*	
1986	0.8229			*			*		
1987	0.8160			*			*		
1988	0.8317			*	*	*			
1989	0.8298			*	*	*			
Tukey's minimum significant difference = 0.00852									
Month		5	6	7	8	9	10	11	12
May	0.9202		*	*	*	*	*	*	*
June	0.8953	*		*	*	*	*	*	*
July	0.8767	*	*		*	*	*	*	*
August	0.8460	*	*	*		*	*	*	*
September	0.7812	*	*	*	*		*	*	*
October	0.7460	*	*	*	*	*		*	*
November	0.7310	*	*	*	*	*	*		*
December	0.7163	*	*	*	*	*	*	*	
Tukey's minimum significant difference = 0.0120									
Pole Stand				A	C				
Antenna	0.8132				*				
Control	0.8208			*					
Tukey's minimum significant difference = 0.00386									

[a] $\alpha = 0.05$, Tukey's H.S.D.

Table 11. ANOVA results for bulk oak across all years using the rate of change in dry matter mass as the dependent variable.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	Signif. F	of F	r^2
Model	20	0.0001763		4.63	0.0001	.17
Year	4		.00000580	0.76	0.5509	
Site	1		.00000040	0.21	0.6456	
Year*Site	4		.00000393	0.52	0.7244	
Plot(Site)	4		.00000216	0.28	0.8886	
Month	7		.00016430	12.33	0.0001	
Error	446	0.0008491				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]							
Year				5	6	7	8	9	
1985	0.0011646								
1986	0.0009492								
1987	0.0011144								
1988	0.0008791								
1989	0.0011019								
Tukey's minimum significant difference = 0.000554									
Month		5	6	7	8	9	10	11	12
May	0.0004298					*	*		
June	0.0004590					*	*		
July	0.0007652					*	*		
August	0.0010793					*			
September	0.0021380	*	*	*	*			*	*
October	0.0017610	*	*	*				*	
November	0.0005752					*	*		
December	0.0011338					*			
Tukey's minimum significant difference = 0.000780									
Pole Stand				A	C				
Antenna	0.0010674								
Control	0.0010128								
Tukey's minimum significant difference = 0.000251									

[a] $\alpha = 0.05$, Tukey's H.S.D.

Table 12. ANOVA results for bulk oak across all years using the the dry matter mass remaining as the dependent variable.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	3.9746		176.54	0.0000	.89
Year	4		0.236017	52.42	0.0001	
Site	1		0.001506	1.34	0.2480	
Year*Site	4		0.068572	15.23	0.0001	
Plot(Site)	4		0.003429	0.76	0.5506	
Month	7		3.753552	476.34	0.0000	
Error	446	0.5021				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]							
Year				5	6	7	8	9	
1985	0.8076				*	*	*		
1986	0.8551			*		*	*	*	
1987	0.8340			*	*			*	
1988	0.8376			*	*			*	
1989	0.8098				*	*	*		
Tukey's minimum significant difference = 0.0135									
Month		5	6	7	8	9	10	11	12
May	0.9388			*	*	*	*	*	*
June	0.9240			*	*	*	*	*	*
July	0.9022	*	*		*	*	*	*	*
August	0.8717	*	*	*		*	*	*	*
September	0.8052	*	*	*	*		*	*	*
October	0.7452	*	*	*	*	*		*	*
November	0.7230	*	*	*	*	*	*		*
December	0.6953	*	*	*	*	*	*	*	
Tukey's minimum significant difference = 0.0190									
Pole Stand				A	C				
Antenna	0.8275								
Control	0.8311								
Tukey's minimum significant difference = 0.00610									

[a] $\alpha = 0.05$, Tukey's H.S.D.

Table 13. ANOVA results for bulk maple across all years using the rate of change in dry matter mass as the dependent variable.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	0.0001038		3.65	0.0001	.14
Year	4		.00000946	1.66	0.1579	
Site	1		.00000025	0.18	0.6741	
Year*Site	4		.00000278	0.49	0.7442	
Plot(Site)	4		.00000164	0.29	0.8853	
Month	7		.00009197	9.21	0.0001	
Error	446	0.0006349				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]							
Year				5	6	7	8	9	
1985	0.0011016								
1986	0.0009660								
1987	0.0009980								
1988	0.0010746								
1989	0.0007327								
Tukey's minimum significant difference = 0.000479									
Month				5	6	7	8	9	10	11	12
May	0.0012073					*				*	
June	0.0010605					*					
July	0.0001658			*	*		*	*	*		
August	0.0013237					*				*	
September	0.0014387					*				*	*
October	0.0013840					*				*	*
November	0.0005070			*			*	*	*		
December	0.0007062							*	*		
Tukey's minimum significant difference = 0.000674											
Pole Stand						A		C			
Antenna	0.0010037										
Control	0.0009573										
Tukey's minimum significant difference = 0.000217											

[a] $\alpha = 0.05$, Tukey's H.S.D.

Table 14. ANOVA results for bulk maple across all years using the the dry matter mass remaining as the dependent variable.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	5.50632		257.15	0.0000	.92
Year	4		2.682975	626.49	0.0000	
Site	1		0.030733	28.71	0.0001	
Year*Site	4		0.063818	14.90	0.0001	
Plot(Site)	4		0.022324	5.21	0.0004	
Month	7		2.367865	315.95	0.0000	
Error	446	0.47750				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]							
Year				5	6	7	8	9	
1985	0.6017				*	*	*	*	
1986	0.7529			*			*	*	
1987	0.7596			*			*	*	
1988	0.6692			*	*	*		*	
1989	0.8389			*	*	*	*		
Tukey's minimum significant difference = 0.0131									
Month		5	6	7	8	9	10	11	12
May	0.8256		*	*	*	*	*	*	*
June	0.7915	*			*	*	*	*	*
July	0.7873	*			*	*	*	*	*
August	0.7497	*	*	*		*	*	*	*
September	0.7043	*	*	*	*		*	*	*
October	0.6595	*	*	*	*	*			*
November	0.6433	*	*	*	*	*			*
December	0.5879	*	*	*	*	*	*	*	
Tukey's minimum significant difference = 0.0185									
Pole Stand					A	C			
Antenna	0.7138					*			
Control	0.7298				*				
Tukey's minimum significant difference = 0.00595									

[a] $\alpha = 0.05$, Tukey's H.S.D.

of dry matter mass remaining (x_i) as the dependent variable are presented in Tables 10 (pine), 12 (oak), and 14 (maple). The analyses using x_i as the dependent variable do not employ our usual arcsin square-root transformation of x_i in order to allow comparison with the mean-square-error of the rate of change analyses.

Recall that the central focus of the analysis in previous reports was to develop a linear statistical model that would be able to detect subtle ELF effects, and then statistically explain all possible ELF effects using only factors (covariates) that could not have been affected by the ELF fields. Thus, the goal is to show that all year, site, and year-site interactions could be explained by factors other than the ELF fields.

Inspection of tables 9, 11, and 13 shows that the analyses using the rate of change of dry matter mass for the dependent variable explains all site main effects and year-site interactions. Furthermore, the only year effect that was significant a (α = .05) was for the pine analysis (p=.0486). In this case, Tukey's honestly significant difference multiple range test could identify no pair of means as being different.

The analyses using dry matter mass remaining, presented in Tables 10, 12, and 14, provide very different results. All year and year-site interactions are highly significant, and the contribution of site is highly significant except for the oak analysis.

From this comparison, it is clear that the analyses using the rate of change of decomposition seem to address the central concern of the ELF study. Essentially, all site and year main effects and year-site interactions have been explained. However, it is not clear if this explanation has been accomplished because of advantage two listed above (i.e., the ability to adjust for differences in elapsed time between sampling dates) or because of disadvantage one (loss of statistical power resulting from variance inflation when two random variables are subtracted).

Recall from last year's annual report that the difference

between two independent normally distributed random variables (x_{i-1} with mean μ_{i-1} and variance σ_{i-1}^2 and x_i with mean μ_i and variance σ_i^2) is distributed as a normal random variable with mean equal to the difference between the two means ($\mu_{i-1} - \mu_i$) and variance equal to the sum of the variances ($\sigma_{i-1}^2 + \sigma_i^2$). Therefore, the resulting random variable (δx_i) will be more variable than either of the original random variables. If we assume that $\sigma_{i-1}^2 = \sigma_i^2$, then the magnitude of the increase in the standard deviation will be about 40% (s.d. $\delta x_i = (\sigma^2 + \sigma^2)^{0.5} = 2^{0.5}\sigma$). Therefore, the difference between means would need to be about 40% greater to detect a significant difference for the change in dry matter mass analysis than for the proportion of dry matter mass remaining analysis.

To better understand the ramifications of the variance inflation, the Tukey's minimum significant differences were reduced to the level that would have been detectable without the variance inflation (Tukey's minimum significant difference / $2^{.5}$) for the "years" comparison. The two years with the fastest decomposition, 1986 and 1987, would have been different than the year with the slowest decomposition when the "uninflated" minimum significant difference was used. A similar result occurred for maple (the two years with the most rapid decomposition, 1985 and 1988, would have decomposed significantly faster than the slowest year, 1989). There would still have been no difference between years for oak. Although these comparisons are not valid statistical tests, they do indicate that the variance inflation may be reducing the power of our analyses to an unacceptable level.

We suggest that, for future reports, the percent of dry matter mass remaining be retained as the dependent variable. However, we suggest that an additional covariate, the number of days that actual sample collection diverged from the planned sample collection date, be included. This would correct the predicted decomposition for variability in the date of sample collection while avoiding disadvantage 3, the creation of an

autocorrelated error structure, when δx_i values are calculated.

New analysis approach 2: The means model

We have previously used what is referred to as the "effects" model for ANOVA and ANACOV analysis. In this form, treatments of a factorial experiment are treated as main effects, while the "lack of additivity" is combined into an interaction term.

As mentioned above, the main focus of analysis for possible ELF effects is to try to explain three terms in the linear model:

1. Because of the pre- and post-exposure design of the study, explaining year-to-year differences may indicate that no ELF effect occurs.
2. Because of the inclusion of treatment (exposed to ELF fields) and control sites, explaining site to site differences may indicate that no ELF effect occurs.
3. If no year by site interaction occurs, then we can conclude that no ELF effect occurs.

In the litter decomposition study, there are nearly always significant year-by-site interactions. Furthermore, these interactions are highly significant. The interpretation of the year-by-site 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 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 exposure, or if it is only random variation due to microclimatic factors not represented in the analysis.

An alternative ANOVA model, referred to by Milliken and Johnson (1984) as the means model, can be formulated. 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. This approach is mathematically equivalent to the effects model, but it allows more detailed analysis of the treatment combinations.

The means model will be demonstrated using the bulk pine experiment. Table 15 presents the ANOVA results using the "effects" model, and Table 16 presents the analogous results for the "means" model. These analyses use the same dependent variable that has been used in previous annual reports, the arcsin square-root of dry matter mass remaining. Recall that this transformation homogenizes the error variance for proportion data. Multiple range tests are only presented for the year and site factors. The results are presented in the traditional "lines format". Means connected by a letter are not significantly different, while means not connected by a letter are different.

Inspection of Table 16 shows that the means models allow us to analyze the information at a much more disaggregated level. For example, this representation allows us to identify a significant difference between the control and antenna sites beginning in the 1988 experiment and continuing in the 1989 experiment. This divergence was identified by one of the peer reviewers of the 1989 report, and was concealed in the interaction term of the effects model. This issue will be addressed more completely in the body of the report, and updated to include data from the 1990 field season.

WORK ELEMENTS

The work elements of the Litter Decomposition and Microflora project acknowledge the two diverse study areas included within this project. Data from several 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 rationale for study, measures, and analyses conducted in each work element of this project.

Table 15. ANOVA results for bulk pine using the effects model. The dependent variable is the arcsin square-root of the proportion of dry matter mass remaining.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	4.9421		256.76	0.0000	.92
Year	4		0.23596	61.29	0.0001	
Site	1		0.01156	12.02	0.0006	
Year*Site	4		0.04523	11.75	0.0001	
Plot(Site)	4		0.00414	1.08	0.3683	
Month	7		4.62910	687.13	0.0000	
Error	445	0.4283				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation	Means	Significant Differences[a]		
		Grouping		
Year				
1988	1.1602	A		
1989	1.1515	A	B	
1986	1.1481	A	B	
1987	1.1397		B	
1985	1.0944			C
Site				
Control	1.1436	A		
Antenna	1.1336		B	

Table 16. ANOVA results for bulk pine using the means model. The dependent variable is the arcsin square-root of the proportion of dry matter mass remaining.

ANOVA TABLE

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	4.9421		256.76	0.0000	.92
Site-Year	9		0.27949	36.30	0.0001	
Plot(Site)	4		0.00414	1.08	0.3683	
Month	7		4.62910	687.13	0.0000	
Error	445	0.4283				

MEANS AND SIGNIFICANT DIFFERENCES

Source of Variation		Means	Significant Differences[a]			
Year	Site		Grouping			
1988	Control	1.1804	A			
1989	Control	1.1642	A	B		
1986	Antenna	1.1504		B	C	
1986	Control	1.1458		B	C	
1988	Antenna	1.1400			C	
1987	Control	1.1398			C	
1987	Antenna	1.1395			C	
1989	Antenna	1.1389			C	
1985	Antenna	1.0999				D
1985	Control	1.0886				D

ELEMENT 1: LITTER DECOMPOSITION AND NUTRIENT FLUX

Introduction

Litter decomposition comprises a complex of processes involving a variety of organisms engaged in the degradation of a wide range of organic substrates. Loss of dry matter mass over time from freshly fallen foliar litter samples has traditionally been used as a measure of fully integrated litter decomposition (Kendrick 1959, Jensen 1974, Millar 1974, Witkamp and Ausmus 1976). Both the accuracy and precision of dry matter mass loss as a sensitive index of organic matter deterioration, however, decline with time beyond approximately one year, depending on the ecosystem (Fogel and Cromack 1978). We have also found that mass loss characterization on the basis of individual leaves provides additional information about the decomposition process and the rates at which it naturally proceeds for different litter species, beyond that provided by study of mass loss for bulk samples. Bulk sample estimates of mass loss rates actually represent running averages of the decomposition rates (including fragmentation) operating in the individual leaves comprising the bulk sample. Bulk sample mass loss data for pine litter overestimate mass loss, because fragment loss is not controlled. On the other hand, bulk oak leaf samples provide lower estimates of mass loss than do individual oak leaves, presumably because a high proportion of fragments are trapped between leaves in bulk samples. Regardless, bulk samples are essential for conversion of nutrient concentrations determined for bulk litter samples from percent values to masses for calculation of nutrient flux. The increased sample sizes accompanying individual leaf studies also permit more accurate establishment of decomposition rates for comparison between subunits, years, and monthly sampling dates.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar

1978). Conversely, dry matter mass loss and nutrient flux are useful measures 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 fields represent one possible cause of environmental perturbation.

Studies of litter decomposition and associated nutrient flux extend the usefulness of litter production data collected in the course of forest vegetation studies. Knowledge of litter biomass production and nutrient content conversely 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. The conifer species selected for study (Pinus resinosa) exists as scattered mature specimens throughout the area. These three study species represent a range of decomposition strategies and rates. Red pine was also selected because the influence of fragmentation can be eliminated through experiments with individual fascicles.

A sixth year's experience with red pine, northern red oak, and red maple foliar litter decomposition and nutrient flux has been gained on the three study units (sites). Experience to date supports the contention that mass loss over time from freshly fallen foliar litter can be characterized with sufficient precision to detect subtle environmental perturbations.

Methods

Litter decomposition is being quantified as percent change over time in dry matter mass. Experiments are conducted annually and focus on the year following each year's autumn litterfall.

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 approximately 15 random samples taken at regular intervals during field sample preparation from each of the annual pine, oak, and maple litter parent collections. Analysis of litter nutrient content is being conducted by the Soils Analysis Laboratory, School of Forestry and Wood Products, Michigan Technological University. Laboratory protocol includes analysis of NBS standard no. 1575 (pine needles), as every 20th sample for N and P, and as every 15th sample for cations. All mass loss data (dry matter as well as nutrient masses) 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 lay flat on the ground.

All samples are disbursed in the field during early December, and subsets are retrieved at approximately monthly intervals from early May to early november. Snow cover at the study sites dictates early May to be the earliest possible recovery date, because samples are frozen to the ground until snowmelt is complete. Likewise, snow cover dictates early November as the latest possible recovery date from the plantation subunits, because samples are frozen to the ground by the early December sampling date.

Raw data are expressed as the proportion (X) of original dry matter mass remaining over time. Dry matter mass loss is being studied by an individual fascicle/leaf method as well as via bulk litter samples. Nutrient flux can be determined only for the bulk litter samples. Individual fascicles/leaves offer the opportunity to study decomposition of basic foliage units. Each individual fascicle or leaf is completely intact at the time of disbursal. The influence of fragmentation on individual pine fascicle decomposition is especially easy to eliminate by discarding any fascicles broken during the course of study.

Individual leaf density (g cm^{-1}) is determined for each individual oak leaf, for use as a covariate.

Sufficient samples were recovered each month to permit analysis of differences in dry matter losses between subunits, years, and monthly sampling dates by ANOVA and ANACOV. Dry matter mass loss data are transformed to the arc sin square root of X, to homogenize variances prior to correlation analysis, ANOVA, and ANACOV (Steel and Torrie 1980). The arc sin square root transformation is recommended for use with data expressed as decimal proportions less than 1.00, especially when proportions within a data set vary widely.

In all statistical analyses performed, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$, regardless of the statistical test employed. Differences which are significant ($p \leq 0.05$) are presented along with the attained significance level (p) of the test statistic. Multiple range comparisons among significant differences detected by ANOVA and ANACOV are being identified by the least square means pairwise comparison procedure (SAS Institute, Inc. 1985). All ANOVAs and ANACOVs presented here have been conducted on the mainframe computer at MTU, using PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985).

Sufficient decomposition and weather data are available for a substantial modeling effort. Several weather and biotic variables have been evaluated as covariates to date. Our use of ANACOV to explain differences detected by ANOVA has been introduced under Project Design (pages 11 - 14). Covariates under evaluation include individual oak leaf density, initial lignin and nutrient content, nutrient content of retrieved samples, vegetative cover variables, litterfall characteristics, and weather variables (both integrated and periodic in nature). Our success so far with weather-related variables probably underestimates their importance biologically, because they have largely been calculated independently of one another and/or have been calculated as cumulative values. For this reason, we are

using actual evapotranspiration (AET: e.g., Thornthwaite and Mather 1957, Meentemeyer 1978, Meentemeyer and Berg 1986), which integrates temperature, precipitation, water-holding capacity, and lattitude. Other monthly and seasonal weather-related covariates are being developed, in order to accomodate the nonlinear progress of mass loss through the year caused by fluctuations in energy and moisture inputs to the decomposition system. As a guiding principle, only variables which can be shown to be unaffected by ELF electromagnetic fields to date will be considered as potentially useful covariates, since ANOVA and ANACOV are proposed as our principle tools for detection of any ELF-induced shift(s) of litter decomposition rates.

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. The residual portions of the autumn, 1988-1990, parent litter collections have also been archived to permit establishment of a future decomposition experiment, which will compare the decomposition of samples derived from litter collected during different years. This experiment would afford an opportunity to determine whether or not source litter quality variables could be responsible for any unexplained differences which remain among our annual experiments.

Initial lignin content of the 15 parent litter collections (3 spp., 5 yr) is being evaluated as a covariate. Lignin content is being estimated using the technique described by TAPPI (Official Testing Method T 222 om-88, revised 1988), entitled "Acid-insoluble lignin in wood and pulp". The only modification to this procedure involves autoclaving the digesting sample for 1 hour rather than boiling it for 4 hours (step 9.4; V.L.C. Chiang, personal communication). Other studies have found lignin content useful for explaining differences in decomposition rate (e.g., Melillo et al. 1982). We anticipate that lignin content may be

most useful in evaluating the maple data, as the influence of lignin on decomposition rate increases as weight loss progresses (Meentemeyer and Berg 1986, Berg et al. 1984, Fogel and Cromack, Jr. 1977).

Our approach to studying the nutritional aspects of litter decomposition has shifted, from the original intent to consider nutrient fluxes as dependent variables, toward use of percent nutrient contents as covariates to help explain dry matter mass loss. In light of this shift of emphasis, we have cautiously reduced the intensity of nutrient analysis conducted on samples retrieved from the field. 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 recrieved samples, in order to devote available resources to mass loss studies.

1989-90 Study

Fresh-fallen red pine litter was again collected on polyethylene tarps (provided with drainage) 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 subunit 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. For the 1988-89 study, individual leaf envelopes measured 22 cm x 28 cm, and each contained one pine fascicle and one oak leaf.

Prior to the 1986-87 study, individual leaf envelopes contained multiple tethered leaves of a single species, and one

envelope per month per species was recovered from each plantation or hardwood stand subunit plot. Beginning with the 1987 field season, we collected 1 envelope (containing one pine fascicle and one oak leaf) from each of 8 locations per plot each month. Two advantages to this modified method were forseen:

1. The individual study leaves of each species are more clearly independent of one another.
2. Recovery of individual leaf envelopes from 24 locations per subunit (instead of 3) better represents site variability.

This adjustment in experimental design for the study of individual leaf decomposition may prevent comparison of individual oak leaf data collected in the plantations in different years by the two methods. Regardless, the ability to compare antenna and ground subunits with the corresponding subunits at the control site will be enhanced by the improvement in experimental design.

It should be emphasized that the experimental design regarding bulk litter envelopes 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.

1990-91 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter were collected again in 1990 as described for the 1989-90 study. The same experimental design established for the 1984-85 through 1989-90 studies is being followed for bulk litter samples in the 1990-91 study. The same experimental design for individual fascicle/leaf study established with the 1986-87 study is being continued with the 1990-91 study, with the single exception that only pine fascicles and oak leaves are included.

Description of Progress

1989-90 Study

Tables 17 and 18 present mean dry matter mass loss summaries (raw, untransformed data) for the bulk and individual fascicle pine samples retrieved in 1989 (by sampling date and subunit), along with standard deviations and minimum detectable differences (based on 95 percent confidence intervals for sample means). Tables 19 and 20 present the corresponding data from all five study subunits for bulk and individual oak leaf samples. Corresponding data for bulk maple samples are presented in Table 21. The data show that the following shifts in bulk and individual fascicle/leaf sample means should be detectable (α = 0.05).

A. Pine
    1. Plantation Subunits
        a. Individual Fascicles - 3%
        b. Bulk Samples - 4%
    2. Hardwood Stand Subunits
        a. Individual Fascicles - 3%
        b. Bulk Samples - 4%

B. Oak
    1. Plantation Subunits
        a. Individual Leaves - 5%
        b. Bulk Samples - 3%
    2. Hardwood Stand Subunits
        a. Individual Leaves - 4%
        b. Bulk Samples - 2%

C. Maple
    1. Plantation Subunits
        a. Bulk Samples - 9%
    2. Hardwood Stand Subunits
        a. Bulk Samples - 9%

Table 17. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1990, for bulk red pine foliar litter samples disbursed in early December, 1989.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
8 May	0.95	0.01	1	0.94	0.01	1
6 June	0.93	0.02	3	0.93	0.01	2
5 July	0.90	0.02	3	0.88	0.02	2
1 August	0.88	0.02	2	0.83	0.02	2
3 September	0.84	0.03	3	0.81	0.02	3
6 October	0.79	0.03	4	0.74	0.01	2
10 November	0.74	0.03	4	0.73	0.01	2

Table 17. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
8 May	0.93	0.02	3	0.96	0.01	1
6 June	0.93	0.01	2	0.96	0.01	1
5 July	0.90	0.02	2	0.92	0.02	2
1 August	0.87	0.03	3	0.88	0.02	3
3 September	0.83	0.02	3	0.84	0.05	6
6 October	0.78	0.03	4	0.76	0.01	2
10 November	0.74	0.03	4	0.74	0.03	4

Table 17. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
8 May	0.94	0.01	1
6 June	0.92	0.02	2
5 July	0.87	0.01	2
1 August	0.86	0.01	1
3 September	0.83	0.02	3
6 October	0.79	0.02	3
10 November	0.75	0.01	1

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 18. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1990, for individual red pine fascicles disbursed in early December, 1989.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
8 May	0.95	0.01	1	0.95	0.02	1
6 June	0.93	0.04	2	0.95	0.02	1
5 July	0.90	0.03	2	0.90	0.04	2
1 August	0.85	0.05	3	0.87	0.06	3
3 September	0.80	0.03	2	0.82	0.05	3
6 October	0.77	0.04	2	0.76	0.05	3
10 November	0.73	0.03	2	0.75	0.03	2

Table 18. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
8 May	0.94	0.05	3	0.96	0.02	1
6 June	0.92	0.02	1	0.96	0.02	1
5 July	0.89	0.03	2	0.94	0.03	1
1 August	0.84	0.02	1	0.91	0.04	2
3 September	0.80	0.04	3	0.85	0.05	2
6 October	0.77	0.04	2	0.81	0.05	3
10 November	0.73	0.05	3	0.78	0.05	3

Table 18. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
8 May	0.94	0.02	1
6 June	0.92	0.04	2
5 July	0.89	0.03	1
1 August	0.85	0.03	2
3 September	0.79	0.04	2
6 October	0.77	0.03	2
10 November	0.72	0.03	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 19. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1990, for bulk northern red oak foliar litter samples disbursed in early December, 1989.

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Unit: Hardwood Stand Mean	S.D.	%
8 May	0.97	0.01	1	0.97	0.01	1
6 June	0.94	0.01	1	0.95	0.01	1
5 July	0.91	0.01	1	0.91	0.02	2
1 August	0.89	0.02	2	0.88	0.02	2
3 September	0.85	0.02	2	0.82	0.02	2
6 October	0.78	0.05	6	0.75	0.01	2
10 November	0.74	0.01	2	0.75	0.06	9

Table 19. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D.	%	Control Unit: Hardwood Stand Mean	S.D.	%
8 May	0.97	0.01	1	0.97	0.00	1
6 June	0.94	0.01	2	0.96	0.01	1
5 July	0.90	0.02	2	0.93	0.02	2
1 August	0.87	0.02	2	0.89	0.02	2
3 September	0.82	0.02	2	0.83	0.01	1
6 October	0.76	0.02	3	0.76	0.01	1
10 November	0.72	0.02	3	0.74	0.03	4

Table 19. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
8 May	0.96	0.01	1
6 June	0.93	0.01	1
5 July	0.89	0.01	1
1 August	0.85	0.02	3
3 September	0.82	0.02	3
6 October	0.78	0.02	3
10 November	0.75	0.04	6

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 20. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1990, for individual northern red oak leaves disbursed in early December, 1989.

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Unit: Hardwood Stand Mean	S.D.	%
8 May	0.95	0.02	1	0.96	0.02	1
6 June	0.87	0.06	3	0.93	0.04	2
5 July	0.80	0.07	4	0.89	0.04	2
1 August	0.79	0.06	3	0.84	0.03	2
3 September	0.73	0.07	4	0.81	0.03	7
6 October	0.64	0.07	5	0.75	0.06	3
10 November	0.59	0.07	5	0.70	0.07	4

Table 20. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D.	%	Control Unit: Hardwood Stand Mean	S.D.	%
8 May	0.95	0.02	1	0.97	0.01	1
6 June	0.87	0.05	3	0.94	0.03	2
5 July	0.84	0.06	3	0.92	0.03	1
1 August	0.78	0.07	4	0.87	0.04	2
3 September	0.72	0.06	4	0.80	0.06	3
6 October	0.69	0.04	3	0.75	0.05	3
10 November	0.64	0.10	7	0.71	0.05	3

Table 20. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
8 May	0.93	0.04	2
6 June	0.86	0.07	3
5 July	0.80	0.06	3
1 August	0.75	0.08	5
3 September	0.72	0.07	4
6 October	0.67	0.08	5
10 November	0.60	0.08	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

Table 21. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1990, for bulk red maple foliar litter samples disbursed in early December, 1989.

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Unit: Hardwood Stand Mean	S.D.	%
8 May	0.93	0.03	4	0.93	0.04	4
6 June	0.83	0.05	6	0.85	0.03	4
5 July	0.78	0.03	4	0.82	0.02	3
1 August	0.74	0.03	4	0.75	0.03	4
3 September	0.70	0.04	6	0.71	0.06	9
6 October	0.67	0.04	6	0.63	0.04	6
10 November	0.61	0.07	12	0.67	0.09	13

Table 21. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D.	%	Control Unit: Hardwood Stand Mean	S.D.	%
8 May	0.93	0.03	4	0.93	0.03	4
6 June	0.82	0.02	3	0.87	0.05	6
5 July	0.77	0.03	4	0.84	0.03	4
1 August	0.72	0.05	7	0.80	0.04	5
3 September	0.69	0.04	6	0.76	0.04	6
6 October	0.63	0.03	5	0.67	0.04	7
10 November	0.62	0.07	12	0.69	0.04	7

Table 21. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
8 May	0.88	0.02	3
6 June	0.84	0.04	5
5 July	0.80	0.05	6
1 August	0.72	0.03	4
3 September	0.71	0.06	9
6 October	0.65	0.03	5
10 November	0.58	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

For individual pine fascicles, Figures 1 and 2 present comparisons of monthly dry matter mass loss progress during the 1989-90 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Figure 3 presents comparisons of monthly dry matter mass loss progress during the 1984-85 through 1989-90 experiments at the ground site plantation. Again, means are plotted between bars depicting their 95 percent confidence intervals. Note that actual retrieval dates are slightly misrepresented, in order to avoid confusion associated with overlapping error bars. Figure 3a presents the same data as Figure 3, but without error bars, and properly represents retrieval date as elapsed time since sample disbursal. Figure 3b also presents the same data without error bars, but represents retrieval date as the Julian date. Thus, Figures 3, 3a, and 3b provide different perspectives on the time factor involved in comparing data from the six annual experiments. Figures 4 through 7 present corresponding comparisons for the antenna and control plantations, and for the antenna and control hardwood stands, respectively. The following Figures present analogous comparisons:

Figures 8 through 14 - Individual Oak Leaves
Figures 15 through 21 - Bulk Pine Fascicles
Figures 22 through 28 - Bulk Oak Leaves
Figures 29 through 35 - Bulk Maple Leaves

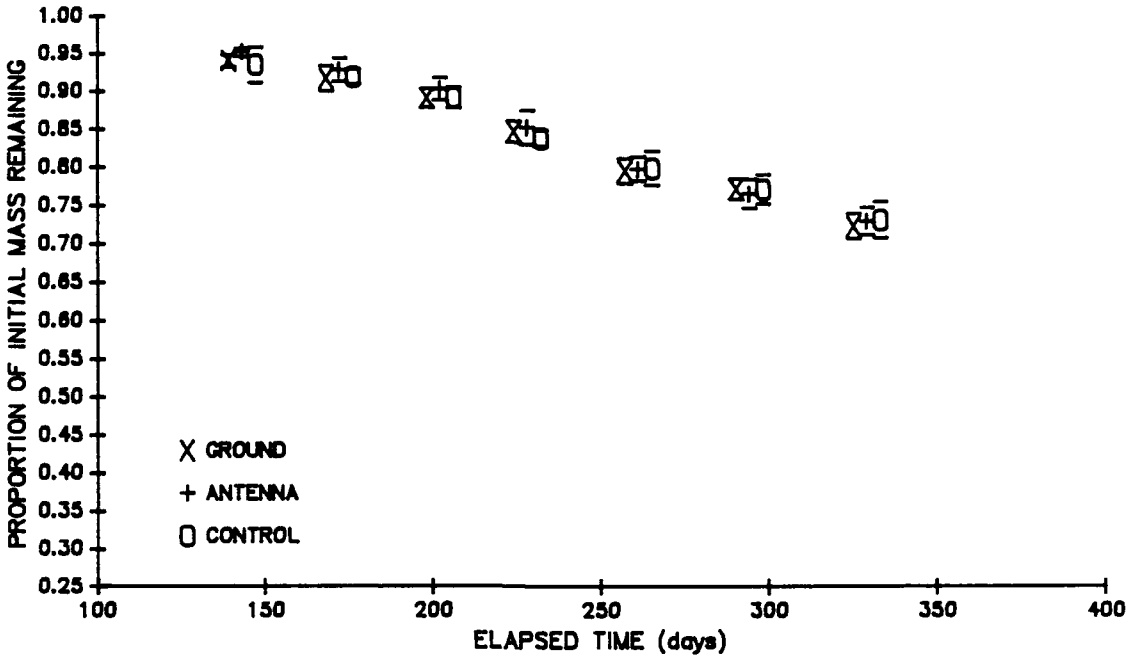


FIGURE 1. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the three plantation subunits during the 1989–1990 experiment.

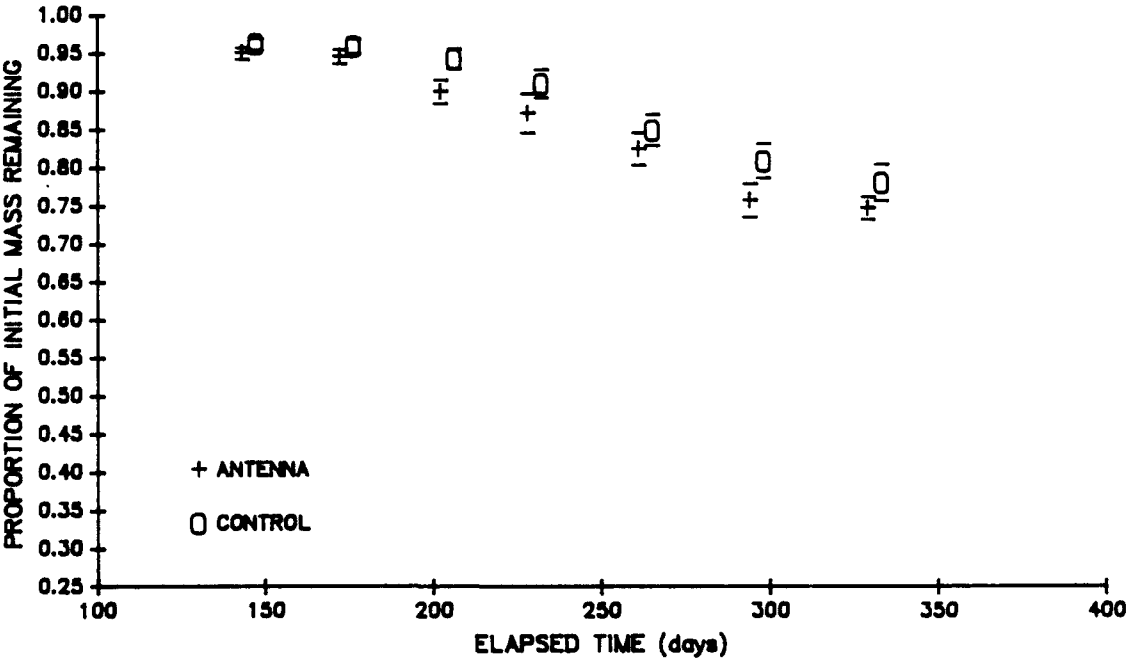


FIGURE 2. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the two hardwood stand subunits during the 1989–1990 experiment.

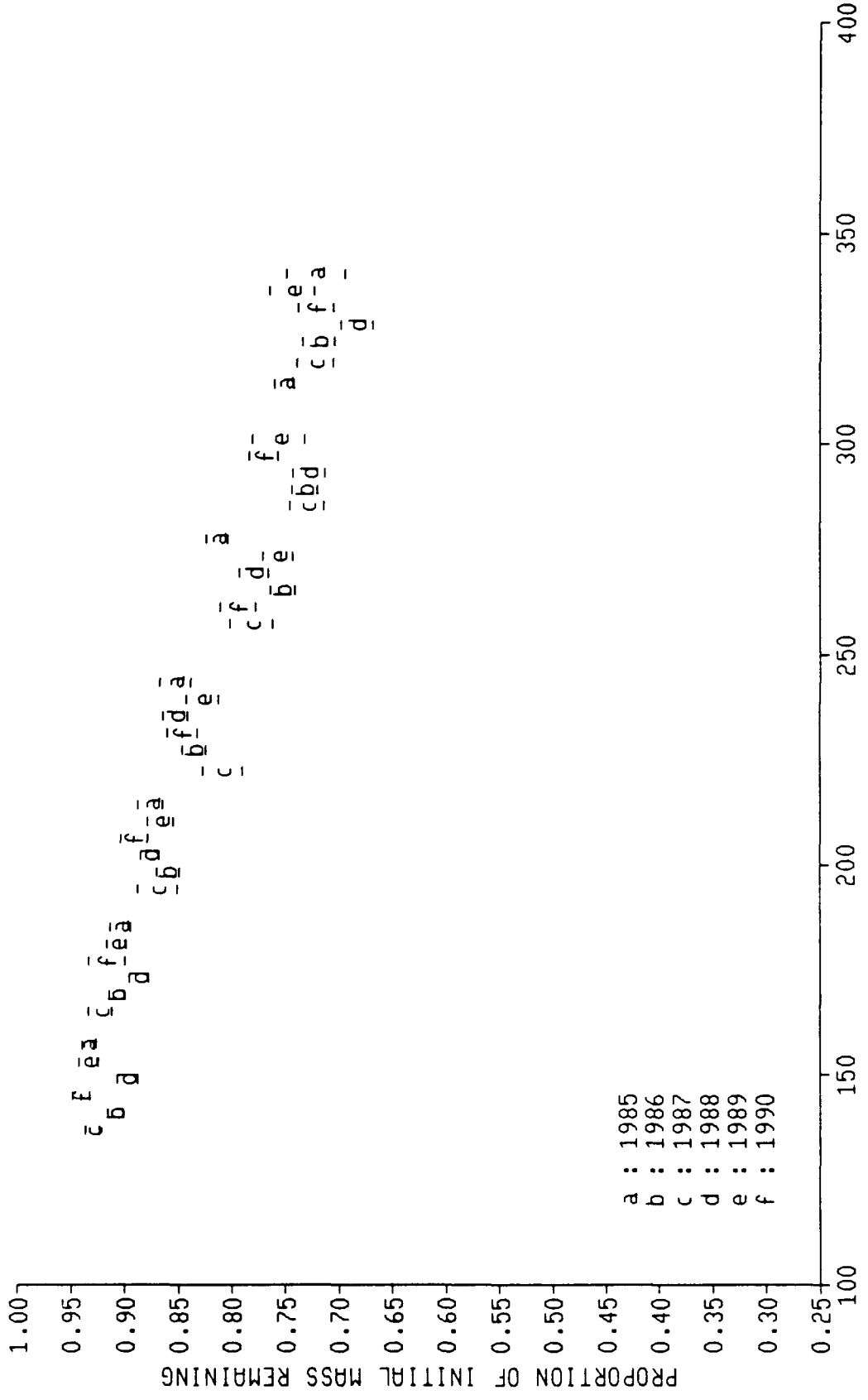


Figure 3. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

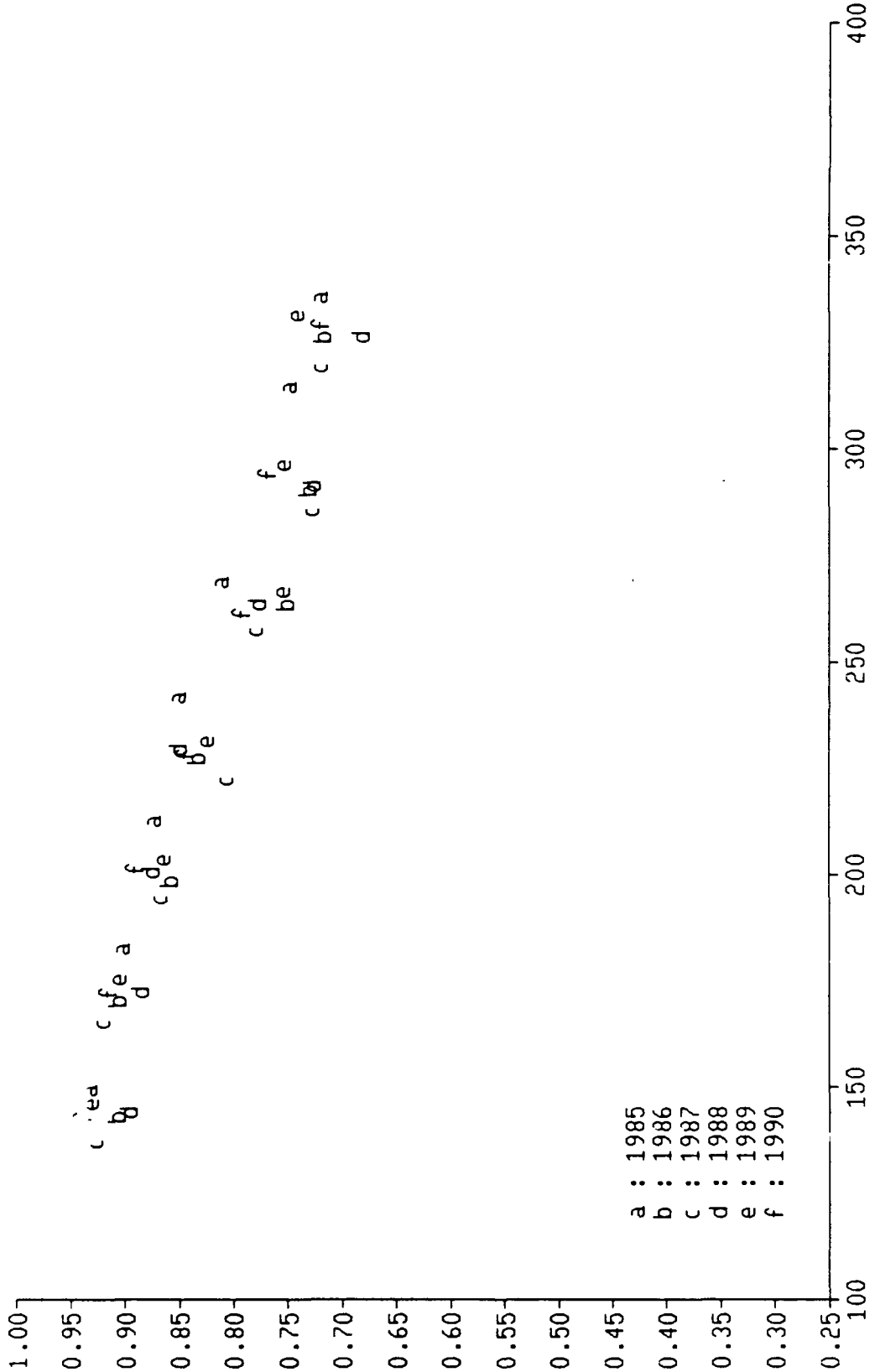


Figure 3a. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

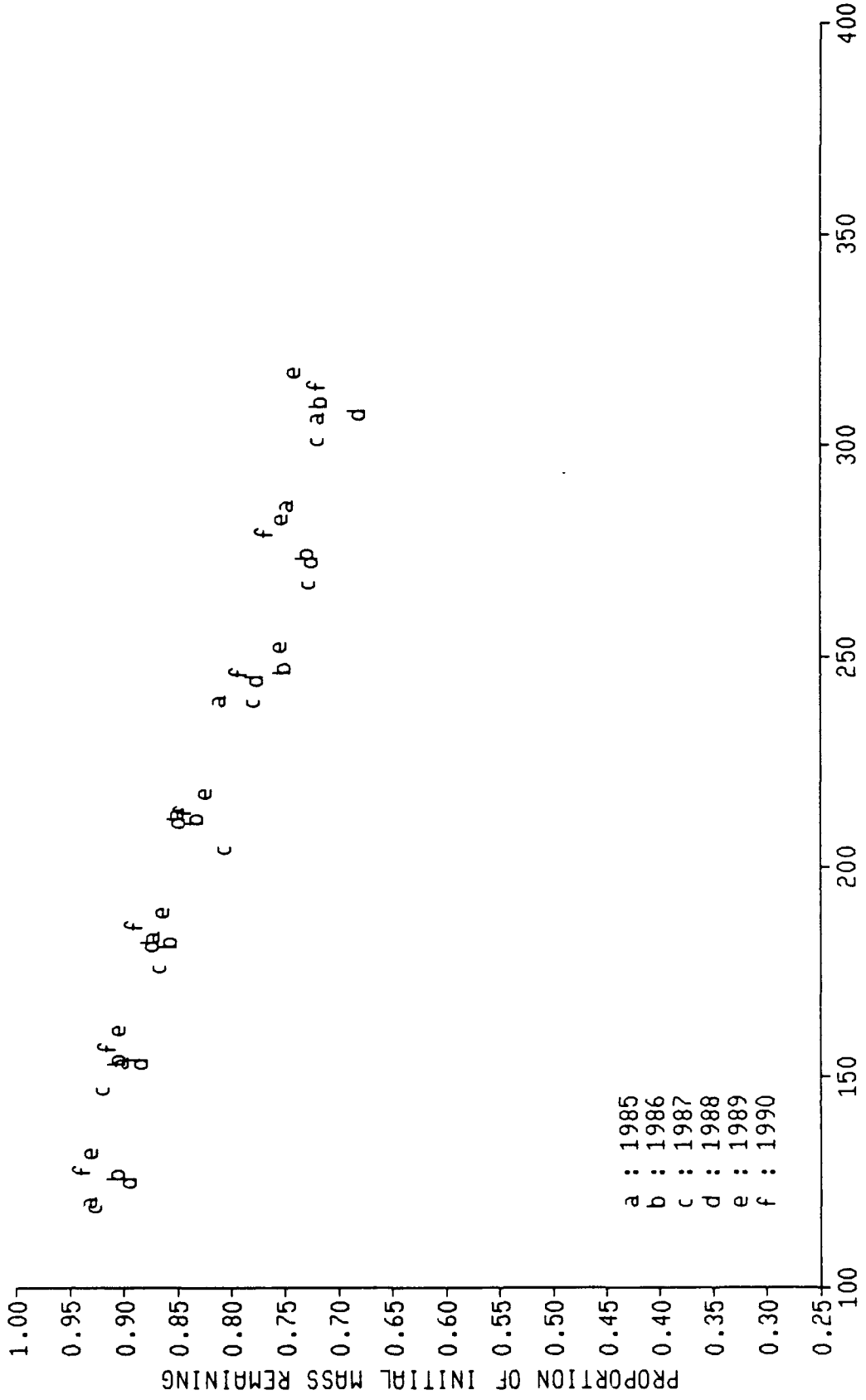


Figure 3b. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

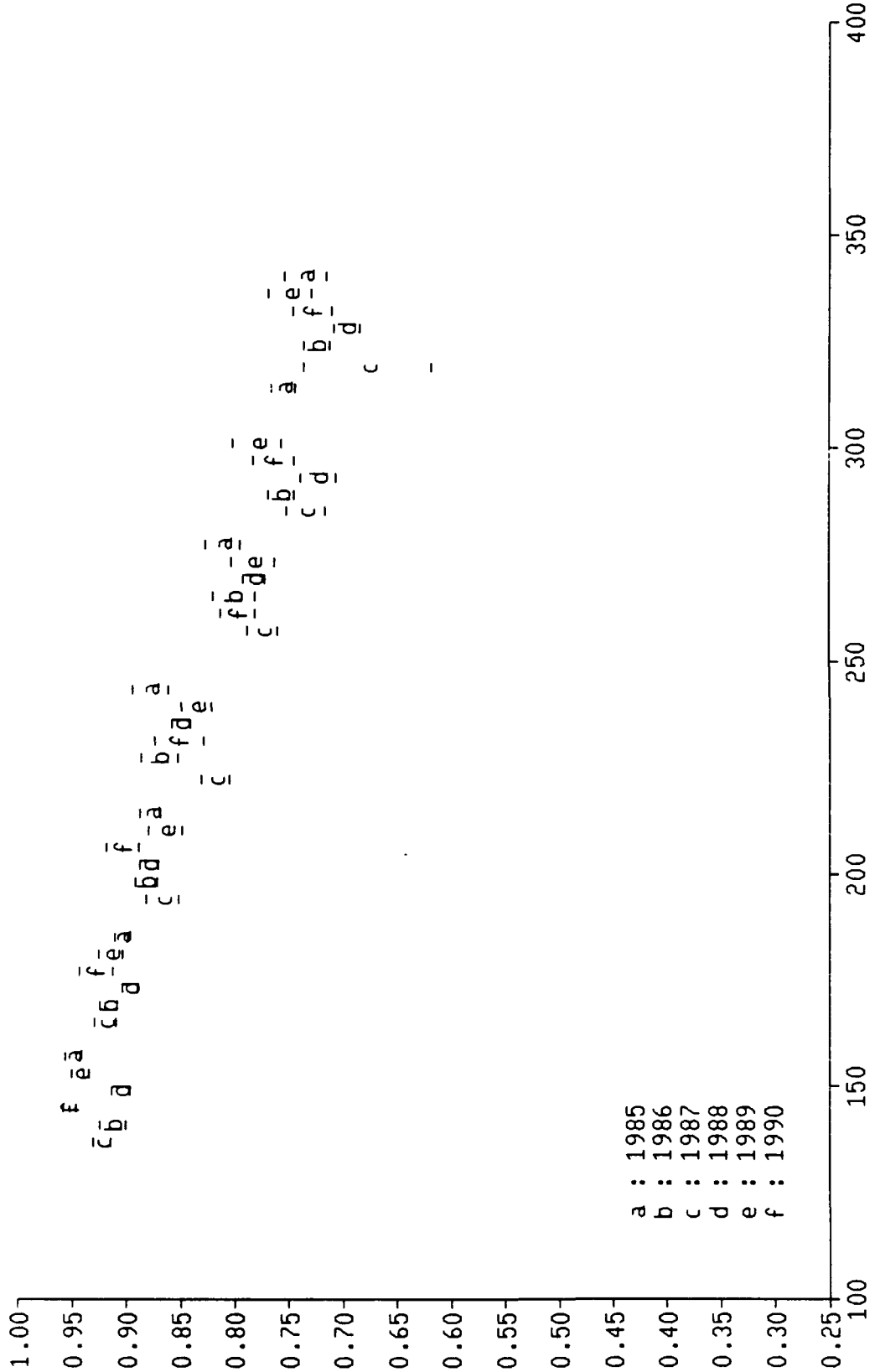


Figure 4. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

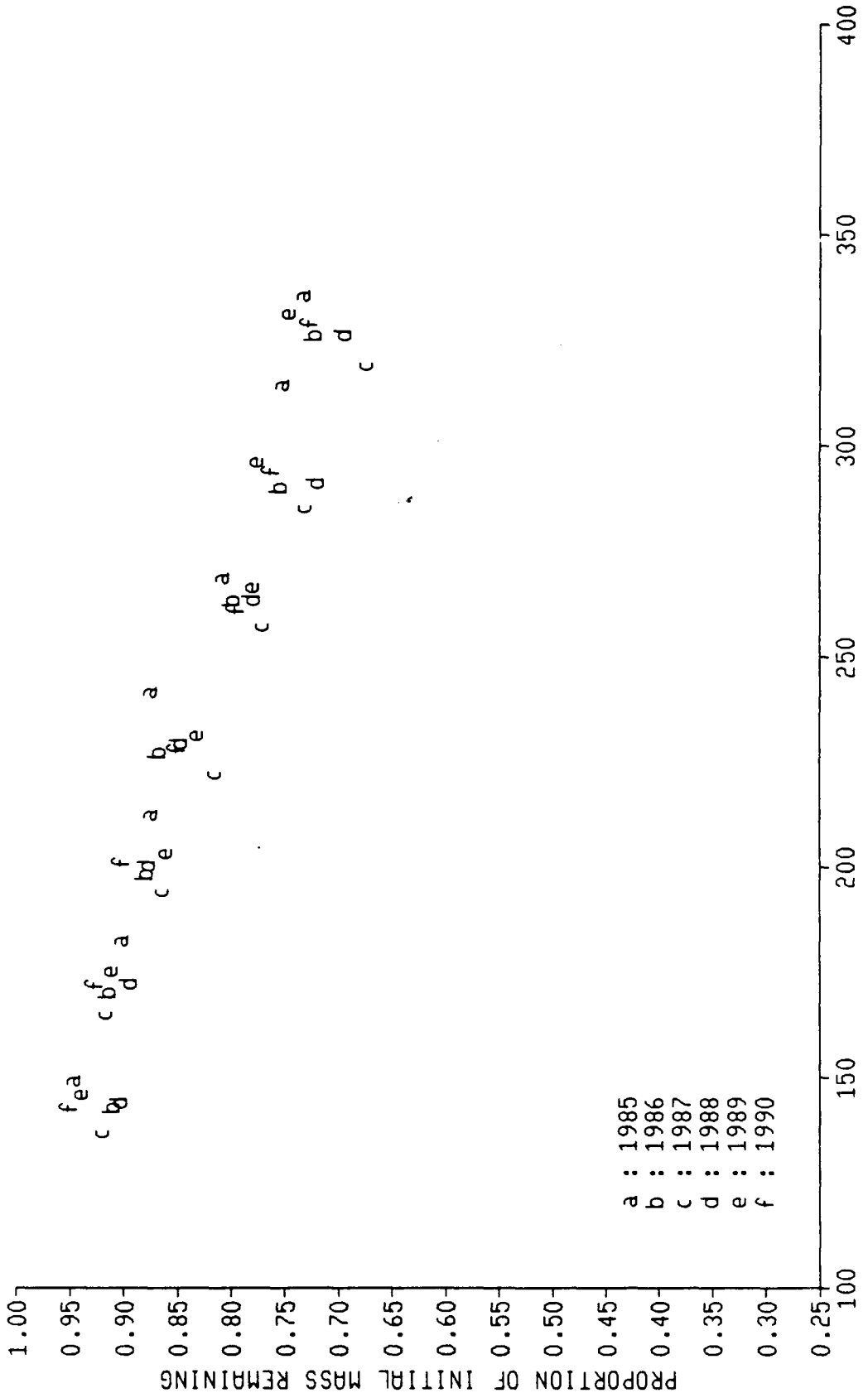


Figure 4a. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

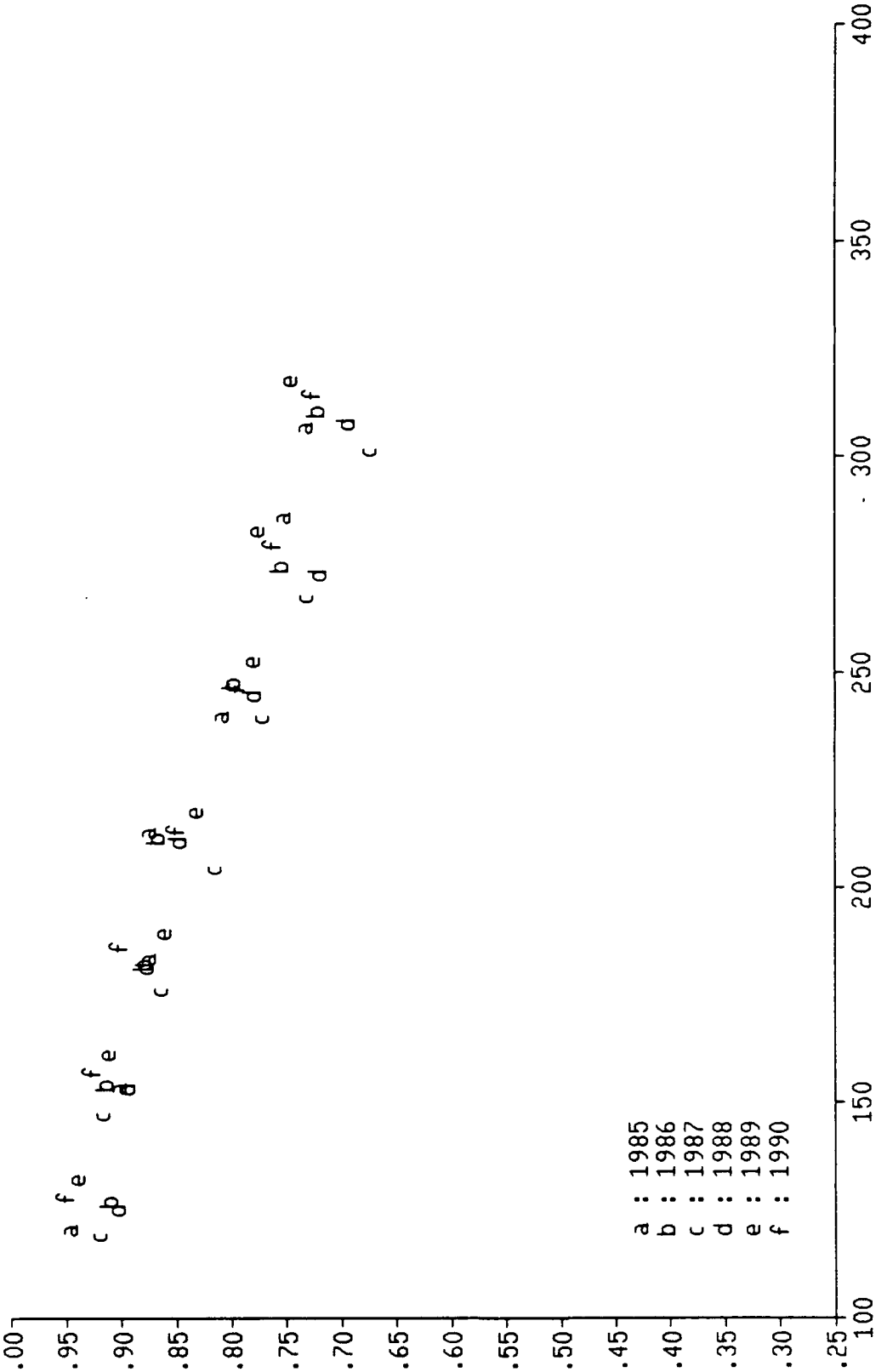


Figure 4b. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

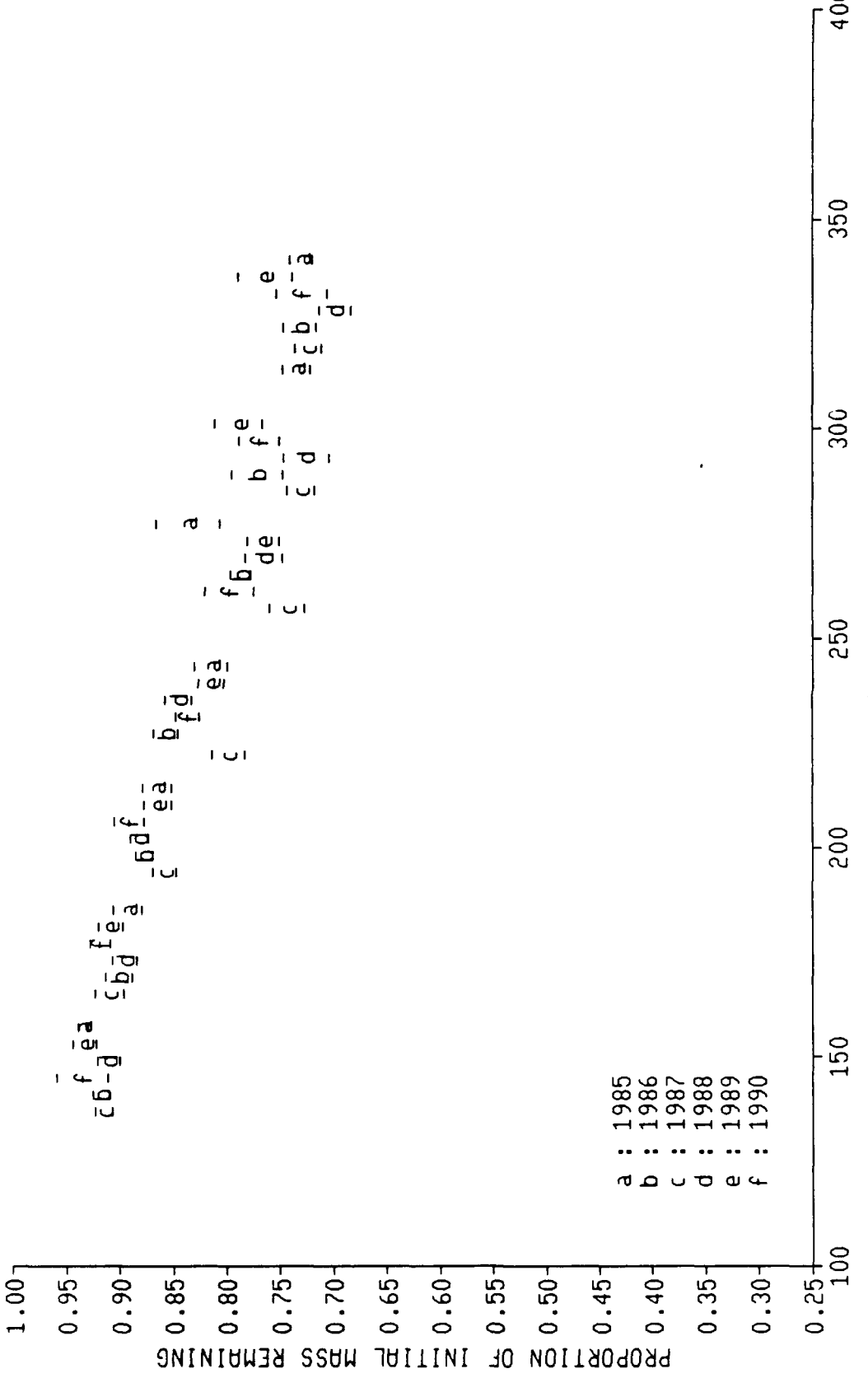


Figure 5. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

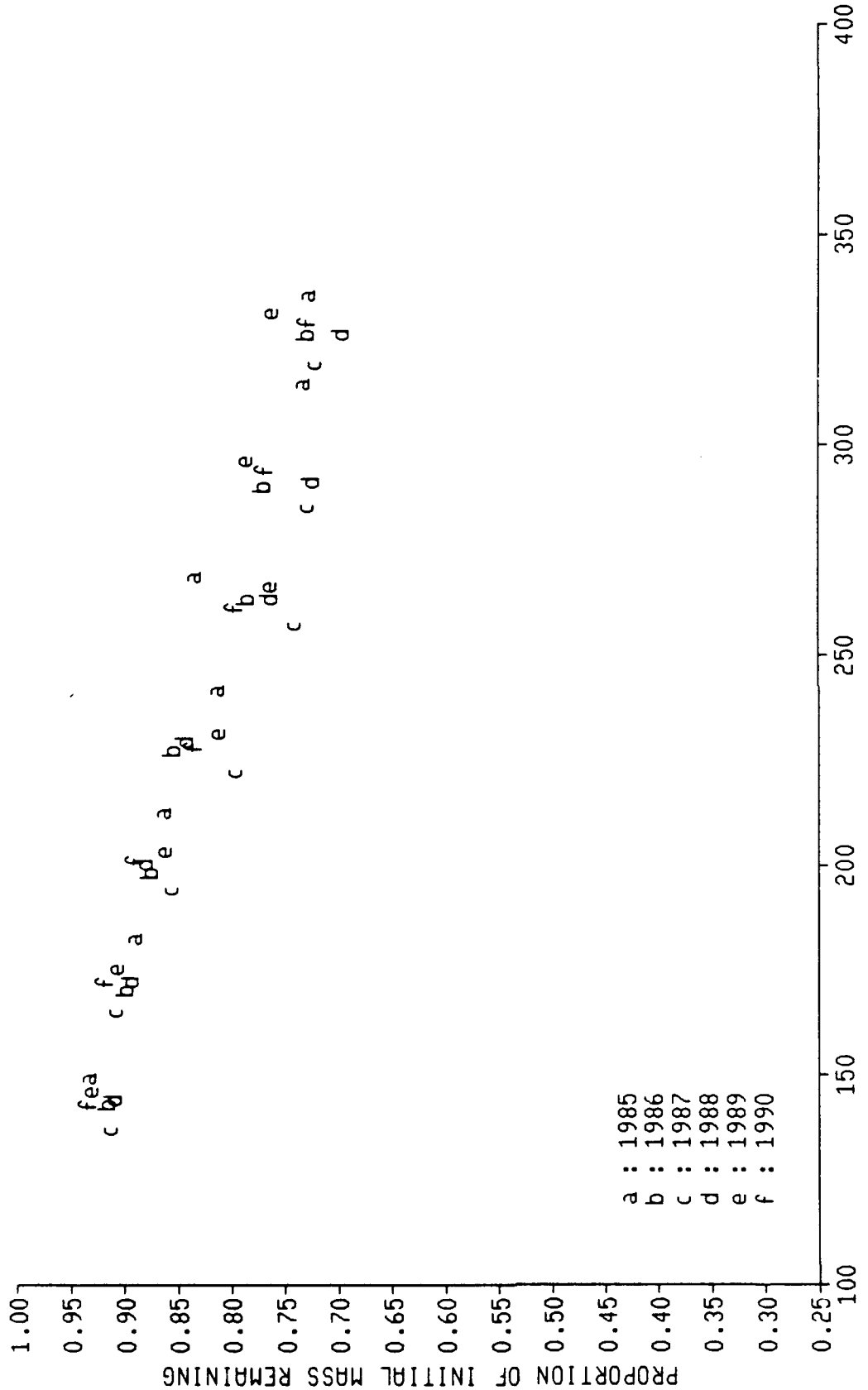


Figure 5a. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

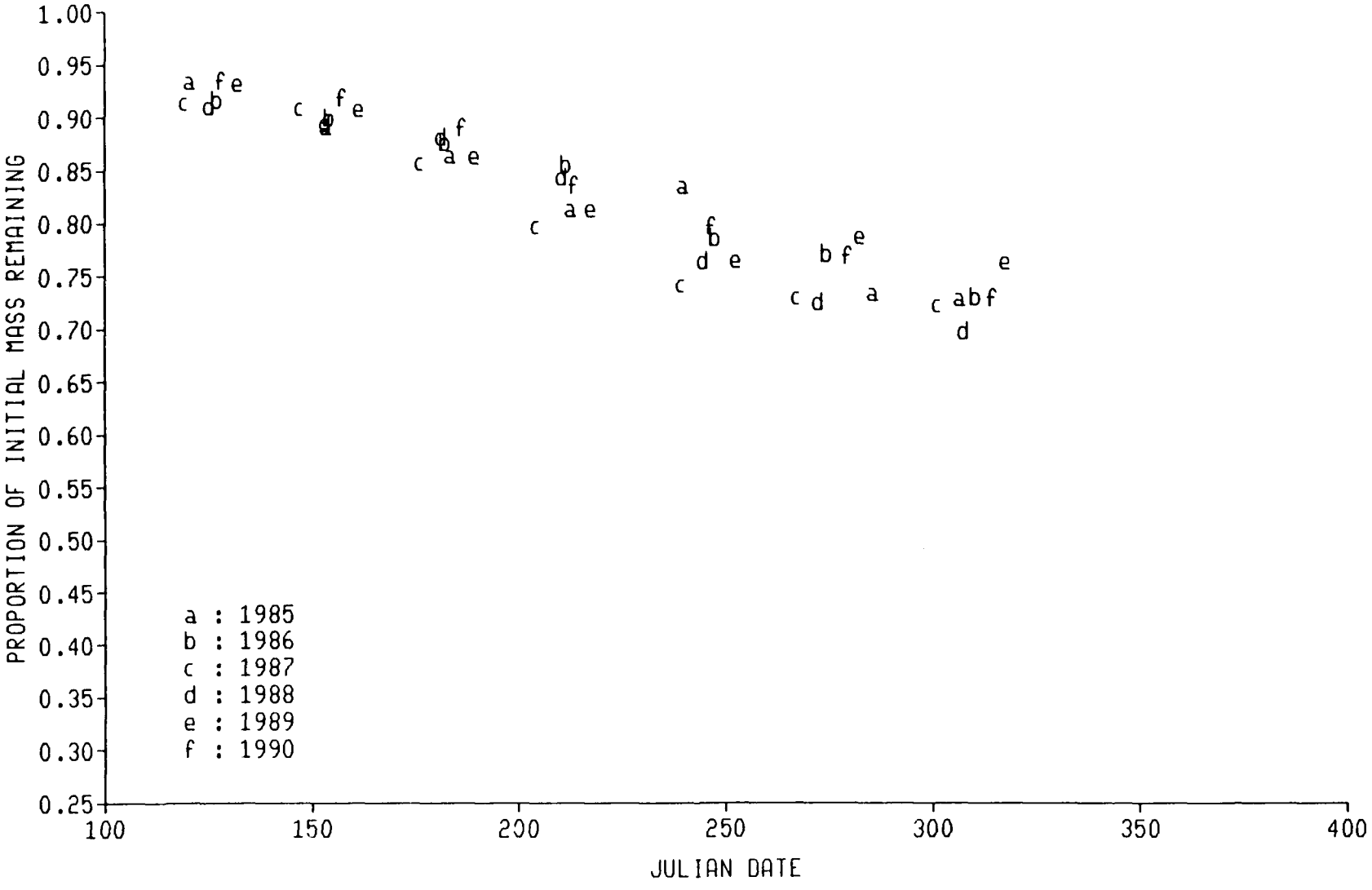


Figure 5b. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

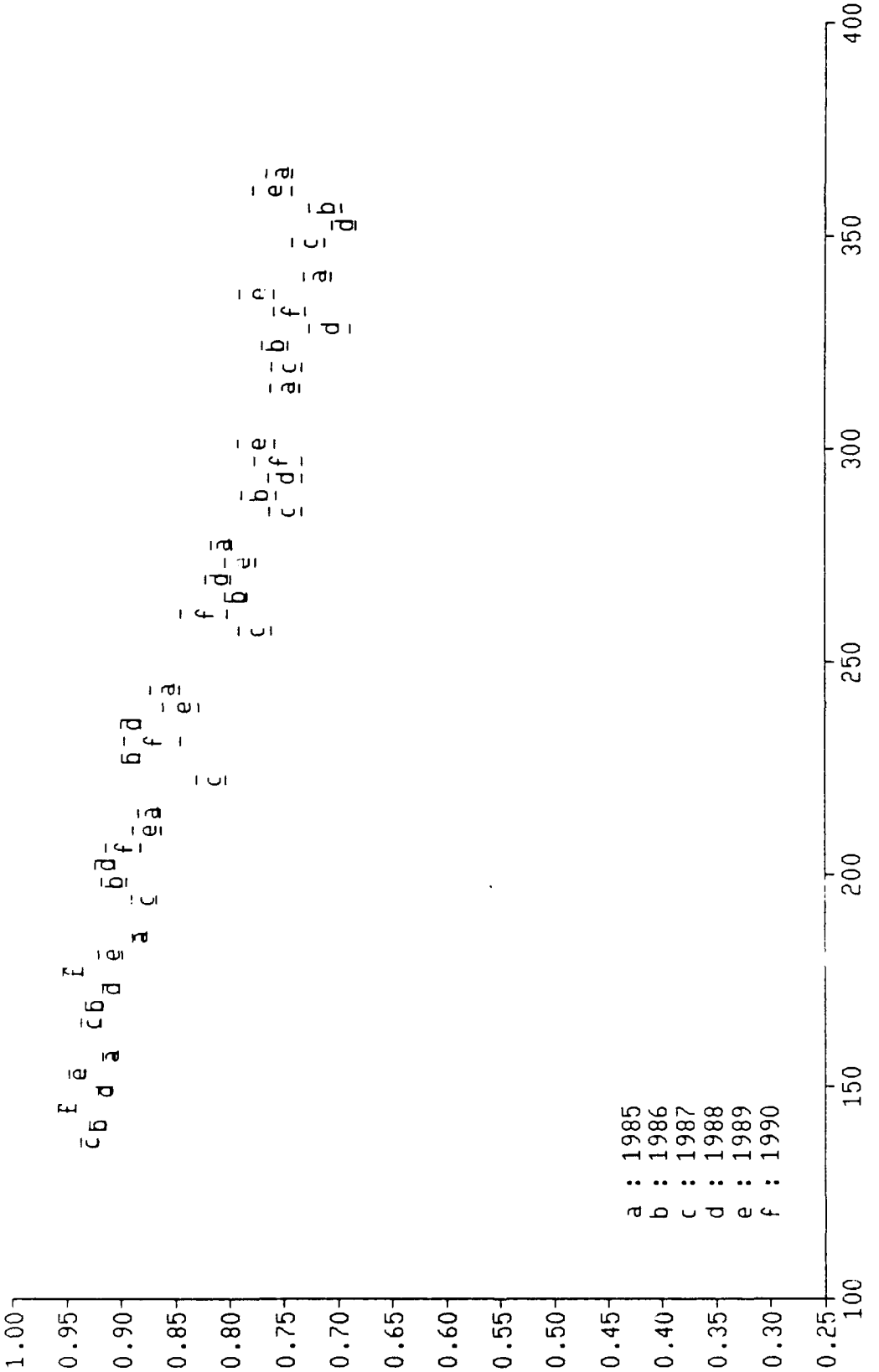


Figure 6. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

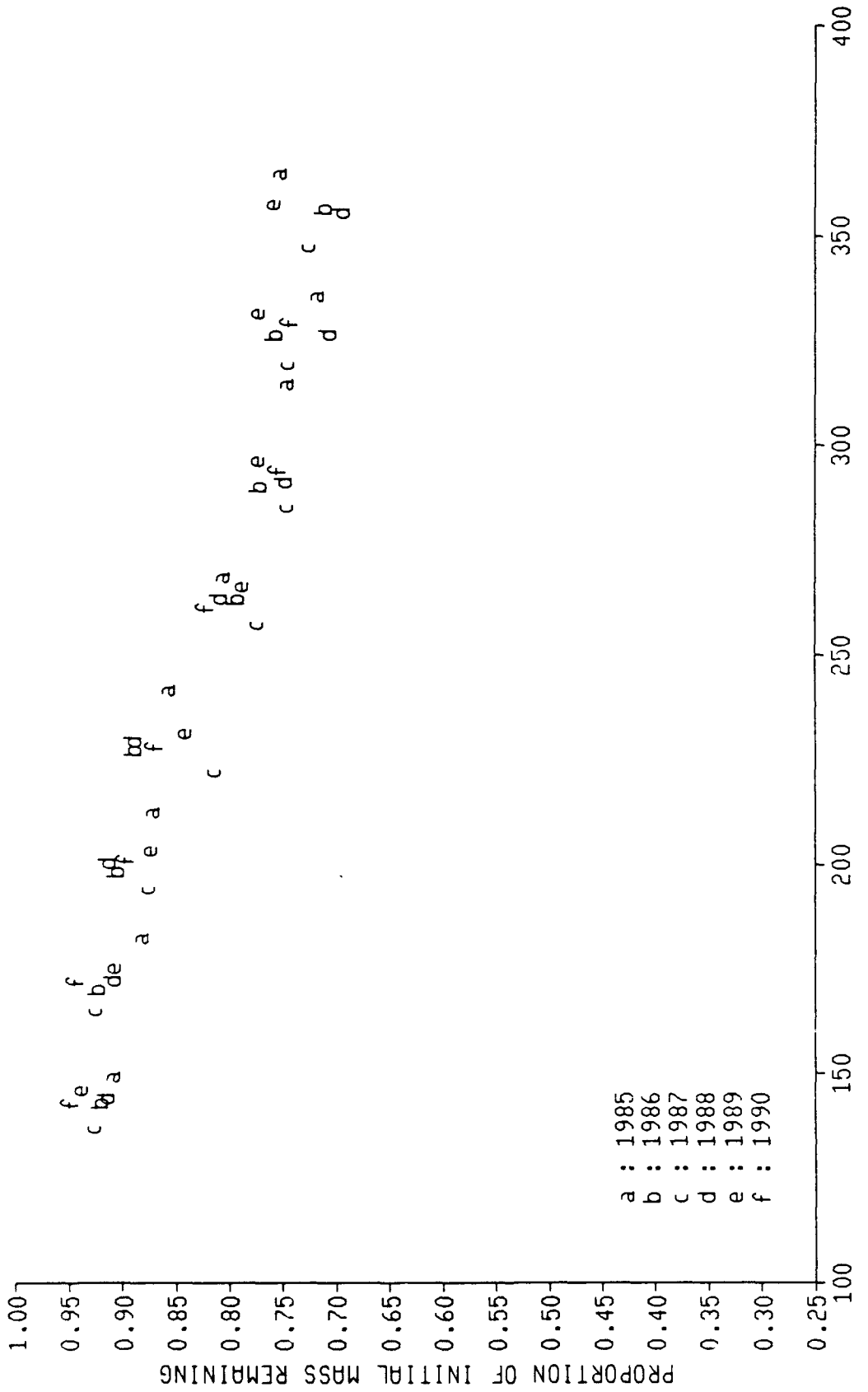


Figure 6a. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

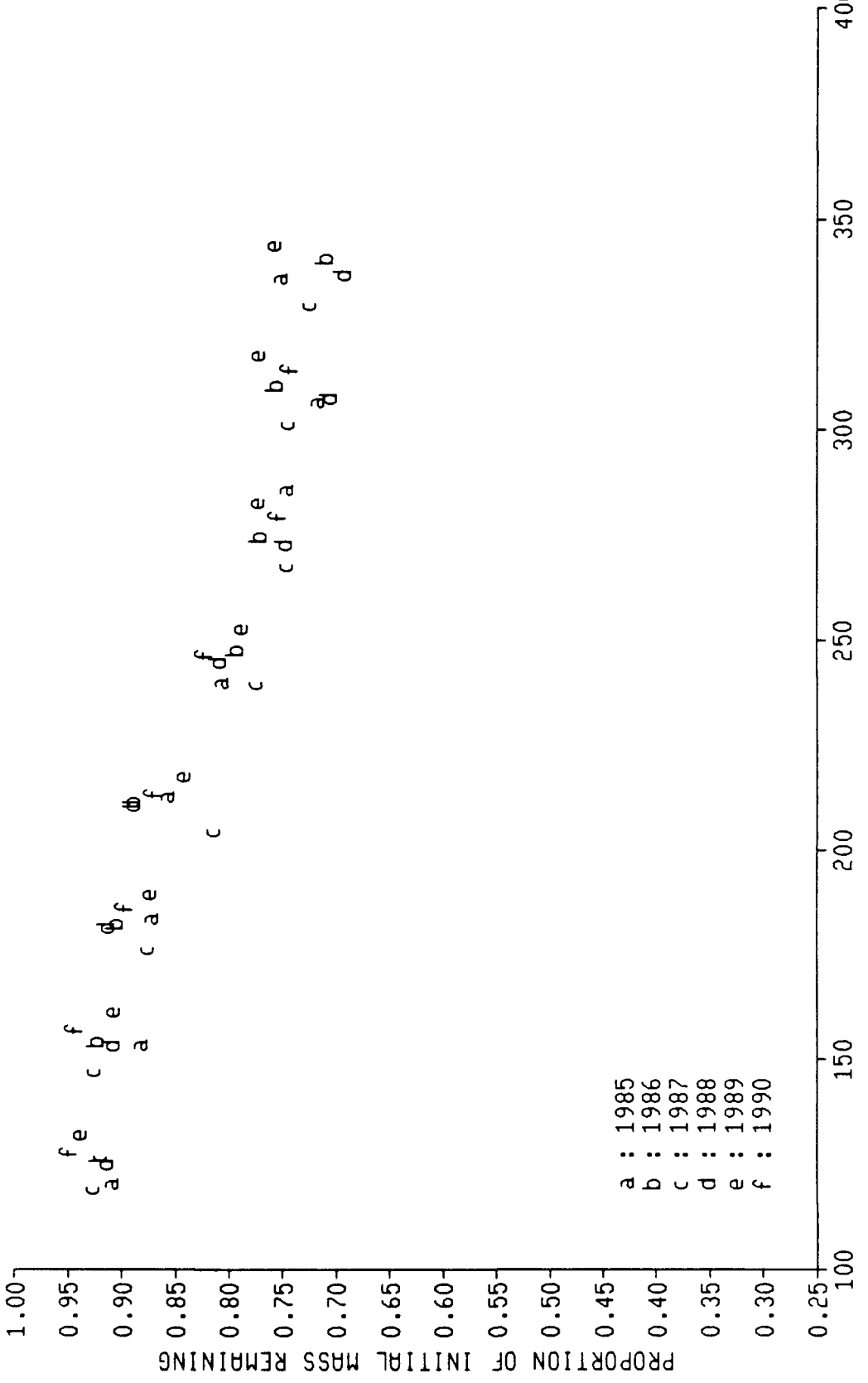


Figure 6b. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

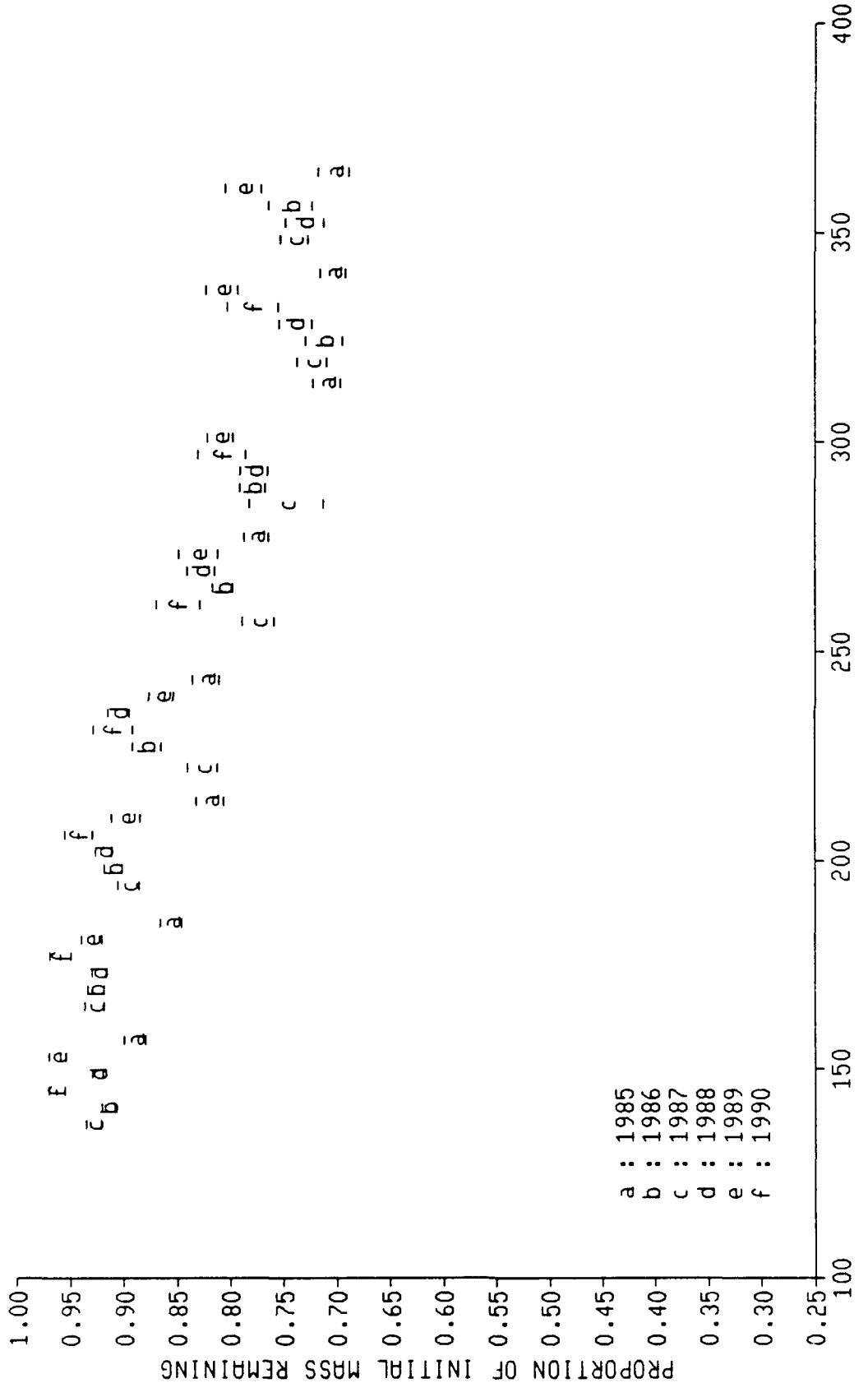


Figure 7. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

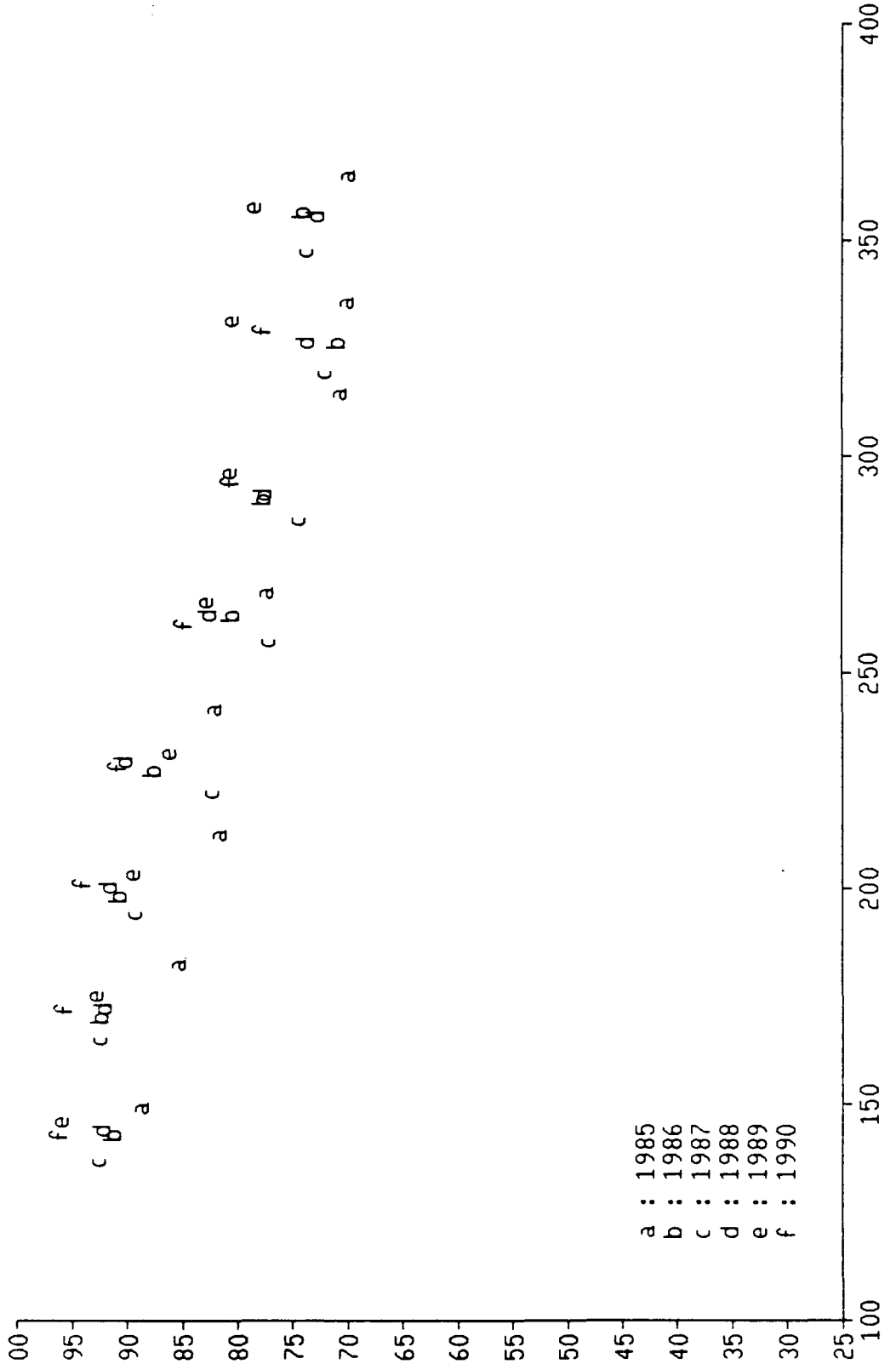


Figure 7a. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

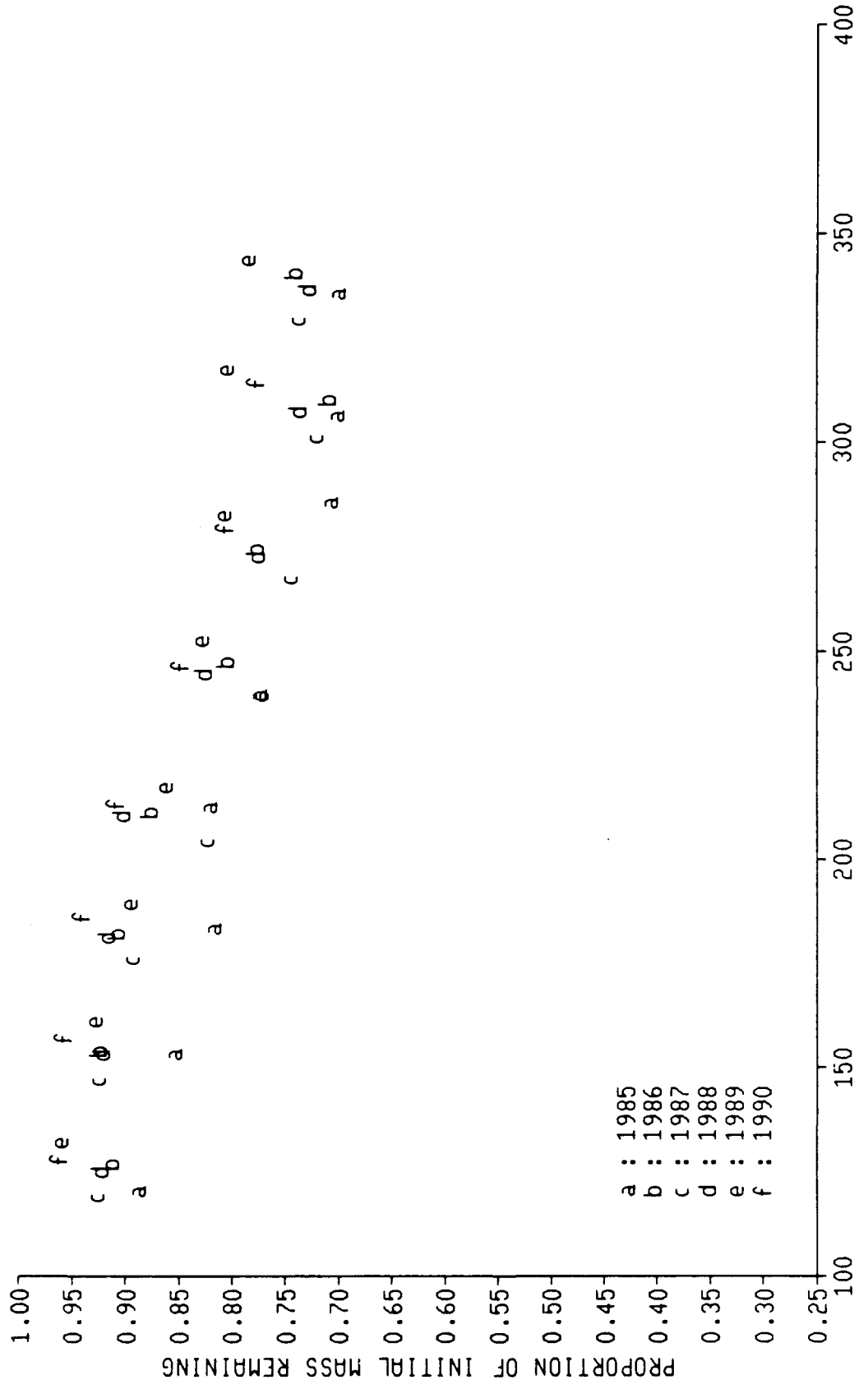


Figure 7b. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

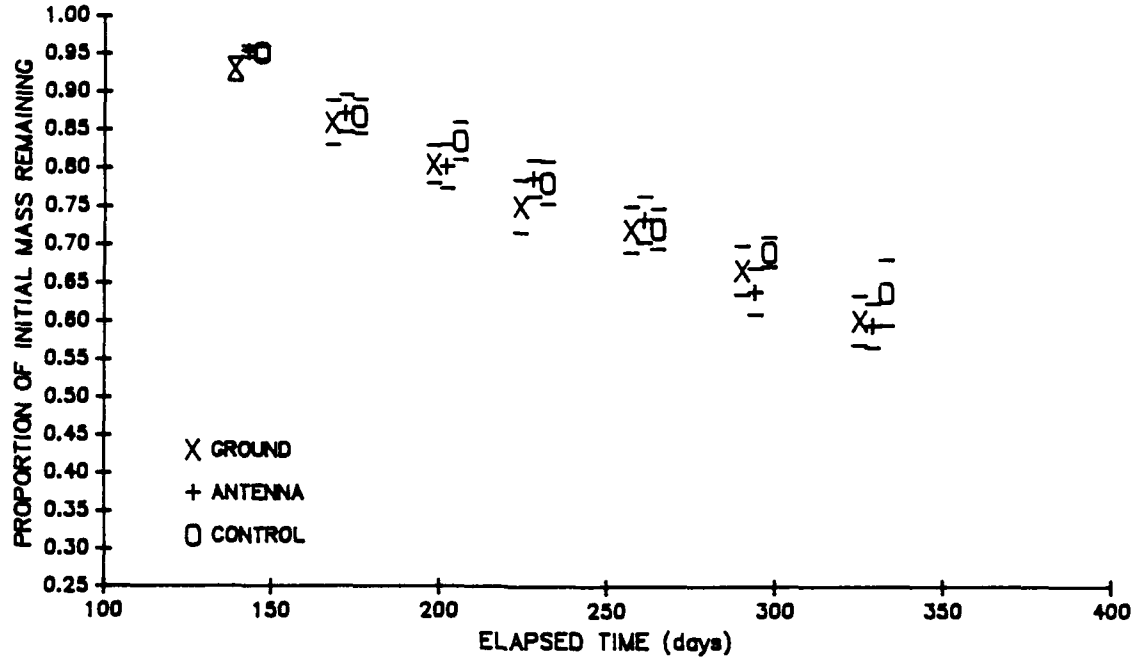


FIGURE 8. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the three plantation subunits during the 1989–1990 experiment.

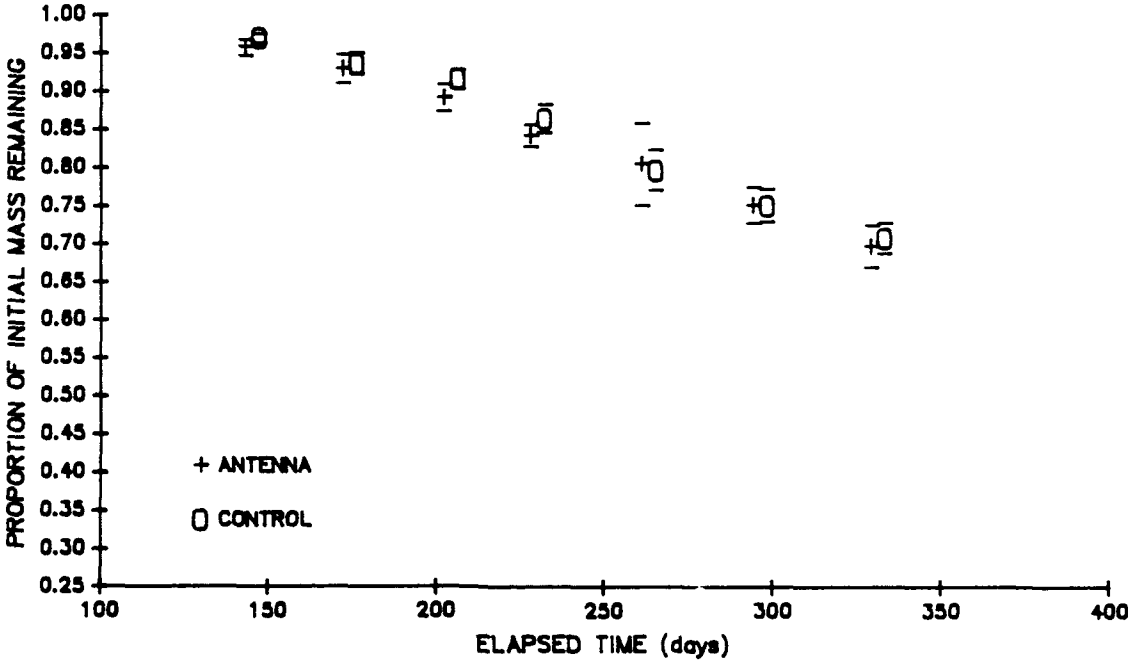


FIGURE 9. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the two hardwood stand subunits during the 1989–1990 experiment.

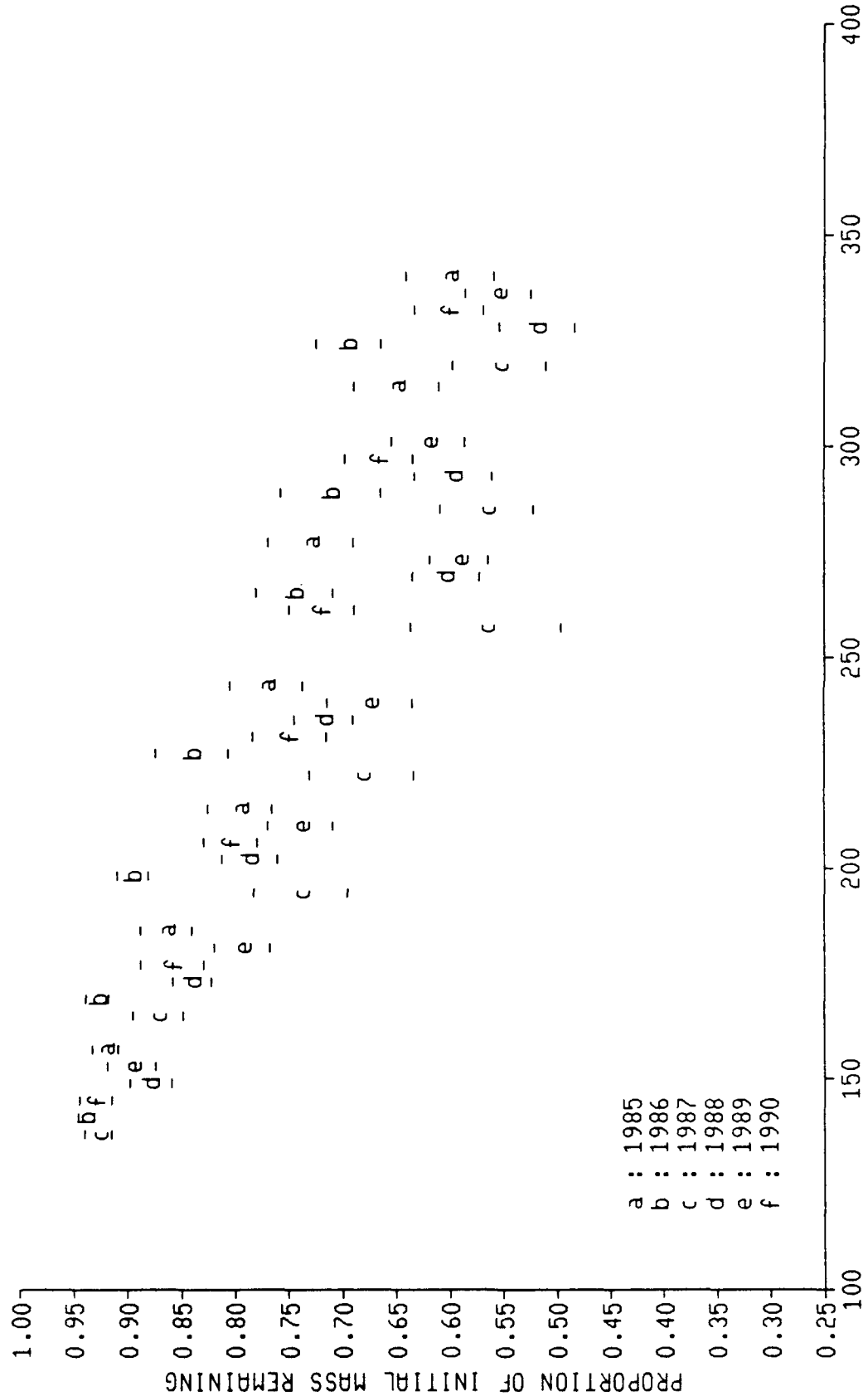


Figure 10. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

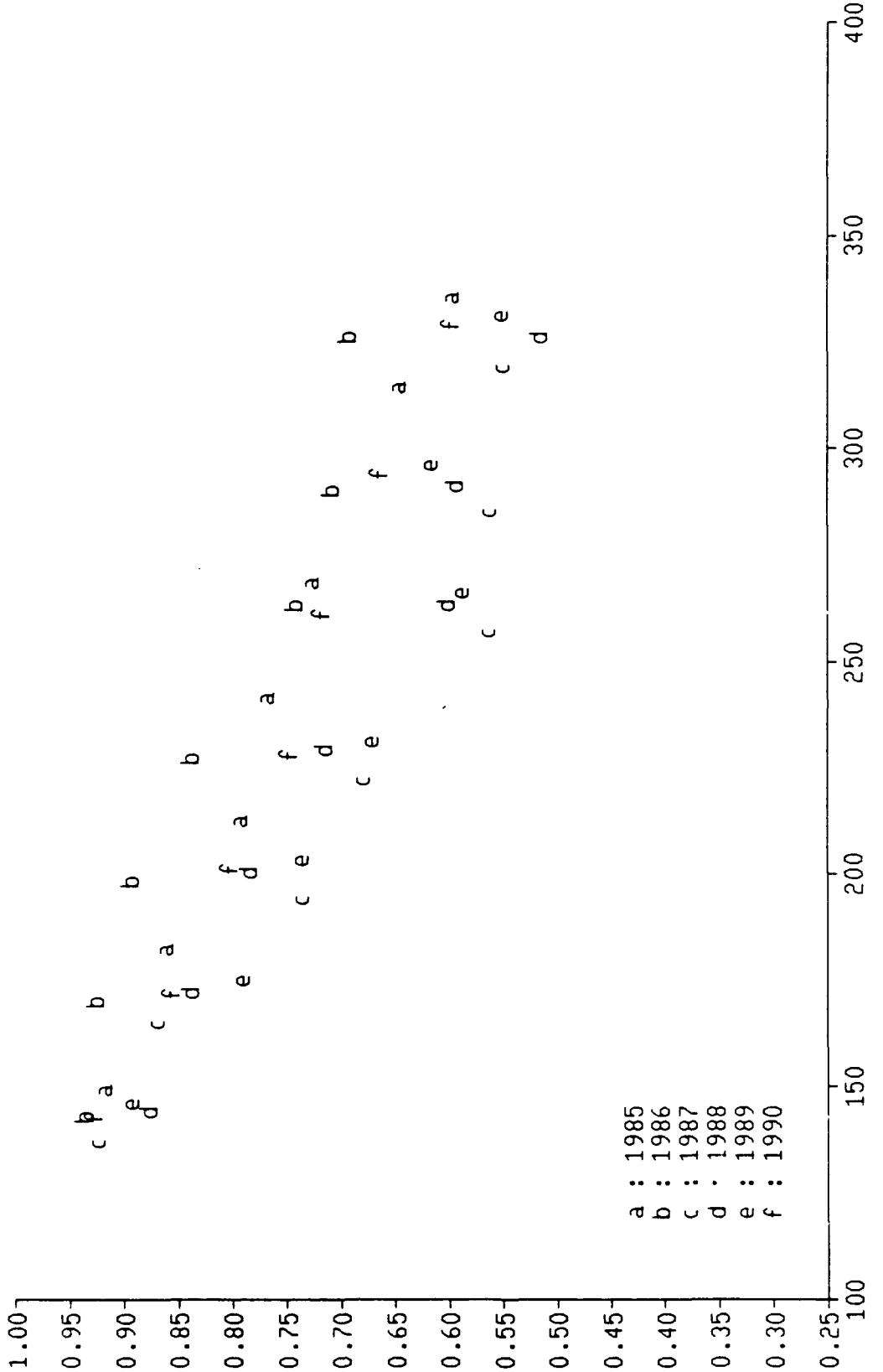


Figure 10a. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

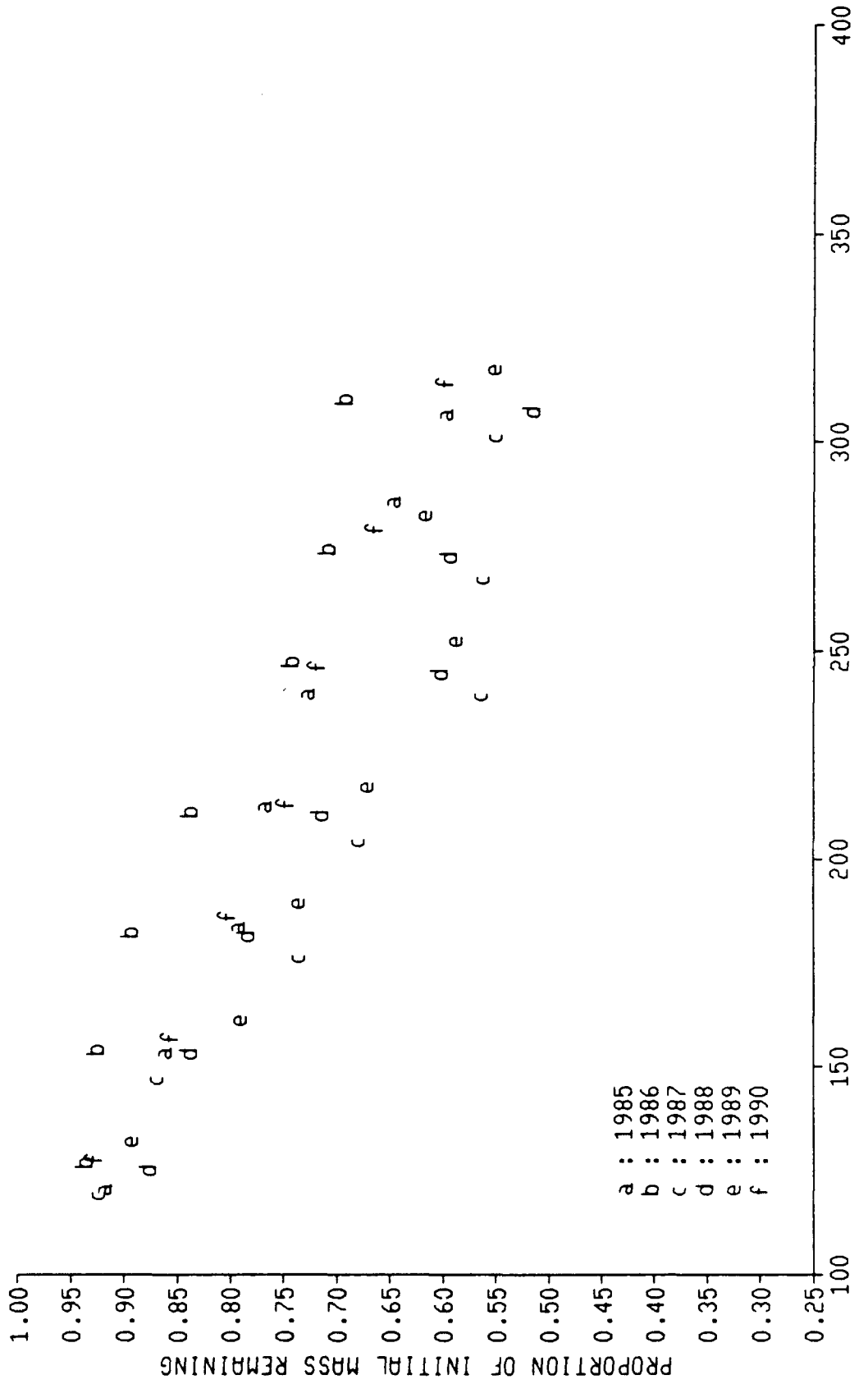


Figure 10b. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

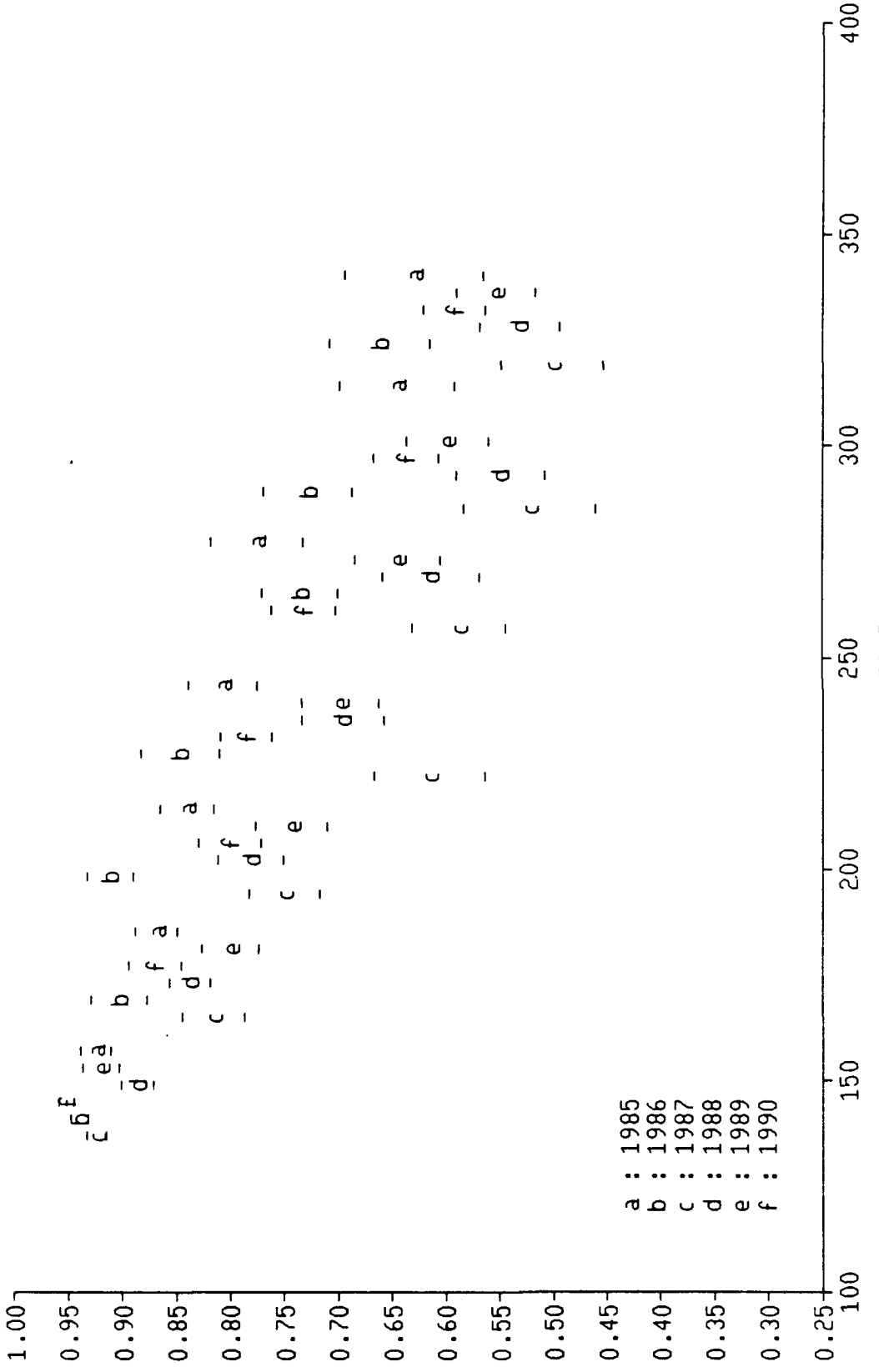


Figure 11. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

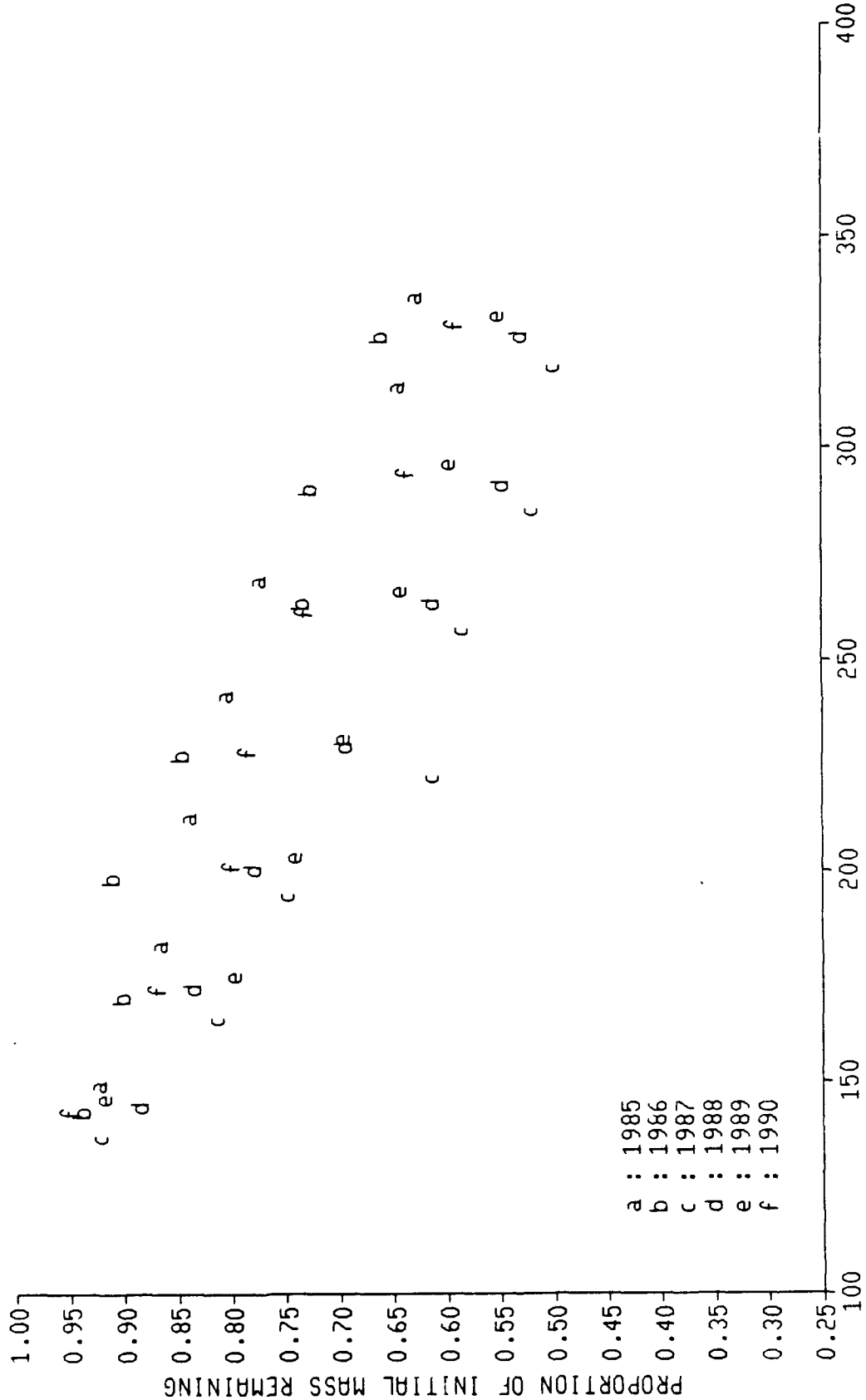


Figure 11a. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

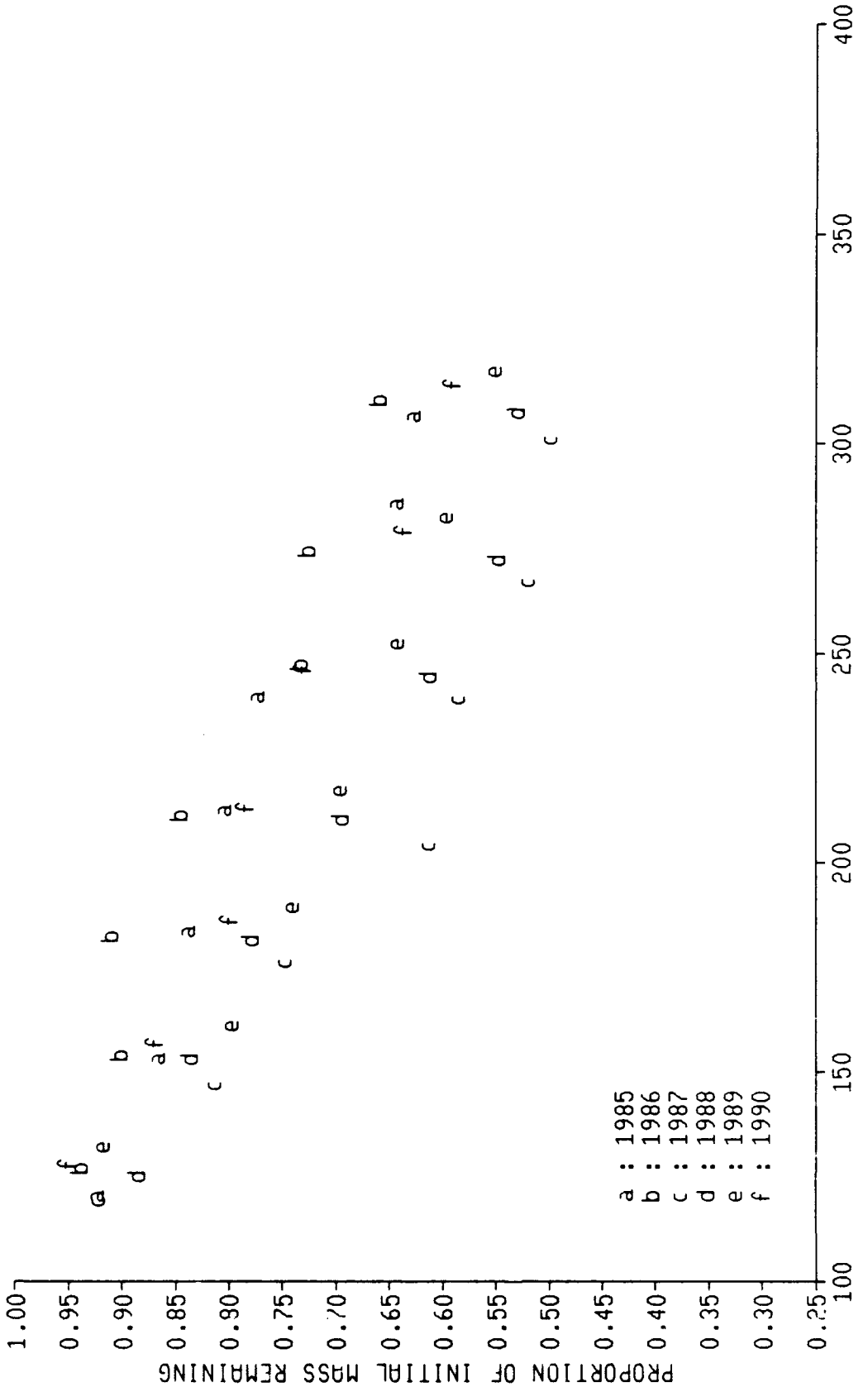


Figure 11b. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

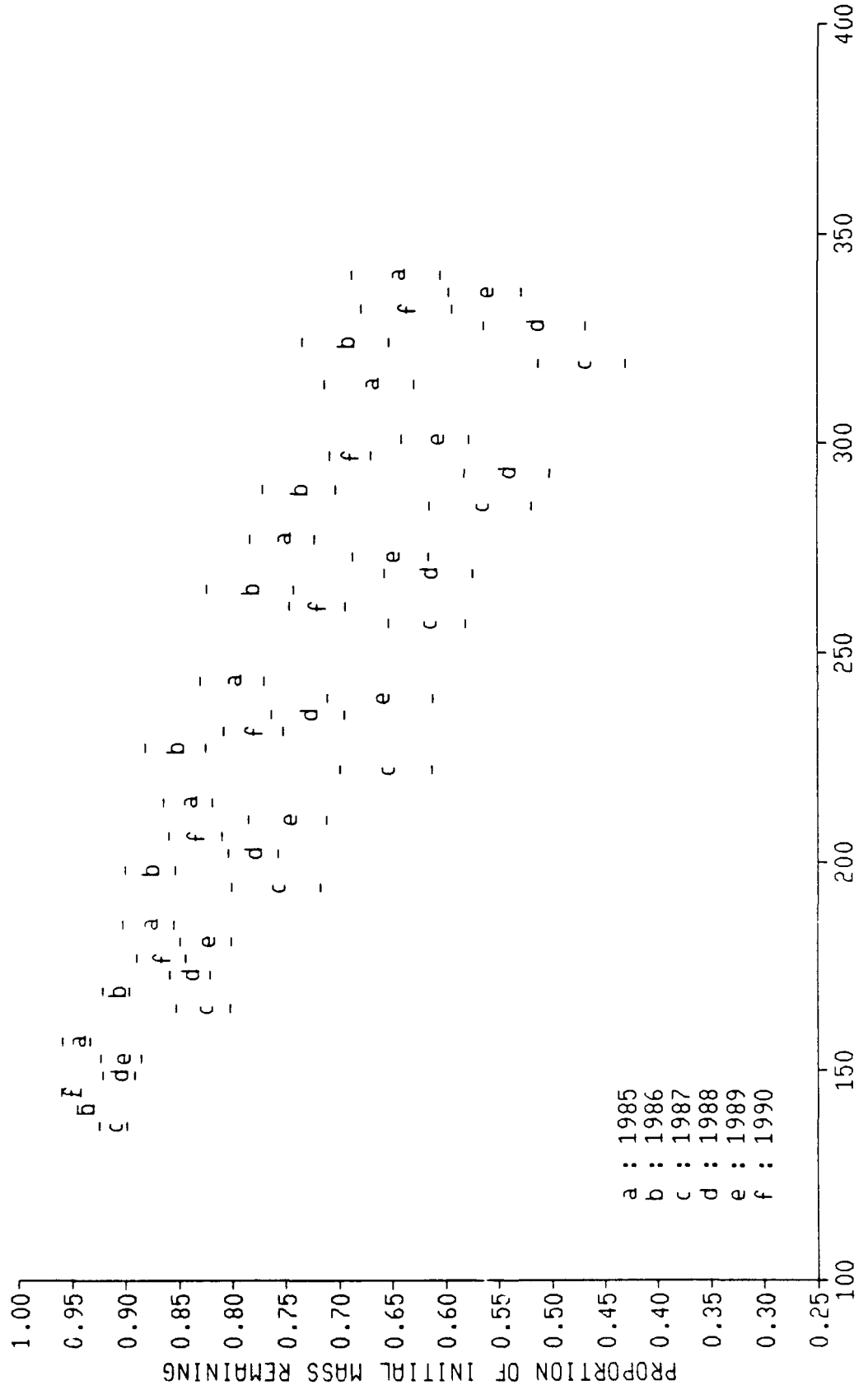


Figure 12. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

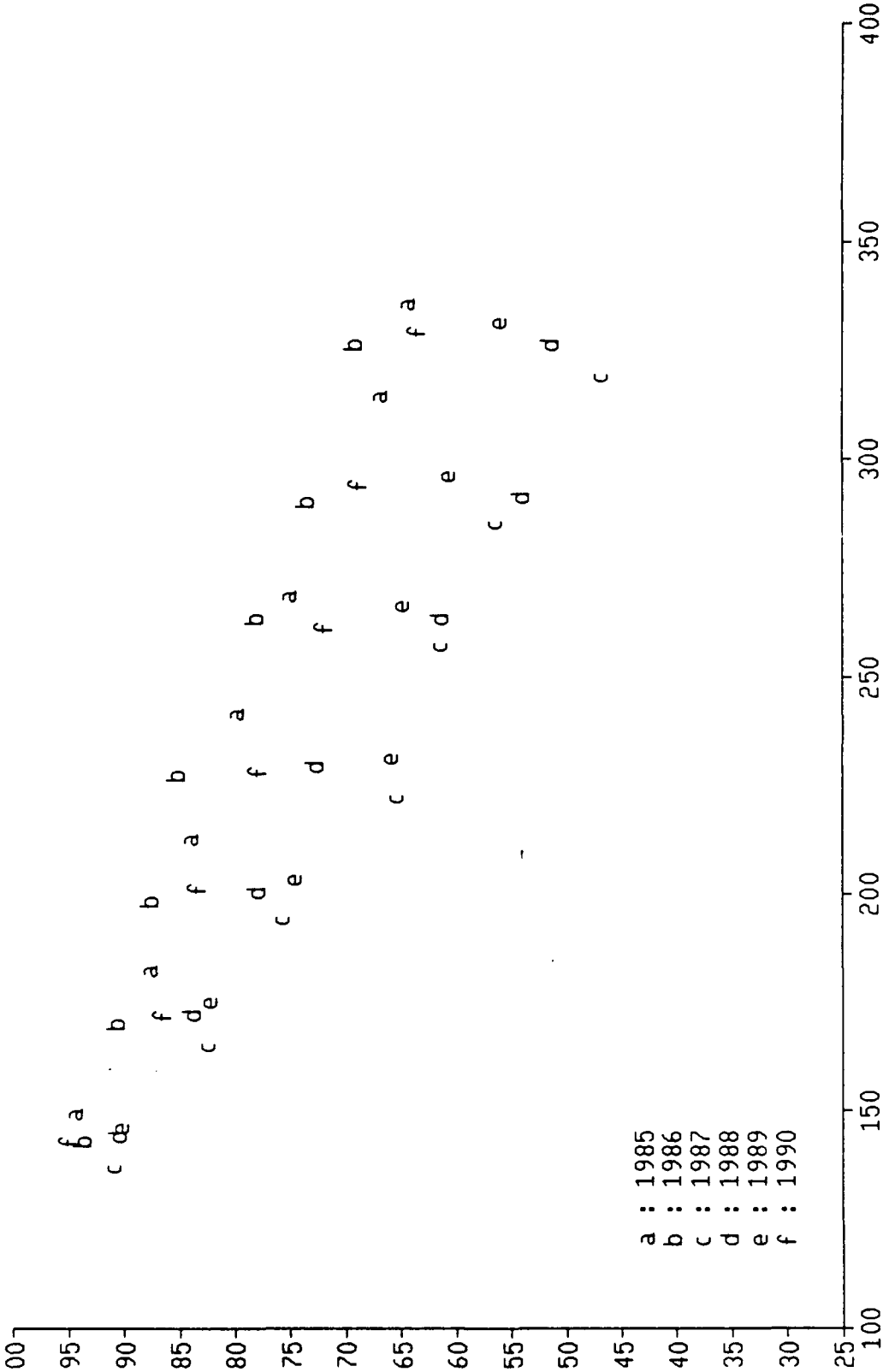


Figure 12a. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

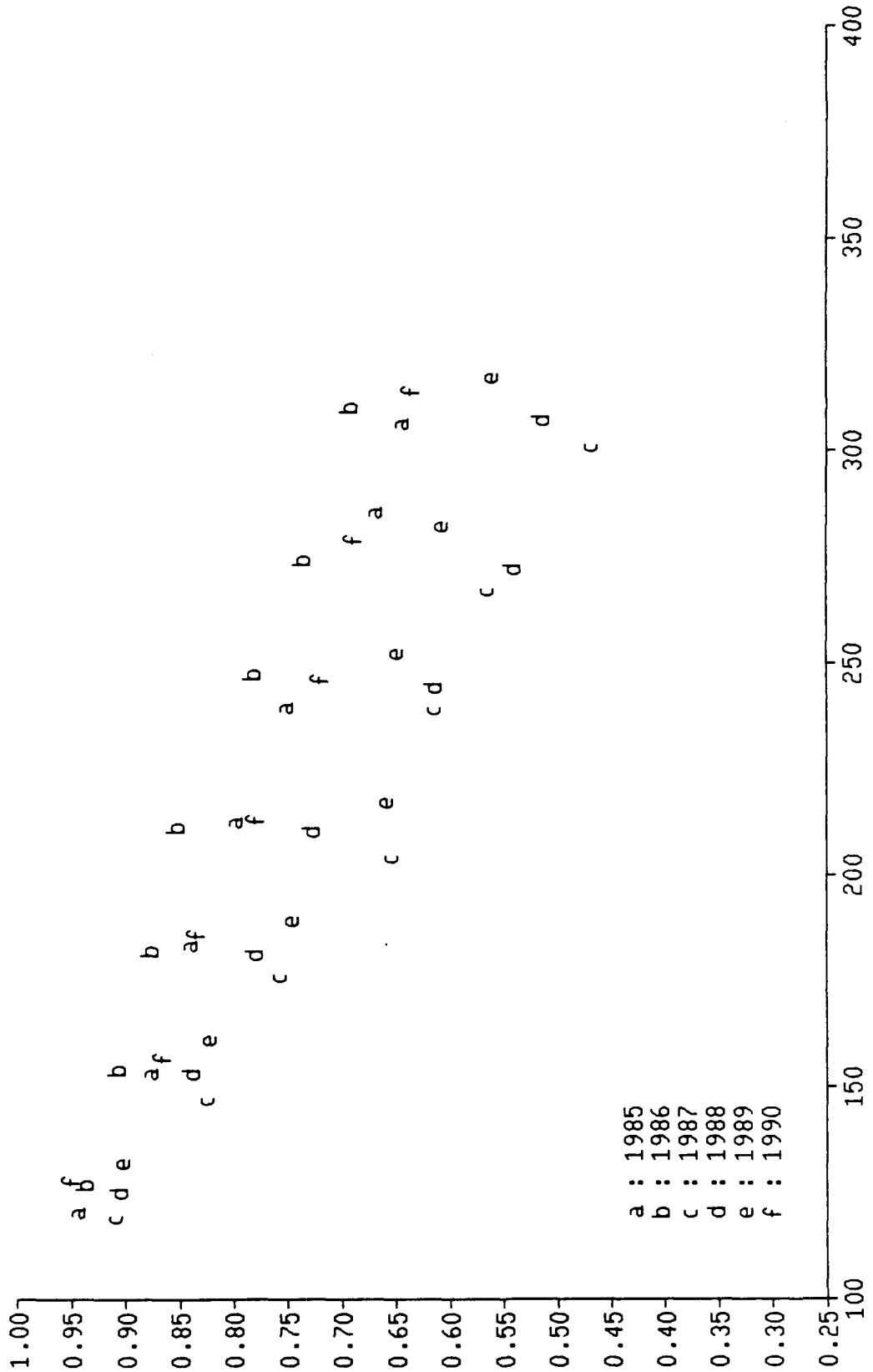


Figure 12b. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

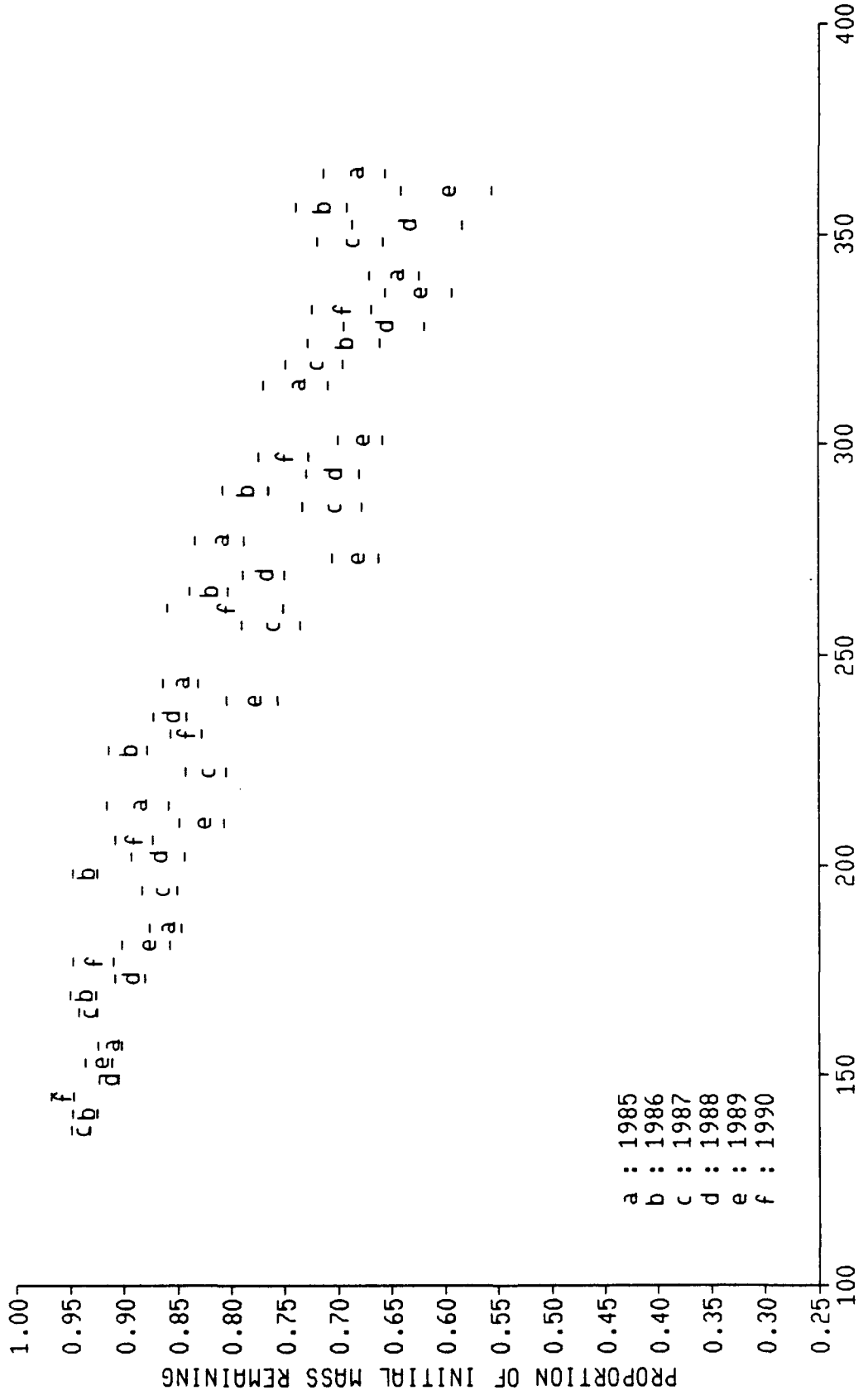


Figure 13. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

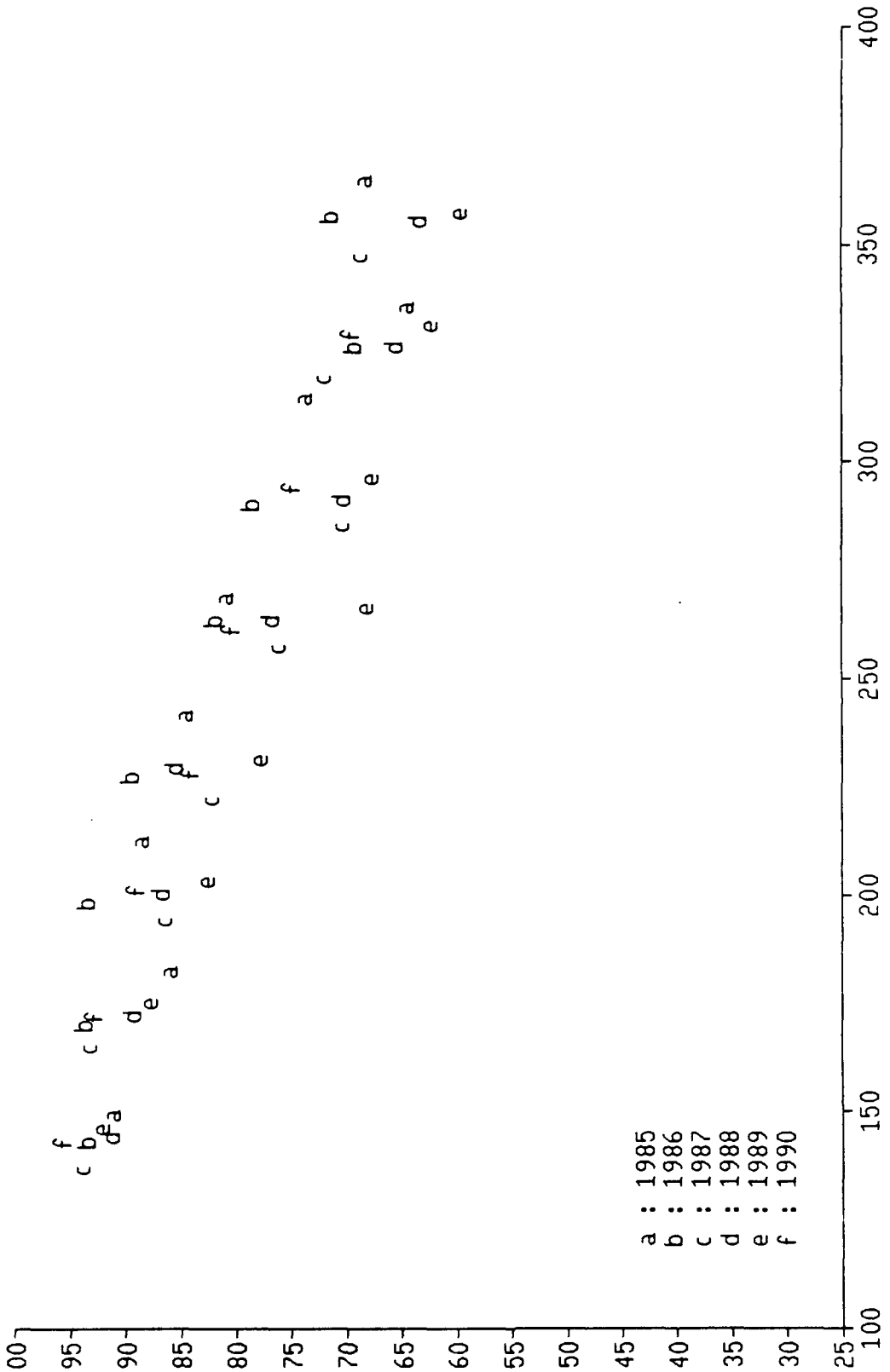


Figure 13a. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

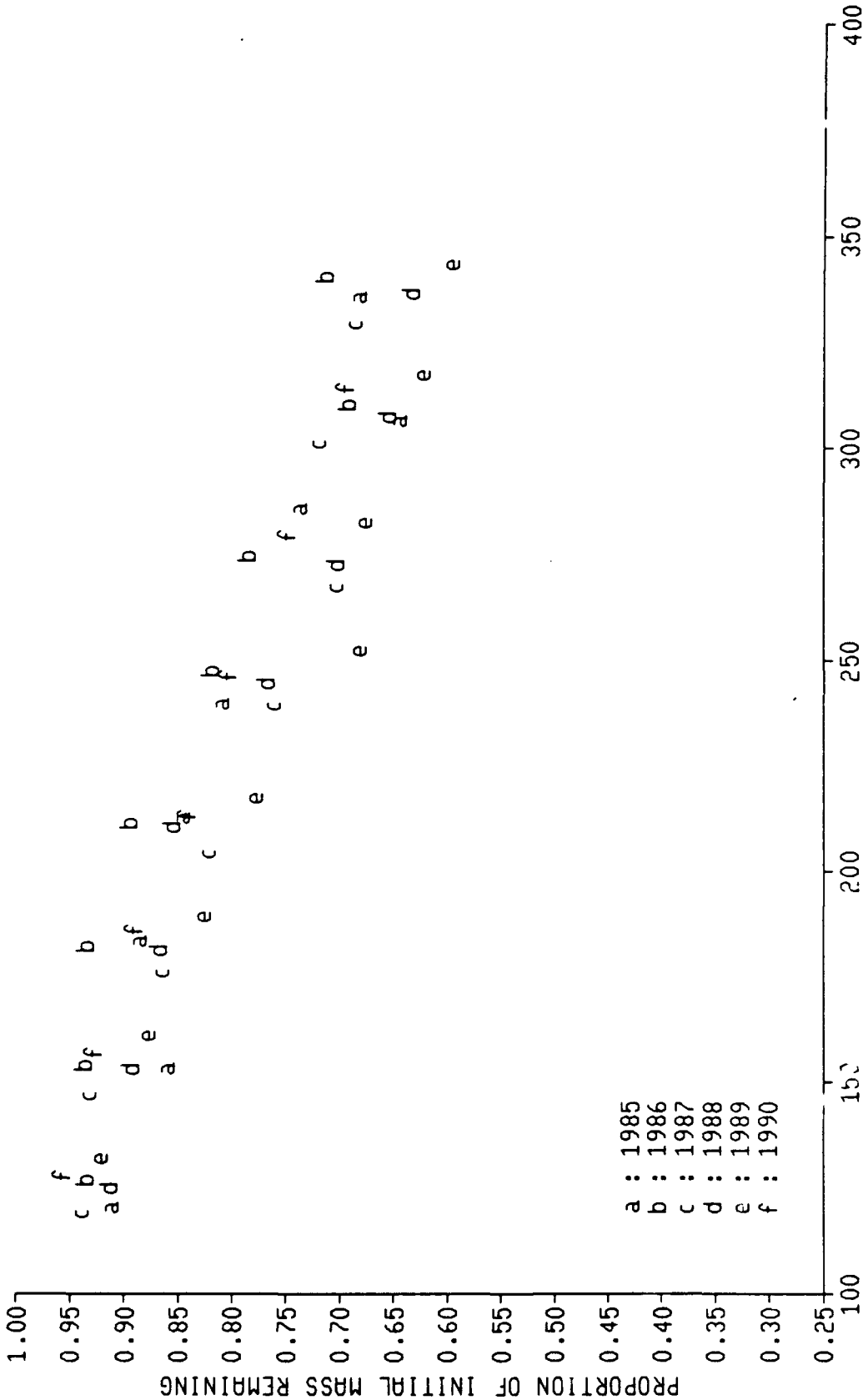


Figure 13b. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

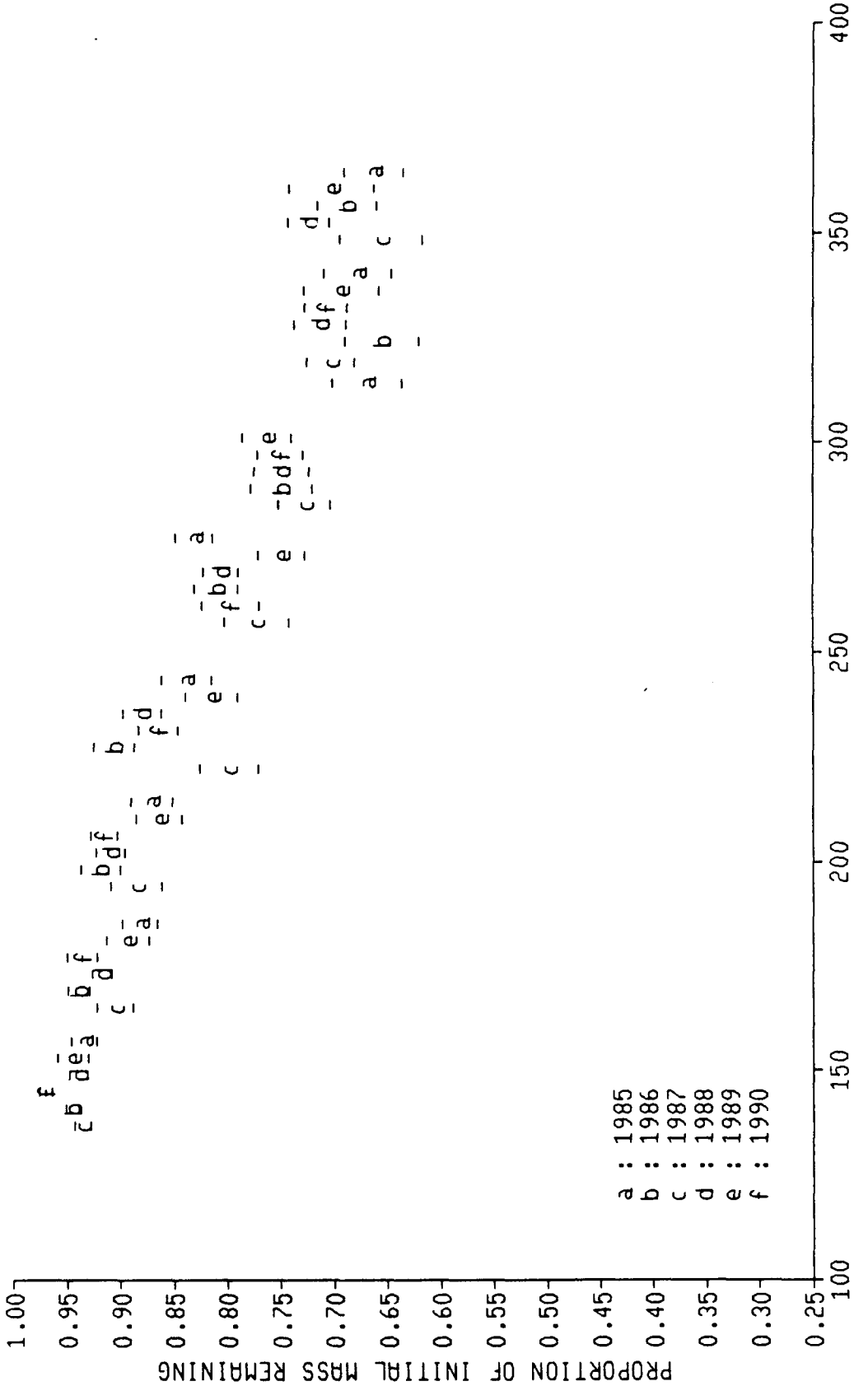


Figure 14. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

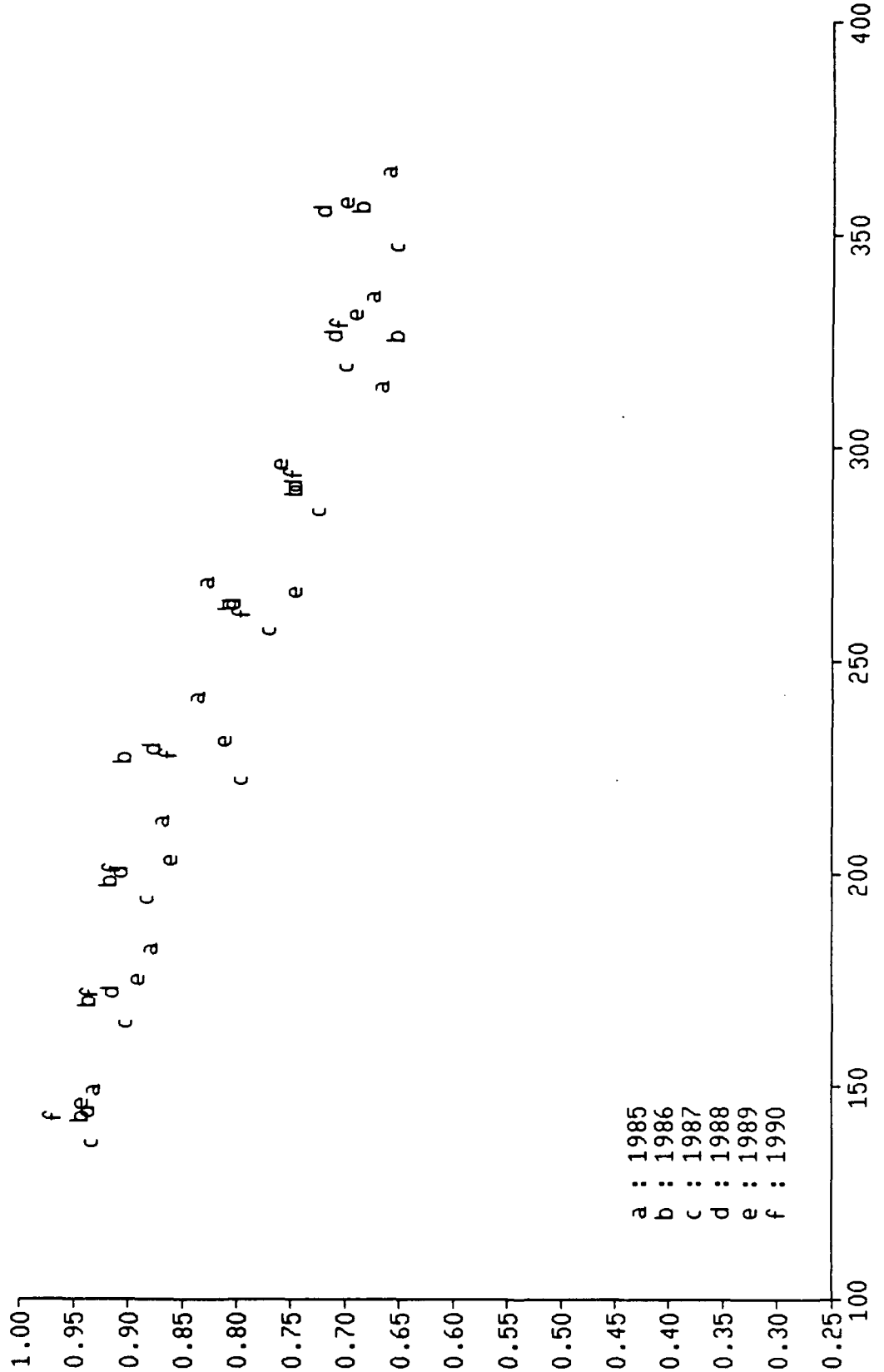


Figure 14a. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

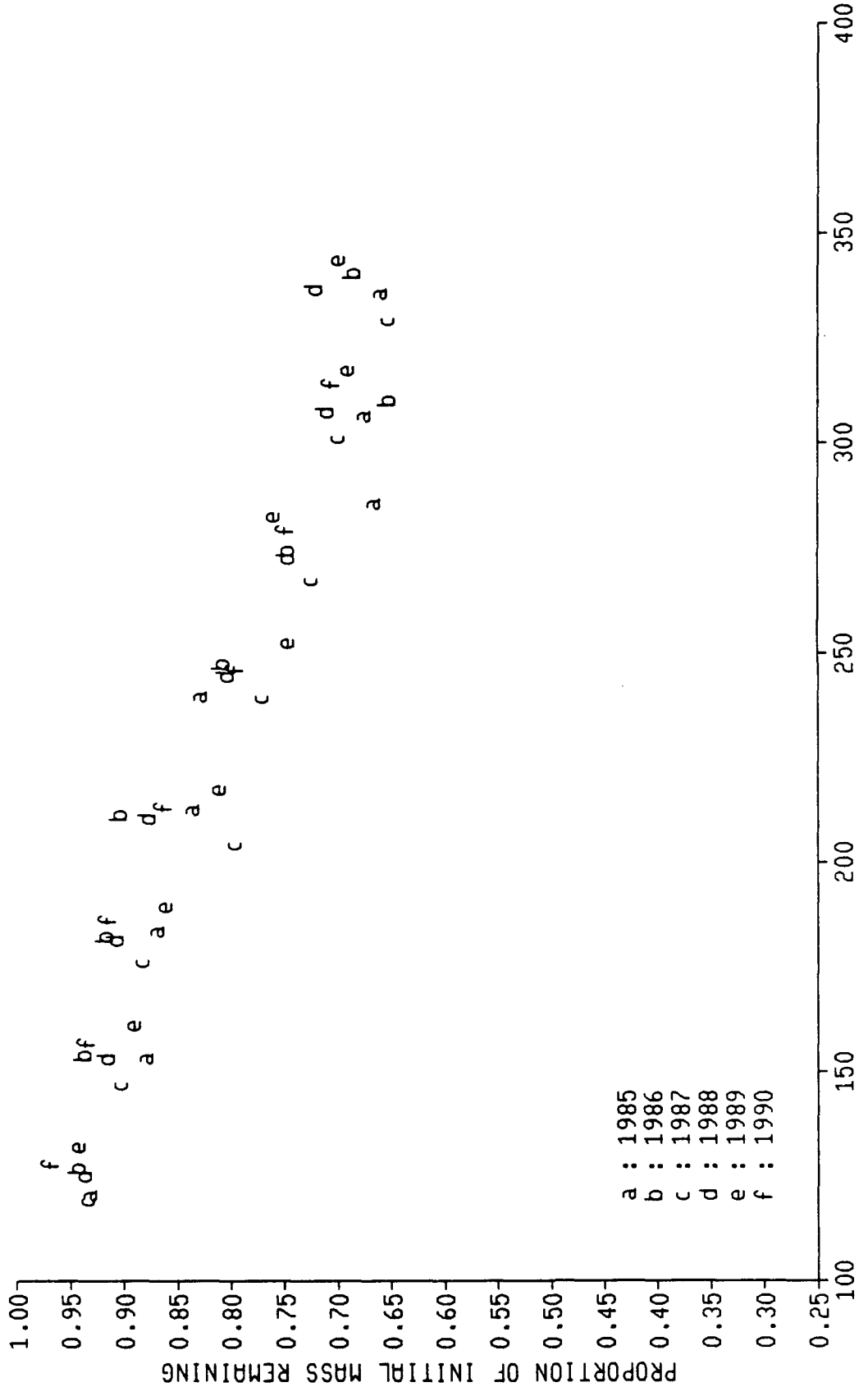


Figure 14b. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

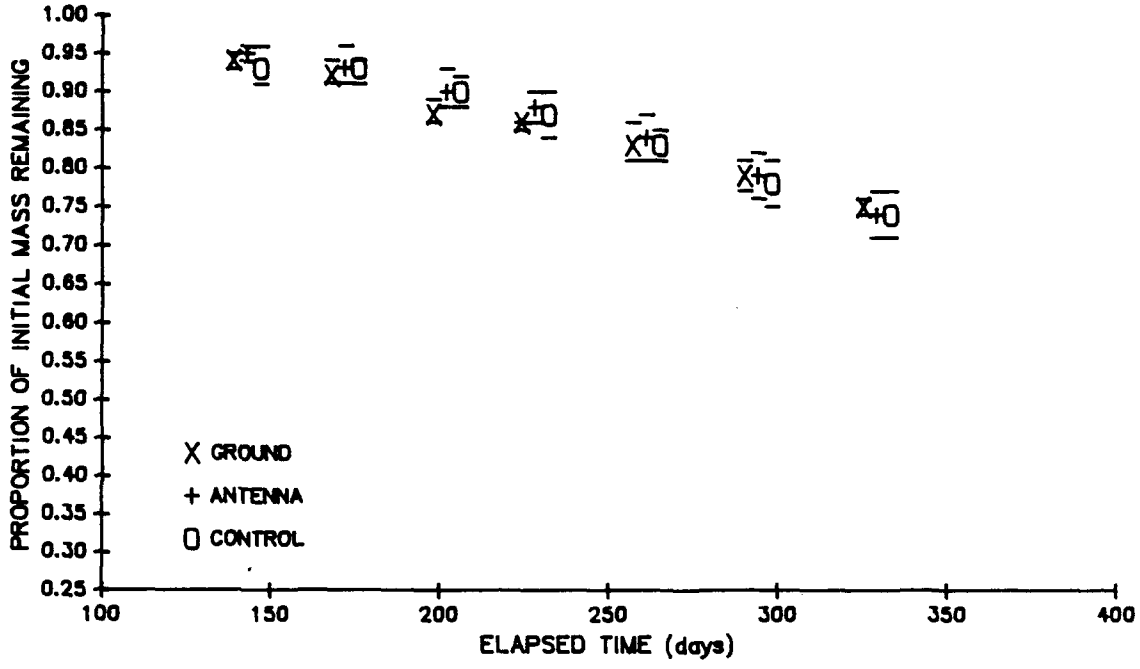


FIGURE 15. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the three plantation subunits during the 1989–1990 experiment.

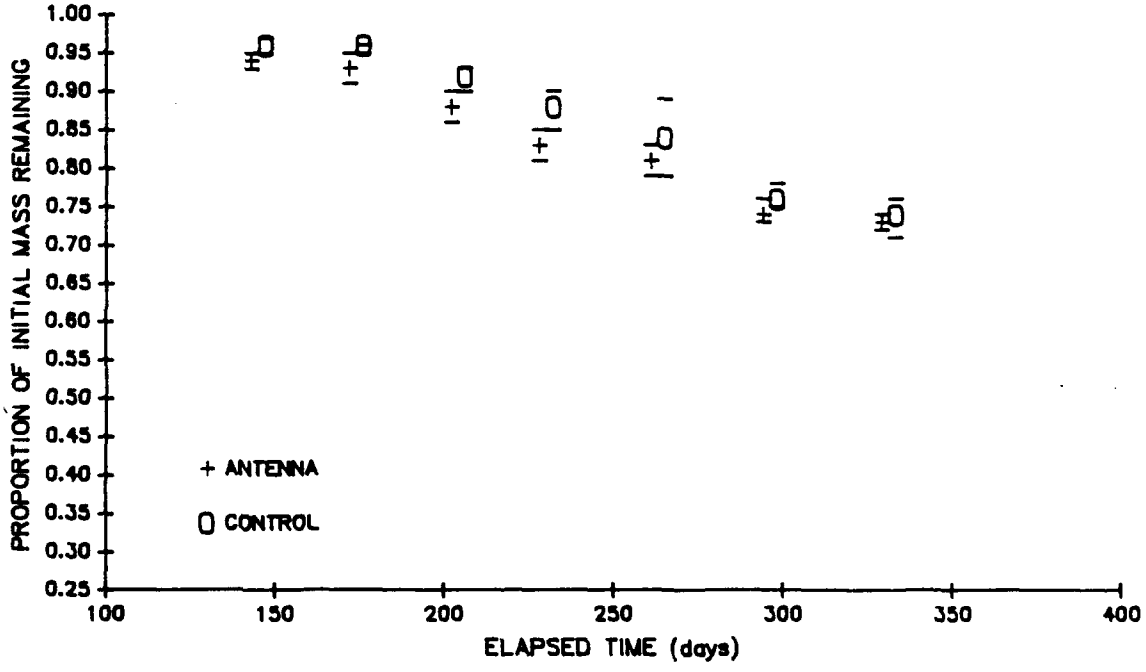


FIGURE 16. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the two hardwood stand subunits during the 1989–1990 experiment.

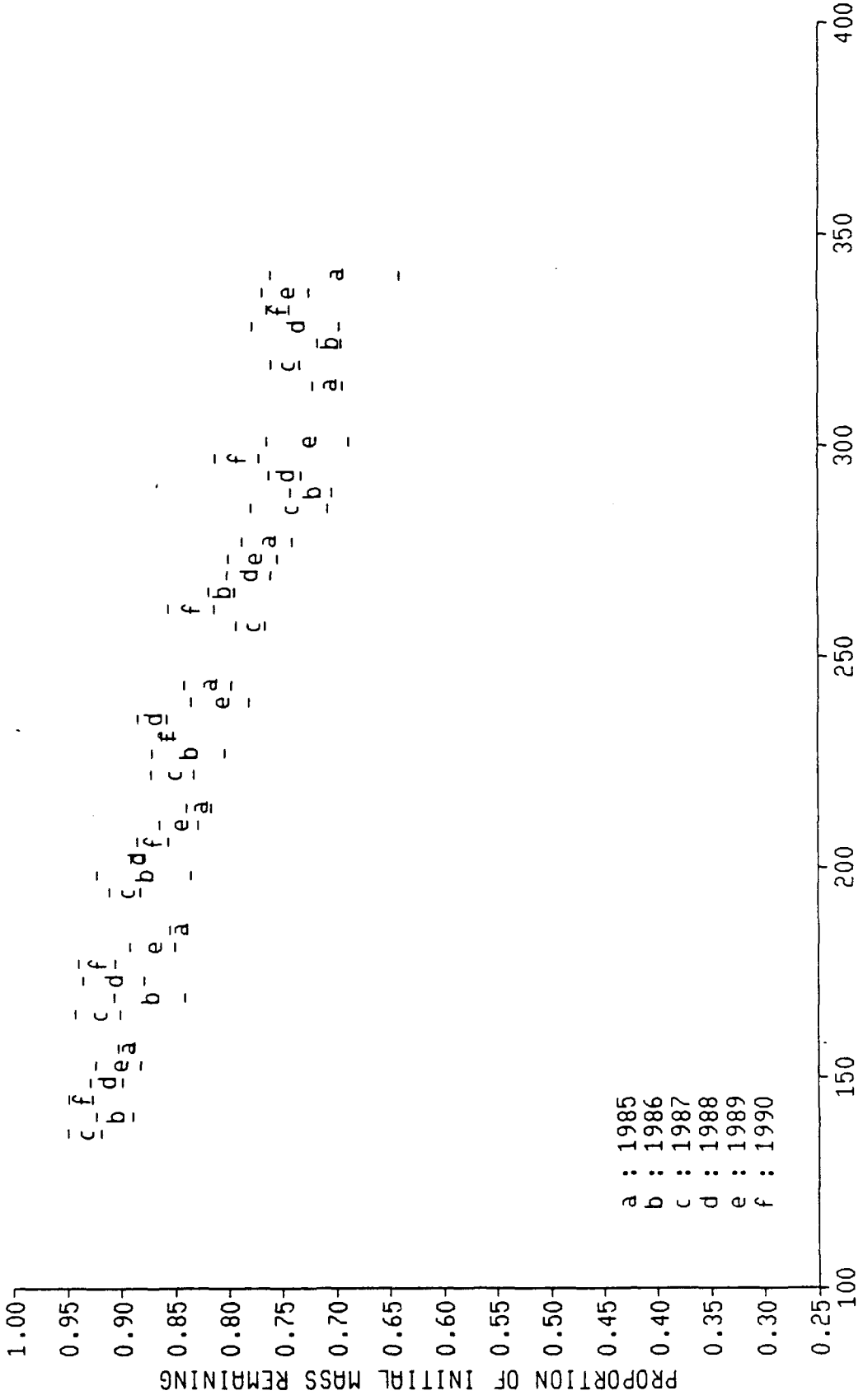


Figure 17. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

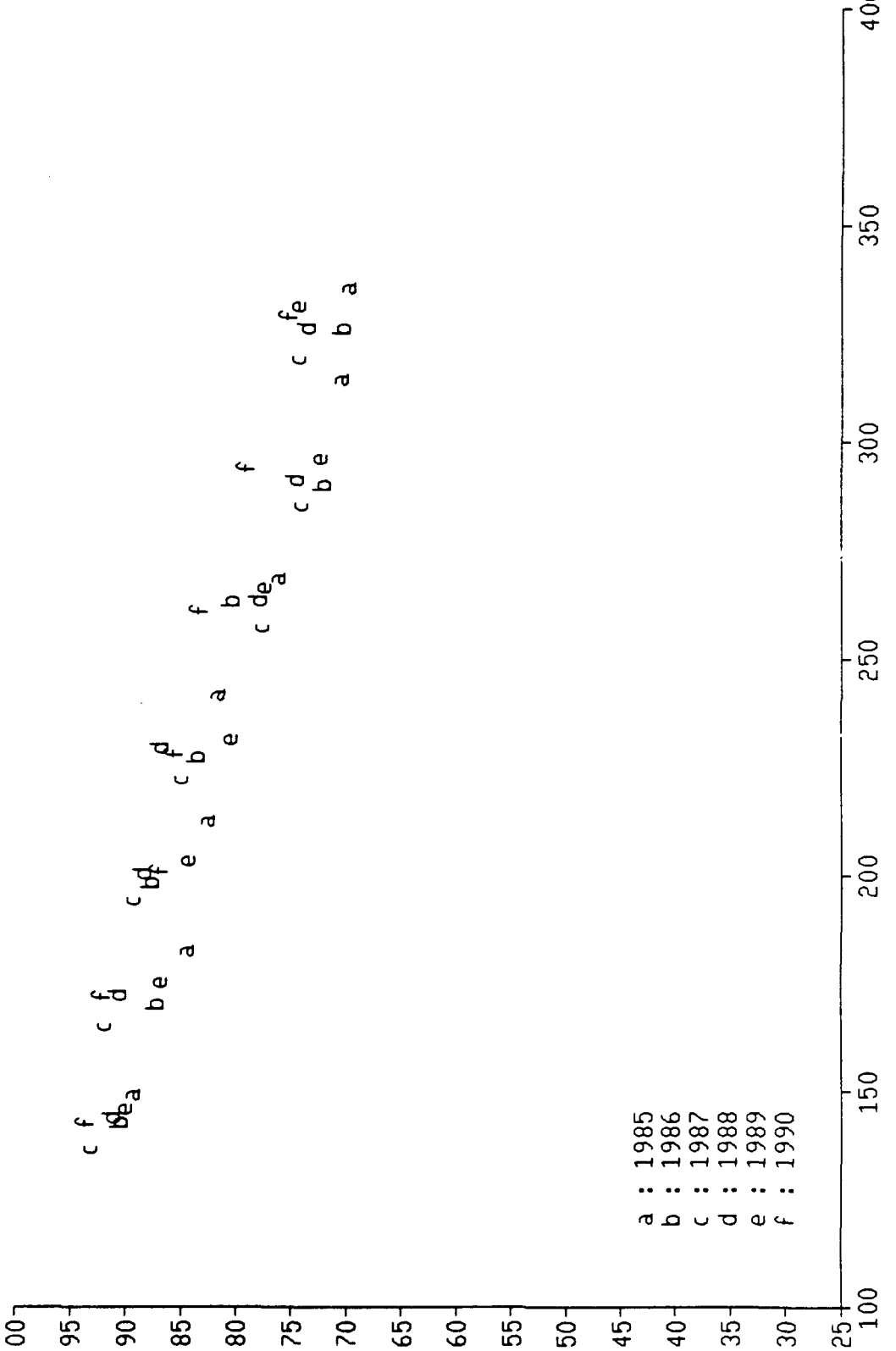


Figure 17a. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

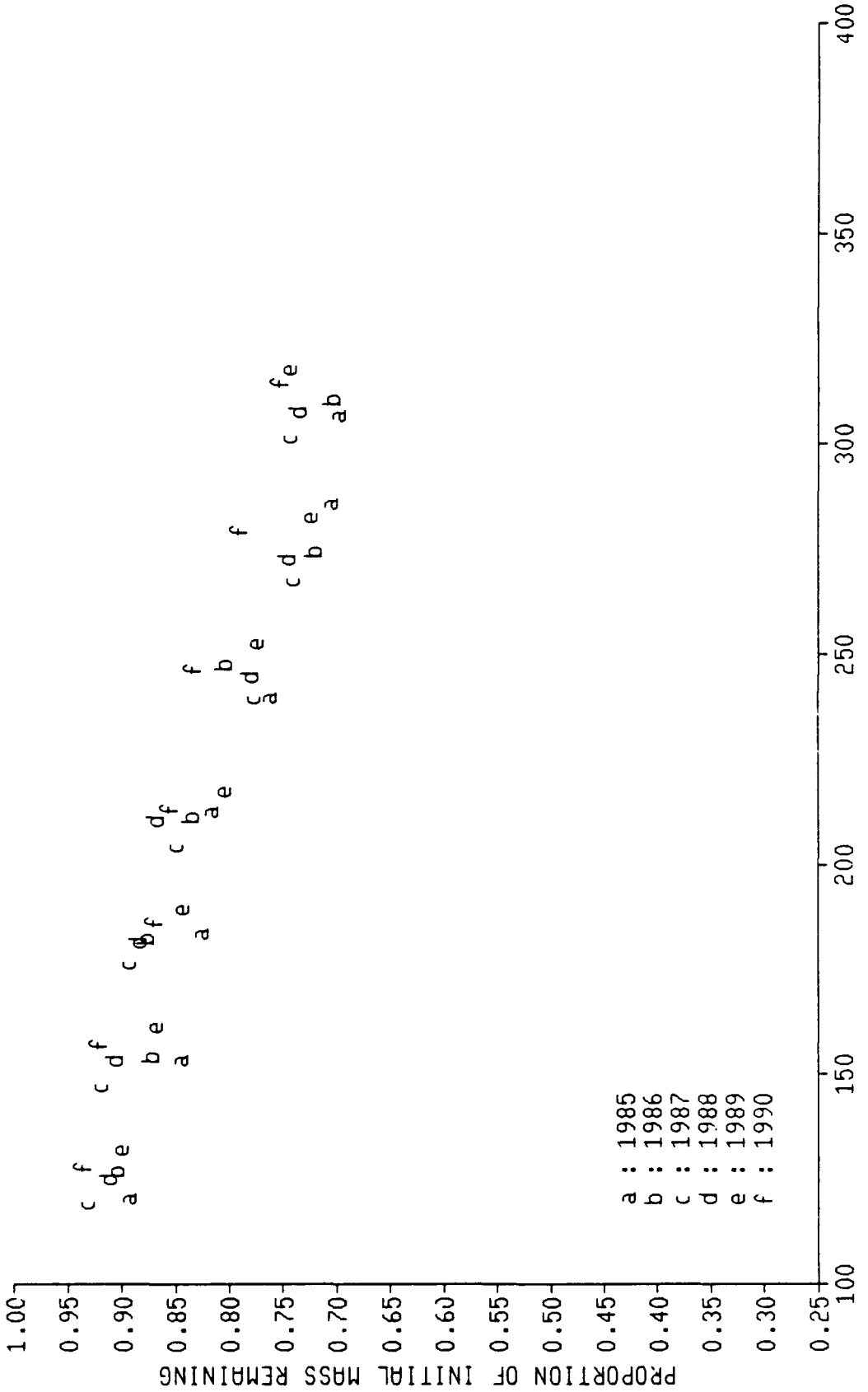


Figure 17b. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

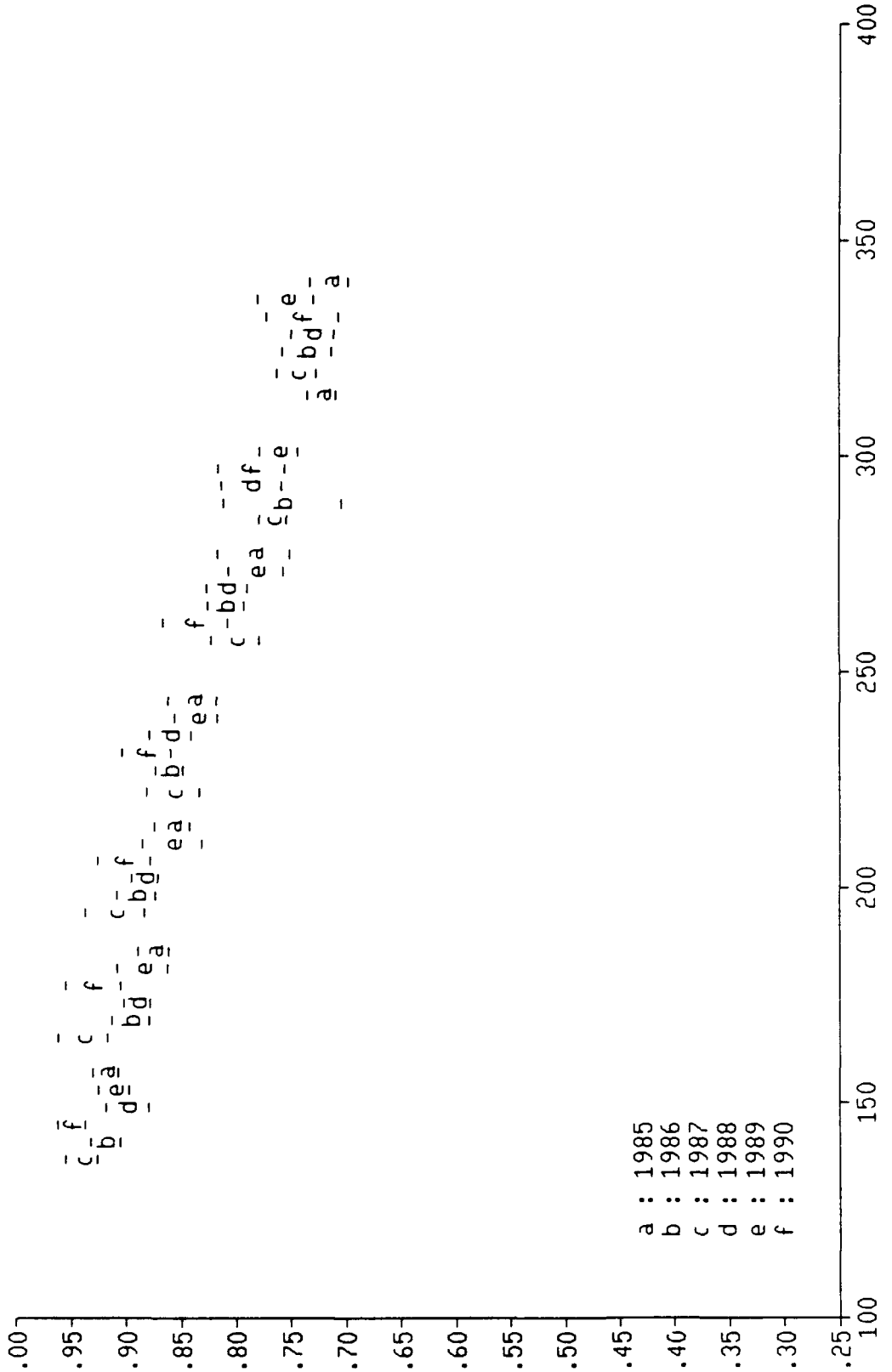


Figure 18. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

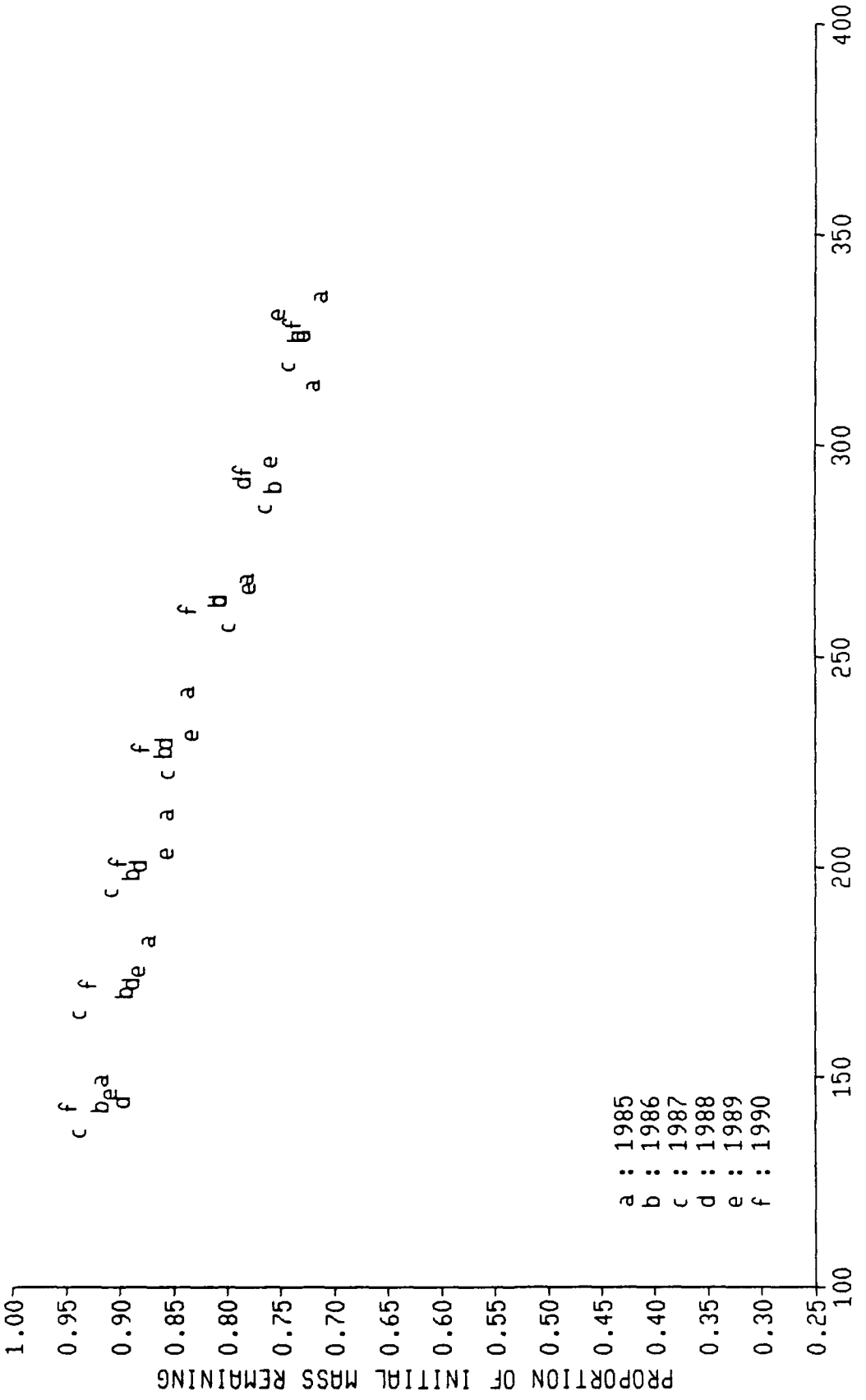


Figure 18a. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

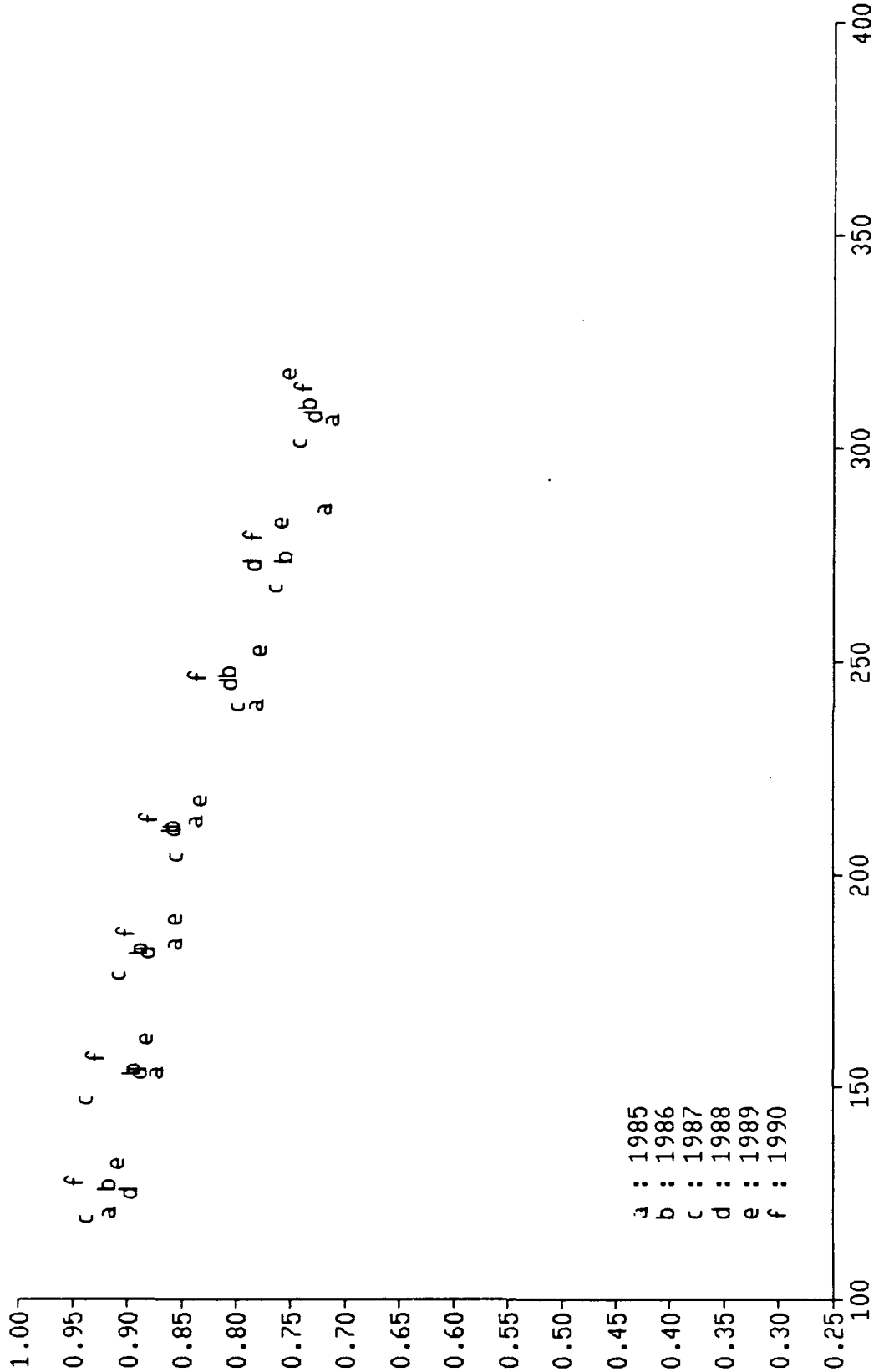


Figure 18b. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

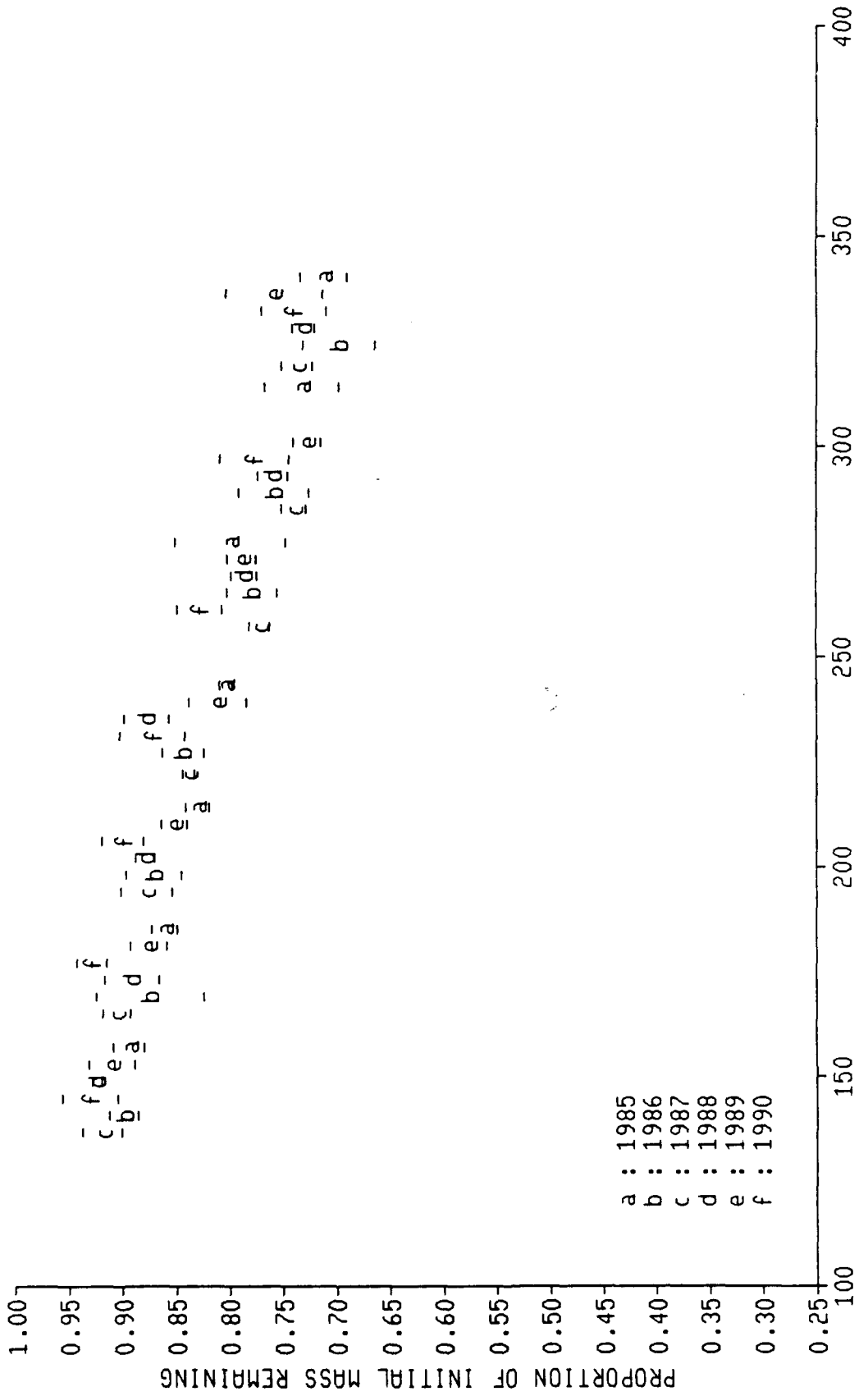


Figure 19. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

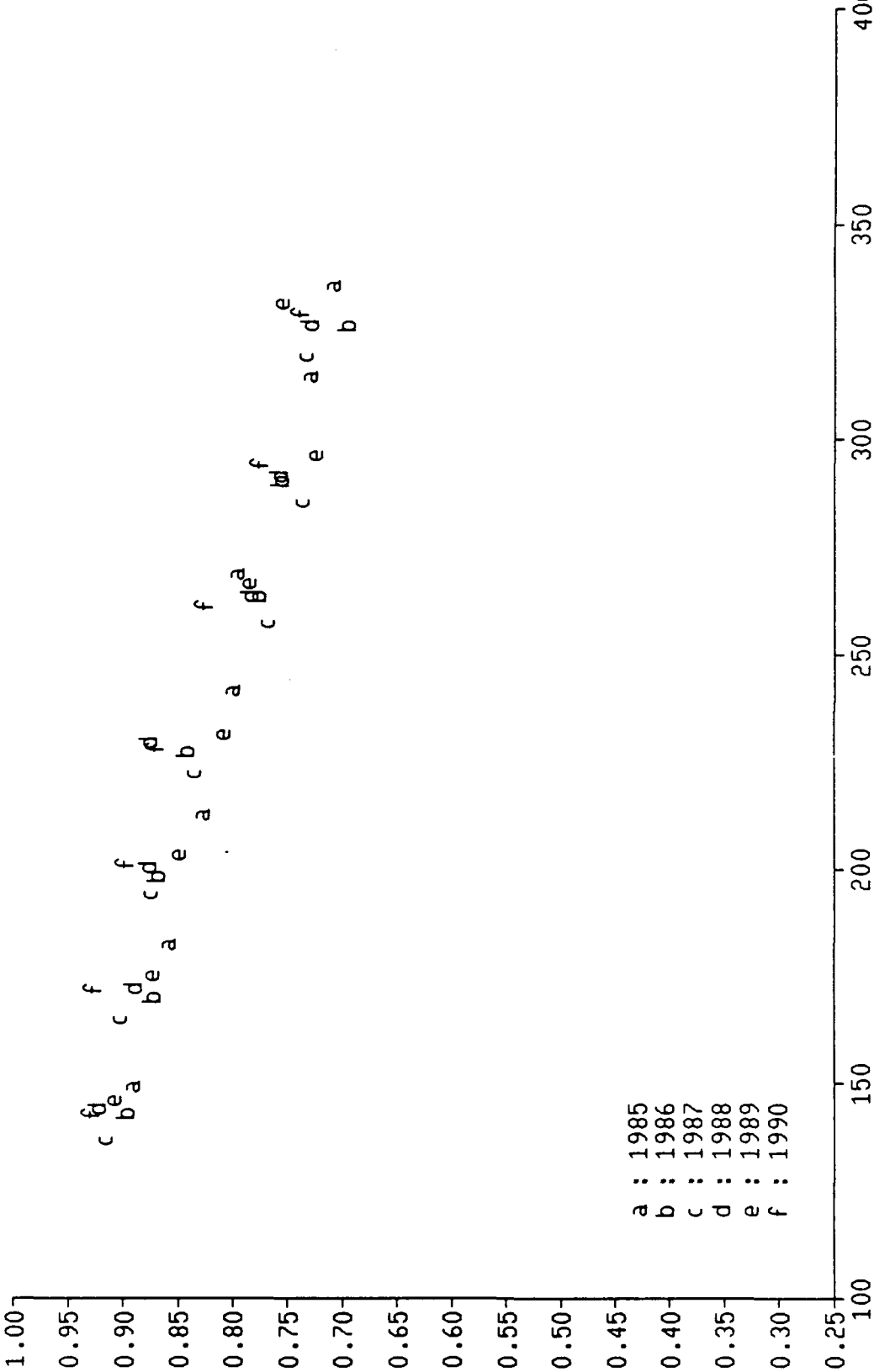


Figure 11a. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

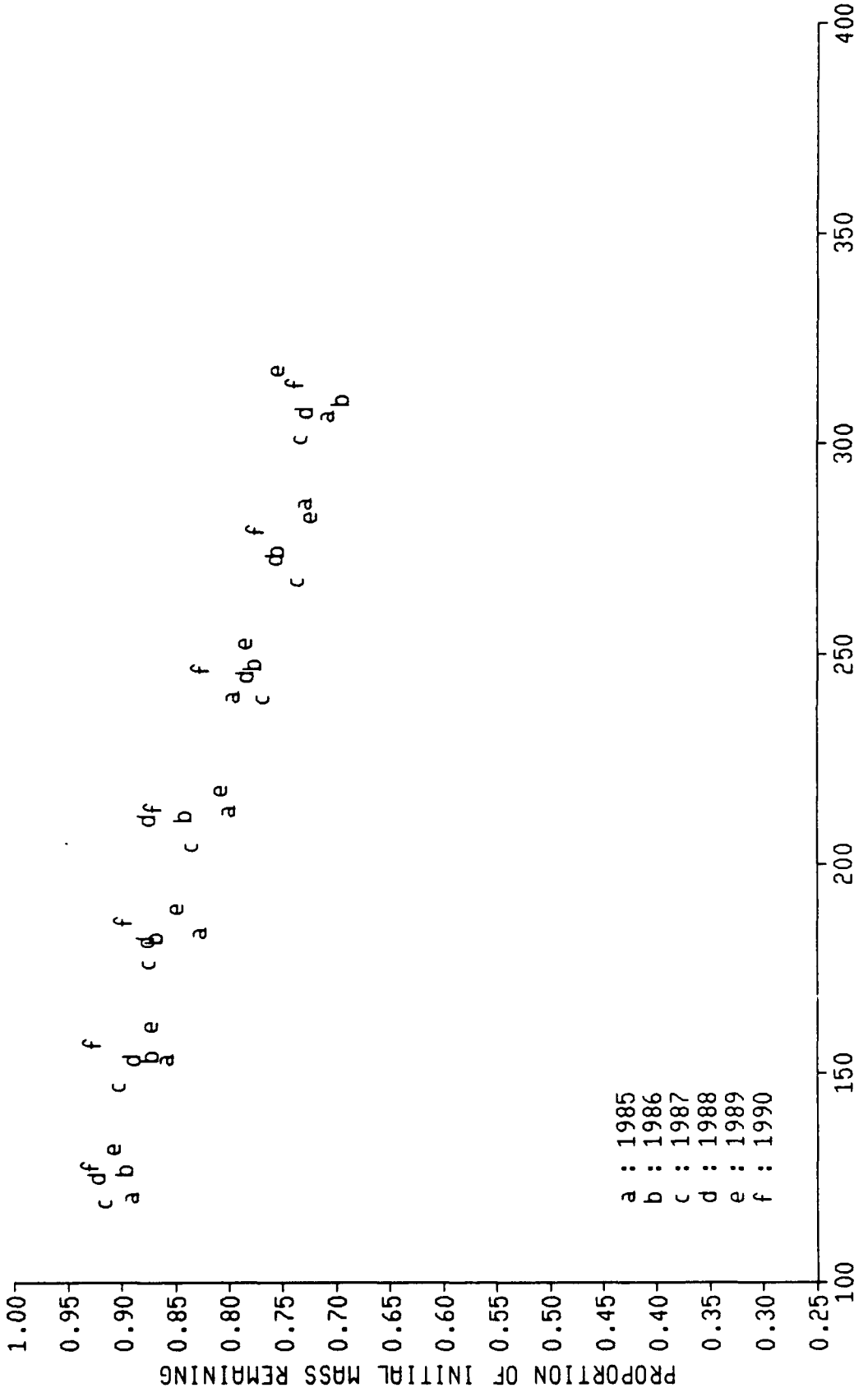


Figure 19b. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

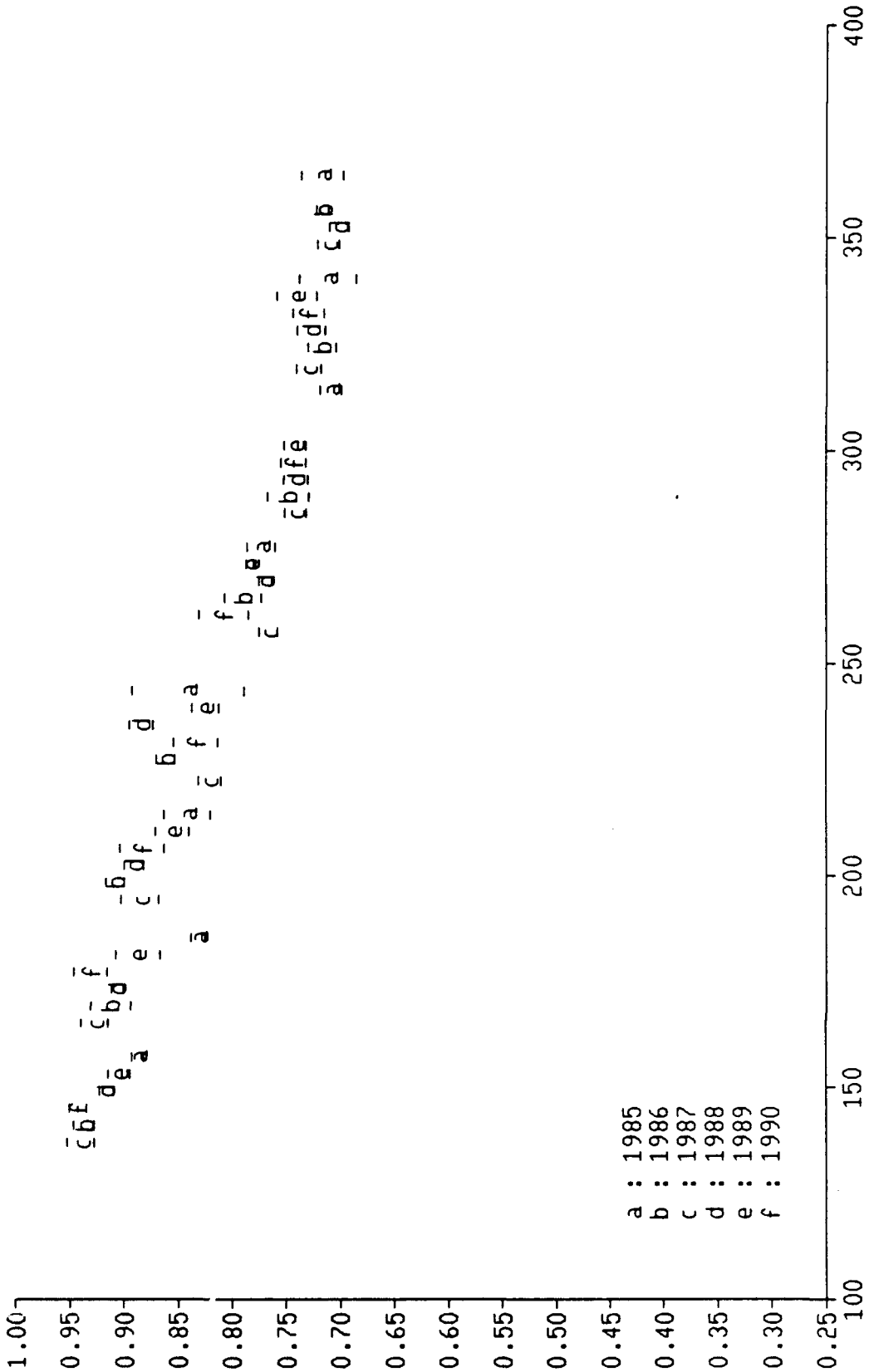


Figure 20. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

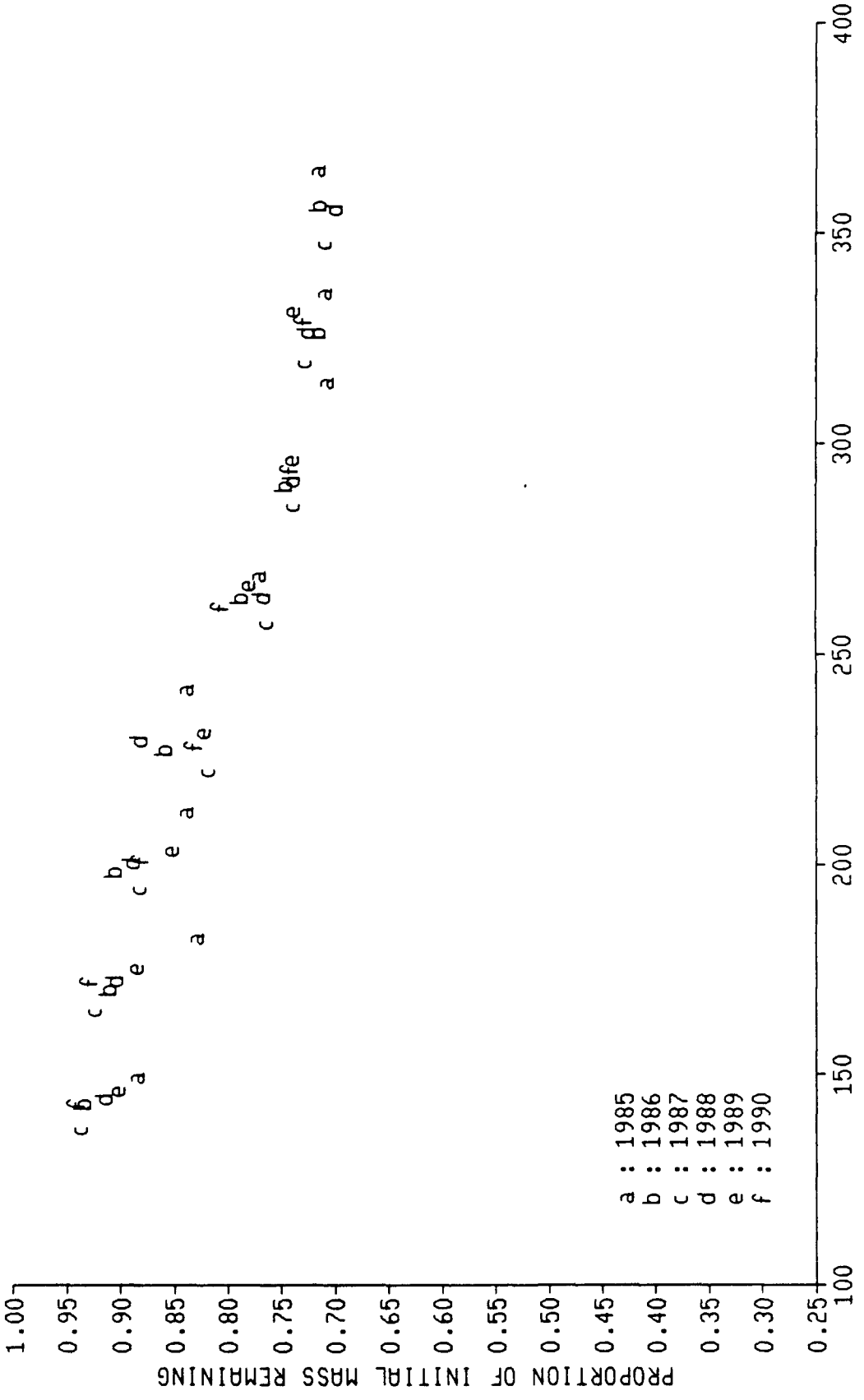


Figure 20a. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

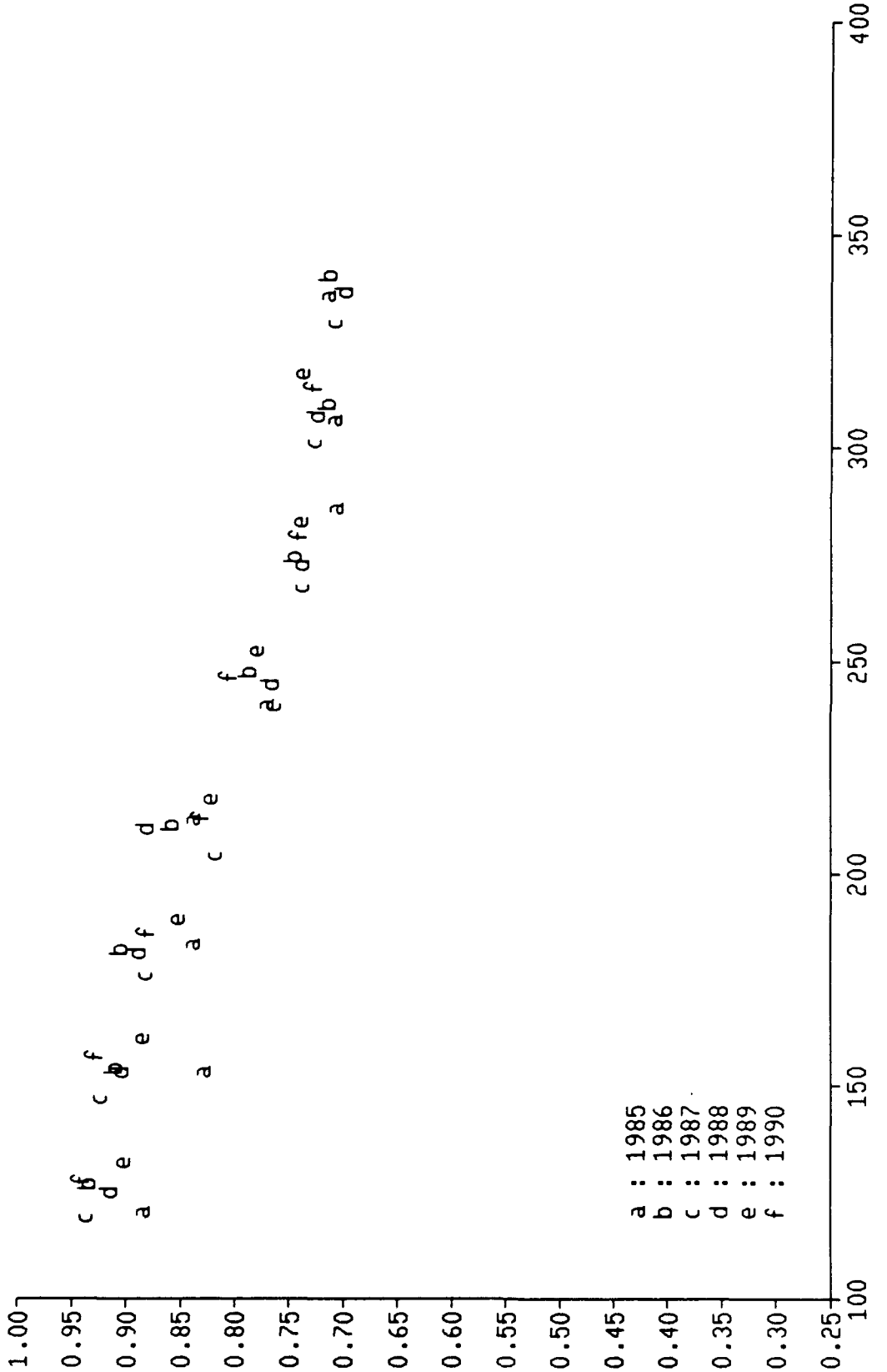


Figure 20b. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

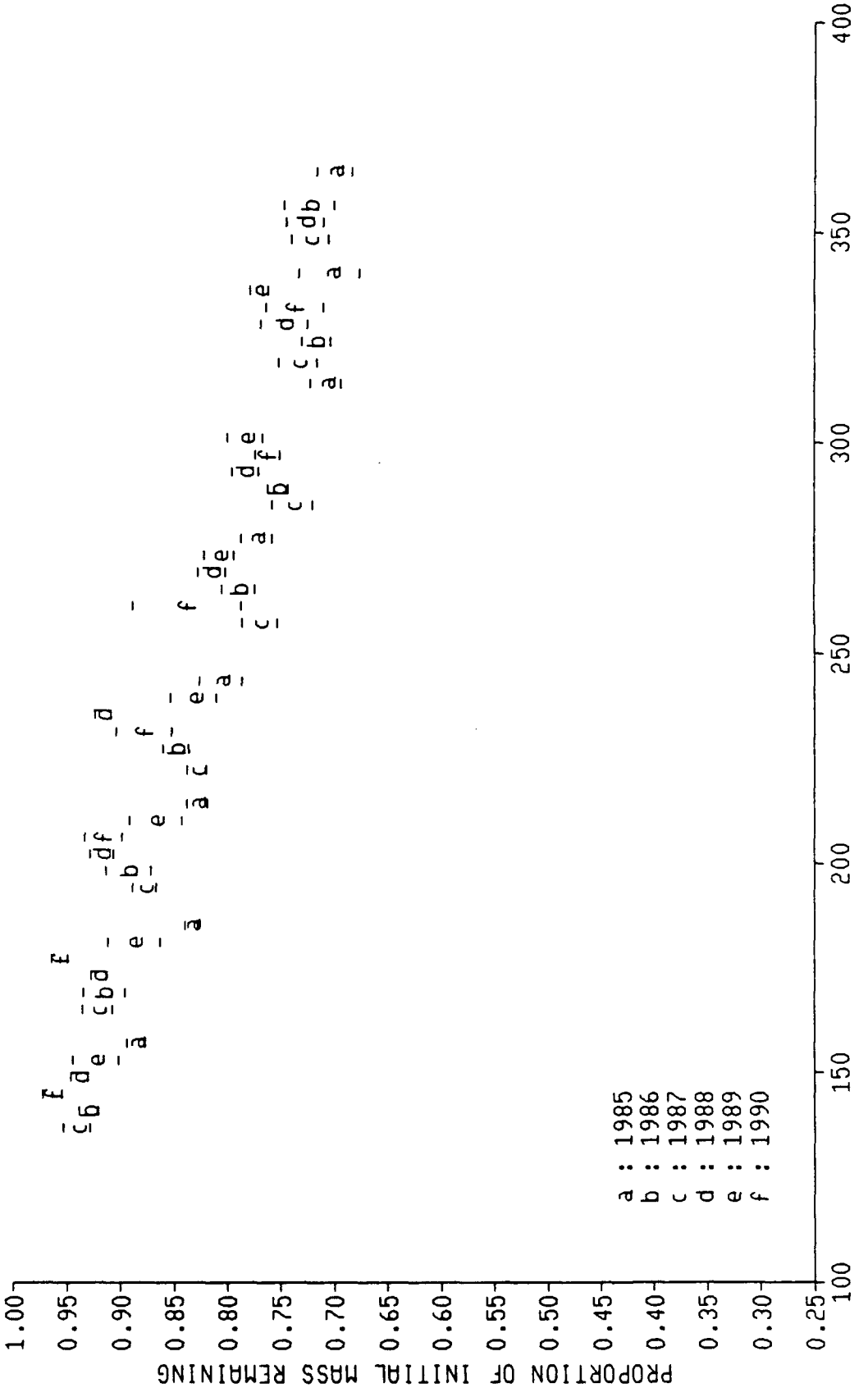


Figure 21. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

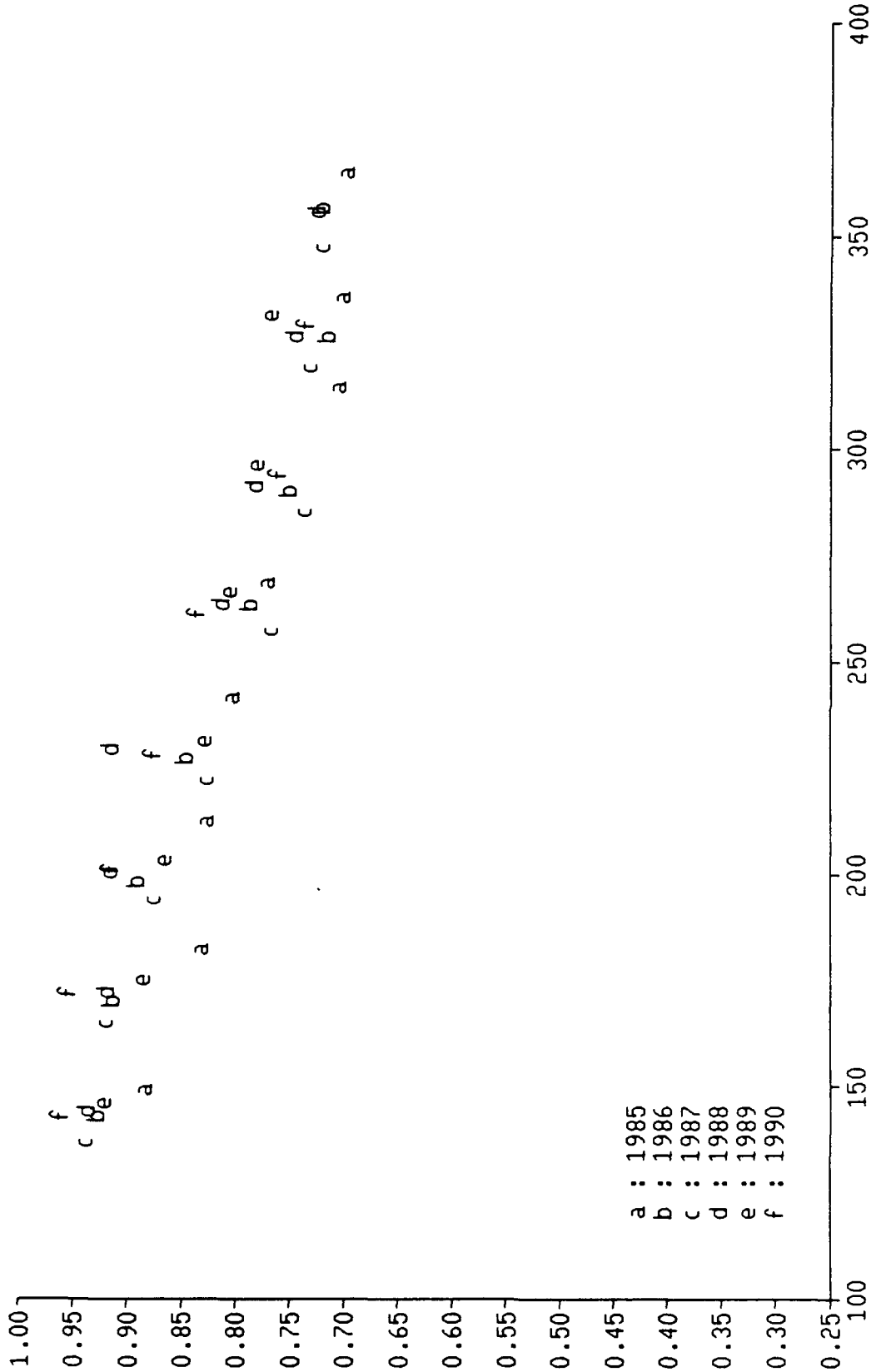


Figure 21a. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

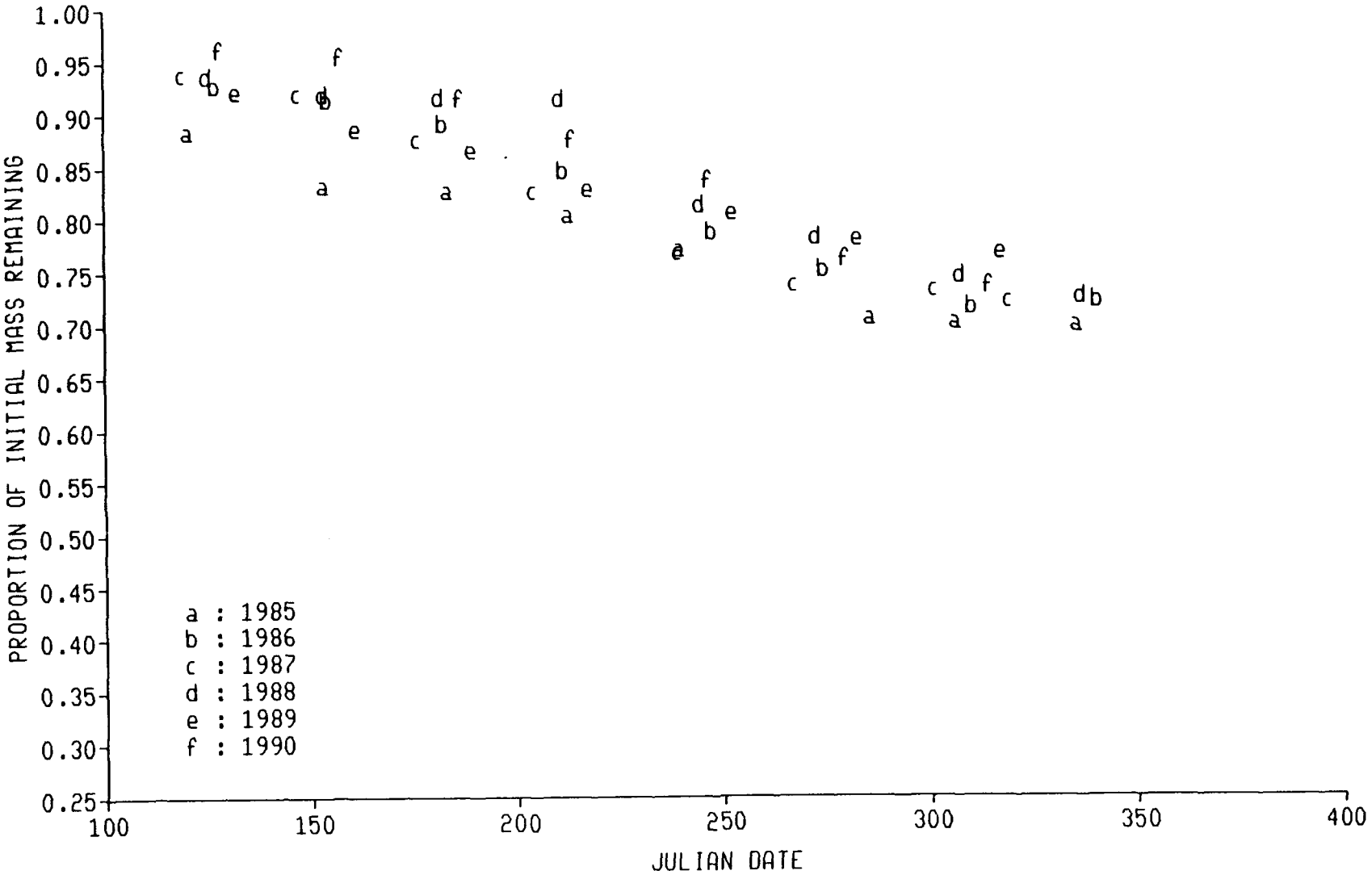


Figure 21b. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

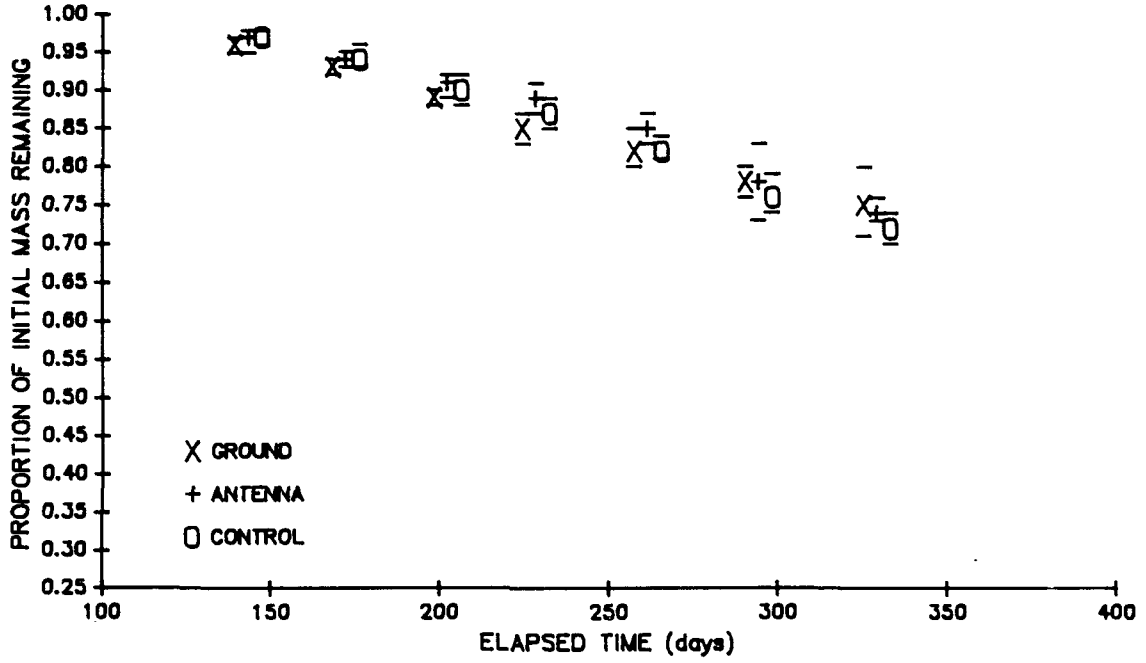


FIGURE 22. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the three plantation subunits during the 1989–1990 experiment.

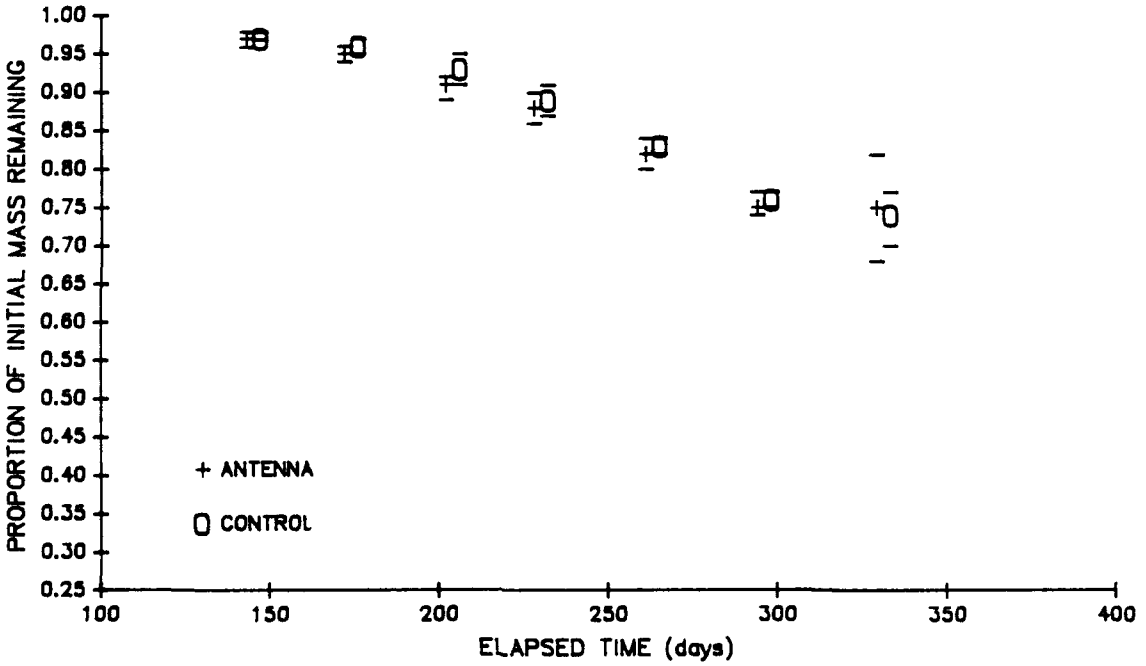


FIGURE 23. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1989–1990 experiment.

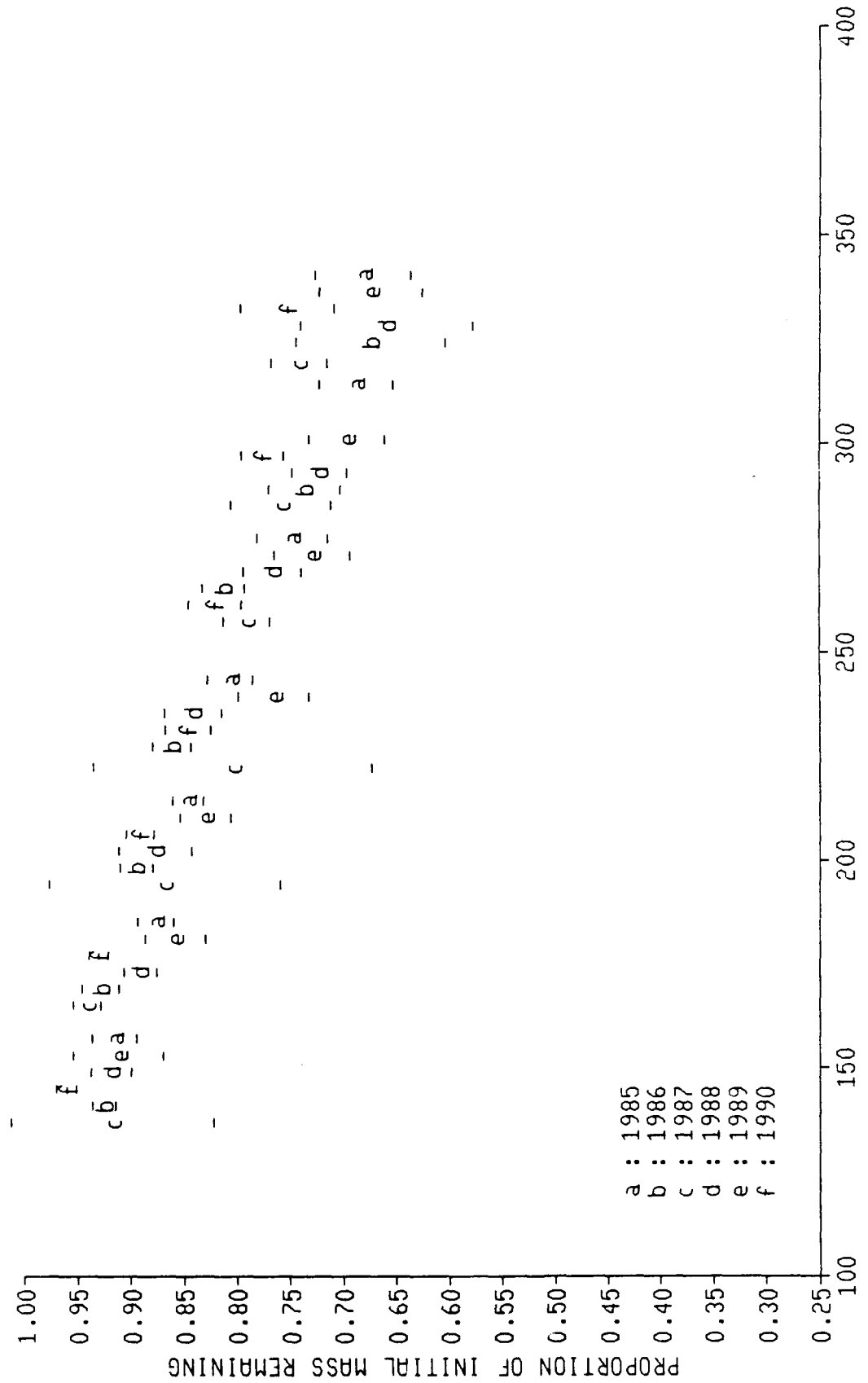


Figure 24. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

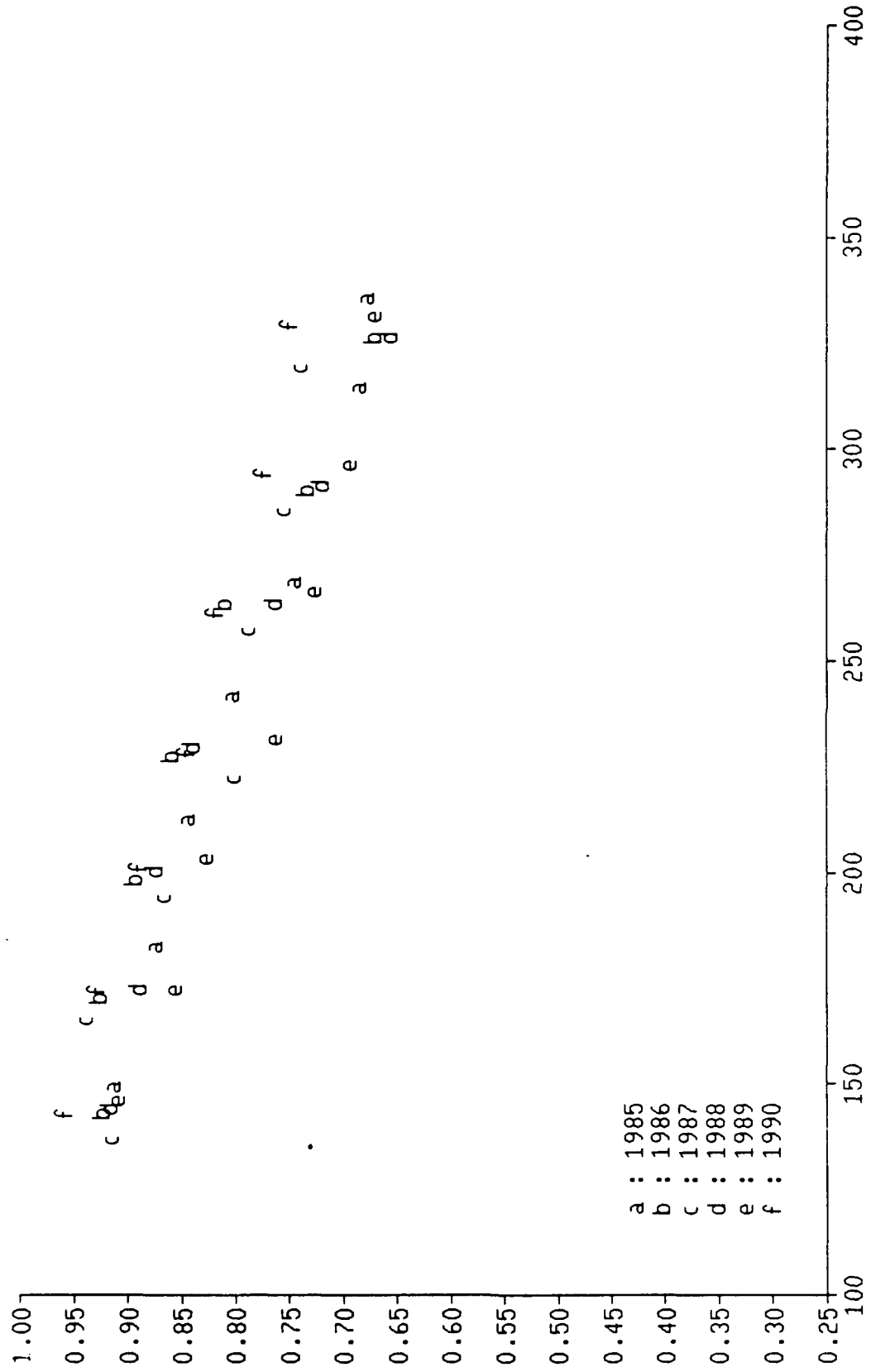


Figure 24a. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

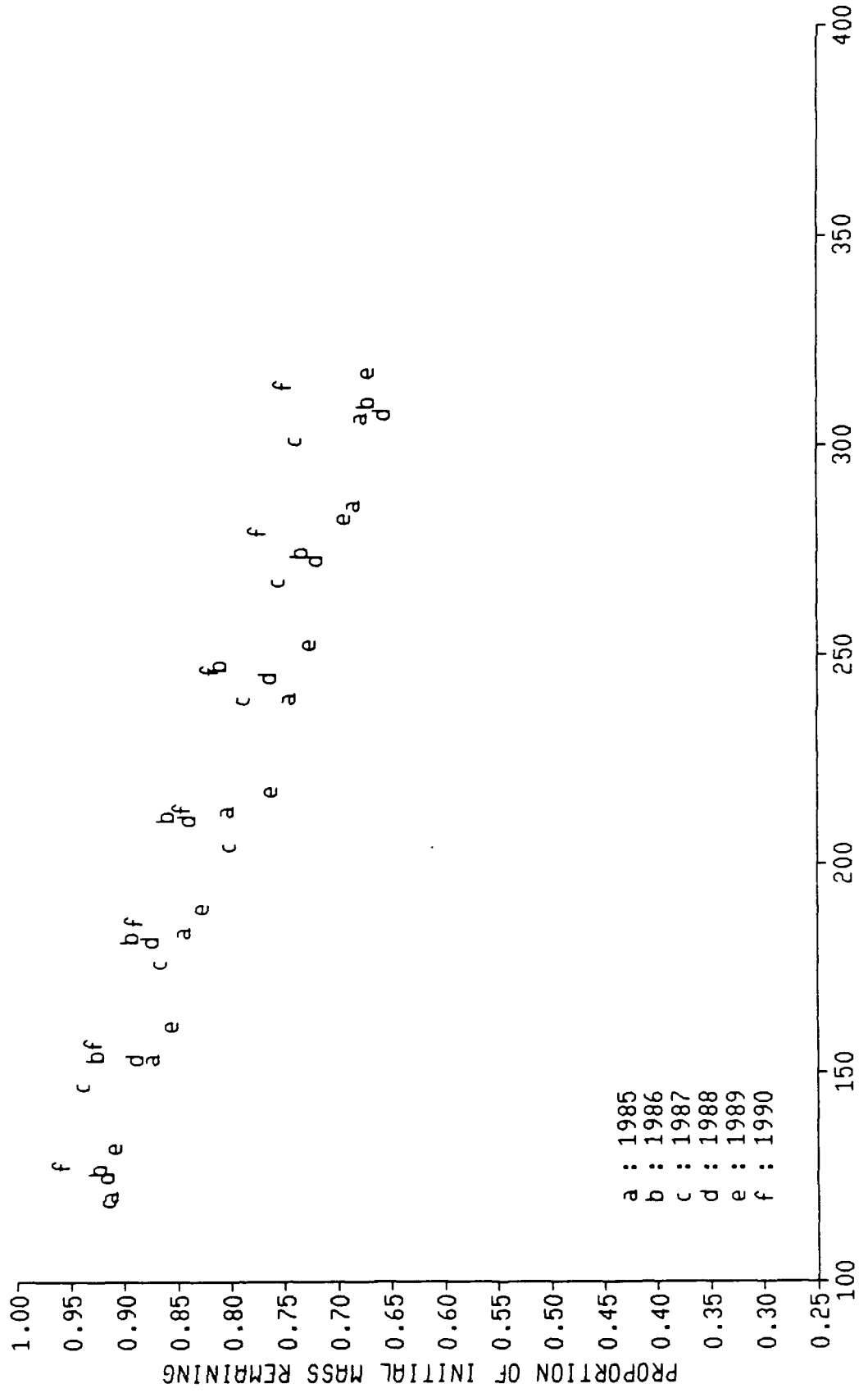


Figure 24b. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

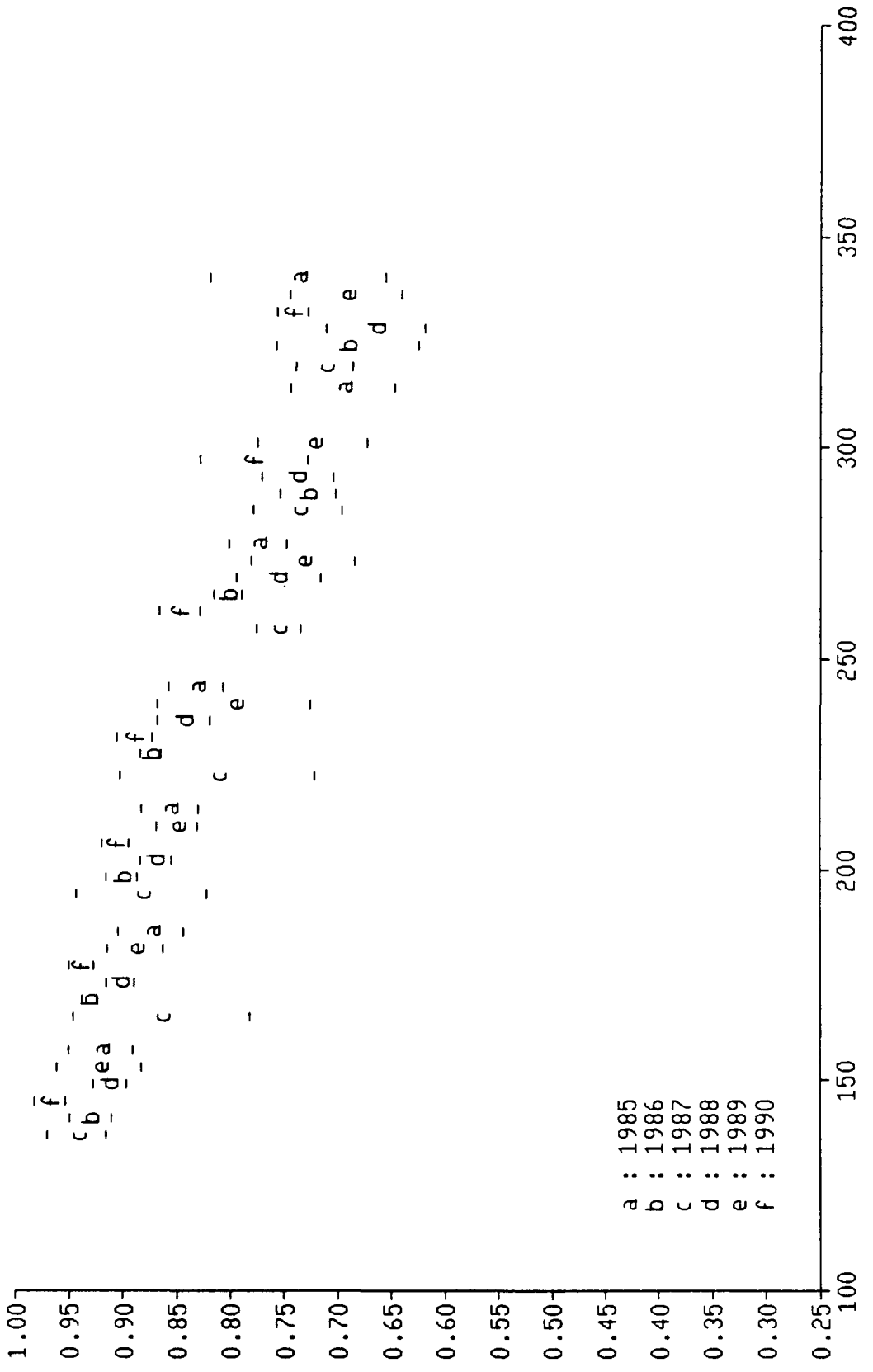


Figure 25. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

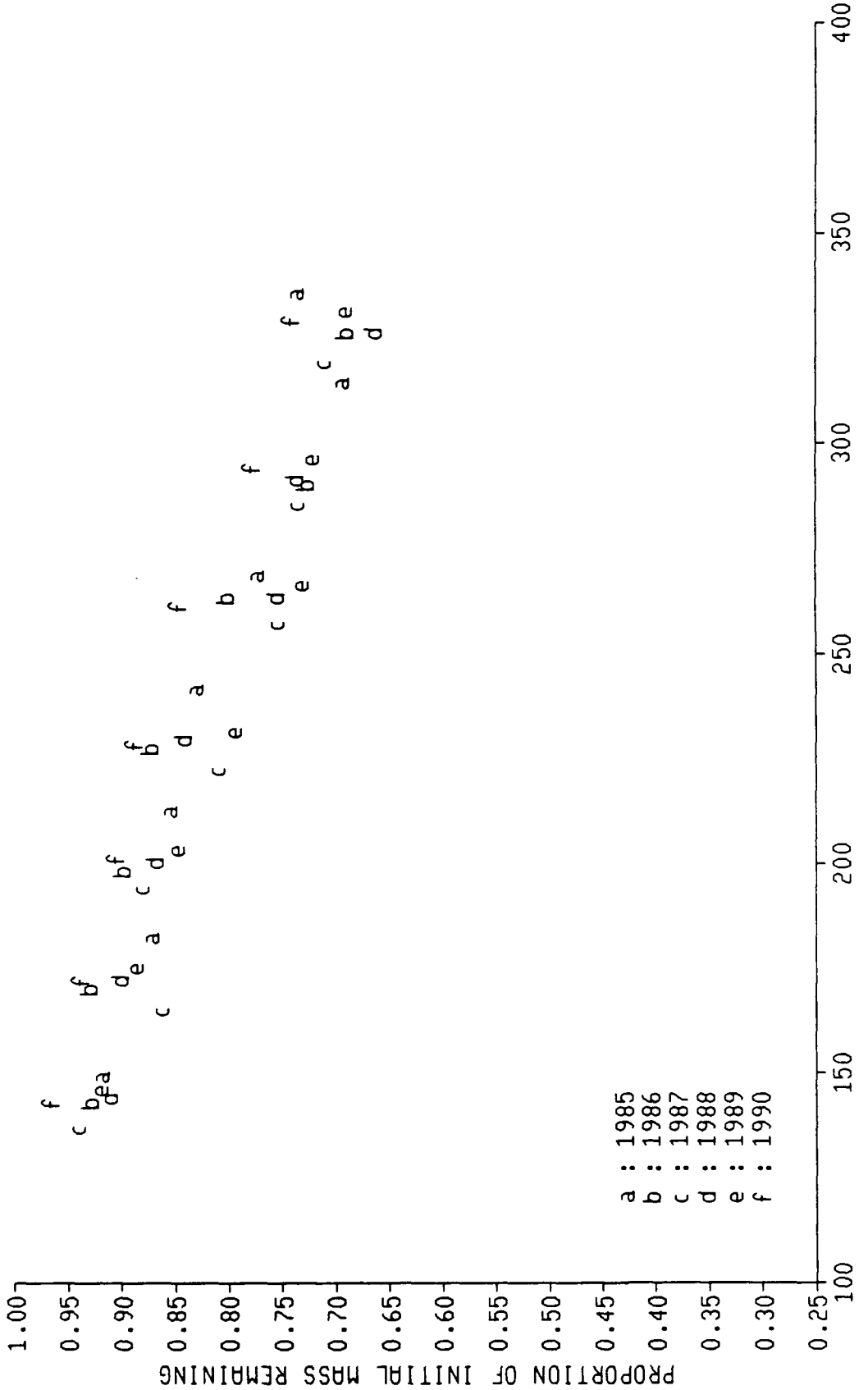


Figure 25a. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

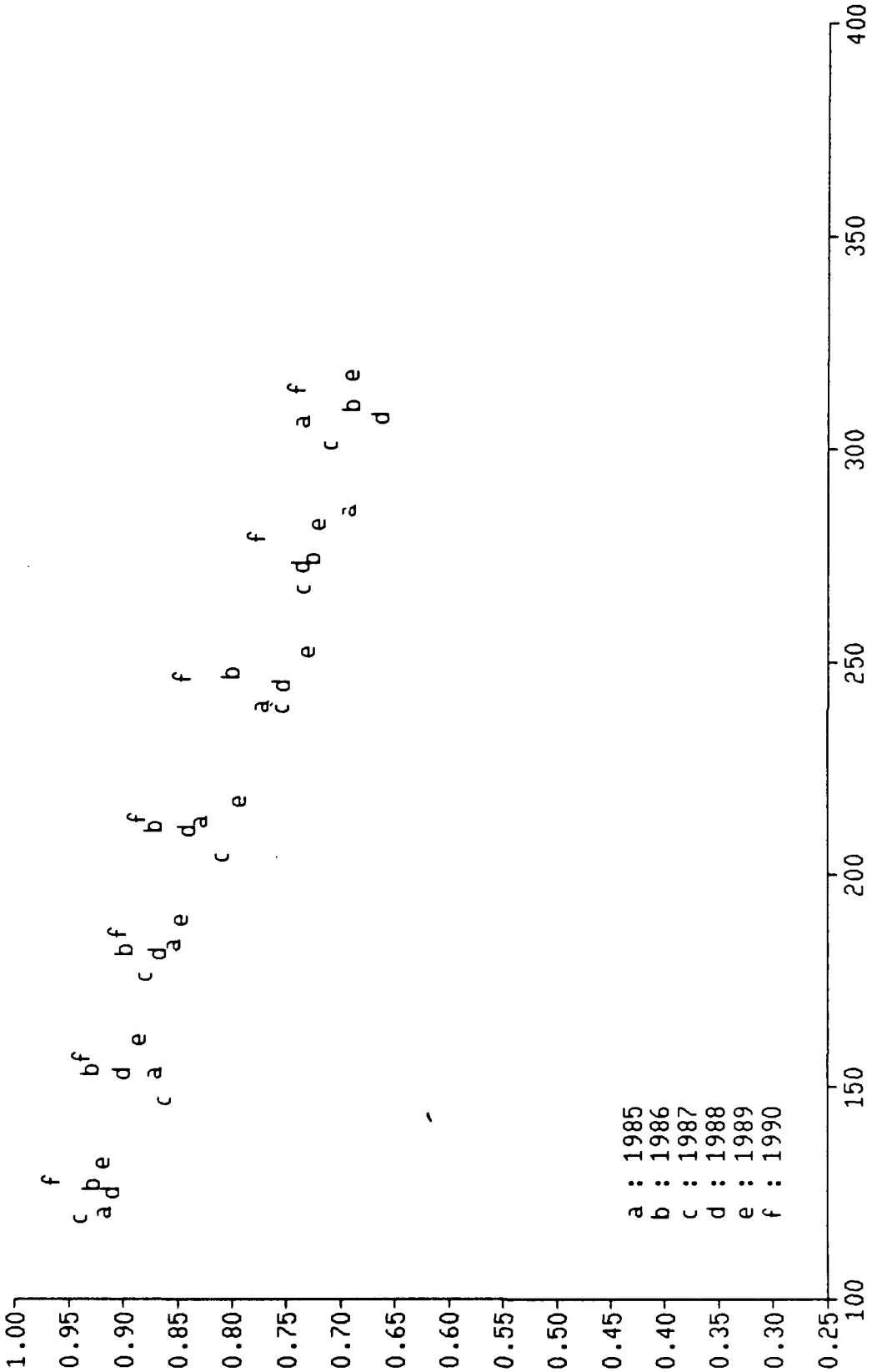


Figure 25b. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

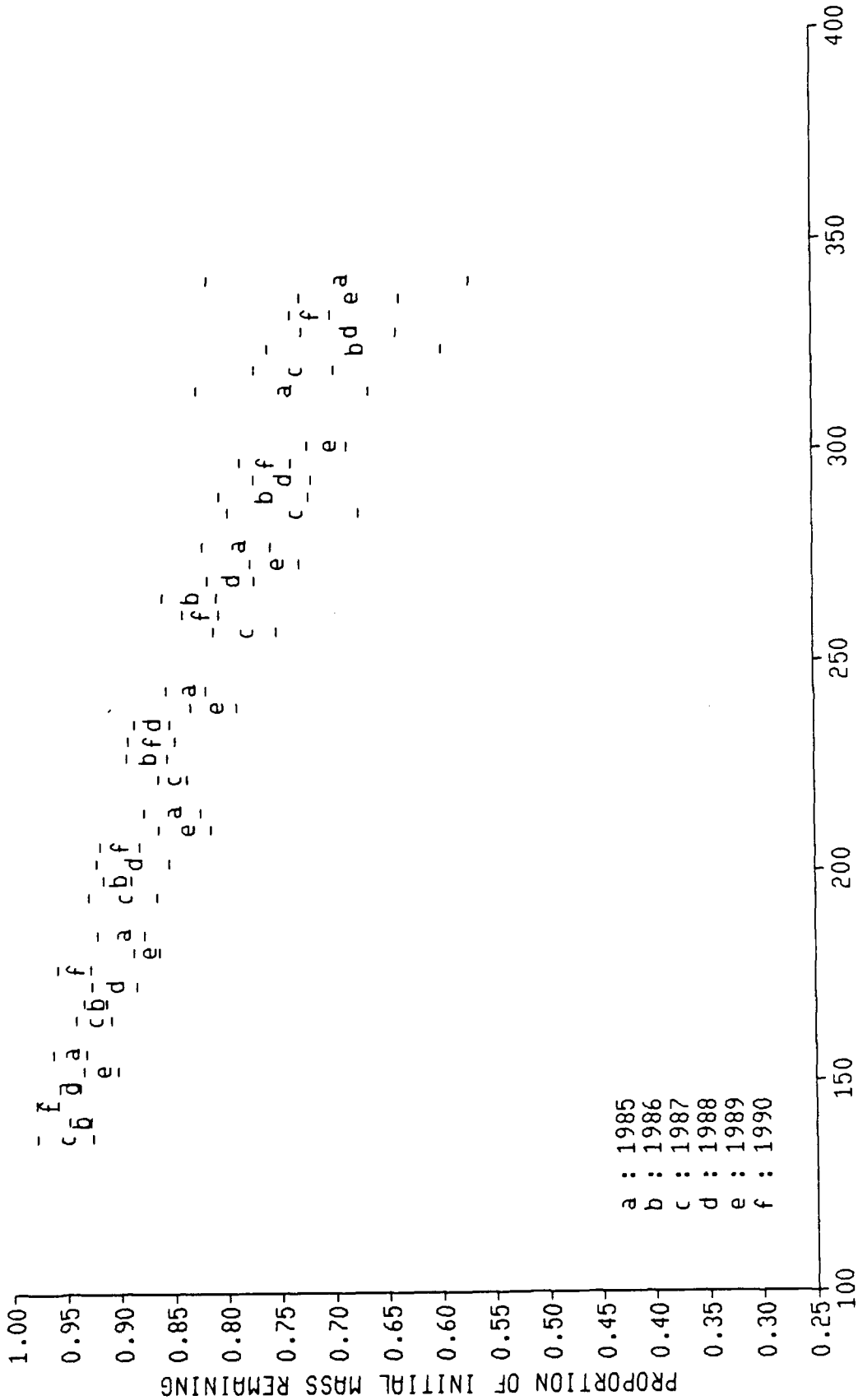


Figure 26. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

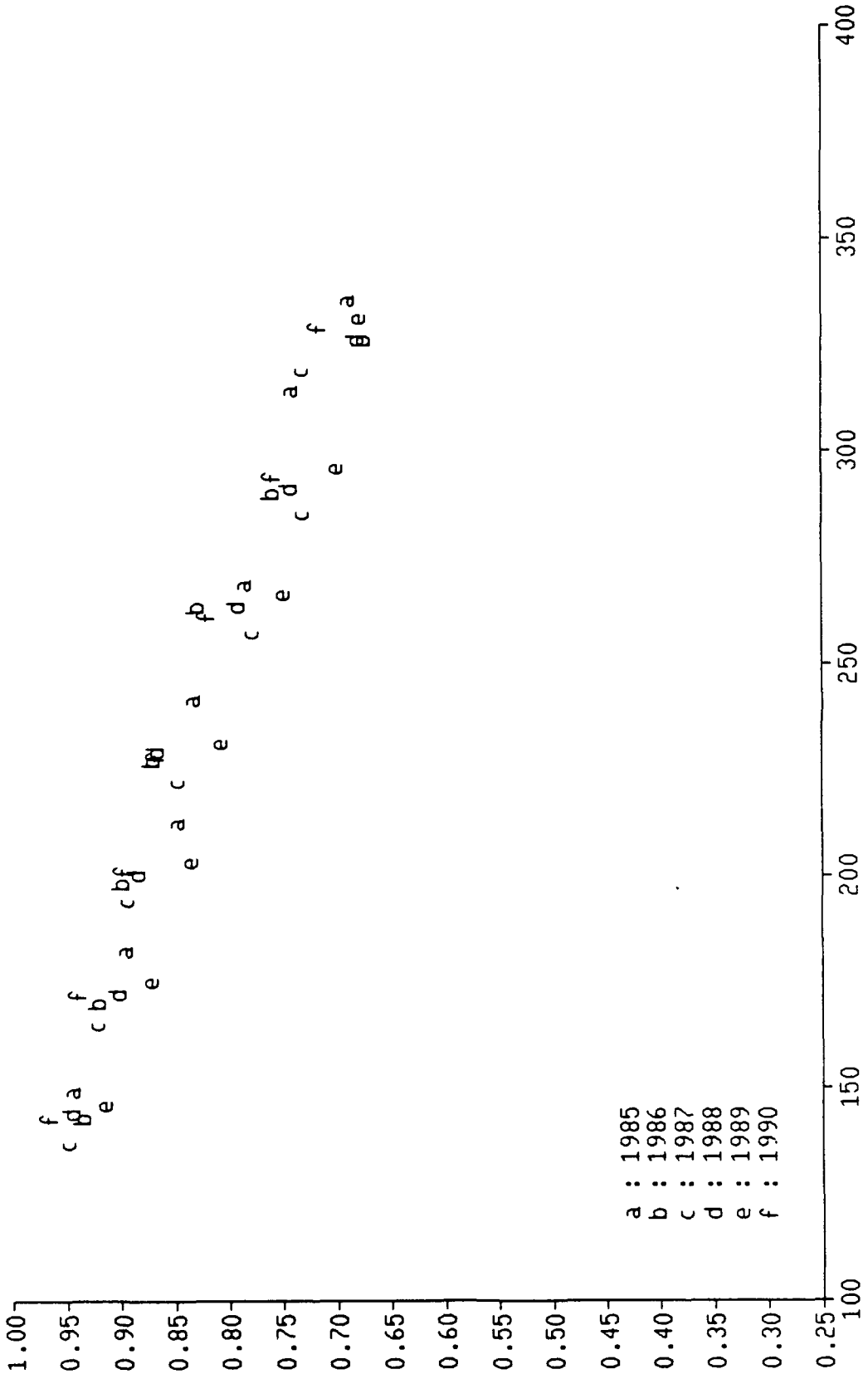


Figure 26a. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

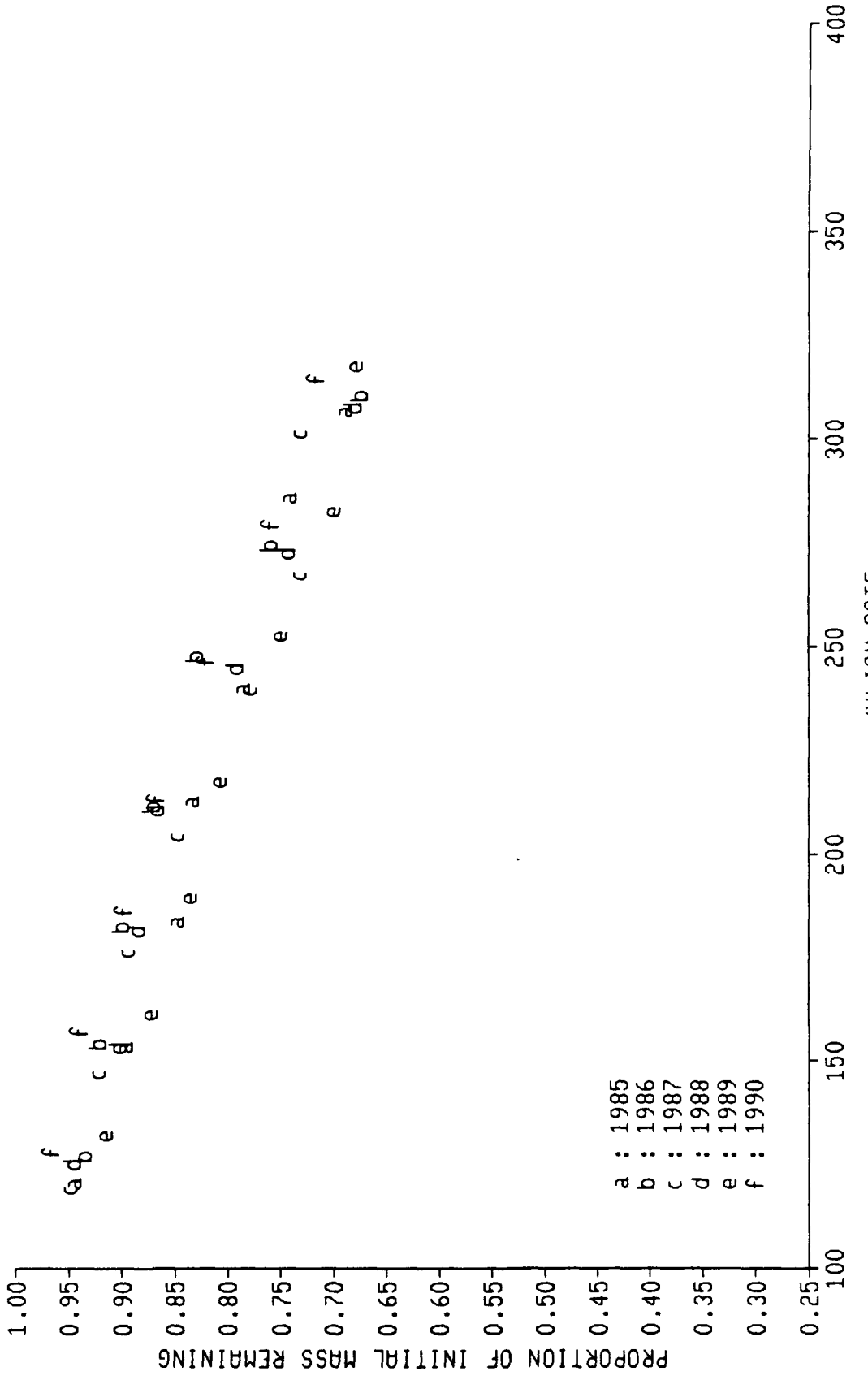


Figure 26b. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

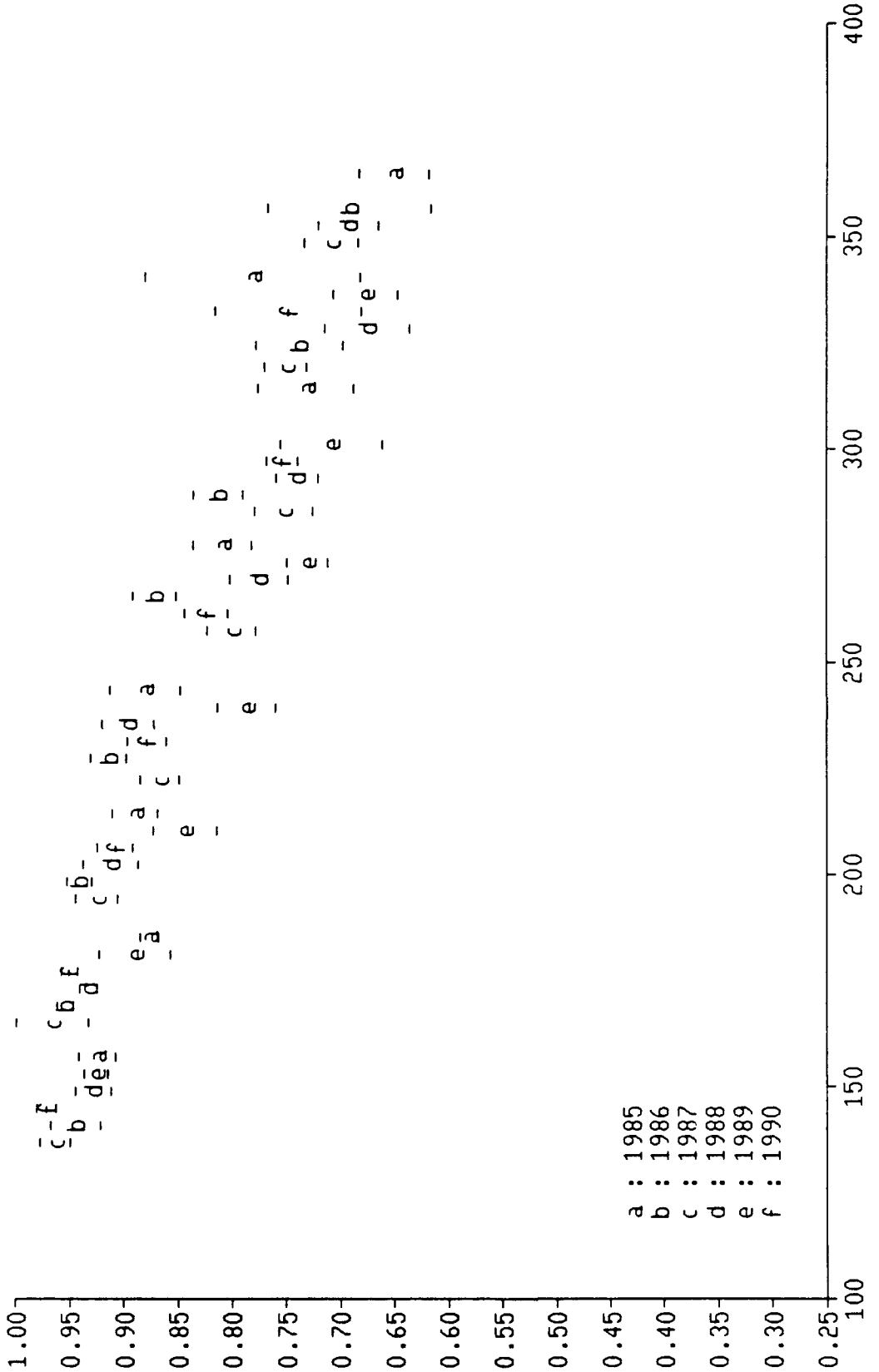


Figure 27. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

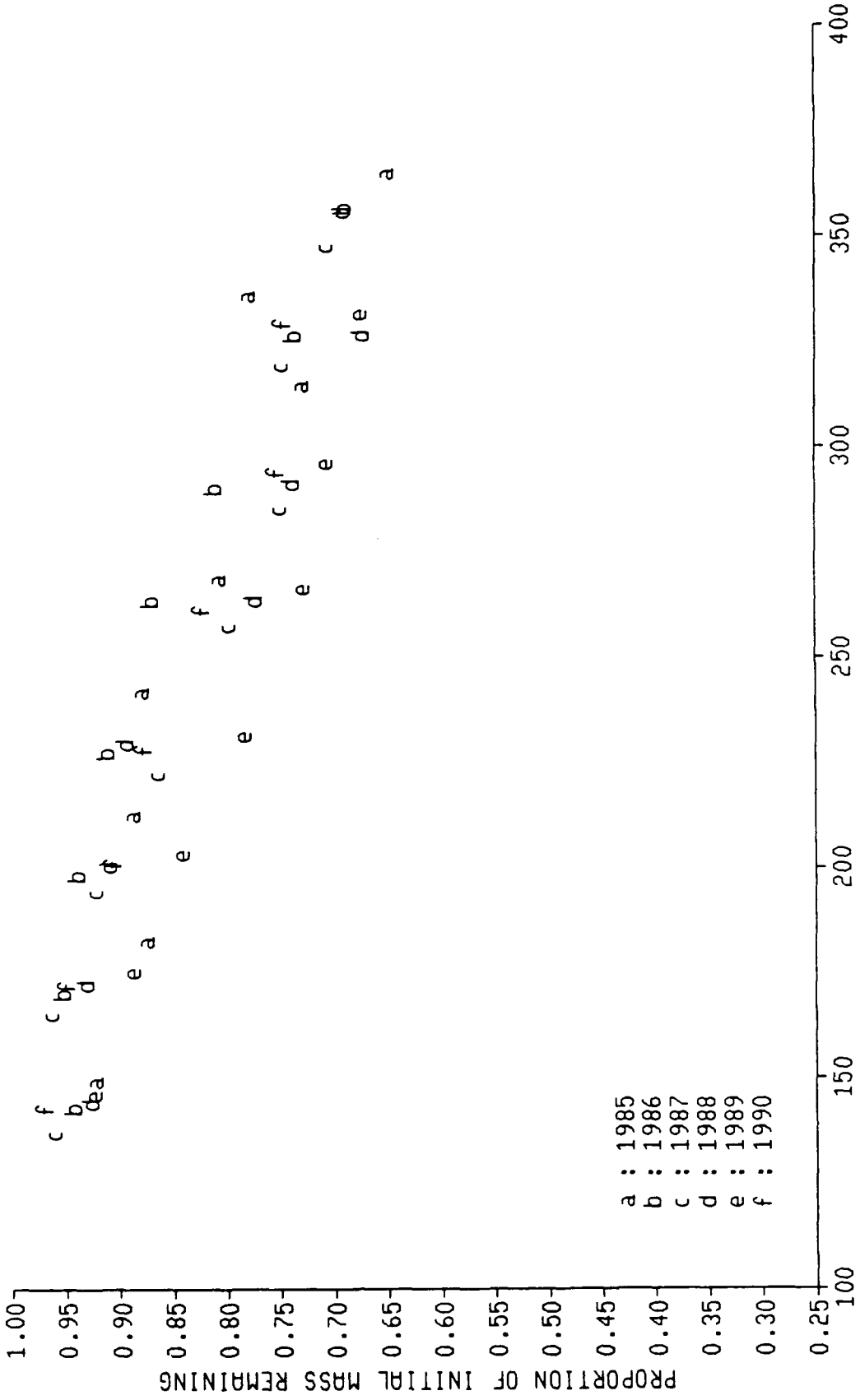


Figure 27a. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

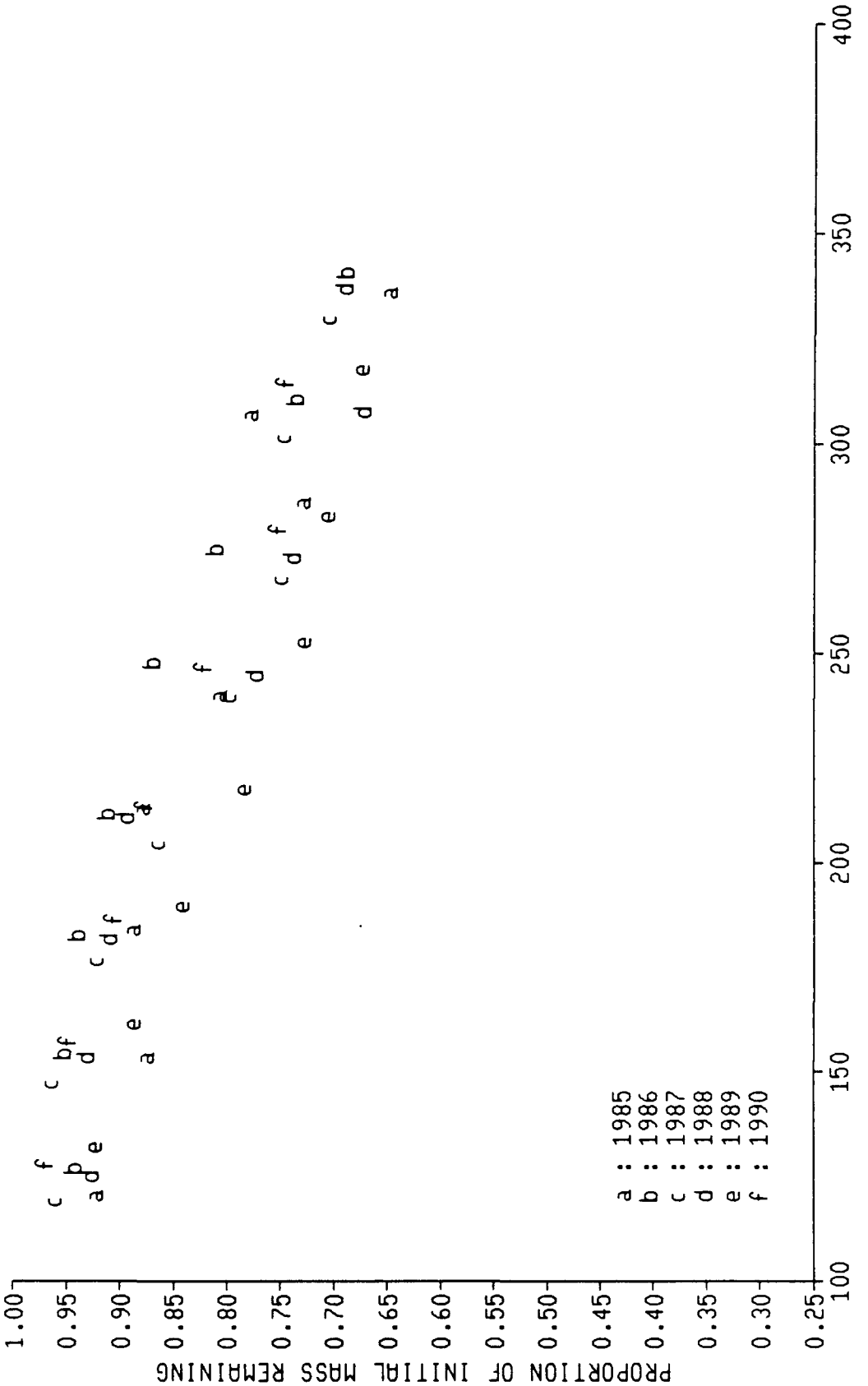


Figure 27b. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

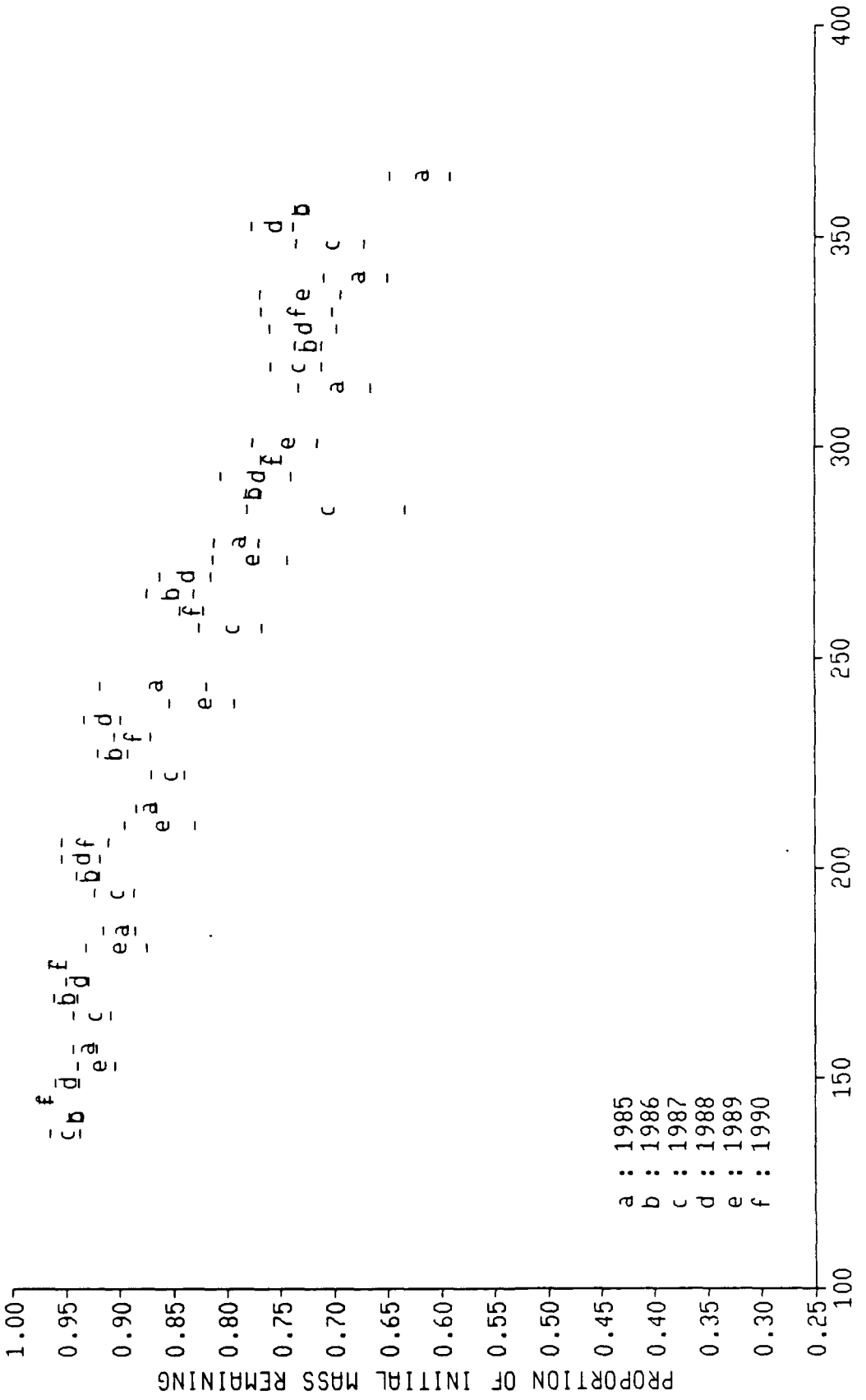


Figure 28. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

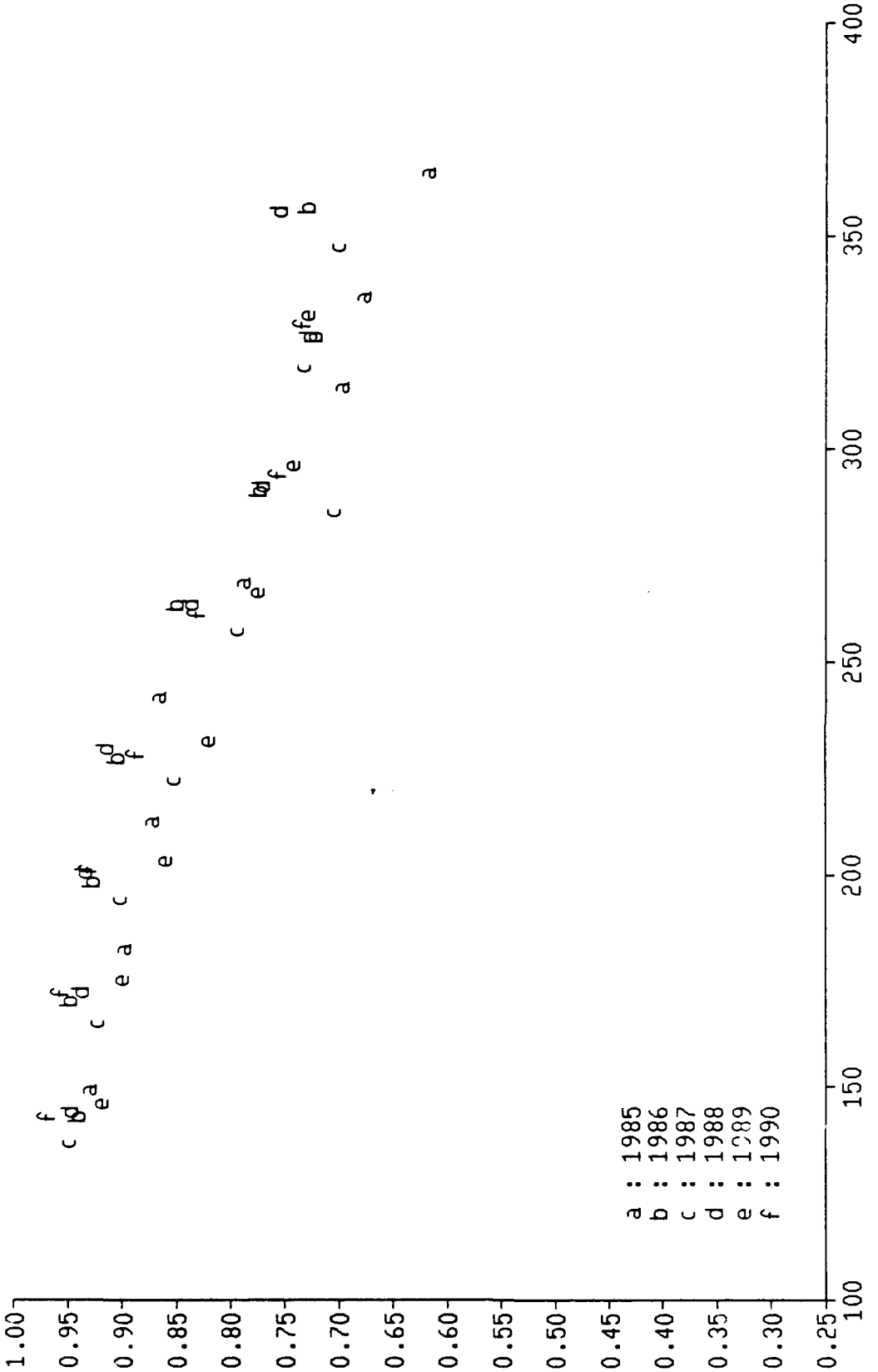


Figure 28a. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

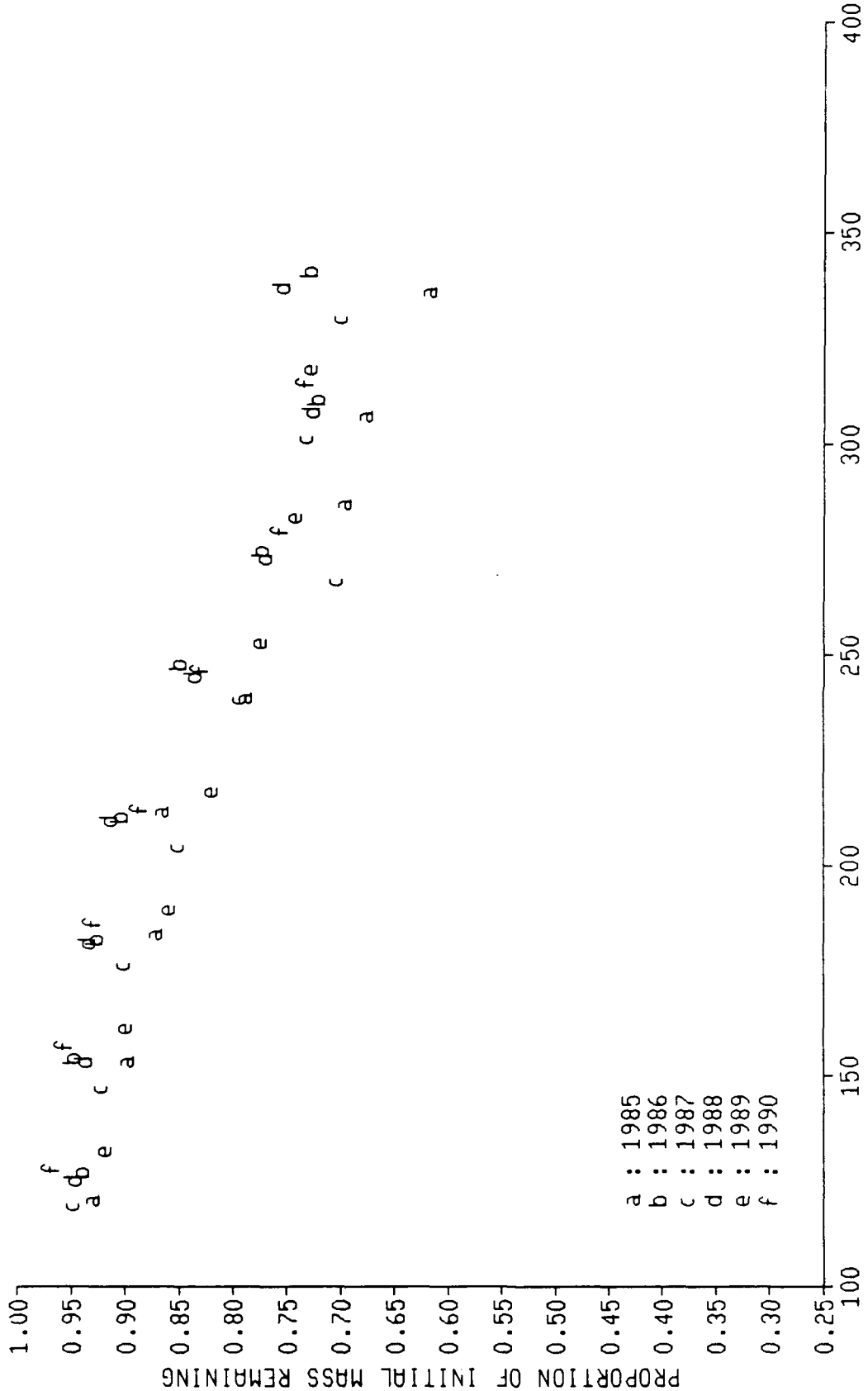


Figure 28b. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

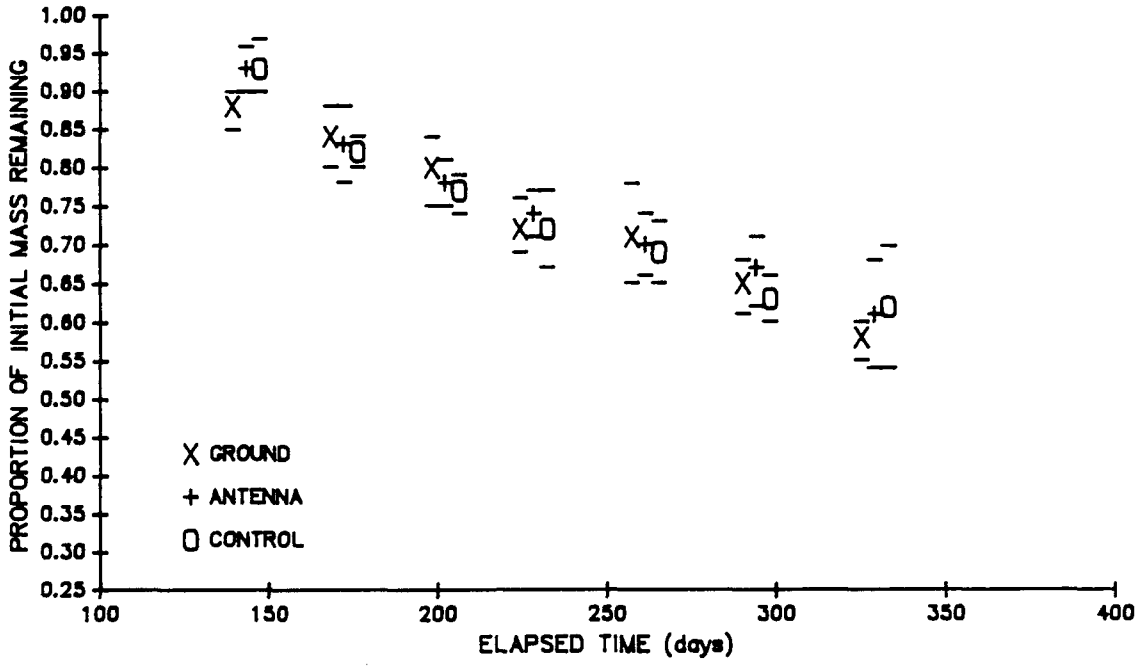


FIGURE 29. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the three plantation subunits during the 1989–1990 experiment.

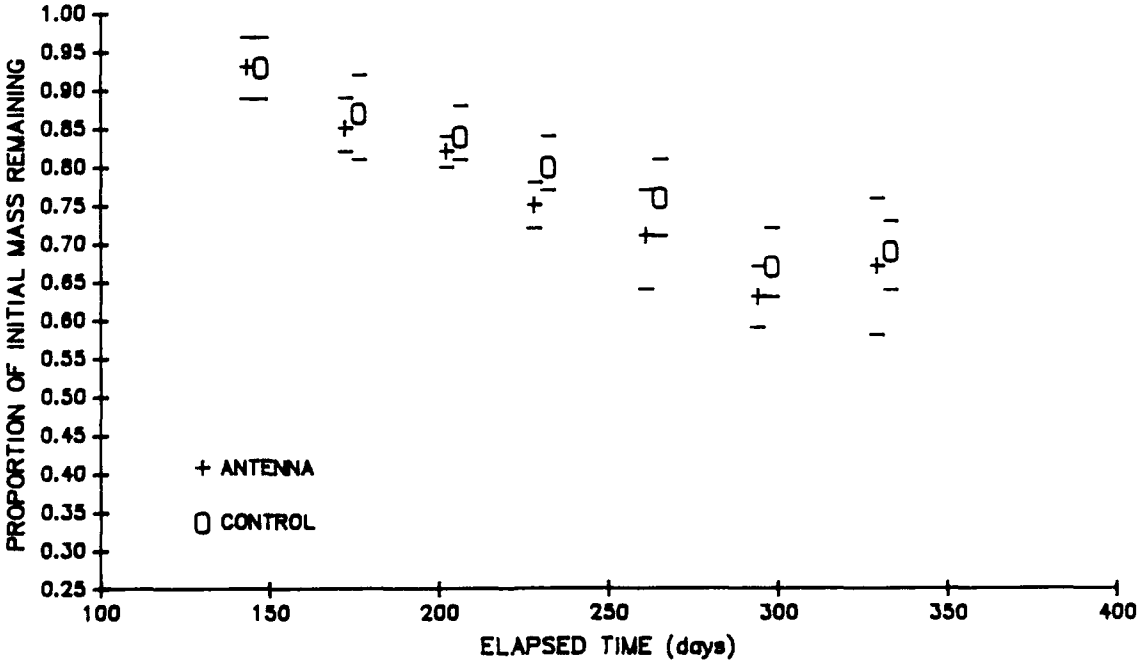


FIGURE 30. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1989–1990 experiment.

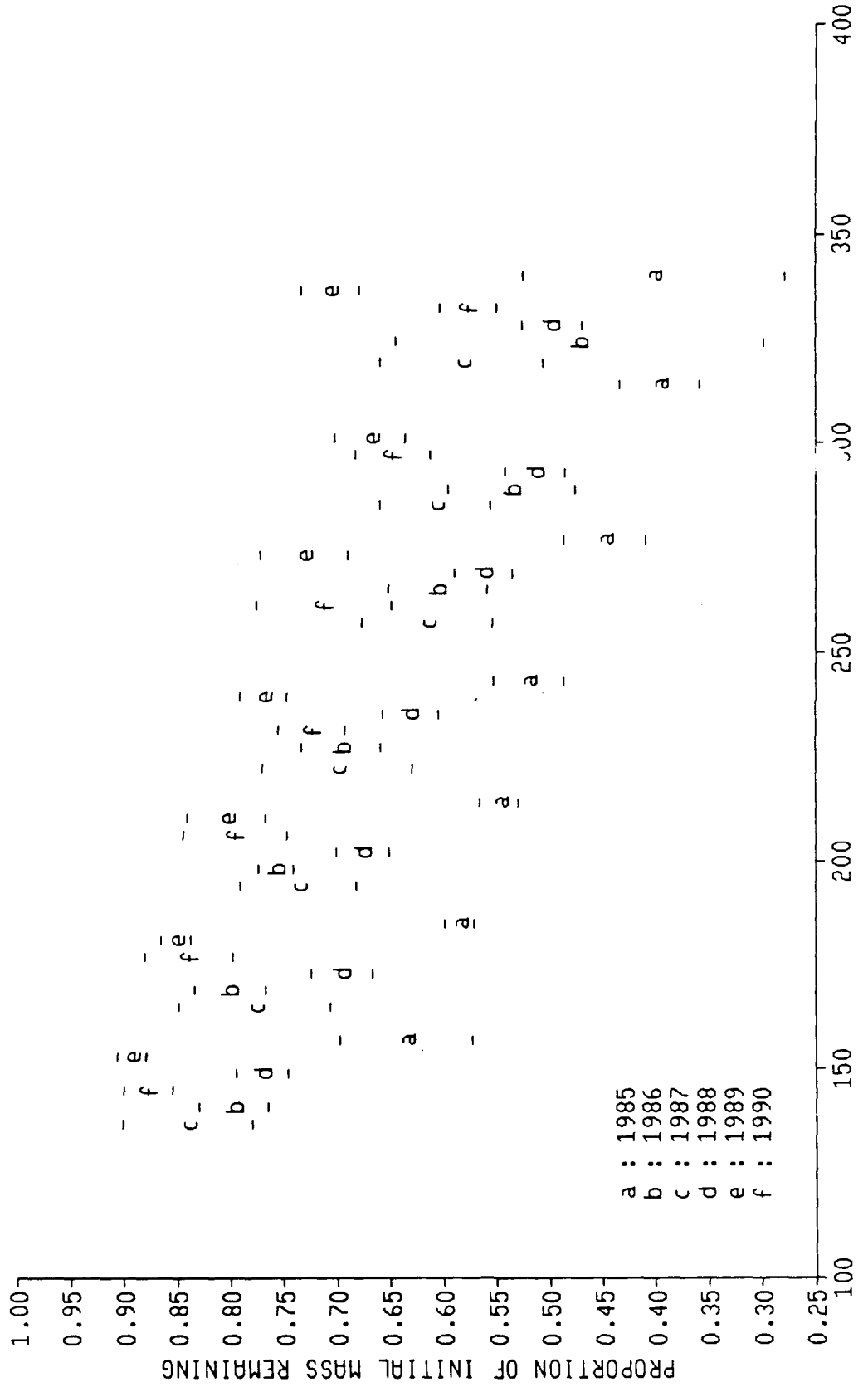


Figure 31. Proportion (X) of initial dry matter mass remaining for bulk m ple leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

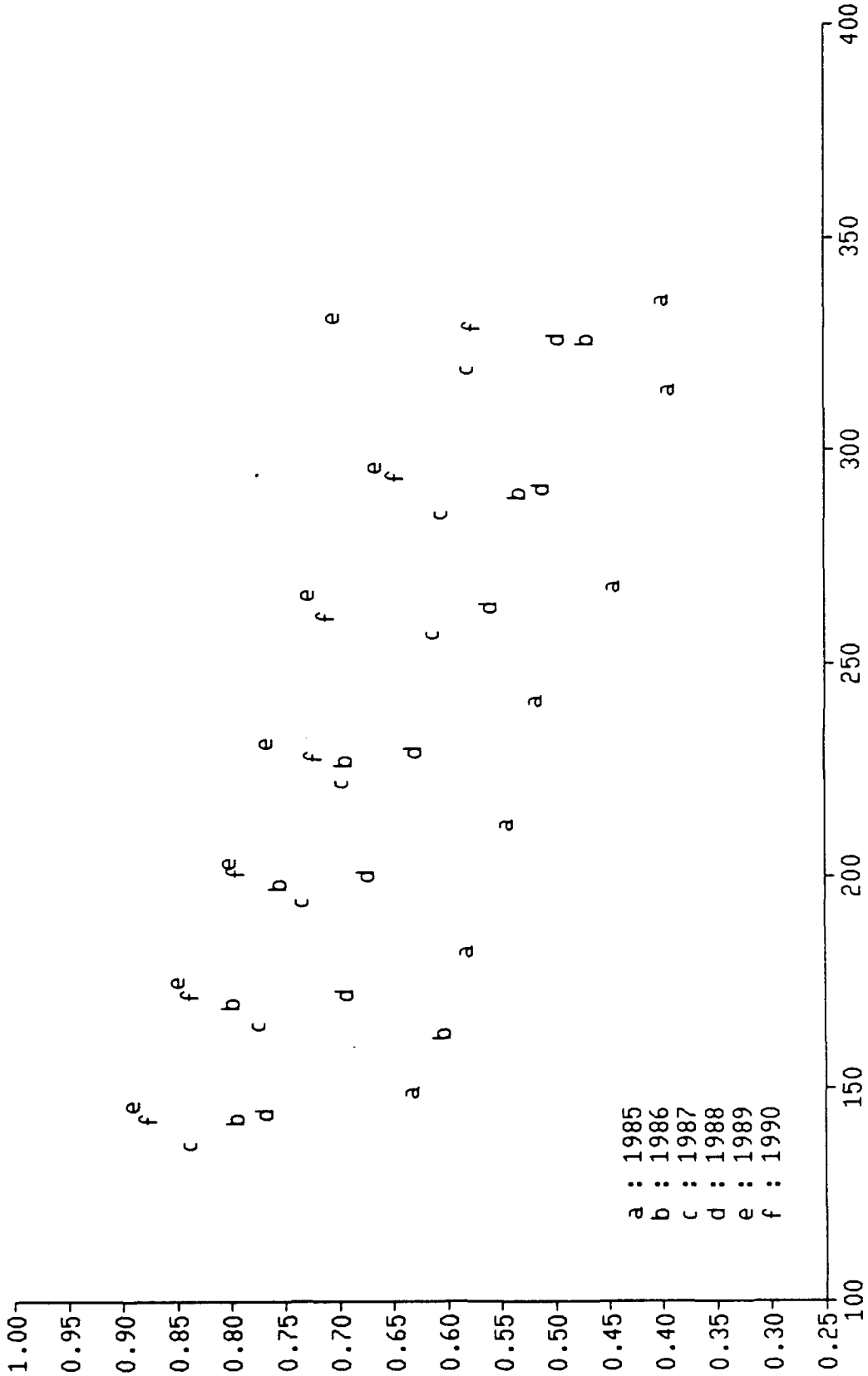


Figure 31a. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

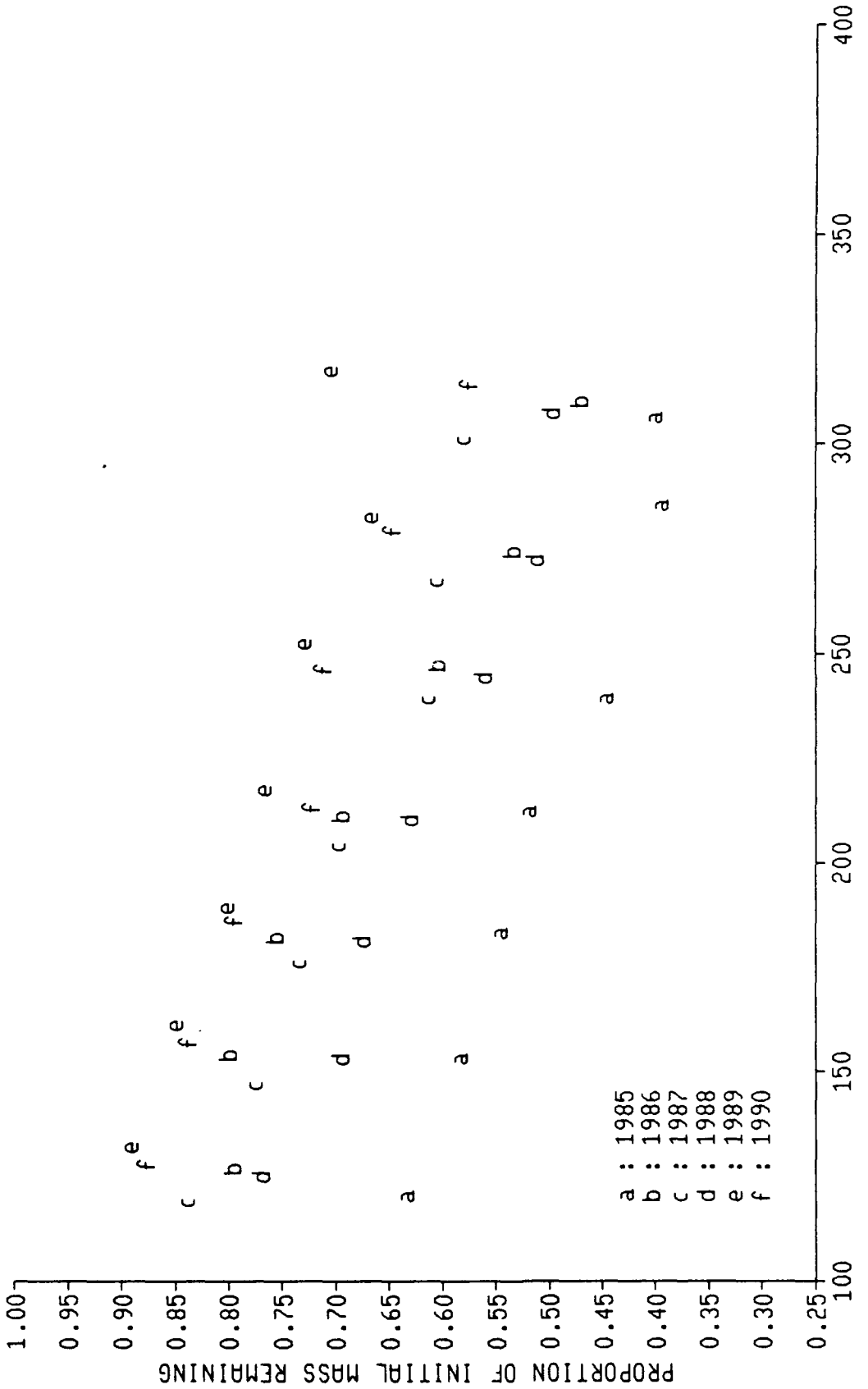


Figure 31b. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the ground unit plantation during the six consecutive annual experiments completed to date.

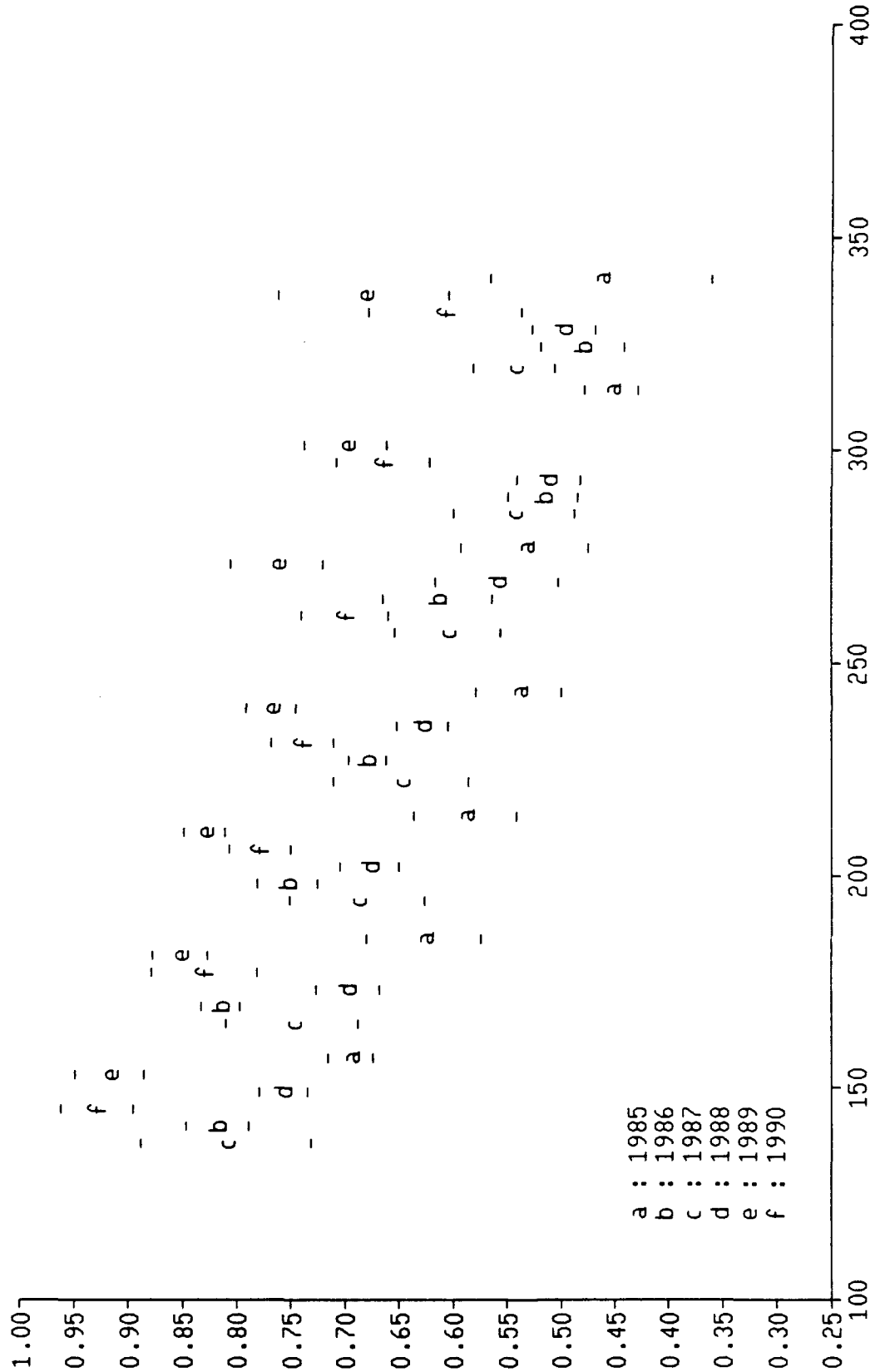


Figure 32. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

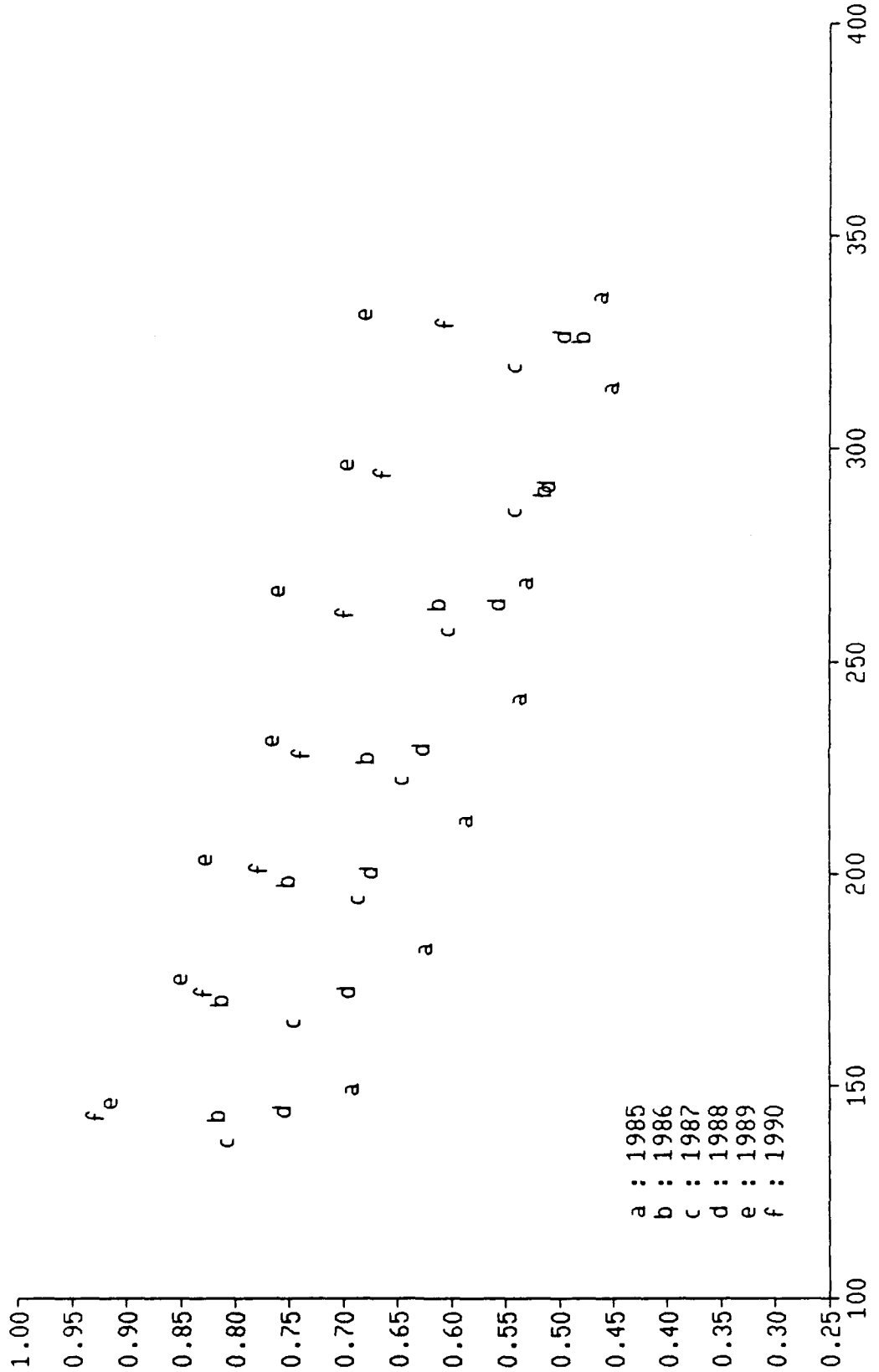


Figure 32a. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

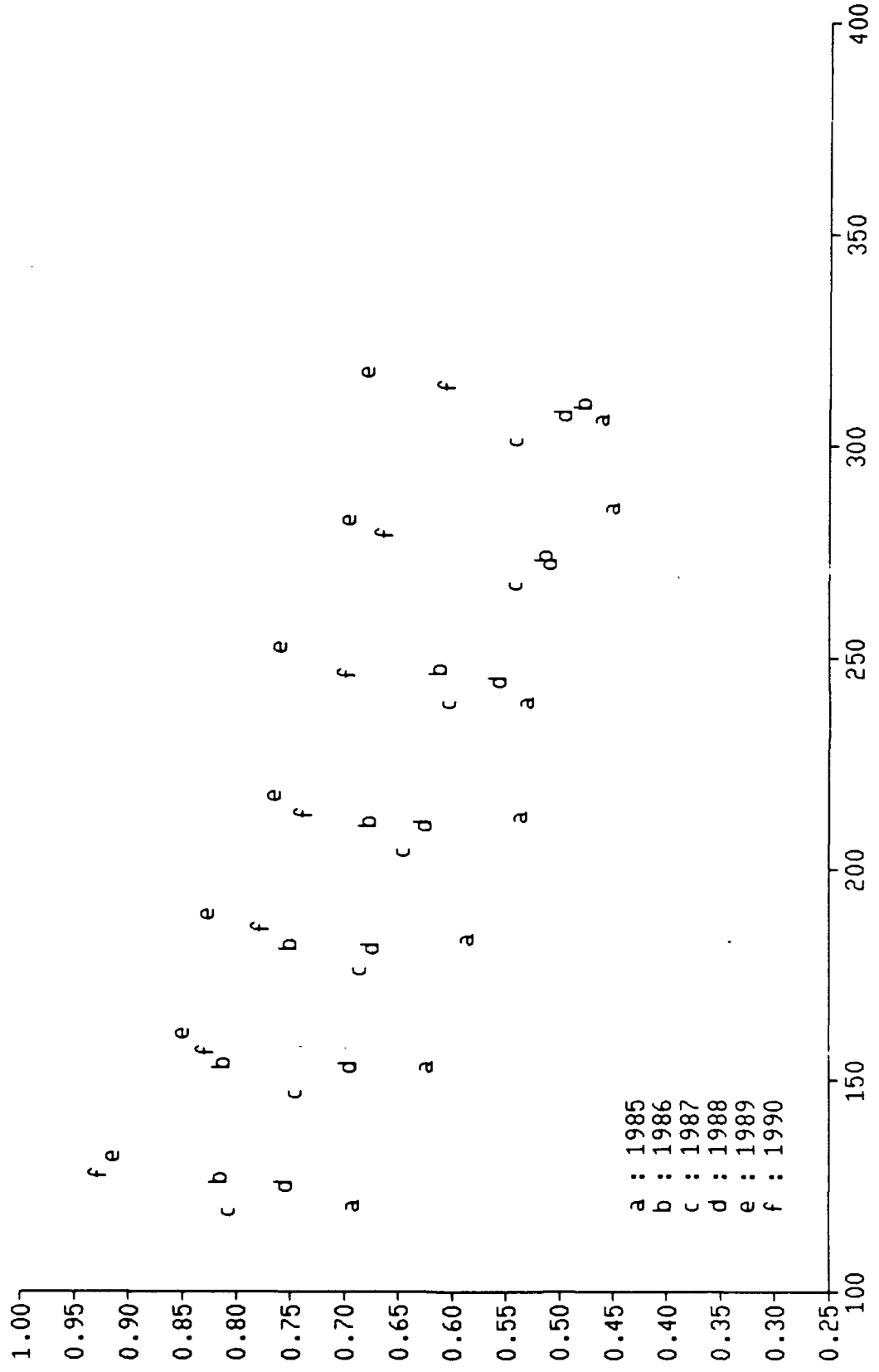


Figure 32b. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit plantation during the six consecutive annual experiments completed to date.

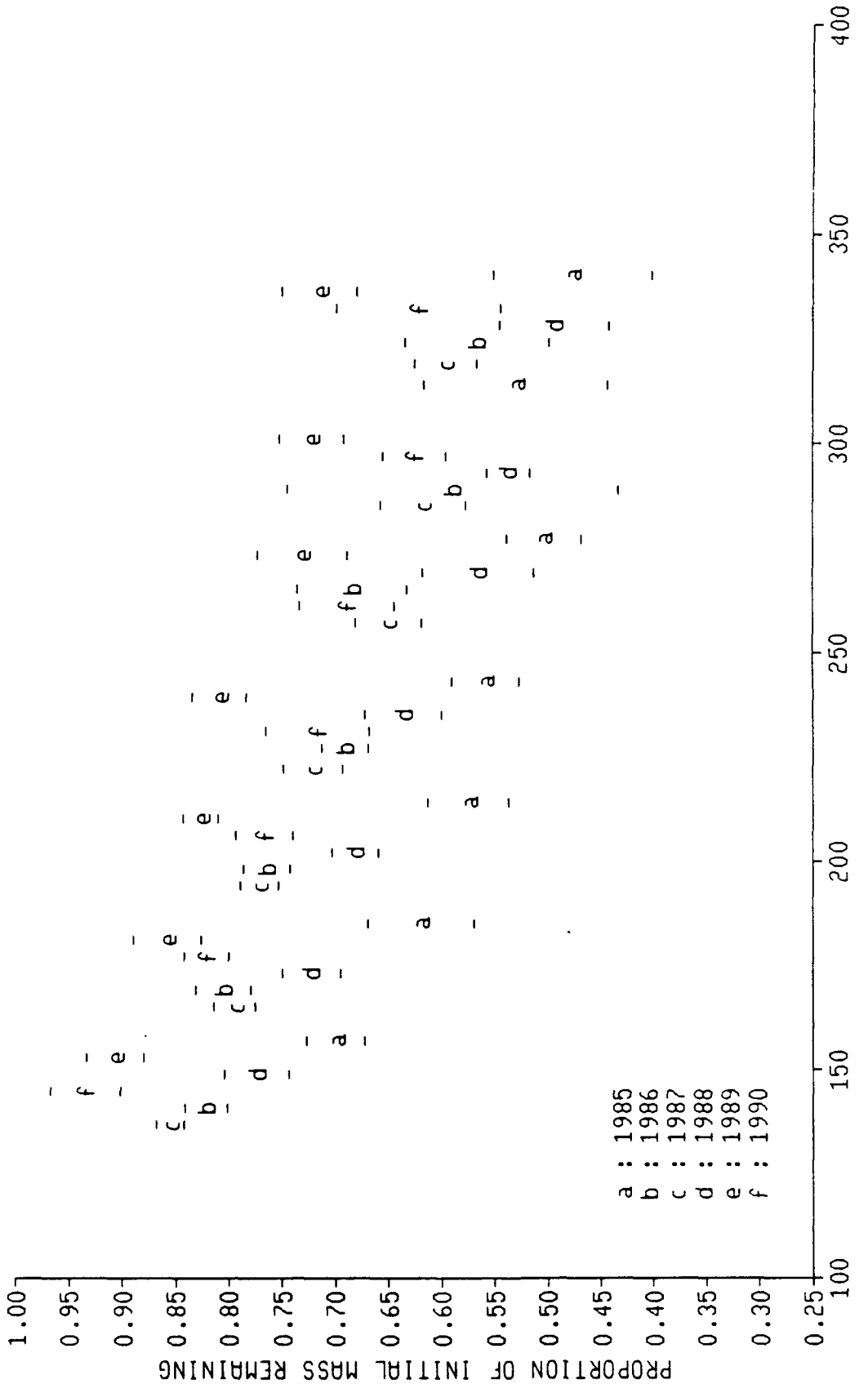


Figure 33. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

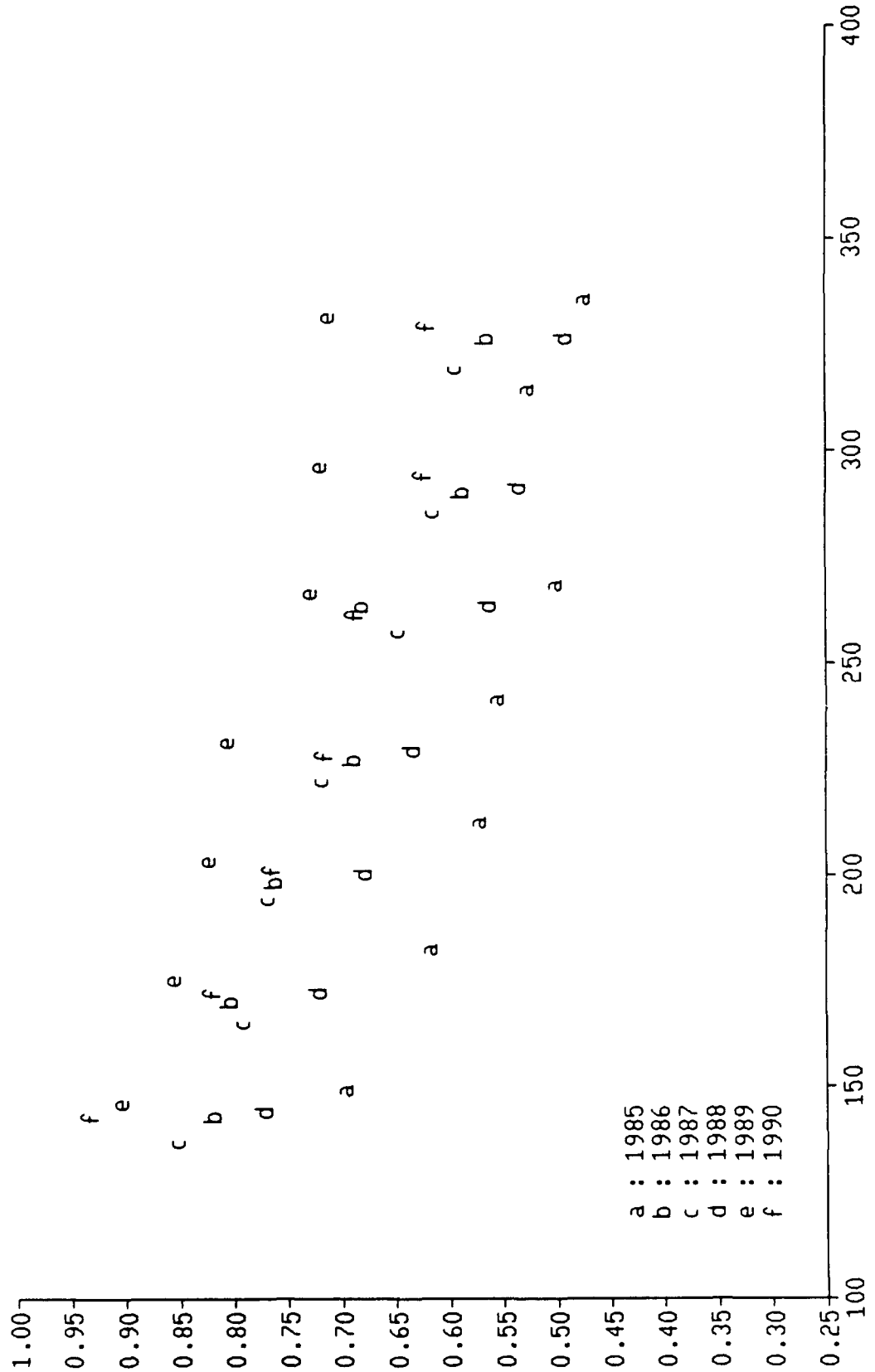


Figure 33a. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

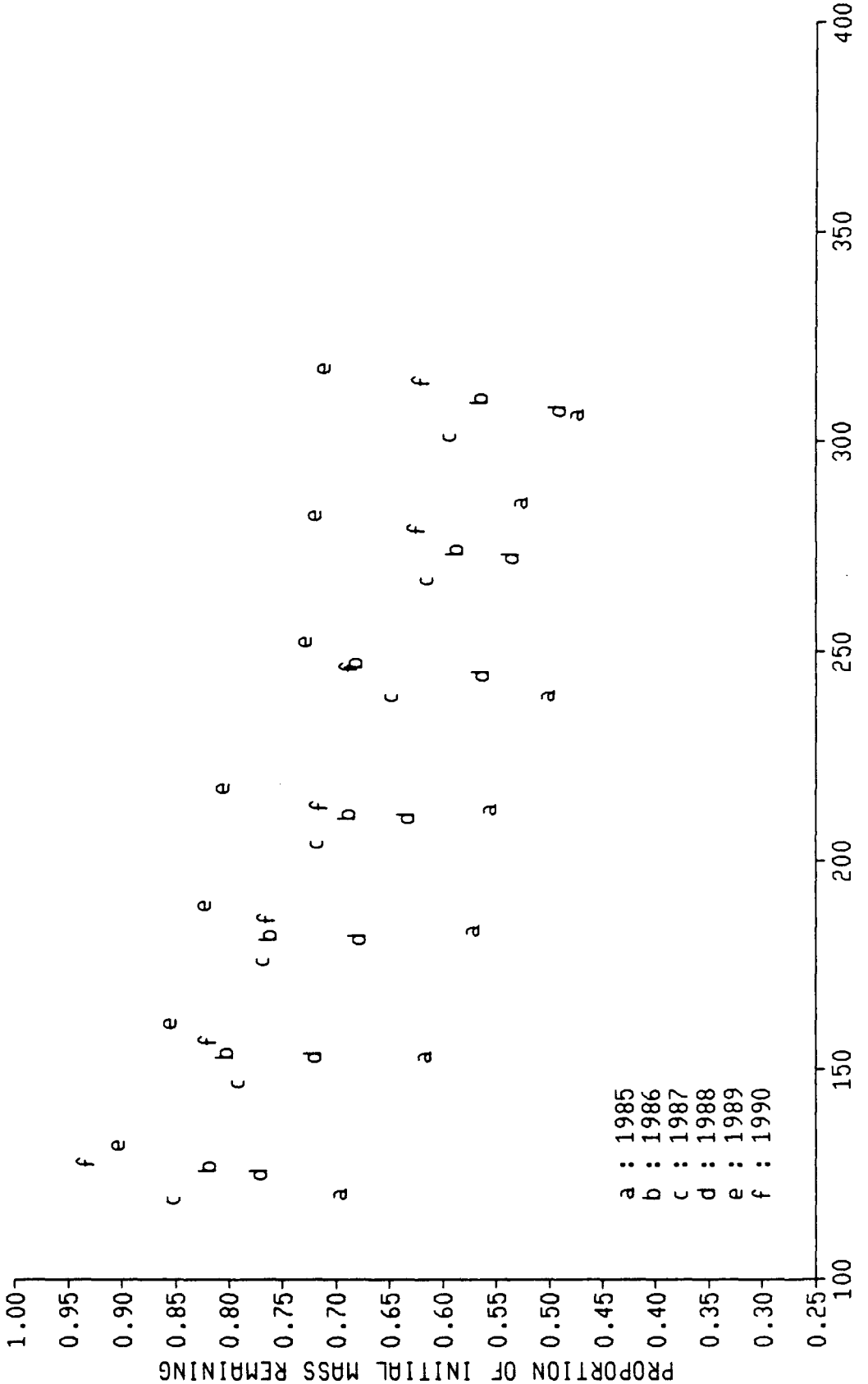


Figure 33b. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit plantation during the six consecutive annual experiments completed to date.

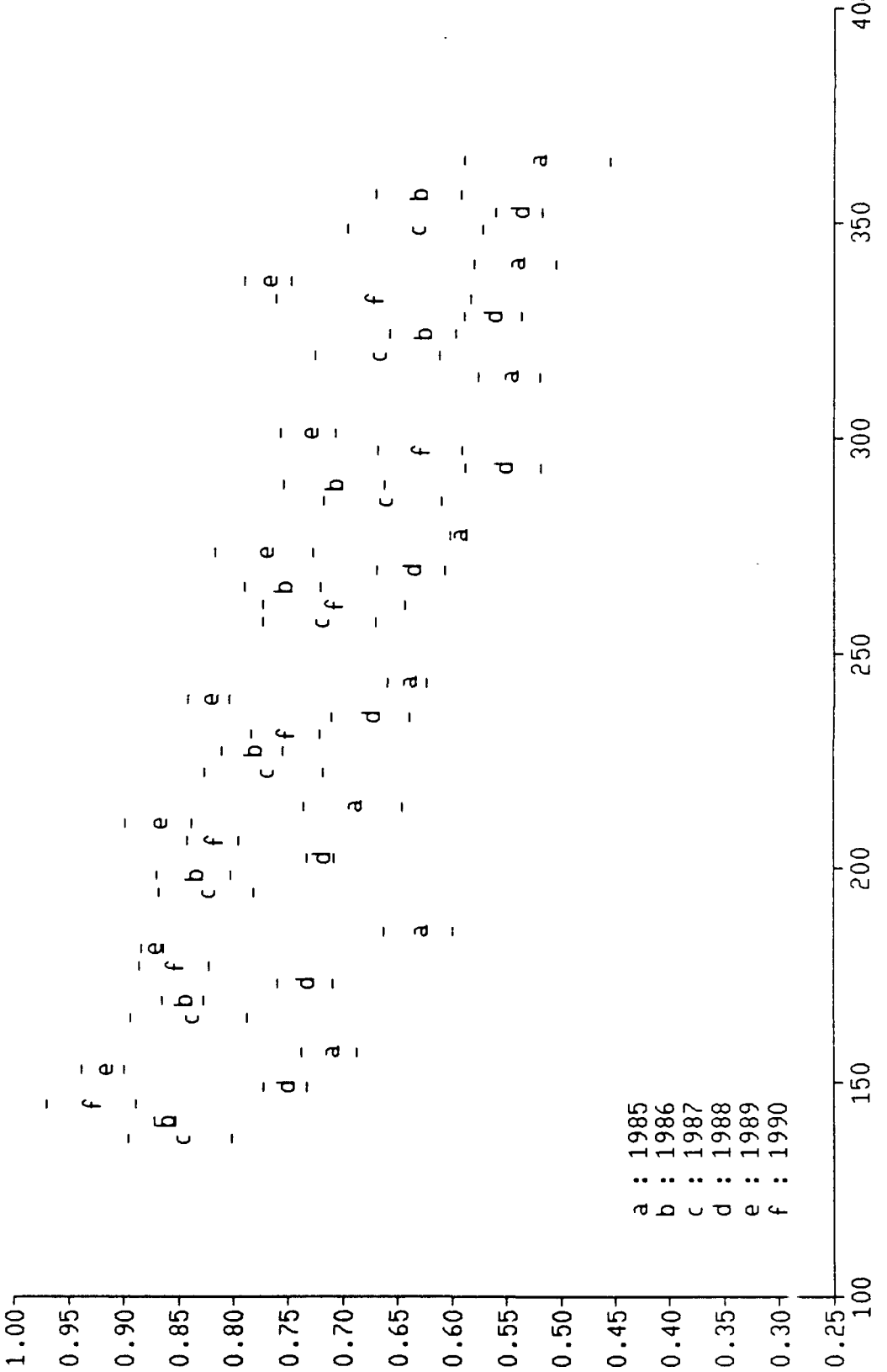


Figure 34. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

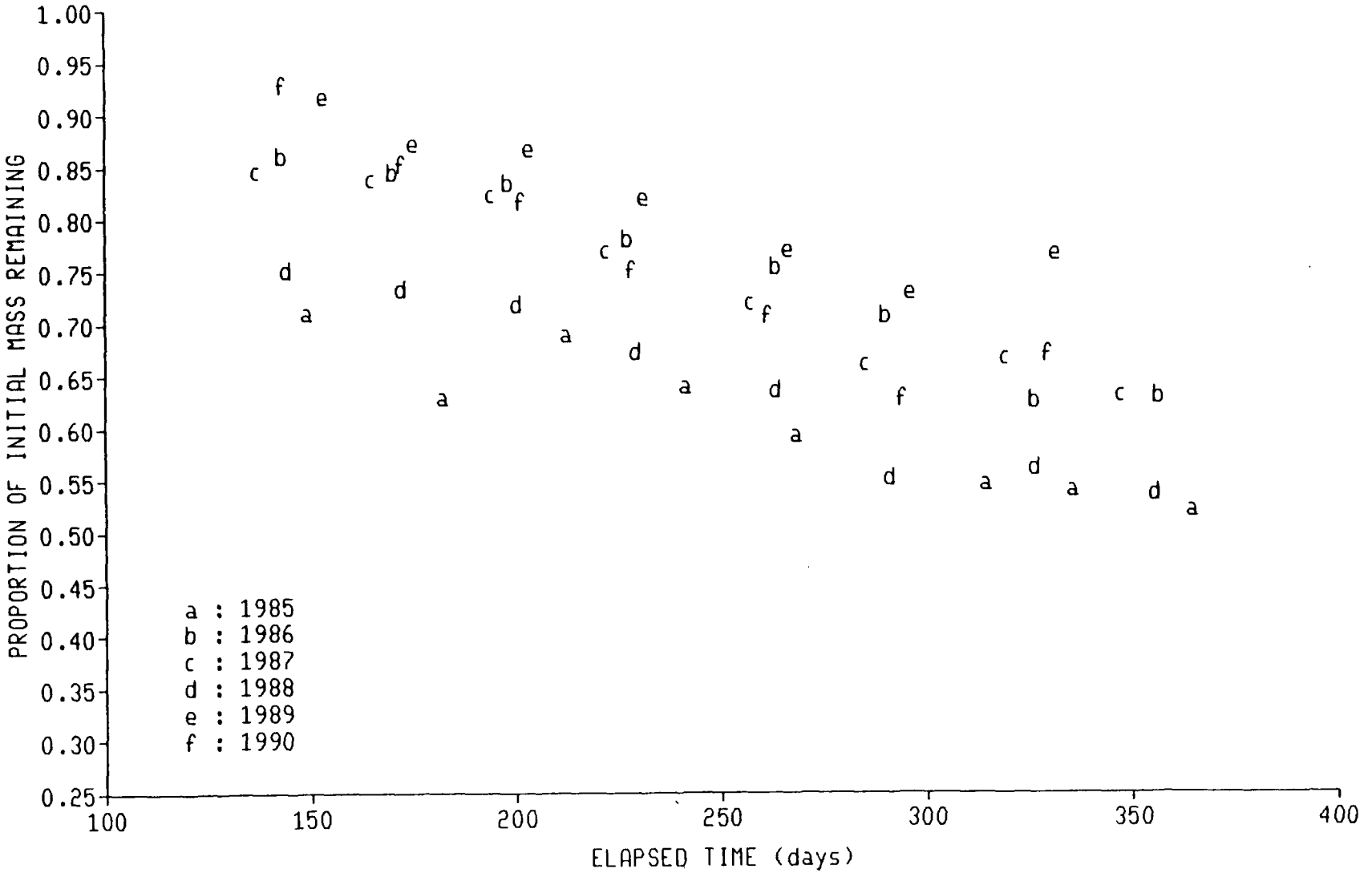


Figure 34a. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

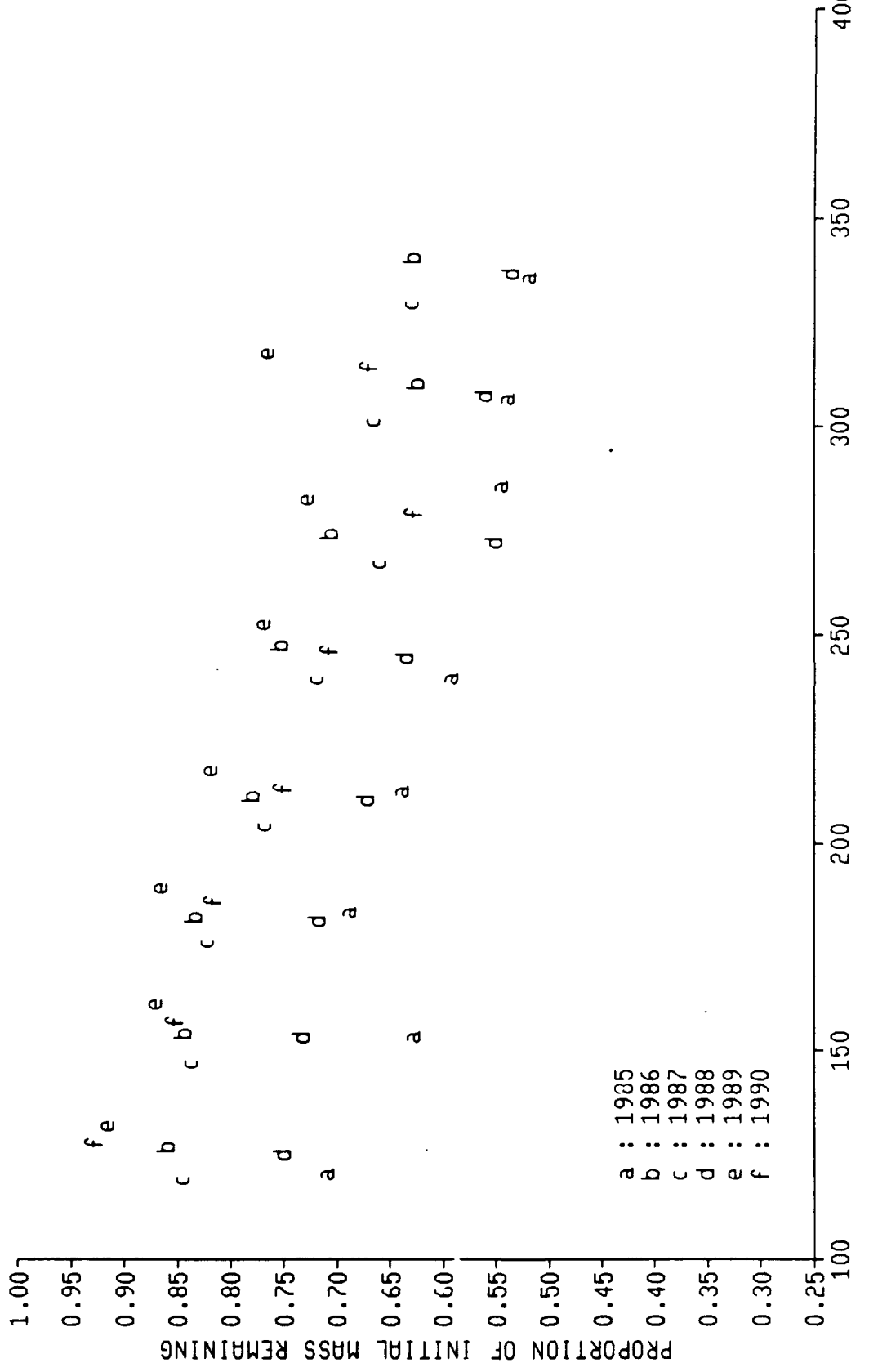


Figure 34b. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit hardwood stand during the six consecutive annual experiments completed to date.

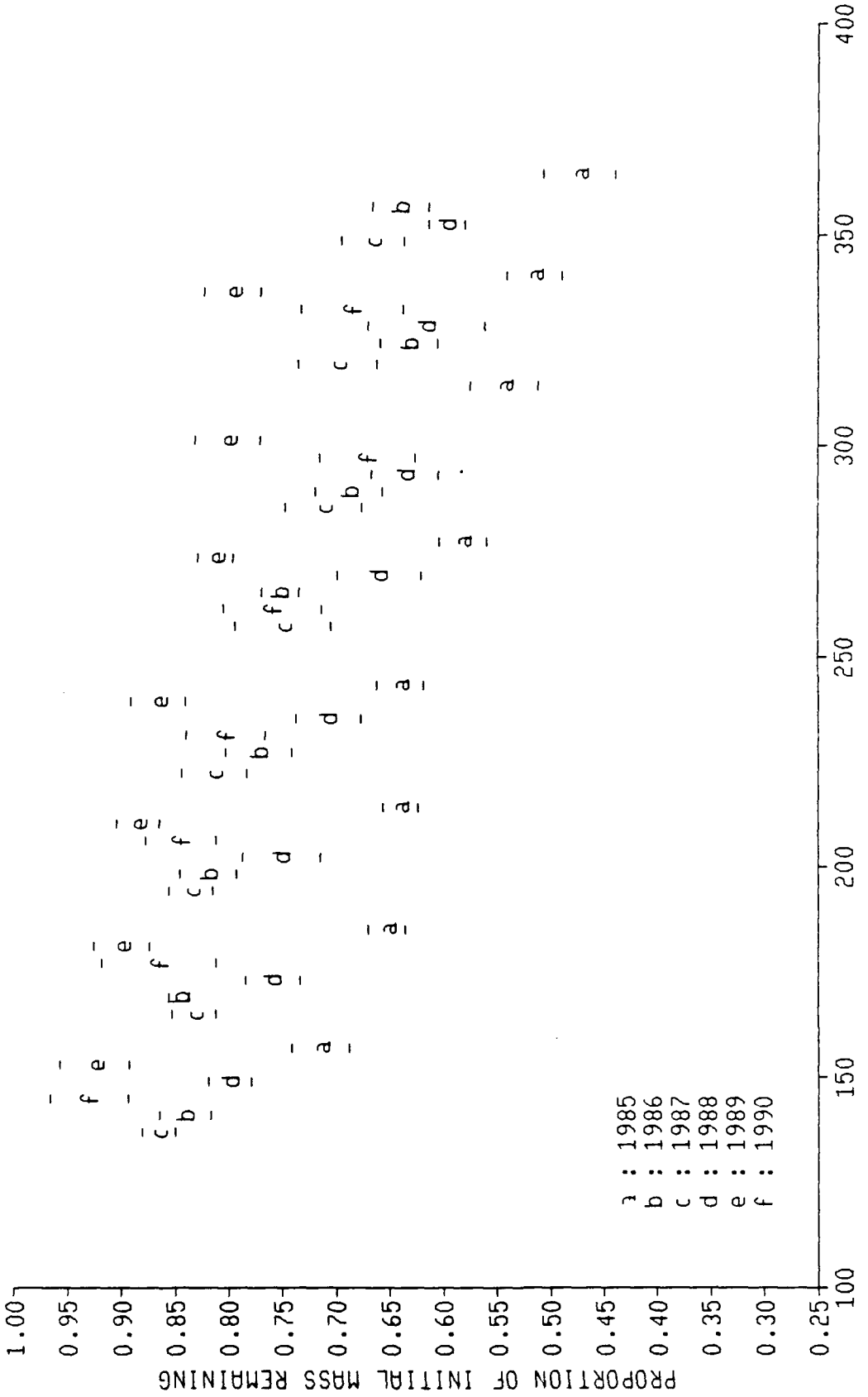


Figure 35. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

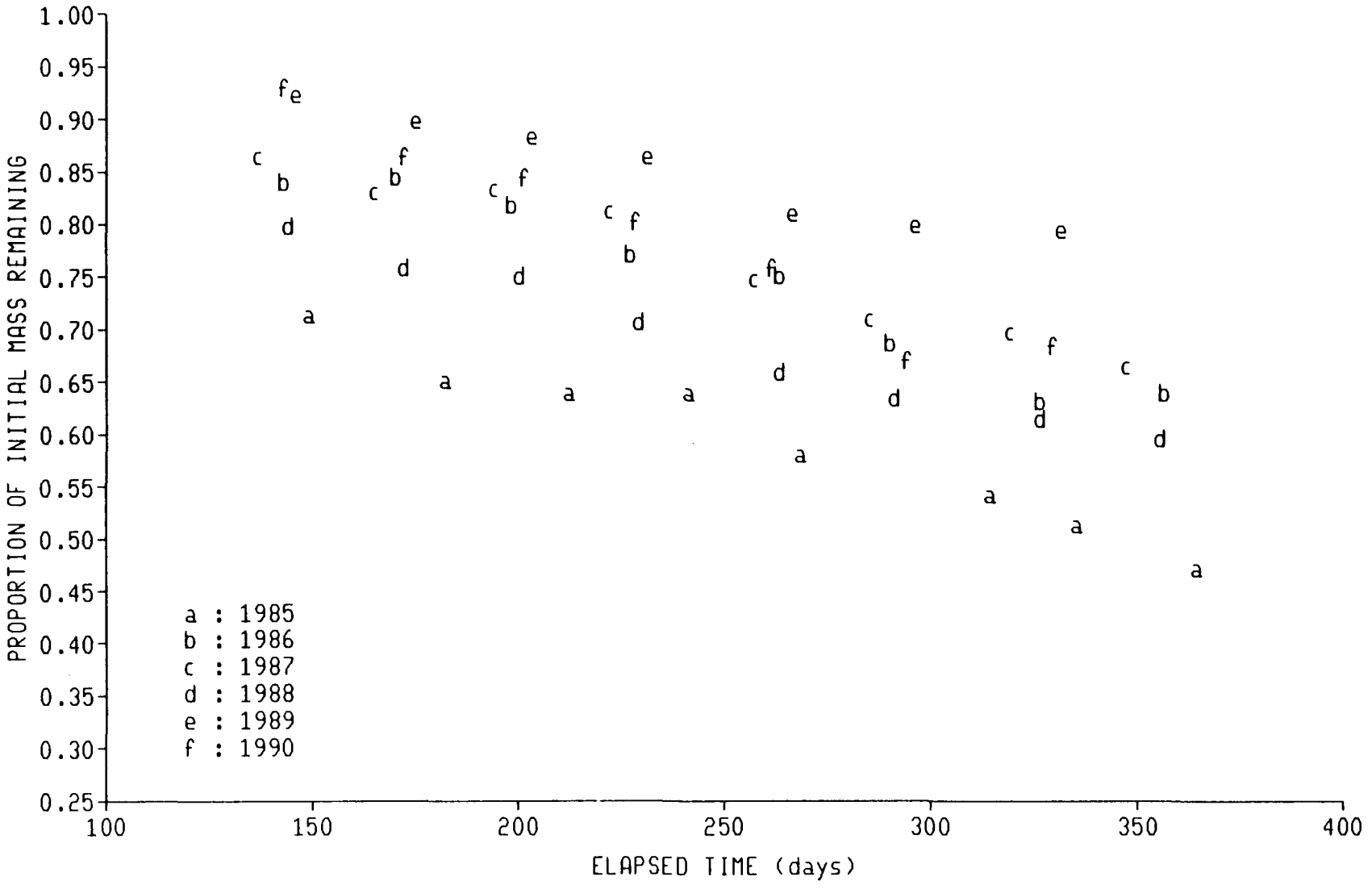


Figure 35a. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

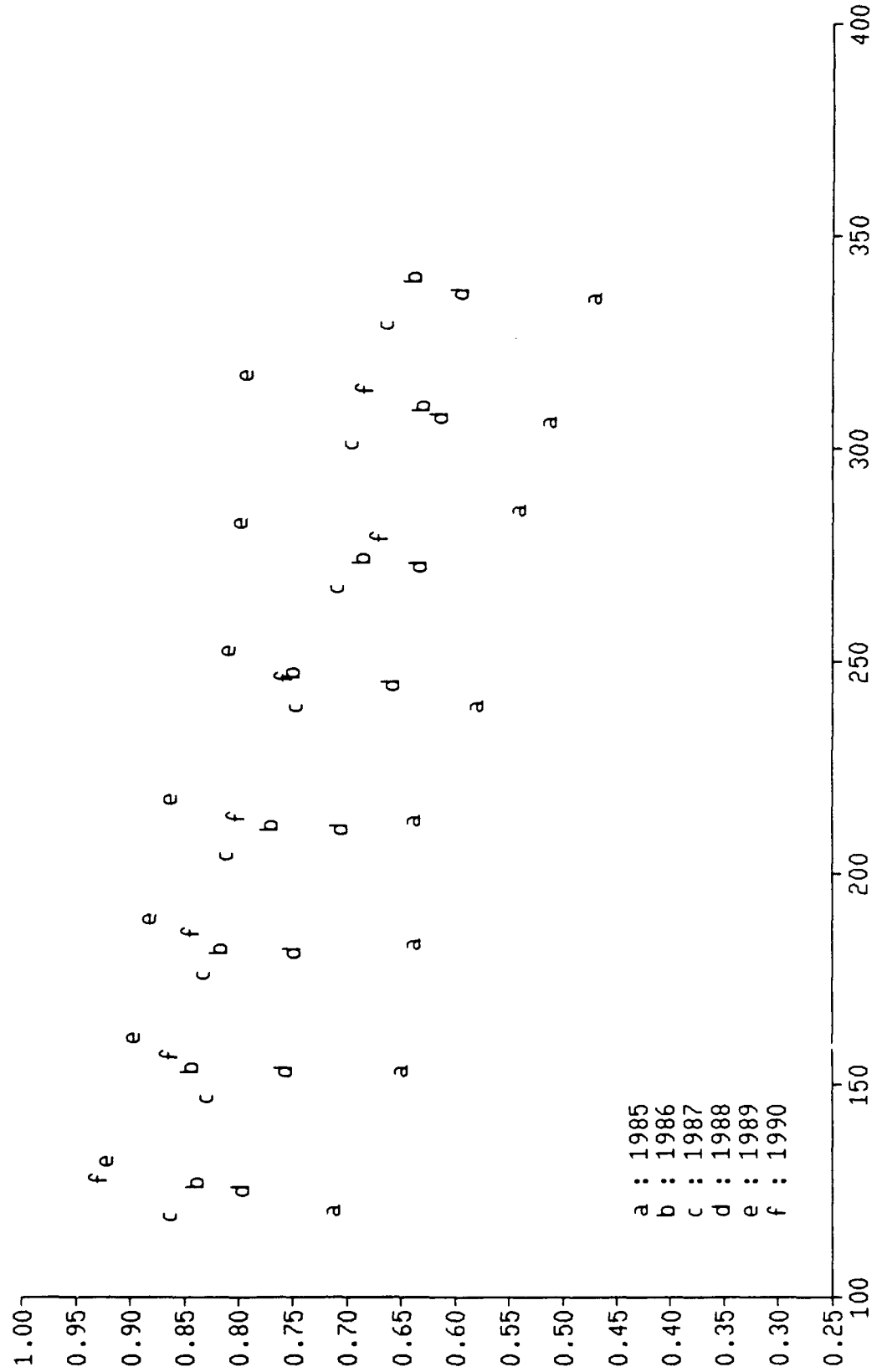


Figure 35b. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit hardwood stand during the six consecutive annual experiments completed to date.

Results of ANOVA and ANACOV

For this year's draft report, ANOVA and ANACOV studies are restricted to the bulk litter data sets for all three litter species. ANOVA for the individual pine needles and oak leaves will be available for the final draft. All ANOVA effects models and all ANACOV models presented here include both the year-by-site interaction term and a blocking term (plot nested within site). In many cases, the year-by-site interaction is statistically highly significant. A significant year-by-site interaction indicates that the pattern of significant differences among years depends on the site. When a significant year-by-site interaction is detected by a model, the effects of year and site can not be evaluated independently. The ANOVA means model is particularly useful for explanation of decomposition patterns indicated by significant year-by-site interactions. The objectives of our ANACOV studies with each litter species are to explain differences detected by ANOVA in dry matter mass loss pattern, among years, among the three study site pine plantations and between the two study site hardwood stands, and also to determine the basis for significant year-by-site interactions.

ANOVA Results - Bulk Leaf Litter Samples

The presentation of ANOVA results is organized as follows:

1) each ANOVA table precedes the table of means and multiple comparisons for that model (e.g., Tables 22 and 23),
2) the effects model precedes the means model for each litter species (e.g., Tables 22 - 25), and
3) results of hardwood stand ANOVAs (Tables 22 - 33) are presented prior to results of plantation ANOVAs (Tables 34 - 45).

Bulk Pine Needle Litter (Hardwood Stands)

Tables 22 through 25 present the results of ANOVA for bulk pine needle litter in the antenna and control site hardwood stands. The effects model indicates that bulk pine needles have generally decomposed faster in the antenna hardwood stand than in the control hardwood stand over the six years of study. Also, nearly all comparisons among years (except 1986 with 1987, and 1987 with 1989) indicate significant differences in mass loss progress. Progress was fastest in 1985, followed by 1989, 1987, 1986, 1988, and 1990. The year-by-site interaction term is highly significant. Monthly comparisons indicate that mass loss progresses significantly through the year until October. Detectable differences were all well below 1 percent of the yearly, site and monthly mean values. As mentioned in previous reports, our small detectable differences account for the statistical significance of some apparently small differences between mean values.

During the 1990 field season (Figure 16), decomposition progress in the control site hardwood stand appeared to catch up to that in the antenna hardwood stand during September and October, due to a quicker slow-down in mass loss progress during September in the antenna stand, followed by practically no progress (especially in the antenna stand) during October. As a result, samples in both hardwood stands finished the season with similar masses. In 1989, mass loss progress accumulated faster in the antenna hardwood stand through September, but slowed down during October, actually becoming negative in the antenna stand (1989 Annual Report, Figure 16, page 55). We anticipate that an important result of this apparent slow-down in mass loss progress is a false indication of similarity in decomposition progress by the end of the year. This general pattern of differences between the two hardwood stands is more evident with the bulk oak and maple samples than with the bulk pine samples. We expect that sample decomposition is actually progressing during October, despite cooler temperatures, but that decomposition is being

Table 22. ANOVA table (**effects**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	19	5.33		256.30	0.0000	0.91
Year	5		0.36	66.67	0.0001	
Hardwood Stand	1		0.01	5.98	0.0048	
Year * Stand	5		0.07	11.91	0.0001	
Plot (Stand)	2		0.00	1.14	0.3208	
Month	6		4.87	741.75	0.0000	
Error	482	0.53				
Corrected Total	501	5.85				

Table 23. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 22.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7 8 9
1985	1.107	0.004	0.71	1985	
1986	1.167	0.004	0.67	1986	*
1987	1.158	0.004	0.68	1987	*
1988	1.182	0.004	0.66	1988	* * *
1989	1.152	0.004	0.68	1989	* * *
1990	1.192	0.004	0.66	1990	* * * * *
Month					M J J A S O
May	1.298	0.004	0.63	May	
June	1.259	0.004	0.62	June	*
July	1.220	0.004	0.64	July	* *
August	1.173	0.004	0.67	Aug	* * *
September	1.097	0.004	0.71	Sept	* * * *
October	1.045	0.004	0.75	Oct	* * * * *
November	1.026	0.004	0.76	Nov	* * * * *
Hardwood Stand					A C
Antenna	1.152	0.002	0.34	Antenna	
Control	1.167	0.002	0.34	Control	*

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Least Squares Means procedure.

Table 24. ANOVA table (**means**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	5.33		231.18	0.0000	0.91
Siteyear	11		0.43	38.92	0.0001	
Plot (Stand)	4		0.00	0.69	0.5998	
Month	6		4.87	739.37	0.0000	
Error	480	0.53				
Corrected Total	501	5.85				

Table 25. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 24.

Source of Variation		Mean[a]	Significant Differences[c]		
Siteyear					
Control	1990	1.214	A		
Control	1988	1.203	A		
Antenna	1986	1.171	B		
Antenna	1990	1.170	B		
Control	1989	1.164	B		
Control	1986	1.164	B		
Antenna	1988	1.160	B	C	
Antenna	1987	1.159	B	C	
Control	1987	1.157	B	C	
Antenna	1989	1.139		C	
Antenna	1985	1.113	D		
Control	1985	1.103	D		
Month					
May		1.298	A		
June		1.260	B		
July		1.220	C		
August		1.173	D		
September		1.097	E		
October		1.045	F		
November		1.027	G		

a/ mean of transformed data
b/ α = .05, Tukey's H.S.D.

masked by additions of inorganic (e.g., soil) and organic matter (e.g., microbial biomass). If this is the case, we suspect that exclusion of the early November sample data would improve the effectiveness of our ANACOV models, which are largely based on the driving influence of weather variables on mass loss progress.

The means model clarifies the year-by-site interaction detected by the effects ANOVA. Decomposition progressed faster in the antenna hardwood stand than in the control hardwood stand during 1988, 1989, and 1990, whereas no significant differences were detected for 1985, 1986, or 1987. As pointed out below, this pattern of differences between the two hardwood stands has emerged from the analyses of all three litter species.

Bulk Oak Leaf Litter (Hardwood Stands)

Tables 26 through 29 present the results of ANOVA for bulk oak leaf litter in the hardwood stand subunits. The effects model detected no significant difference between the patterns of mass loss progress experienced by bulk oak leaf samples in the two hardwood stands over the six years of study. However, all comparisons except one (1987 with 1988) among years indicated significant differences in mass loss progress. Progress for bulk oak leaf samples was fastest in 1990, followed by 1989, 1985, 1987, 1988, and 1986. This ranking of years is very different from that noted for bulk pine fascicles, which decomposed more slowly in 1990 than in any other study year. The year-by-site interaction term was again highly significant. Monthly comparisons for bulk oak litter also indicated that decomposition progressed significantly through the year until October. Detectable differences were all well below 1 percent of the yearly, site and monthly mean values.

For the 1990 field season, there appears to be only a very slight difference in mass loss progress through September, with a marked slow-down in October accompanied by increased variability and a suspicious reversal of site rank (Figure 23). For 1989, however, progress in the antenna stand was clearly faster than in

Table 26. ANOVA table (**effects**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	19	7.62		167.87	0.0000	0.87
Year	5		0.97	81.42	0.0001	
Hardwood Stand	1		0.01	2.45	0.1180	
Year * Stand	5		0.13	11.05	0.0001	
Plot (Stand)	2		0.00	0.66	0.5196	
Month	6		6.52	455.03	0.0000	
Error	483	1.15				
Corrected Total	502	8.77				

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

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7 8 9
1985	1.160	0.005	0.84	1985	
1986	1.226	0.005	0.80	1986	*
1987	1.193	0.005	0.82	1987	* *
1988	1.195	0.005	0.82	1988	* *
1989	1.130	0.005	0.87	1989	* * * *
1990	1.095	0.005	0.89	1990	* * * * *
Month					M J J A S O
May	1.321	0.006	0.89	May	
June	1.280	0.006	0.92	June	*
July	1.240	0.006	0.94	July	* *
August	1.188	0.006	0.99	Aug	* * *
September	1.102	0.006	0.07	Sept	* * * *
October	1.026	0.006	0.15	Oct	* * * * *
November	1.010	0.006	0.16	Nov	* * * * *
Hardwood Stand					A C
Antenna	1.164	0.003	0.51	Antenna	
Control	1.170	0.003	0.50	Control	

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ $\alpha = .05$, Least Squares Means procedure.

Table 28. ANOVA table (**means**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	7.62		151.70	0.0000	0.87
Siteyear	11		1.11	46.26	0.0001	
Plot (Stand)	4		0.01	0.64	0.6362	
Month	6		6.52	454.39	0.0000	
Error	481	1.15				
Corrected Total	502	8.77				

Table 29. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 28.

Source of Variation		Mean[a]	Significant Differences[c]	
Siteyear				
Antenna	1986	1.236	A	
Control	1988	1.218	A	
Control	1986	1.217	A	
Antenna	1987	1.211	A	
Control	1987	1.175	B	
Antenna	1988	1.173	B	
Antenna	1985	1.171	B	
Control	1985	1.149	B	C
Control	1989	1.148	B	C
Control	1990	1.115	D	C
Antenna	1989	1.112	D	E
Antenna	1990	1.079		E
Month				
May		1.321	A	
June		1.280	B	
July		1.240	C	
August		1.188	D	
September		1.102	E	
October		1.026	F	
November		1.011	F	

a/ mean of transformed data
b/ α = .05, Tukey's H.S.D.

the control hardwood stand (1989 Annual Report, Figure 23, page 65). Again, we suspect that the October slow-down and site rank reversal witnessed in 1990 is due to inorganic and organic mass gains which accompany this stage of litter decomposition.

The means model explains the year-by-site interaction detected by the effects ANOVA. Decomposition progressed faster in the antenna hardwood stand than in the control hardwood stand during 1988, 1989, and 1990, whereas decomposition progressed faster in the control stand during 1987, and no significant differences were detected for 1985 or 1986. Again, this is very nearly the same pattern of differences (by year) between the two hardwood stands as was detected by the means model for bulk pine needle samples.

Bulk Maple Leaf Litter (Hardwood Stands)

Tables 30 through 33 present the results of ANOVA for bulk maple leaf litter in the two hardwood stand subunits. As was the case for oak leaves, the effects model detected no significant difference between the patterns of mass loss progress experienced by bulk maple leaf samples in the two hardwood stands over the six years of study. However, all comparisons except two (1986 with 1987, and 1987 with 1990) among years indicate significant differences in mass loss progress. Progress for bulk maple leaf samples was fastest in 1985, followed by 1988, 1986, 1987, 1990, and 1989. This ranking of years differs considerably from those for both pine and oak. The year-by-site interaction term is again highly significant. Monthly comparisons again indicate that mass loss progresses steadily through the year until October. Detectable differences were approximately 1 percent of the yearly and monthly mean values, and less for site means.

During both 1990 (Figure 30) and 1989 (1989 Annual Report, Figure 30, page 76), progress in the antenna stand was clearly faster than in the control hardwood stand. During both years, however, maple litter showed a much stronger tendency to gain mass during October than did either oak leaves or pine needles.

Table 30. ANOVA table (**effects**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	19	7.20		183.06	0.0000	0.88
Year	5		3.61	348.75	0.0000	
Hardwood Stand	1		0.00	0.35	0.5535	
Year * Stand	5		0.07	7.01	0.0001	
Plot (Stand)	2		0.01	1.47	0.2321	
Month	6		4.87	741.75	0.0000	
Error	482	0.53				
Corrected Total	501	5.85				

Table 31. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 30.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7 8 9
1985	0.908	0.005	1.08	1985	
1986	1.076	0.005	0.91	1986	*
1987	1.082	0.005	0.91	1987	*
1988	0.976	0.005	1.00	1988	* * *
1989	1.165	0.005	0.84	1989	* * * *
1990	1.092	0.005	0.89	1990	* * * *
Month					M J J A S O
May	1.174	0.005	0.83	May	
June	1.119	0.005	0.88	June	*
July	1.107	0.005	0.89	July	* *
August	1.057	0.005	0.93	Aug	* * *
September	1.005	0.005	0.98	Sept	* * * *
October	0.949	0.005	1.03	Oct	* * * * *
November	0.941	0.005	1.04	Nov	* * * * *
Hardwood Stand					A C
Antenna	1.039	0.003	0.57	Antenna	
Control	1.061	0.003	0.55	Control	

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ $\alpha = .05$, Least Squares Means procedure.

Table 32. ANOVA table (**means**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	21	7.21		165.70	0.0000	0.88
Siteyear	11		3.68	177.57	0.0000	
Plot (Stand)	4		0.01	1.22	0.3022	
Month	6		3.41	274.07	0.0000	
Error	480	0.99				
Corrected Total	501	8.20				

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

Source of Variation		Mean[a]	Significant Differences[c]	
Siteyear				
Control	1989	1.188	A	
Antenna	1989	1.142	B	
Control	1990	1.115	B	C
Control	1987	1.095	D	C
Antenna	1986	1.082	D	
Antenna	1990	1.079	D	
Control	1986	1.070	D	
Antenna	1987	1.069	D	
Control	1988	0.999	E	
Antenna	1988	0.953	F	
Antenna	1985	0.911	G	
Control	1985	0.898	G	
Month				
May		1.176	A	
June		1.119	B	
July		1.107	B	
August		1.057	C	
September		1.005	D	
October		0.949	E	
November		0.940	E	

a/ mean of transformed data
b/ α = .05, Tukey's H.S.D.

Pine needles showed the least tendency in this regard, for several reasons. First, it is much easier to remove adherent soil from pine needle samples than from leaves (especially maple leaves). Because maple leaves are more brittle than pine needles (and oak leaves) from the start, they are more difficult to clean on retrieval. Also, because maple leaves decompose faster than pine needles and oak leaves, the extraneous matter they accumulate probably becomes a higher proportion of final sample mass for maple than for pine or oak.

The means model clarifies the year-by-site interaction detected by the effects ANOVA. Decomposition progressed faster in the antenna hardwood stand than in the control hardwood stand during 1988, 1989, and 1990, whereas no significant differences were detected for 1985, 1986, or 1987. This is the same pattern of differences (by year) between the two hardwood stands as that detected by the means model for bulk pine needle samples, and nearly the same as detected for bulk oak leaf samples.

Bulk Pine Needle Litter (Plantations)

Tables 34 through 37 present the results of ANOVA for bulk pine leaf litter in the plantation subunits. The effects model detected generally faster decomposition progress for bulk pine needle samples in the ground and control site plantations, compared to the antenna site plantation, over the six years of study. All comparisons among years indicated significant differences in mass loss progress. Progress for bulk pine needle samples was fastest in 1985, followed by 1989, 1986, 1988, 1987, and 1990. This ranking of years bears strong similarity to that witnessed with bulk pine samples in the hardwood stands, where decomposition progressed farthest in 1985 and was slowest in 1990. The year-by-site interaction term is again highly significant. Monthly comparisons indicate that decomposition progresses significantly throughout the study year. Detectable differences were well below 1 percent of the yearly, site, and monthly mean values.

Table 34. ANOVA table (**effects**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	26	6.65		222.88	0.0000	0.89
Year	5		0.41	71.15	0.0001	
Plantation	2		0.02	7.55	0.0006	
Year * Site	10		0.03	2.47	0.0065	
Plot (Site)	3		0.01	1.47	0.2210	
Month	6		6.14	890.95	0.0000	
Error	728	0.84				
Corrected Total	754	7.49				

Table 35. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 34.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7 8 9
1985	1.120	0.003	0.53	1985	
1986	1.148	0.003	0.51	1986	*
1987	1.171	0.003	0.50	1987	* *
1988	1.161	0.003	0.51	1988	* * *
1989	1.138	0.003	0.52	1989	* * * *
1990	1.193	0.003	0.49	1990	* * * * *
Month					M J J A S O
May	1.281	0.003	0.46	May	
June	1.244	0.003	0.47	June	*
July	1.210	0.003	0.49	July	* *
August	1.169	0.003	0.50	Aug	* * *
September	1.103	0.003	0.53	Sept	* * * *
October	1.049	0.003	0.56	Oct	* * * * *
November	1.029	0.003	0.57	Nov	* * * * * *
Plantation					G A
Ground	1.148	0.002	0.34	Ground	
Antenna	1.168	0.002	0.34	Antenna	*
Control	1.149	0.002	0.34	Control	*

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Least Squares Means procedure.

Table 36. ANOVA table (**means**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	29	6.66		201.27	0.0000	0.89
Siteyear	17		0.44	25.51	0.0001	
Plot (Site)	6		0.01	1.96	0.0686	
Month	6		6.14	896.36	0.0000	
Error	725	0.83				
Corrected Total	754	7.49				

Table 37. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 36.

Source of Variation		Mean[a]	Significant Differences[c]			
Siteyear						
Antenna	1990	1.206			A	
Control	1990	1.190	B		A	
Antenna	1987	1.190	B		A	
Ground	1990	1.184	B		A	C
Ground	1987	1.170	B		D	C
Antenna	1986	1.167	B		D	C
Control	1988	1.162	E		D	C
Antenna	1988	1.161	E	F	D	C
Ground	1988	1.160	E	F	D	C
Control	1987	1.152	E	F	D	G
Antenna	1989	1.150	E	F	D	G
Ground	1986	1.139	E	F	H	G
Control	1986	1.138	E	F	H	G
Antenna	1985	1.136	E	F	H	G
Control	1989	1.136		F	H	G
Ground	1989	1.127	I		H	G
Control	1985	1.118	I		H	
Ground	1985	1.106	I			
Month						
May		1.281		A		
June		1.244		B		
July		1.210		C		
August		1.169		D		
September		1.103		E		
October		1.049		F		
November		1.028		G		

a/ mean of transformed data
b/ α = .05, Tukey's H.S.D.

During both 1990 (Figure 15) and 1989 (1989 Annual Report, Figure 15, page 55), decomposition progress in the three plantations followed very similar patterns. However, in 1989, the greater mass loss progress through early October in the ground and control plantations than in the antenna plantation was partially masked by the greater mass gain during October of samples in the ground and control plantations than in the antenna plantation. It appears that, once first-year decomposition progresses up to or beyond some threshold, total mass loss data begin to reflect greater accumulation of extraneous mass. For instance, bulk pine needle samples in the three plantations decomposed progressively through 1990, reaching final X_w values of approximately 0.75 in early November. Similar samples at the antenna site in 1989 reached approximately 0.76 by early October, and did not lose further mass by early November. However, samples at the ground and control plantations in 1989 reached approximately 0.73 by early October, and then experienced mass gains resulting in final X_w values of about 0.76 by early November.

The means model detected no significant differences in decomposition progress among the three plantations during 1988, 1989, or 1990. In 1987, decomposition was faster in the control plantation than in the antenna plantation, with no significant difference in progress between the ground and control plantations. In 1986, decomposition progress was faster in the control and ground plantations than in the antenna plantation. In 1985, decomposition was faster in the ground plantation than in the antenna plantation, with intermediate progress occurring in the control plantation. This pattern is not very different from that observed in the hardwood stands, where decomposition progress at the control site also appeared to slow down somewhat, relative to progress at the antenna site, beginning in 1988.

Bulk Oak Leaf Litter (Plantations)

Tables 38 - 41 present the results of ANOVA for bulk oak leaf litter in the plantation subunits. The effects model detected no significant differences in decomposition progress among the three plantations over the six years of study. All but two comparisons among years (1985 with 1988, and 1986 with 1987) indicated significant differences in mass loss progress. Progress for bulk oak leaf samples was fastest in 1989, followed by 1985, 1988, 1987, 1986, and 1990. This ranking of years bears little similarity to that witnessed with bulk oak samples in the hardwood stands, where decomposition progressed farthest in 1990, followed by 1989, 1985, 1987, 1988, and 1986. The year-by-site interaction term is again highly significant. Monthly comparisons indicate that decomposition progresses significantly throughout the study year. Nearly all detectable differences were well below 1 percent of the yearly, site, and monthly mean values.

During both 1990 (Figure 22) and 1989 (1989 Annual Report, Figure 22, page 65), mass loss progress in the three plantations followed very similar patterns. We note that there was no conspicuous year-end mass gain in 1989, even though X_W dropped below 0.75 in September, and below 0.70 by early November.

The means model detected no significant differences in decomposition progress among the three plantations from 1986 through 1990. However, for 1985, the means model found that decomposition proceeded faster in the ground plantation than in the control plantation, with no significant difference between either the ground and antenna plantations or the antenna and control plantations.

Table 38. ANOVA table (**effects**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** sub-units, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	26	10.00		157.96	0.0000	0.85
Year	5		0.67	54.85	0.0001	
Plantation	2		0.00	0.30	0.7378	
Year * Site	10		0.06	2.66	0.0034	
Plot (Site)	3		0.01	1.52	0.2089	
Month	6		9.22	630.68	0.0000	
Error	724	1.76				
Corrected Total	750	11.77				

Table 39. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 38.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7 8 9
1985	1.132	0.004	0.69	1985	
1986	1.171	0.004	0.67	1986	*
1987	1.160	0.004	0.68	1987	*
1988	1.144	0.004	0.69	1988	* *
1989	1.109	0.004	0.71	1989	* * * *
1990	1.203	0.004	0.65	1990	* * * * *
Month					M J J A S O
May	1.318	0.005	0.74	May	
June	1.262	0.005	0.78	June	*
July	1.212	0.005	0.81	July	* *
August	1.160	0.005	0.84	Aug	* * *
September	1.090	0.005	0.90	Sept	* * * *
October	1.032	0.005	0.95	Oct	* * * * *
November	0.995	0.005	0.98	Nov	* * * * * *
Plantation					G A
Ground	1.144	0.003	0.51	Ground	
Antenna	1.153	0.003	0.51	Antenna	*
Control	1.162	0.003	0.51	Control	* *

a/ mean of transformed data

b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean

c/ $\alpha = .05$, Least Squares Means procedure.

Table 40. ANOVA table (**means**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	29	10.01		141.40	0.0000	0.85
Siteyear	17		0.73	19.99	0.0001	
Plot (Site)	6		0.01	1.02	0.4108	
Month	6		9.22	629.35	0.0000	
Error	721	1.76				
Corrected Total	750	11.77				

Table 41. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 40.

Source of Variation		Mean[a]	Significant Differences[c]			
Siteyear						
Antenna	1990	1.216			A	
Control	1990	1.198		B	A	
Ground	1990	1.196		B	A	
Control	1986	1.178		B	C	
Control	1987	1.174		B	C	D
Antenna	1986	1.170		B	E C	D
Ground	1986	1.169		B	E C	D
Ground	1987	1.168		B	E C	D
Control	1988	1.163		B	E C	D
Control	1985	1.150		F	E C	D
Antenna	1987	1.141	G	F	E C	D
Antenna	1988	1.138	G	F	E	D
Antenna	1985	1.134	G	F	E	
Ground	1988	1.134	G	F	E	
Antenna	1989	1.120	G	F	H	
Control	1989	1.116	G	F	H	
Ground	1985	1.111	G		H	
Ground	1989	1.094			H	
Month						
May		1.318			A	
June		1.262			B	
July		1.212			C	
August		1.160			D	
September		1.090			E	
October		1.032			F	
November		0.995			G	

a/ mean of transformed data
b/ α = .05, Tukey's H.S.D.

Bulk Maple Leaf Litter (Plantations)

Tables 42 - 45 present the results of ANOVA for bulk maple leaf litter in the plantation subunits. The effects model detected no significant differences in decomposition progress among the three plantations over the six years of study. However, all but one comparison among years (1986 with 1987) indicated significant differences in mass loss progress. Progress for bulk maple samples was fastest in 1985, followed by 1988, 1986, 1987, 1990, and 1989. This ranking of years is identical to that witnessed with bulk maple samples in the hardwood stands. The year-by-site interaction term is again highly significant. Monthly comparisons indicate that decomposition progresses significantly throughout the study year. Detectable differences were between 0.8 and 1.2 percent of the yearly and site means, and approximately 0.6 percent of the monthly mean values.

Relative mass loss progress in the three plantations differed considerably between 1990 (Figure 29) and 1989 (1989 Annual Report, Figure 29, page 76). There was no conspicuous year-end mass gain in 1990, even though X_w dropped to approximately 0.65 in early October, reaching nearly 0.60 by early November. In 1989, however, X_w for bulk maple samples in the ground plantation rebounded (on average) from approximately 0.67 in early October to 0.72 in early November. We have noticed that the general quality of hardwood leaf litter parent collections taken from the same locations vary among years, due at least partially to differences in defoliator activity. Differences among years in substrate quality are probably responsible for some of the differences in patterns of mass loss observed.

The means model detected no significant differences in decomposition progress among the three plantations from 1988 through 1990, or for 1986. However, in 1987, decomposition progressed fastest in the antenna plantation, with no significant difference between the ground and control plantations. For 1985, the means model found that decomposition proceeded fastest in the

Table 42. ANOVA table (**effects**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** sub-units, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	26	13.79		199.10	0.0000	0.88
Year	5		5.78	433.77	0.0000	
Plantation	2		0.01	1.20	0.3013	
Year * Site	10		0.15	5.62	0.0001	
Plot (Site)	3		0.01	1.63	0.1812	
Month	6		7.74	484.20	0.0000	
Error	723	1.93				
Corrected Total	749	15.71				

Table 43. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 42.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7 8 9
1985	0.829	0.005	1.18	1985	
1986	0.977	0.005	1.00	1986	*
1987	0.985	0.005	0.99	1987	*
1988	0.913	0.005	1.07	1988	* * *
1989	1.098	0.005	0.89	1989	* * * *
1990	1.050	0.005	0.93	1990	* * * * *
Month					M J J A S O
May	1.143	0.005	0.86	May	
June	1.070	0.005	0.92	June	*
July	1.022	0.005	0.96	July	* *
August	0.969	0.005	1.01	Aug	* * *
September	0.917	0.005	1.07	Sept	* * * *
October	0.864	0.005	1.13	Oct	* * * * *
November	0.844	0.005	1.16	Nov	* * * * * *
Hardwood Stand					G A
Ground	0.964	0.003	0.61	Ground	
Antenna	0.972	0.003	0.60	Antenna	
Control	0.991	0.003	0.59	Control	* *

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Least Squares Means procedure.

Table 44. ANOVA table (**means**) model for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	29	13.84		184.08	0.0000	0.88
Siteyear	17		5.92	152.25	0.0000	
Plot (Site)	6		0.07	4.58	0.0001	
Month	6		7.74	497.42	0.0000	
Error	720	1.87				
Corrected Total	749	15.71				

Table 45. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 44.

Source of Variation		Mean[a]	Significant Differences[c]
Siteyear			
Control	1989	1.109	A
Antenna	1989	1.101	A
Ground	1989	1.087	B A
Antenna	1990	1.060	B C
Control	1990	1.048	D C
Ground	1990	1.044	D C
Control	1987	1.013	D E
Control	1986	1.000	F E
Ground	1987	0.993	F E
Ground	1986	0.971	F G
Antenna	1986	0.970	F G
Antenna	1987	0.951	H G
Control	1988	0.922	H I
Ground	1988	0.911	I
Antenna	1988	0.908	I
Control	1985	0.853	J
Antenna	1985	0.845	J
Ground	1985	0.790	K
Month			
May		1.143	A
June		1.070	B
July		1.022	C
August		0.970	D
September		0.917	E
October		0.863	F
November		0.844	F

a/ mean of transformed data
b/ α = .05, Tukey's H.S.D.

ground plantation, with no significant difference between the antenna and control plantations. This pattern of site differences by year does not match the pattern noted in the hardwood stands, where decomposition at the control site slowed down, beginning in 1988, relative to the antenna site. With respect to evaluating the potential for ELF field effects on decomposition rates, we expect that we would see a clearer pattern in the hardwood stands, where conditions are more stable than in the rapidly developing and changing red pine plantations.

ANOVA Results - Summary

The following outline summarizes the results of ANOVA on transformed dry matter mass loss data.

I. Subunits

A. Hardwood Stands
1. Pine - faster in antenna stand
2. Oak - n.s.d.
3. Maple - n.s.d.

B. Plantations
1. Pine - faster in ground and control plantations
2. Oak - n.s.d.
3. Maple - n.s.d.

II. Years

A. Hardwood Stands
1. Pine - 1985 fastest, followed by 1989 (n.s.d. 1987), 1987 (n.s.d. 1986), 1986, 1988, 1990
2. Oak - 1990 fastest, followed by 1989, 1985, 1987 (n.s.d. 1988), 1988, 1986
3. Maple - 1985 fastest, followed by 1988, 1986 (n.s.d. 1987), 1987 (n.s.d. 1990), 1990, 1989

B. Plantations

1. Pine - 1985 fastest, followed by 1989, 1986, 1988, 1987, 1990
2. Oak - 1989 fastest, followed by 1985 (n.s.d. 1988), 1988, 1987 (n.s.d. 1986), 1986, 1990
3. Maple - 1985 fastest, followed by 1988, 1986 (n.s.d. 1987, 1987, 1990, 1989

III. Year-by-Site Interaction

A. Hardwood Stands

1. Pine - 1985-1987: n.s.d.;
   1988-1990: antenna faster
2. Oak - 1985-1986: n.s.d.;
   1987: control faster;
   1988-1990: antenna faster
3. Maple - 1985-1987: n.s.d.;
   1988-1990: antenna faster

B. Plantations

1. Pine - 1985: ground faster than antenna, control n.s.d. intermediate
   1986: control and ground faster than antenna
   1987: control faster than antenna, control n.s.d. intermediate
   1988-1990: n.s.d.
2. Oak - 1985: ground faster than control, antenna n.s.d. intermediate
   1986-1990: n.s.d.
3. Maple - 1985: ground fastest, antenna n.s.d. faster than control
   1986: n.s.d.
   1987: antenna fastest, ground n.s.d. faster than control
   1988-1990: n.s.d.

Dry matter mass loss for all three litter species has proceeded faster in the antenna site hardwood stand than in the control site hardwood stand since 1988. Prior to 1988, pine and maple litter mass loss progress did not differ significantly between the two hardwood stands. The same was true for oak litter prior to 1987; however, oak litter decomposition was faster in the control site hardwood stand during 1987. While ELF field exposures have increased dramatically at the antenna site since 1987, we are attempting to explain these year-by-site interactions with ANACOV, using covariates unrelated to ELF field exposures.

We suspect that the often observed decline (or reversal) in mass loss progress between the October and November sample dates (October effect) provides an exaggerated impression of the autumn slow-down in decomposition rate. In some cases, this effect creates a false appearance of similarity in the state of decomposition progress achieved by the hardwood stands or plantations at the end of a year. For example (see Figures 2, 16, 24, 29 and 30), progress in one hardwood stand may be clearly greater through the early October sampling date, only to have a decline, or even a reversal, of mass loss rate leave the year-end X^W values for the two hardwood stands nearly identical. The October effect may even occasionally contribute to year-end site rank reversal (see Figures 23 and 29). For any given year, the magnitude of the mass loss rate decline is generally greatest for the site where mass loss has advanced fastest. Apparently related to decomposition rate, the potential magnitude of the October effect is generally most pronounced and therefore most frequently observed with maple litter, and least noticeable with pine litter. Maple litter has shown a much stronger tendency to gain mass during October than have either oak or pine litter. Pine needles showed the least tendency in this regard, for several reasons. First, it is much easier to remove adherent soil from pine needle samples than from leaves (especially maple leaves). Because maple leaves are more brittle than pine needles (and oak leaves) from the start, they are more difficult to clean

on retrieval. Also, because maple leaves decompose faster than pine needles and oak leaves, the extraneous matter they accumulate probably becomes a higher proportion of final sample mass for maple than for pine or oak. We presume that sample decomposition is actually progressing during October, despite cooler temperatures, but that decomposition is being masked by additions of inorganic (e.g., soil) and organic matter (e.g., microbial biomass).

It appears that, once first-year decomposition progresses to or beyond some threshold, total mass loss data begin to reflect greater accumulation of extraneous mass, perhaps due to rapidly increasing colonization by decomposer microfauna and microflora. For instance, bulk pine needle samples in the three plantations decomposed progressively through 1990, reaching final X_w values of approximately 0.74 in early November (see Table 17). Similar samples at the antenna site in 1989 reached approximately 0.76 by early October, and did not lose further mass by early November (see 1989 Annual Report, Table 3, page 21). However, samples at the ground and control plantations in 1989 reached approximately 0.73 by early October, and then experienced mass gains resulting in final X_w values of about 0.76 by early November.

As might be expected, thresholds for the October effect appear to differ among litter species. For example, oak litter in the three plantations during 1989 did not experience a conspicuous year-end mass gain (1989 Annual Report, Figure 22, page 65), even though X_w dropped below 0.75 in September, and below 0.70 by early November.

Likewise, thresholds for the October effect appear to differ among years. We have noticed that the general quality of leaf litter parent collections vary among years, even though they are taken from the same locations each year. Differences among years are due at least partially to differences in defoliator activity. Differences among years in substrate quality are probably responsible for some of the differences in patterns of mass loss observed. For example, relative maple litter mass loss progress in the three plantations differed considerably between

1990 (Figure 29) and 1989 (1989 Annual Report, Figure 29, page 76). There was no conspicuous year-end mass gain in 1990, even though X_w dropped to approximately 0.65 in early October, reaching nearly 0.60 by early November. In 1989, however, X_w for bulk maple samples in the ground plantation rebounded (on average) from approximately 0.67 in early October to 0.72 in early November.

If the above observations concerning a mid-autumn shift in the relationship between mass loss and decomposition are correct, we suspect that exclusion of the early November sample data would improve the effectiveness of our modeling efforts in two ways. First, our ANOVAs would provide clearer recognition of differences in mass loss rates among plantations and hardwood stands. Second, the effectiveness of our ANACOV models, which are largely based on the driving influence of weather variables on mass loss progress, should improve substantially.

Covariate Selection for Preliminary ANACOV

Prerequisites for including most variables in our covariate analyses are 1) significant correlation ($p \leq 0.05$) with transformed mass loss data, 2) a reasonable likelihood that the variable can eventually be shown to be independent of ELF field influence, and 3) a reasonable hypothetical relationship between mass loss and the potential covariate.

Potential covariates can be categorized as follows.

1) Covariates which characterize the annual parent litter collections, prior to disbursal, provide a single value which applies to all samples prepared from a parent collection (e.g., initial lignin content).

2) Covariates which characterize the individual leaf samples, prior to disbursal in the field, provide each sample with a unique value (e.g., individual oak leaf density).

3) Covariates which characterize the retrieved litter samples also provide each sample with a unique value (e.g., percent nitrogen content, percent phosphorus content).

4) Covariates which characterize temporally unchanging aspects of the study sites provide samples retrieved in different years with spatially dependent values (e.g., distributions of numbers and basal areas of residual hardwood stumps, by species).

5) Covariates which characterize dynamic aspects of the study sites and their weather provide individual samples with more or less unique values (e.g., air or soil temperature degree days, total precipitation, frequency of precipitation events, and actual evapotranspiration; also numbers and average heights of pine seedlings, by quarter-plot).

Because each year's parent litter collections are distributed to all sites, covariates in category 1 (e.g., initial content of N, P, K, Ca, Mg, and lignin) can be used to distinguish among years, but not among sites. Unfortunately, while Proc GLM permits ANACOV with these covariates, we have not yet found a way to evaluate multiple comparisons within these models. Therefore, unless these covariates explain all differences among years, we remain uncertain of exactly what they accomplish. This problem arises because there is only one estimate of parent litter nutrients for each year. Therefore, perfect colinearity exists between these covariates and one of the degrees of freedom associated with years. This results in one fewer degrees of freedom associated with Type III sum of squares for Year, and 0 degrees of freedom associated with the covariate. When SAS detects this perfect colinearity, no estimates of adjusted means or standard errors are computed, and therefore no multiple comparisons are made.

At present, the only category 2 covariate is initial individual oak leaf density (g/cm^2). Because each leaf in the field has its own unique density value, this variable can help to explain differences among years as well as among sites. Although the annual parent collections representing each litter species are made at the same location each year, both category 1 and category 2 covariates help to characterize the differences in substrate quality between the annual collections.

Category 3 covariates include the percent N, P, K, Ca, and Mg contents of the retrieved bulk litter samples. Nutrient analysis has been scaled back, due to resource limitations, to analysis of samples retrieved during alternate months (May, July, September, and November samples). Samples retrieved during the remaining months (and the unutilized portions of analyzed samples) have been archived, anticipating that further analysis (possibly including lignin content) may eventually be warranted and possible. An alternative approach would be to estimate the nutrient contents for intervening sampling dates by interpolation, and to use the estimates along with the

measurements in covariates for ANACOV.

Category 4 covariates include the 1987 values for numbers and basal areas per hectare of stumps (plantations) or live stems (hardwood stands) by species. These covariates are expected to change little with time and, therefore, can not help to explain differences among years. Also because these variables change little with time, there is a greater possibility (than with temporally variable covariates) that they may eventually be shown to be correlated spatially with measures of ELF field exposure. On the other hand, because each of these covariates varies among the three contiguous plots comprising each individual plantation and hardwood stand subunit, as well as among the subunits themselves, there is reason to hope that they can be shown to be statistically independent of the ELF field exposures and/or intensities. Also, any variable with values which could not have changed since exposure to ELF fields began must be independent of ELF (i.e., could not possibly be affected by ELF fields). If, however, as we suspect, the numbers of certain spp. of stumps in the plantations should turn out to be surrogates for the shading (or other) effect of sprouts on decomposition, then these covariates might effectively mask an effect of ELF fields on sprouting capacity or rate of sprout growth. For this reason, we hope to gather additional data on the extent of sprouting, for consideration as covariates. The mechanical severence of sprouts from all three plantations in 1986, and from the ground and antenna plantations in 1989, will make analysis and interpretation of this data very difficult. We have anticipated from the beginning of the research program, however, that it was going to be much more difficult to explain differences between years and sites in the plantations than in the hardwood stands. The temporally evolving values of a number of potentially important covariates are changing at different rates in the different plantations, with intermittent disturbances imposed in addition.

Category 5 covariates include measures of air and surface soil temperatures, total precipitation and precipitation event

frequency, and actual evapotranspiration (AET: e.g., Thornthwaite and Mather 1957, Meentemeyer 1978, and Meentemeyer and Berg 1986). AET calculations are based on 25 mm soil moisture retention, to reflect the relatively xeric conditions experienced by litter near the surface of the forest floor. Only cumulative variables have been used to date. These have been some of the most useful covariates to date. Nevertheless, our success with these variables to date almost certainly underestimates their importance biologically. With the exception of AET, each of these variables is calculated independently of the others. Although AET integrates temperature, precipitation, water-holding capacity, and the effect of lattitude, we suspect that AET fails to account for the inhibiting effect of energy inputs on decomposition progress during dry mid-summer periods. During such periods, warm weather has the effect of drying out the litter, thus depressing the rate of decomposition progress. For this reason, in 1991, we will develop additional covariates based on monthly (and seasonal) contributions of degree days and precipitation (e.g., ATDD-MAY, PRT-MAY, PR.10-MAY, etc., and ATDD-SPRING, PRT-SPRING, PR.10-SPRING, etc.). Use of this type of covariate should permit expression, within the ANACOV model, of the differential seasonal effects of temperature with respect to concurrent precipitation.

Other Category 5 covariates which will soon be available for use with the three plantation data sets include, or are based on, the numbers and mean heights of the red pine seedlings on each plantation quarter-plot. These variables will reflect the shading of litter samples, and the gradual conversion of these hardwood clearings to conifer stands. Unfortunately, the number of seedlings on each quarter-plot is declining (due to both root disease and destructive sampling) and their mean height is increasing, while electromagnetic field strengths are also increasing. Analysis of the spatial distributions of seedling numbers, mortality, and height, with respect to 76 Hz field strengths, should establish the relative independence of these variables from influence by 76 Hz fields.

Exceptions to the application of our stated criteria for covariate selection have been made for the first time in this report, to permit presentation of covariate models which consider the currently available electromagnetic field data sets (1985-1988). We emphasize that the fundamental goal of our covariate analysis remains the explanation of differences in litter decomposition rates without resorting to the use of electromagnetic field data. Therefore, where 76 Hz and 60 Hz field variables are included in a covariate analysis, the corresponding models without 76 Hz variables and with no electromagnetic field variables are also presented. Also, the use of electromagnetic field variables in our covariate analysis raises several statistical concerns, re: experimental design, interpretation of the covariate-related statistics in the ANACOV table, and recognition of actual vs. spurious relationships between decomposition rate and electromagnetic field strengths.

All variables used in one or more ANACOV model(s) presented in this report are defined in Table 46. The values for ATDDRT and ST5DDRT achieved at each study plot by each sampling date in 1990 are provided in Table 47. Corresponding values for PRWRT, PR.01RT, and PR.10RT are presented in Table 48. Temperature and precipitation data for 1985-1989 are presented in Tables 48-57 (pages 87-96) of our Annual Report 1989. Tables 49-54 present the seasonal cumulative AET values achieved at each plot by each sampling date in 1985-1990. The mean percent acid-insoluble lignin content of the parent litter collections for all three species from 1985-1989 are presented in Table 55. The percent nitrogen and phosphorus contents of bulk samples retrieved in May, July, September and November of 1988 are presented in Tables 124-126, and 127-129, respectively, of our Annual Report 1989. The mean 60 Hz longitudinal, magnetic, and transverse field exposure levels experienced on each plot from 1985-1988 are presented in Tables 56-58. Corresponding data for 76 Hz field exposure levels are presented in Tables 59-61. Values for 76 Hz magnetic and transverse field strength levels used in covariance models, for 1988 to present, were derived from algorithms

developed by Dr. David Reed of the Herbaceous Plant Cover and Trees project. Corresponding values for 76 Hz longitudinal field exposure levels were derived from mapped isobars provided by IITRI. Prior to 1988, plot averages (Tables 59-61) have been used, because specific sample locations were not mapped.

Tables 62-63 present the results of correlation analyses for transformed bulk pine litter mass loss, in the antenna and control hardwood stands, respectively, with potential covariates. Tables 64-65 and 66-67 report the results of corresponding correlation analyses for bulk oak and maple litter, respectively. Tables 68-70 present results of analogous correlation analyses for bulk pine litter in the three study site plantations; Tables 71-73 and 74-76 report results of corresponding analyses for bulk oak and maple litter in the three plantations. Analyses were prepared using data from both hardwood stands, and also for the control and antenna stands separately. Analyses were prepared using data either from all months (May - November) or from November samples only. Season-end analyses may be most helpful in understanding the relationships between mass loss and those variables which do not vary within a year (e.g., STDPCLIG, and the electromagnetic field strength variables). In the future, however, we will provide results of October-only correlation analyses, in order to reduce the apparent effect of late-season shifts in stage of decomposition. Note the much poorer, and typically non-significant, correlation of mass loss with AET in November, compared with the May through November correlation coefficients. Correlation analyses are also provided for all years available (1985-1988) vs. 1988-1989, as ELF exposures began to increase steeply in 1988.

Table 46. Definitions for names of variables used in at least one ANACOV model presented in this report.

ATDDRT	- the running total, on each plot and for each year, of air temperature degree days (30 cm above ground level, 4.4°C basis); data available for analysis, 1985-1989.
ST5DDRT	- the running total, on each plot and for each year, of soil temperature degree days (5 cm below ground level, 4.4°C basis); data available for analysis, 1985-1989.
PR.01RT	- the running total, on each site and for each year, of days with rainfall totalling at least 0.01 inch; data available for analysis, 1985-1989.
PR.1RT	- the running total, on each site and for each year, of days with rainfall totalling at least 0.1 inch; data available for analysis, 1985-1989.
PRWRT	- the running total, on each site and for each year, of precipitation; data available for analysis, 1985-1989.
AET	- "actual evapotranspiration", calculated by the method of Thornthwaite and Mather (1957), as applied by Meentemeyer (1978); data available for analysis, 1985-1989.
PCN	- percent nitrogen content of samples retrieved from the field; data available for analysis, 1985-1986 (May - Nov.), 1987-1988 (May, July, Sept., Nov.).
PCP	- percent phosphorus content of samples retrieved from the field; data available for analysis, 1985-1986 (May - Nov.), 1987-1988 (May, July, Sept., Nov.).
STDPCLIG	- initial percent lignin content of the annual parent litter collections, from which samples for the field are taken; data available for analysis, 1985-1989.
L60	- longitudinal 60 Hz field strength (mV/m); data available for analysis, 1985-1988.
L76	- longitudinal 76 Hz field strength (mV/m); data available for analysis, 1985-1989.
M76	- magnetic flux 76 Hz exposure levels (mG); data available for analysis, 1985-1989.
T76	- transverse 76 Hz field strength (V/m); data available for analysis, 1985-1989.
PH	- mean pH of rhizosphere soil associated with the red pine mycorrhizae collected from each plot for monthly (May - October) mycorrhizoplane streptomycete sampling; data available for analysis, 1986-1990.
DELAY	- elapsed time in days between excavation of red pine seedlings and delivery of mycorrhizae to the lab for streptomycete isolation; data available for analysis, 1987-1990.

Table 47. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1990.

	8 May	6 Jun	5 Jul	1 Aug	3 Sep	6 Oct	10 Nov
ATDDRT							
111	155	301	608	935	1336	1568	1605
112	155	312	681	1012	1416	1649	1685
113	154	308	673	1000	1401	1633	1670
211	157	324	705	1048	1465	1712	1752
212	155	318	690	1027	1439	1679	1716
213	155	317	691	1028	1442	1679	1716
311	177	354	729	1078	1511	1772	1816
312	180	368	769	1125	1564	1826	1875
313	175	356	748	1099	1530	1792	1838
221	162	338	711	1048	1455	1699	1743
222	159	321	681	1005	1400	1627	1663
223	157	317	672	993	1387	1614	1651
321	174	366	755	1104	1533	1797	1853
322	170	353	735	1075	1490	1743	1793
323	173	367	760	1113	1546	1814	1868
ST5DDRT							
111	117	292	646	976	1384	1668	1717
112	114	286	627	954	1370	1666	1725
113	120	298	654	995	1419	1727	1797
211	110	297	655	999	1411	1698	1753
212	108	281	632	977	1398	1686	1732
213	118	313	671	1007	1428	1728	1798
311	103	275	615	939	1337	1630	1695
312	108	297	651	994	1417	1718	1769
313	114	320	691	1054	1503	1824	1906
221	80	207	482	770	1130	1380	1430
222	81	209	483	775	1140	1400	1454
223	87	217	503	798	1158	1402	1439
321	68	222	533	850	1235	1501	1551
322	61	206	503	806	1201	1467	1520
323	51	182	469	774	1166	1443	1501

Table 48. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1990.

	8 May	6 Jun	5 Jul	1 Aug	3 Sep	6 Oct	10 Nov
PRWRT							
11	0.5	4.4	7.0	9.0	11.4	14.4	17.0
21	0.5	4.7	7.5	9.6	12.3	15.5	18.3
31	0.6	6.2	8.4	11.7	12.9	16.4	19.1
22	0.5	4.7	7.5	9.6	12.3	15.5	18.3
32	0.6	6.2	8.4	11.7	12.9	16.4	19.1
PR.01RT							
11	4	14	26	36	44	60	77
21	5	17	30	41	50	70	84
31	5	18	28	39	46	59	71
22	5	17	30	41	50	70	84
32	5	18	28	39	46	59	71
PR.1RT							
11	2	9	16	20	25	33	40
21	2	9	15	20	25	33	39
31	3	12	18	24	28	37	42
22	2	9	15	20	25	33	39
32	3	12	18	24	28	37	42

Table 49. Seasonal cumulative AET[a] for each litter retrieval date in 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
30 April	33.9	33.9	33.9	33.9	33.9	33.9
2 June	119.8	119.8	119.8	119.8	119.8	119.8
2 July	188.7	188.7	188.6	188.7	188.7	188.7
31 July	257.8	257.8	256.8	257.8	257.8	257.8
27 August	350.2	350.2	346.0	347.0	347.0	347.0
12 October	449.9	448.8	445.2	446.2	445.1	442.0
2 November	472.3	469.5	467.7	468.7	465.9	462.7
1 December	472.3	469.5	467.7	468.7	465.9	462.7

Table 49. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
30 April	40.7	40.7	40.7	37.3	40.7	40.7
2 June	130.8	130.8	130.8	127.4	134.7	134.7
2 July	202.6	202.6	202.6	199.2	206.4	206.4
31 July	226.5	226.5	226.5	223.1	230.4	230.4
27 August	296.0	296.0	296.0	292.6	299.8	299.8
12 October	388.0	392.2	388.0	384.6	396.1	396.1
2 November	408.7	414.7	408.7	405.4	418.6	418.6
1 December	408.7	414.7	408.7	405.4	418.6	418.6

Table 49. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Plot 1	Plot 2	Plot 3
30 April	33.9	33.9	33.9
2 June	119.5	119.5	119.5
2 July	184.9	184.9	184.9
31 July	250.9	250.9	250.9
27 August	340.2	340.2	340.2
12 October	435.1	435.1	435.1
2 November	455.9	455.9	455.9
1 December	455.9	455.9	455.9

a/ calculated according to Thornthwaite and Mather (1957), based on 25 mm soil moisture retention.

Table 50. Seasonal cumulative AET[a] for each litter retrieval date in 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
7 May	32.3	32.3	32.3	32.3	32.3	32.3
3 June	40.4	40.4	40.4	40.4	40.4	40.4
1 July	64.4	64.4	64.4	64.4	64.4	64.4
30 July	108.1	108.1	108.1	108.1	108.1	108.1
4 September	186.5	186.5	186.5	186.5	186.5	186.5
1 October	241.6	241.6	241.6	241.6	241.6	241.6
6 November	271.6	271.6	271.6	271.6	271.6	271.6
6 December	271.6	271.6	271.6	271.6	271.6	271.6

Table 50. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
7 May	34.7	34.7	34.7	35.5	35.5	35.5
3 June	53.1	53.1	53.1	53.1	53.1	53.1
1 July	97.5	97.5	97.5	97.5	97.5	97.5
30 July	152.9	152.9	152.9	152.9	152.9	152.9
4 September	220.8	221.3	220.8	220.8	220.8	220.8
1 October	281.4	284.5	281.4	281.4	281.4	281.4
6 November	314.2	317.3	314.2	314.2	314.2	314.2
6 December	314.2	317.3	314.2	314.2	314.2	314.2

Table 50. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Plot 1	Plot 2	Plot 3
7 May	43.3	43.3	43.3
3 June	58.4	58.4	58.4
1 July	84.1	84.1	84.1
30 July	126.9	126.9	126.9
4 September	205.3	205.3	204.9
1 October	260.4	260.4	257.2
6 November	290.4	290.4	287.3
6 December	290.4	290.4	287.3

a/ calculated according to Thornthwaite and Mather (1957), based on 25 mm soil moisture retention.

Table 51. Seasonal cumulative AET[a] for each litter retrieval date in 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
29 April	37.4	37.4	36.4	37.4	37.4	37.4
27 May	106.1	106.1	105.1	106.1	106.1	106.1
25 June	177.3	177.3	178.8	177.3	177.3	177.3
23 July	283.5	286.5	285.5	283.5	283.5	283.5
27 August	387.4	390.5	388.5	387.4	387.4	386.5
24 September	444.3	447.3	446.1	444.3	444.3	444.1
28 October	471.2	474.1	473.2	471.2	471.2	468.6
25 November	472.8	475.8	474.8	472.8	472.8	470.0

Table 51. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
29 April	36.6	36.6	35.6	36.6	36.6	36.6
27 May	111.0	111.0	107.6	111.0	111.0	111.0
25 June	160.1	160.1	158.8	160.1	160.1	160.1
23 July	264.7	270.6	261.0	261.8	264.7	261.8
27 August	389.1	397.1	382.9	385.2	389.1	385.2
24 September	442.6	450.5	437.0	438.6	442.6	438.6
28 October	467.9	478.4	462.5	463.9	467.9	463.9
25 November	469.5	484.2	464.1	467.5	471.5	467.5

Table 51. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Plot 1	Plot 2	Plot 3
29 April	36.6	36.6	36.6
27 May	105.3	105.3	105.3
25 June	175.7	175.7	175.7
23 July	284.7	284.7	284.7
27 August	380.3	380.3	380.3
24 September	431.7	431.7	431.7
28 October	457.6	457.6	457.6
25 November	459.2	459.2	459.2

a/ calculated according to Thornthwaite and Mather (1957), based on 25 mm soil moisture retention.

Table 52. Seasonal cumulative AET[a] for each litter retrieval date in 1988.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
4 May	29.7	31.5	29.7	31.5	31.5	29.7
1 June	63.3	63.3	63.3	63.3	63.3	63.3
29 June	81.7	81.7	81.7	81.7	81.7	81.7
28 July	151.5	151.5	151.5	151.5	151.5	151.5
31 August	272.3	272.3	272.3	272.3	272.3	268.7
28 September	333.5	333.5	330.6	330.6	333.5	329.8
2 November	354.8	351.9	348.8	351.6	354.8	351.1
1 December	354.8	351.9	348.8	351.6	354.8	351.1

Table 52. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
4 May	39.5	39.5	37.8	42.3	42.3	41.4
1 June	65.5	65.5	65.5	66.5	66.5	66.5
29 June	120.9	120.9	120.9	121.0	121.0	121.0
28 July	170.4	170.4	170.4	170.4	170.4	170.4
31 August	289.0	298.3	289.0	289.0	289.0	289.0
28 September	350.1	368.2	350.1	350.1	350.1	350.1
2 November	368.6	393.1	371.4	371.4	368.6	371.4
1 December	368.6	393.1	371.4	371.4	368.6	371.4

Table 52. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Plot 1	Plot 2	Plot 3
4 May	29.5	28.6	29.5
1 June	61.3	61.3	61.3
29 June	80.7	80.7	80.7
28 July	155.3	155.3	155.3
31 August	265.7	276.6	269.3
28 September	326.8	337.8	330.5
2 November	342.5	359.1	348.9
1 December	342.5	359.1	348.9

a/ calculated according to Thornthwaite and Mather (1957) , based on 25 mm soil moisture retention .

Table 53. Seasonal cumulative AET[a] for each litter retrieval date in 1989.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
12 May	37.3	40.6	40.6	38.1	40.6	40.6
10 June	107.7	109.7	109.7	109.7	109.7	109.7
8 July	184.3	185.8	185.8	186.3	185.8	185.8
5 August	233.1	233.1	233.1	235.1	233.1	233.1
9 September	317.5	317.5	317.5	319.5	317.5	317.5
9 October	338.3	339.1	339.1	341.1	339.1	339.1
13 November	362.3	365.1	365.1	367.1	365.1	365.1
9 December	362.3	365.1	365.1	367.1	365.1	365.1

Table 53. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
12 May	41.5	44.1	43.7	45.9	45.9	46.3
10 June	112.0	113.6	112.6	113.3	113.0	114.0
8 July	170.7	171.5	170.7	170.7	170.0	170.7
5 August	191.9	191.9	191.9	191.9	191.9	191.9
9 September	229.4	229.4	229.4	229.4	229.4	229.4
9 October	243.9	243.9	243.9	244.7	244.7	244.7
13 November	269.9	269.9	269.9	272.8	272.8	272.8
9 December	269.9	269.9	269.9	272.8	272.8	272.8

Table 53. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Plot 1	Plot 2	Plot 3
12 May	40.5	40.5	40.5
10 June	109.4	109.4	109.4
8 July	186.0	185.8	186.0
5 August	236.8	235.8	236.6
9 September	331.9	330.9	331.1
9 October	355.1	354.1	354.3
13 November	381.1	380.1	380.3
9 December	381.1	380.1	380.3

a/ calculated according to Thornthwaite and Mather (1957), based on 25 mm soil moisture retention.

Table 54. Seasonal cumulative AET[a] for each litter retrieval date in 1990.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
8 May	45.2	45.2	45.2	47.2	46.2	46.2
6 June	112.3	112.3	112.3	116.8	112.7	112.7
5 July	203.5	203.5	203.5	205.9	201.9	201.9
1 August	263.7	263.7	263.7	263.9	262.8	262.8
3 September	329.8	329.8	329.8	329.9	328.4	328.4
6 October	388.2	387.6	387.6	388.3	384.4	384.4
10 November	409.1	406.4	406.4	409.2	403.4	403.4

Table 54. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
8 May	48.2	49.2	48.2	48.2	50.2	48.2
6 June	118.1	119.3	117.1	117.1	123.2	117.1
5 July	213.2	218.1	212.2	212.2	221.8	212.2
1 August	297.1	298.6	296.1	296.1	301.7	296.1
3 September	337.4	337.4	336.4	336.4	341.3	336.4
6 October	395.7	395.7	394.7	395.8	400.7	395.3
10 November	414.5	414.7	413.5	418 8	423.9	416.4

Table 54. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Plot 1	Plot 2	Plot 3
8 May	45.9	44.9	44.9
6 June	111.0	110.8	110.6
5 July	193.4	196.0	195.2
1 August	248.8	250.5	250.5
3 September	308.1	309.0	309.0
6 October	362.9	363.2	363.2
10 November	383.8	382.1	382.3

a/ calculated according to Thornthwaite and Mather (1957), based on 25 mm soil moisture retention.

Table 55. Percent initial acid-insoluble lignin content

Year	Species		
	Pine	Oak	Maple
1985	30.62	32.17	20.70
1986	32.90	33.80	33.33
1987	32.33	27.50	25.89
1988	30.22	30.07	21.31
1989	33.43	27.84	30.32

Table 56. Estimated average annual 60 Hz Longitudinal (mV/m) field exposure levels, by plot, for 1985-1989.

Site Treatment	Plot	Year 1985	1986	1987	1988	1989
Ground						
Plantation	1	0.3519	0.3519	1.7587	0.6104	
	2	0.2851	0.2851	0.9544	0.4879	
	3	0.3185	0.3185	1.1674	0.5491	
Antenna						
Plantation	1	0.5126	0.3522	0.2869	0.2828	
	2	0.5126	0.3522	0.2869	0.2828	
	3	0.5126	0.3522	0.2869	0.2828	
Hardwoods	1	0.4939	0.3558	0.2849	0.2963	
	2	0.4939	0.3558	0.2849	0.2963	
	3	0.4939	0.3558	0.2849	0.2963	
Control						
Plantation	1	0.0500	0.0500	0.0500	0.0500	
	2	0.0646	0.0646	0.0646	0.0646	
	3	0.0791	0.0791	0.0791	0.0791	
Hardwoods	1	0.0490	0.0490	0.0490	0.0490	
	2	0.0614	0.0614	0.0614	0.0614	
	3	0.0738	0.0738	0.0738	0.0738	

Table 57. Estimated average annual 60 Hz Magnetic Flux (mG) field exposure levels, by plot, for 1985-1989.

Site Treatment	Plot	Year				
		1985	1986	1987	1988	1989
Ground						
Plantation	1	0.0016	0.0016	0.0058	0.0093	
	2	0.0015	0.0015	0.0047	0.0067	
	3	0.0015	0.0015	0.0052	0.0080	
Antenna						
Plantation	1	0.0011	0.0048	0.0077	0.0130	
	2	0.0009	0.0046	0.0075	0.0128	
	3	0.0007	0.0044	0.0073	0.0126	
Hardwoods	1	0.0013	0.0040	0.0058	0.0097	
	2	0.0011	0.0039	0.0056	0.0095	
	3	0.0009	0.0037	0.0054	0.0093	
Control						
Plantation	1	0.0020	0.0020	0.0020	0.0020	
	2	0.0020	0.0020	0.0020	0.0020	
	3	0.0020	0.0020	0.0020	0.0020	
Hardwoods	1	0.0020	0.0020	0.0020	0.0020	
	2	0.0020	0.0020	0.0020	0.0020	
	3	0.0020	0.0020	0.0020	0.0020	

Table 58. Estimated average annual 60 Hz Transverse (V/m) field exposure levels, by plot, for 1985-1989.

Site Treatment	Plot	Year				
		1985	1986	1987	1988	1989
Ground						
Plantation	1	0.0000	0.0000	0.0004	0.0004	
	2	0.0000	0.0000	0.0002	0.0002	
	3	0.0000	0.0000	0.0003	0.0003	
Antenna						
Plantation	1	0.0000	0.0000	0.0000	0.0051	
	2	0.0000	0.0000	0.0000	0.0051	
	3	0.0000	0.0000	0.0000	0.0051	
Hardwoods	1	0.0000	0.0000	0.0000	0.0038	
	2	0.0000	0.0000	0.0000	0.0038	
	3	0.0000	0.0000	0.0000	0.0038	
Control						
Plantation	1	0.0000	0.0000	0.0000	0.0000	
	2	0.0000	0.0000	0.0000	0.0000	
	3	0.0000	0.0000	0.0000	0.0000	
Hardwoods	1	0.0000	0.0000	0.0000	0.0000	
	2	0.0000	0.0000	0.0000	0.0000	
	3	0.0000	0.0000	0.0000	0.0000	

Table 59. Estimated average annual 76 Hz Longitudinal EW (mV/m) field exposure levels, by plot, for 1985-1989.

Site Treatment	Plot	Year				
		1985	1986	1987	1988	1989
Ground						
Plantation	1	0.0000	38.1698	86.0053	393.2960	823.9260
	2	0.0000	6.5540	23.4046	184.5830	465.5572
	3	0.0000	22.3619	54.7049	288.9393	644.7413
Antenna						
Plantation	1	0.0000	5.0830	12.8410	77.0920	112.3500
	2	0.0000	5.0830	12.8410	72.5738	112.3500
	3	0.0000	5.0830	12.8410	68.0556	112.3500
Hardwoods	1	0.0000	5.0830	12.8410	82.2323	112.3500
	2	0.0000	5.0830	12.8410	78.0708	112.3500
	3	0.0000	5.0830	12.8410	73.9093	112.3500
Control						
Plantation	1	0.0000	0.0000	0.0025	0.0102	0.0449
	2	0.0000	0.0000	0.0031	0.0132	0.0573
	3	0.0000	0.0000	0.0036	0.0163	0.0697
Hardwoods	1	0.0000	0.0000	0.0025	0.0100	0.0440
	2	0.0000	0.0000	0.0029	0.0126	0.0546
	3	0.0000	0.0000	0.0034	0.0152	0.0651

Table 60. Estimated average annual 76 Hz Magnetic Flux EW (mG) field exposure levels, by plot, for 1985-1989.

Site Treatment	Plot	Year				
		1985	1986	1987	1988	1989
Ground						
Plantation	1	0.0000	0.3430	0.8179	4.0315	13.7774
	2	0.0000	0.2231	0.5958	2.8562	12.8773
	3	0.0000	0.2831	0.7068	3.4439	13.3273
Antenna						
Plantation	1	0.0000	0.4289	1.0977	4.9401	8.2701
	2	0.0000	0.4289	1.0977	4.9401	8.2701
	3	0.0000	0.4289	1.0977	4.9401	8.2701
Hardwoods	1	0.0000	0.3076	0.8092	3.4658	6.8361
	2	0.0000	0.3076	0.8092	3.4658	6.8361
	3	0.0000	0.3076	0.8092	3.4658	6.8361
Control						
Plantation	1	0.0000	0.0000	0.0000	0.0000	0.0025
	2	0.0000	0.0000	0.0000	0.0000	0.0025
	3	0.0000	0.0000	0.0000	0.0000	0.0025
Hardwoods	1	0.0000	0.0000	0.0000	0.0000	0.0025
	2	0.0000	0.0000	0.0000	0.0000	0.0025
	3	0.0000	0.0000	0.0000	0.0000	0.0025

Table 61. Estimated average annual 76 Hz Transverse EW (V/m) field exposure levels, by plot, for 1985-1989.

Site Treatment	Plot	Year				
		1985	1986	1987	1988	1989
Ground						
Plantation	1	0.0000	0.2506	0.2506	1.9393	2.0561
	2	0.0000	0.0727	0.0727	0.5531	0.8357
	3	0.0000	0.1616	0.1616	1.2462	1.4459
Antenna						
Plantation	1	0.0000	0.0311	0.0614	0.4362	0.2983
	2	0.0000	0.0311	0.0614	0.4362	0.2983
	3	0.0000	0.0311	0.0614	0.4362	0.2983
Hardwoods	1	0.0000	0.0130	0.0356	0.0711	0.2238
	2	0.0000	0.0130	0.0356	0.0711	0.2238
	3	0.0000	0.0130	0.0356	0.0711	0.2238
Control						
Plantation	1	0.0000	0.0000	0.0000	0.0000	0.0010
	2	0.0000	0.0000	0.0000	0.0000	0.0010
	3	0.0000	0.0000	0.0000	0.0000	0.0010
Hardwoods	1	0.0000	0.0000	0.0000	0.0000	0.0010
	2	0.0000	0.0000	0.0000	0.0000	0.0010
	3	0.0000	0.0000	0.0000	0.0000	0.0010

Table 62. Pearson correlation coefficients for transformed bulk pine litter sample mass loss data[a] from the antenna hardwood stand, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8948[c]	-0.0775	-0.9423	0.4278
	0.0001[d]	0.6534	0.0001	0.0766
	252[e]	36	126	18
ATDDRT	-0.9162	0.2224	-0.9427	-0.0774
	0.0001	0.1923	0.0001	0.7603
	252	36	126	18
ST5DDRT	-0.9174	0.0860	-0.9494	-0.5424
	0.0001	0.6180	0.0001	0.0200
	252	36	126	18
PRWRT	-0.8777	-0.2487	-0.9386	-0.3732
	0.0001	0.1436	0.0001	0.1272
	252	36	126	18
PR.10RT	-0.9236	-0.2343	-0.9502	-0.3159
	0.0001	0.1690	0.0001	0.2015
	252	36	126	18
STDPCLIG	.	0.2660	.	0.4054
	.	0.1553	.	0.1911
		30		12
PCN	-0.3903	-0.3876	0.0954	0.9639
	0.0001	0.0613	0.6575	0.0019
	132	24	24	6
PCP	0.0461	-0.3651	0.4647	0.9434
	0.5999	0.0793	0.0221	0.0047
	132	24	24	6
L60	-0.1743	-0.3914	0.0079	0.1255
	0.0238	0.0586	0.9604	0.8128
	168	24	42	6
L76	0.0380	0.3736	-0.0285	0.0339
	0.5481	0.0248	0.7516	0.8938
	252	36	126	18
M76	0.0290	0.1574	0.0398	-0.4426
	0.6760	0.4063	0.7194	0.1496
	210	30	84	12
T76	-0.0232	0.4588	-0.1013	0.3859
	0.7379	0.0108	0.3593	0.2153
	210	30	84	12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 63. Pearson correlation coefficients for transformed bulk pine litter sample mass loss data[a] from the control hardwood stand, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8584[c] 0.0001[d] 250[e]	-0.3510 0.0387 35	-0.8436 0.0001 126	-0.5609 0.0155 18
ATDDRT	-0.8719 0.0001 250	0.2505 0.1466 35	-0.8894 0.0001 126	-0.0067 0.9788 18
ST5DDRT	-0.8806 0.0001 250	0.1319 0.4501 35	-0.9068 0.0001 126	0.0801 0.7519 18
PRWRT	-0.8482 0.0001 250	-0.4842 0.0032 35	-0.8154 0.0001 126	-0.5654 0.0145 18
PR.10RT	-0.9098 0.0001 250	-0.5452 0.0007 35	-0.8811 0.0001 126	-0.5199 0.0270 18
STDPCLIG	. .	0.2954 0.1198 29	. .	0.5902 0.0434 12
PCN	-0.4156 0.0001 130	-0.6579 0.0007 23	0.2603 0.2192 24	-0.2626 0.6151 6
PCP	0.0585 0.5085 130	-0.5231 0.0104 23	0.6484 0.0006 24	-0.1820 0.7301 6
L60	0.0417 0.5937 166	0.3342 0.1191 23	0.0351 0.8253 42	0.1835 0.7278 6
L76	0.0000 1.0000 250	0.0000 1.0000 35	0.0000 1.0000 126	0.0000 1.0000 18
M76	0.0000 1.0000 208	0.0000 1.0000 29	0.0000 1.0000 84	0.0000 1.0000 12
T76	0.0000 1.0000 208	0.0000 1.0000 29	0.0000 1.0000 84	0.0000 1.0000 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 64. Pearson correlation coefficients for transformed bulk oak litter sample mass loss data[a] from the antenna hardwood stand, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8114[c] 0.0001[d] 252[e]	0.3213 0.0560 36	-0.9267 0.0001 126	-0.0319 0.9000 18
ATDDRT	-0.8223 0.0001 252	-0.3224 0.0552 36	-0.8615 0.0001 126	-0.0427 0.8663 18
ST5DDRT	-0.8144 0.0001 252	-0.0132 0.9390 36	-0.8679 0.0001 126	-0.0418 0.8693 18
PRWRT	-0.7633 0.0001 252	0.3522 0.0352 36	-0.9139 0.0001 126	-0.0000 1.0000 18
PR.10RT	-0.8081 0.0001 252	0.3494 0.0368 36	-0.9127 0.0001 126	0.0040 0.9873 18
STDPCLIG	. .	0.2673 0.1533 30	. .	0.0042 0.9898 12
PCN	-0.4494 0.0001 131	-0.3876 0.0613 24	-0.6754 0.0003 24	-0.0964 0.8558 6
PCP	-0.5097 0.0001 130	-0.3823 0.0791 22	-0.4938 0.0195 22	-0.1470 0.8530 4
L60	-0.0681 0.3804 168	0.4078 0.0479 24	0.0494 0.7561 42	-0.7462 0.0885 6
L76	-0.3166 0.0001 252	-0.4959 0.0021 36	-0.1366 0.1273 126	0.1722 0.4944 18
M76	-0.1230 0.0753 210	-0.3918 0.0323 30	0.1329 0.2281 84	0.3594 0.2512 12
T76	-0.2338 0.0006 210	-0.4238 0.0196 30	-0.1880 0.0867 84	-0.1630 0.6126 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 65. Pearson correlation coefficients for transformed bulk oak litter sample mass loss data[a] from the control hardwood stand, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8951[c] 0.0001[d] 251[e]	-0.1793 0.3028 35	-0.8753 0.0001 125	-0.3850 0.1270 17
ATDDRT	-0.8607 0.0001 251	0.4801 0.0035 35	-0.8241 0.0001 125	0.2777 0.2805 17
ST5DDRT	-0.8701 0.0001 251	0.4322 0.0095 35	-0.8443 0.0001 125	0.2810 0.2745 17
PRWRT	-0.8945 0.0001 251	-0.4314 0.0097 35	-0.8753 0.0001 125	-0.4457 0.0730 17
PR.10RT	-0.9114 0.0001 251	-0.2827 0.0998 35	-0.9233 0.0001 125	-0.5328 0.0277 17
STDPCLIG	. .	-0.3577 0.0523 30	. .	-0.0593 0.8547 12
PCN	-0.5375 0.0001 130	-0.0194 0.9283 24	-0.8211 0.0001 22	0.2349 0.6542 6
PCP	-0.6591 0.5085 130	-0.5796 0.0030 24	-0.3596 0.1003 22	0.2920 0.5744 6
L60	0.0096 0.9019 168	0.0561 0.7945 24	0.0319 0.8409 42	0.3950 0.4383 6
L76	0.0000 1.0000 251	0.0000 1.0000 35	0.0000 1.0000 125	0.0000 1.0000 17
M76	0.0000 1.0000 210	0.0000 1.0000 30	0.0000 1.0000 84	0.0000 1.0000 12
T76	0.0000 1.0000 210	0.0000 1.0000 30	0.0000 1.0000 84	0.0000 1.0000 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 66. Pearson correlation coefficients for transformed bulk maple litter sample mass loss data[a] from the antenna site hardwood stand, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.6401[c] 0.0001[d] 252[e]	-0.1386 0.4201 36	-0.5860 0.0001 126	0.6157 0.0065 18
ATDDRT	-0.6521 0.0001 252	0.0678 0.6942 36	-0.7328 0.0001 126	-0.5944 0.0093 18
ST5DDRT	-0.6461 0.0001 252	0.0280 0.8712 36	-0.7167 0.0001 126	-0.5373 0.0215 18
PRWRT	-0.7242 0.0001 252	-0.4895 0.0024 36	-0.6437 0.0001 126	-0.8483 0.0001 18
PR.10RT	-0.7140 0.0001 252	-0.4606 0.0047 36	-0.6116 0.0001 126	-0.8577 0.0001 18
STDPCLIG	. . 	0.6224 0.0002 30	. . 	0.9810 0.0001 12
PCN	-0.5015 0.0001 130	-0.7157 0.0001 24	-0.7432 0.0001 22	-0.8687 0.0247 6
PCP	-0.3407 0.0001 130	-0.7036 0.0001 24	0.2637 0.2356 22	-0.6330 0.1773 6
L60	-0.3657 0.0001 168	-0.5240 0.0086 24	0.0410 0.7964 42	0.4520 0.3681 6
L76	0.2701 0.0001 252	0.5300 0.0009 36	0.3744 0.0001 126	0.6250 0.0055 18
M76	-0.0307 0.6586 210	0.0468 0.8061 30	-0.2981 0.0059 84	-0.4131 0.1819 12
T76	0.4479 0.0001 210	0.7798 0.0001 30	0.6707 0.0001 84	0.9009 0.0001 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 67. Pearson correlation coefficients for transformed bulk maple litter sample mass loss data[a] from the control hardwood stand, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.6342[c] 0.0001[d] 250[e]	-0.4099 0.0145 35	-0.6747 0.0001 125	-0.7651 0.0003 17
ATDDRT	-0.6052 0.0001 250	0.1997 0.2500 35	-0.7115 0.0001 125	-0.6017 0.0106 17
ST5DDRT	-0.5891 0.0001 250	0.2712 0.1150 35	-0.6838 0.0001 125	-0.5244 0.0307 17
PRWRT	-0.6781 0.0001 250	-0.6299 0.0001 35	-0.6622 0.0001 125	-0.6844 0.0024 17
PR.10RT	-0.6697 0.0001 250	-0.4770 0.0038 35	-0.5947 0.0001 125	-0.4360 0.0802 17
STDPCLIG	. .	0.5596 0.0013 30	. .	0.9236 0.0001 12
PCN	-0.5470 0.0001 131	-0.7131 0.0001 24	-0.3960 0.0554 24	0.6308 0.1793 6
PCP	-0.6865 0.0001 131	-0.8261 0.0001 24	-0.0376 0.8615 24	0.6238 0.1857 6
L60	0.0765 0.3260 167	0.1807 0.3981 24	0.1728 0.2738 42	0.4276 0.3977 6
L76	0.0000 1.0000 250	0.0000 1.0000 35	0.0000 1.0000 125	0.0000 1.0000 17
M76	0.0000 1.0000 209	0.0000 1.0000 30	0.0000 1.0000 84	0.0000 1.0000 12
T76	0.0000 1.0000 209	0.0000 1.0000 30	0.0000 1.0000 84	0.0000 1.0000 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 68. Pearson correlation coefficients for transformed bulk pine litter sample mass loss data[a] from the ground plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8656[c] 0.0001[d] 252[e]	0.0053 0.9756 36	-0.9189 0.0001 126	-0.0899 0.7228 18
ATDDRT	-0.8853 0.0001 252	0.2701 0.1111 36	-0.9081 0.0001 126	-0.2359 0.3461 18
ST5DDRT	-0.8987 0.0001 252	0.0180 0.9171 36	-0.9123 0.0001 126	0.0423 0.8677 18
PRWRT	-0.8494 0.0001 252	-0.1900 0.2671 36	-0.9040 0.0001 126	-0.1794 0.4762 18
PR.10RT	-0.8778 0.0001 252	-0.1888 0.2701 36	-0.8997 0.0001 126	-0.0970 0.7017 18
STDPCLIG	. .	0.1198 0.5281 30	. .	0.1042 0.7472 12
PCN	-0.3248 0.0001 132	0.2257 0.2890 24	-0.7106 0.0001 24	0.1658 0.7536 6
PCP	-0.0226 0.7970 132	-0.3458 0.0979 24	-0.1240 0.5638 24	-0.7113 0.1130 6
L60	0.1719 0.0259 168	0.3800 0.0670 24	0.0990 0.5326 42	0.3373 0.5132 6
L76	0.0150 0.8122 252	0.2690 0.1126 36	-0.0572 0.5243 126	0.1674 0.5068 18
M76	0.0479 0.4898 210	0.3580 0.0521 30	0.0335 0.7621 84	0.2326 0.4668 12
T76	0.0912 0.1880 210	0.3511 0.0571 30	0.1310 0.2350 84	0.2757 0.3858 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 69. Pearson correlation coefficients for transformed bulk pine litter sample mass loss data[a] from the antenna plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.9449[c] 0.0001[d] 251[e]	-0.1090 0.5333 35	-0.8598 0.0001 125	0.4461 0.0727 17
ATDDRT	-0.8863 0.0001 251	0.2173 0.2098 35	-0.8869 0.0001 125	-0.2625 0.3087 17
ST5DDRT	-0.9038 0.0001 251	0.1658 0.3412 35	-0.8942 0.0001 125	0.1312 0.6159 17
PRWRT	-0.8333 0.0001 251	-0.3455 0.0421 35	-0.8658 0.0001 125	-0.4509 0.0693 17
PR.10RT	-0.8811 0.0001 251	-0.3326 0.0509 35	-0.8911 0.0001 125	-0.4222 0.0914 17
STDPCLIG	. .	0.4548 0.0116 30	. .	0.5206 0.0827 12
PCN	-0.3028 0.0004 132	0.3126 0.1370 24	-0.2057 0.3349 24	-0.4554 0.3641 6
PCP	-0.2038 0.0200 130	-0.3333 0.1115 24	-0.0738 0.7443 22	0.3113 0.5482 6
L60	-0.1579 0.0410 168	-0.4420 0.0306 24	-0.0634 0.6899 42	-0.4099 0.4196 6
L76	0.0426 0.5018 251	-0.0276 0.8747 35	0.0134 0.8825 125	-0.4842 0.0489 17
M76	-0.0258 0.7104 210	0.3286 0.0763 30	-0.0056 0.9596 84	0.2348 0.4626 12
T76	0.0181 0.7941 210	0.1876 0.3208 30	0.0711 0.5202 84	0.0694 0.8303 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 70. Pearson correlation coefficients for transformed bulk pine litter sample mass loss data[a] from the control plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8308[c] 0.0001[d] 252[e]	-0.0731 0.6717 36	-0.8007 0.0001 126	-0.3140 0.2045 18
ATDDRT	-0.8852 0.0001 252	0.4869 0.0026 36	-0.9035 0.0001 126	0.2777 0.2646 18
ST5DDRT	-0.9055 0.0001 252	0.0470 0.7855 36	-0.9184 0.0001 126	-0.1696 0.5011 18
PRWRT	-0.8114 0.0001 252	-0.1548 0.3675 36	-0.7607 0.0001 126	-0.2620 0.2937 18
PR.10RT	-0.8722 0.0001 252	-0.2229 0.1912 36	-0.8356 0.0001 126	-0.1601 0.5256 18
STDPCLIG	. .	0.1861 0.3248 30	. .	0.4237 0.1699 12
PCN	-0.4838 0.0001 132	0.0470 0.8274 24	-0.4215 0.0402 24	-0.1979 0.7070 6
PCP	0.0601 0.4936 132	-0.0817 0.7043 24	0.2718 0.1988 24	-0.3074 0.5534 6
L60	-0.0159 0.8377 168	0.0894 0.6777 24	-0.0698 0.6603 42	-0.5101 0.3012 6
L76	0.0000 1.0000 252	0.0000 1.0000 36	0.0000 1.0000 126	0.0000 1.0000 18
M76	0.0000 1.0000 210	0.0000 1.0000 30	0.0000 1.0000 84	0.0000 1.0000 12
T76	0.0000 1.0000 210	0.0000 1.0000 30	0.0000 1.0000 84	0.0000 1.0000 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 71. Pearson correlation coefficients for transformed bulk oak litter sample mass loss data[a] from the ground plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8396[c] 0.0001[d] 249[e]	0.0976 0.5769 35	-0.8852 0.0001 125	-0.4857 0.0410 18
ATDDRT	-0.8554 0.0001 249	-0.0479 0.7847 35	-0.8803 0.0001 125	-0.5108 0.0303 18
ST5DDRT	-0.8619 0.0001 249	-0.1075 0.5389 35	-0.8842 0.0001 125	-0.3728 0.1276 18
PRWRT	-0.8142 0.0001 249	-0.0727 0.6780 35	-0.8663 0.0001 125	-0.3355 0.1736 18
PR.10RT	-0.8455 0.0001 249	0.0538 0.7587 35	-0.8626 0.0001 125	0.4248 0.0789 18
STDPCLIG	. .	-0.2544 0.1830 29	. .	-0.1100 0.7335 12
PCN	-0.3874 0.0001 130	-0.6286 0.0013 23	-0.5498 0.0054 24	-0.2844 0.5850 6
PCP	-0.2109 0.0156 131	-0.3355 0.1176 23	0.2057 0.3350 24	-0.5177 0.2929 6
L60	0.1180 0.1300 166	0.3882 0.0672 23	0.0739 0.6418 42	0.1255 0.8127 6
L76	-0.1065 0.0936 249	-0.1733 0.3195 35	-0.1568 0.0809 125	-0.2280 0.3629 18
M76	-0.1178 0.0900 208	-0.1696 0.3791 29	-0.0552 0.6177 84	0.0961 0.7665 12
T76	-0.0648 0.3523 208	-0.2313 0.2274 29	0.0354 0.7491 84	-0.0563 0.8619 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 72. Pearson correlation coefficients for transformed bulk oak litter sample mass loss data[a] from the antenna plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8190[c] 0.0001[d] 251[e]	0.2278 0.1881 35	-0.8385 0.0001 125	-0.1602 0.5391 17
ATDDRT	-0.8633 0.0001 251	-0.3378 0.0471 35	-0.8767 0.0001 125	-0.6054 0.0100 17
ST5DDRT	-0.8712 0.0001 251	-0.2285 0.1867 35	-0.8820 0.0001 125	-0.1638 0.5298 17
PRWRT	-0.7803 0.0001 251	0.2696 0.1173 35	-0.8282 0.0001 125	-0.0551 0.8338 17
PR.10RT	-0.8372 0.0001 251	0.2532 0.1422 35	-0.8591 0.0001 125	-0.3137 0.2201 17
STDPCLIG	. .	0.0615 0.7513 29	. .	-0.3019 0.3669 11
PCN	-0.3779 0.0001 131	-0.4161 0.0483 23	-0.7348 0.0001 23	-0.6170 0.2676 5
PCP	-0.2121 0.0150 131	-0.3433 0.1088 23	-0.2892 0.1808 23	-0.2969 0.6276 5
L60	-0.0288 0.7120 167	0.3343 0.1190 23	-0.0807 0.6161 41	-0.6026 0.2821 5
L76	0.0493 0.4364 251	-0.1470 0.3994 35	0.0396 0.6610 125	-0.1436 0.5824 17
M76	-0.0762 0.2731 209	-0.2730 0.1519 29	-0.0174 0.8763 83	0.1158 0.7345 11
T76	0.0080 0.9088 209	-0.0543 0.7798 29	0.0886 0.4259 83	0.2766 0.4102 11

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 73. Pearson correlation coefficients for transformed bulk oak litter sample mass loss data[a] from the control plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.8335[c] 0.0001[d] 251[e]	0.2770 0.1072 35	-0.8075 0.0001 125	0.2872 0.2637 17
ATDDRT	-0.8958 0.0001 251	0.0320 0.8550 35	-0.9133 0.0001 125	-0.2588 0.3158 17
ST5DDRT	-0.9065 0.0001 251	0.0060 0.9730 35	-0.9225 0.0001 125	-0.4072 0.1047 17
PRWRT	-0.8072 0.0001 251	0.2038 0.2402 35	-0.7710 0.0001 125	0.3749 0.1381 17
PR.10RT	-0.8569 0.0001 251	0.2526 0.1432 35	-0.8516 0.0001 125	0.4603 0.0630 17
STDPCLIG	. .	-0.1808 0.3478 29	. .	-0.0072 0.9831 11
PCN	-0.5974 0.0001 132	-0.4539 0.0259 24	-0.7991 0.0001 24	-0.1077 0.8391 6
PCP	-0.3663 0.0001 132	0.1919 0.3690 24	0.2064 0.3331 24	0.1204 0.8203 6
L60	0.0428 0.5819 168	0.0448 0.8352 24	0.0049 0.9756 42	0.0100 0.9849 6
L76	0.0000 1.0000 251	0.0000 1.0000 35	0.0000 1.0000 125	0.0000 1.0000 17
M76	0.0000 1.0000 209	0.0000 1.0000 29	0.0000 1.0000 83	0.0000 1.0000 11
T76	0.0000 1.0000 209	0.0000 1.0000 29	0.0000 1.0000 83	0.0000 1.0000 11

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 74. Pearson correlation coefficients for transformed bulk maple litter sample mass loss data[a] from the ground plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.6500[c] 0.0001[d] 249[e]	-0.0814 0.6471 34	-0.6374 0.0001 125	0.7293 0.0006 18
ATDDRT	-0.6583 0.0001 249	0.2496 0.1546 34	-0.7814 0.0001 125	-0.3653 0.1361 18
ST5DDRT	-0.6895 0.0001 249	-0.2517 0.1510 34	-0.7855 0.0001 125	-0.6401 0.0042 18
PRWRT	-0.7470 0.0001 249	-0.4867 0.0035 34	-0.7092 0.0001 125	-0.7971 0.0001 18
PR.10RT	-0.7305 0.0001 249	-0.4752 0.0045 34	-0.6620 0.0001 125	-0.7362 0.0005 18
STDPCLIG	. .	0.4582 0.0142 28	. .	0.9740 0.0001 12
PCN	-0.5213 0.0001 130	-0.7698 0.0001 22	-0.7779 0.0001 24	0.3628 0.4797 6
PCP	-0.4613 0.0001 130	-0.5973 0.0033 22	-0.0300 0.8892 24	-0.5070 0.3046 6
L60	0.3630 0.0001 166	0.6331 0.0016 22	-0.0790 0.6188 42	-0.3451 0.5029 6
L76	0.2170 0.0006 249	0.3376 0.0509 34	0.0952 0.2907 125	0.2322 0.3538 18
M76	0.2947 0.0001 207	0.4866 0.0086 28	0.1528 0.1680 83	0.2973 0.3480 12
T76	0.1488 0.0324 207	0.2431 0.2126 28	-0.2810 0.0101 83	-0.3673 0.2402 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 75. Pearson correlation coefficients for transformed bulk maple litter sample mass loss data[a] from the antenna plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.6695[c] 0.0001[d] 251[e]	-0.1116 0.5233 35	-0.6202 0.0001 126	0.6482 0.0036 18
ATDDRT	-0.6945 0.0001 251	0.0845 0.6292 35	-0.7591 0.0001 126	-0.6344 0.0047 18
ST5DDRT	-0.7272 0.0001 251	-0.3817 0.0237 35	-0.7422 0.0001 126	-0.4261 0.0779 18
PRWRT	-0.7203 0.0001 251	-0.3457 0.0419 35	-0.6698 0.0001 126	-0.7799 0.0001 18
PR.10RT	-0.7281 0.0001 251	-0.3159 0.0645 35	-0.6459 0.0001 126	-0.8047 0.0001 18
STDPCLIG	. .	0.3743 0.0455 29	. .	0.8727 0.0002 12
PCN	-0.4002 0.0001 131	-0.5032 0.0144 23	-0.5598 0.0045 24	-0.5853 0.2223 6
PCP	-0.1902 0.0295 131	-0.3885 0.0669 23	0.2403 0.2579 24	-0.7510 0.0853 6
L60	-0.2736 0.0003 167	-0.3810 0.0729 23	0.0427 0.7883 42	0.0444 0.9335 6
L76	0.2495 0.0001 251	0.4159 0.0130 35	-0.0636 0.4791 126	0.0049 0.9846 18
M76	0.3235 0.0001 209	0.5576 0.0017 29	0.1555 0.1577 84	0.3282 0.2976 12
T76	0.0314 0.6521 209	0.1081 0.5766 29	-0.2306 0.0348 84	-0.2458 0.4412 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

Table 76. Pearson correlation coefficients for transformed bulk maple litter sample mass loss data[a] from the control plantation, with potential covariates and available electromagnetic field strength variables.

Variable[b]	May-Nov	Nov	May-Nov	Nov
	1985-1990	1985-1990	1988-1990	1988-1990
AET	-0.7067[c] 0.0001[d] 250[e]	-0.4057 0.0141 36	-0.7444 0.0001 125	-0.6556 0.0031 18
ATDDRT	-0.6736 0.0001 250	0.1365 0.4271 36	-0.7593 0.0001 125	-0.3744 0.1258 18
ST5DDRT	-0.6856 0.0001 250	0.0053 0.9754 36	-0.7456 0.0001 125	-0.3206 0.1945 18
PRWRT	-0.7156 0.0001 250	-0.4971 0.0020 36	-0.7165 0.0001 125	-0.4945 0.0370 18
PR.10RT	-0.7216 0.0001 250	-0.3480 0.0376 36	-0.6628 0.0001 125	-0.2224 0.3751 18
STDPCLIG	. . 	0.5908 0.0006 30	. . 	0.9440 0.0001 12
PCN	-0.5850 0.0001 130	-0.5151 0.0100 24	-0.6821 0.0003 23	-0.2768 0.5953 6
PCP	-0.5081 0.0001 130	-0.4141 0.0442 24	-0.1035 0.6384 23	0.0042 0.9936 6
L60	0.0336 0.6675 166	0.3357 0.1088 24	0.1130 0.4818 41	0.8107 0.0504 6
L76	0.0000 1.0000 250	0.0000 1.0000 36	0.0000 1.0000 125	0.0000 1.0000 18
M76	0.0000 1.0000 208	0.0000 1.0000 30	0.0000 1.0000 83	0.0000 1.0000 12
T76	0.0000 1.0000 208	0.0000 1.0000 30	0.0000 1.0000 83	0.0000 1.0000 12

a/ arcsin square root of Xw, the proportion of initial dry matter mass remaining
b/ see Table 46 for definitions of variables
c/ R
d/ Significance of R
e/ number of observations

ANACOV Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter (Hardwood Stands)

Table 77 presents partial results from several of the bulk pine ANACOV models tested on the hardwood stand data set. Tables 78-80 present the ANACOV tables for models 11-13. SAS could not derive multiple comparisons for models 11-13, because of the nature of the variable STDPCLIG. Note that STDPCLIG has 0 degrees of freedom in our ANACOV models. None of the combinations of covariates tested, except for certain models containing the 76 Hz and/or 60 Hz field strengths, appeared to explain all differences among the years included in the ANACOVs (mainly 1985-1988). The same was true for the year-by-site interaction. No combination of covariates explained differences among months, but this was not considered to be a primary objective, and electromagnetic field data are only available on an annual basis. It is interesting to note that addition of L60 as a covariate to the six covariates in model 11 provides a model (model 12) which appears to explain differences among both years and sites, as well as the year-by-site interaction. Further addition of the 76 Hz field strength variables to model 12 appears to improve the explanation of year-by-site interaction (model 13).

We are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models. It seems possible that they may behave largely as categorical variables in apparently explaining differences among years and sites (and year-by-site interaction), especially considering the relatively small number of years included in the analysis so far. Also, the P values achieved by all four electromagnetic field strength variables (models 12 and 13, Tables 79 and 80) are very high, raising questions about the nature of their contributions to a real explanation of year and site differences. In this regard, however, both PCN and PCP also have P values considerably greater than 0.05, in models 11-13 (Tables 78-80).

Table 77. Results of selected **covariance** analyses for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining from **bulk pine** needle samples in the two **hardwood stand** subunits.

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Hardwood Stand	Y*S	Month
	(ANOVA)	1985-1990	0.0001	0.0148	0.0001	0.0000
1	AET	1985-1990	0.0001	0.0004	0.0001	0.0001
2	ATDDRT	1985-1990	0.0001	0.0001	0.0001	0.0001
3	ST5DDRT	1985-1990	0.0001	0.0001	0.0001	0.0001
4	PRWRT	1985-1990	0.0001	0.0001	0.0001	0.0001
5	PR.10RT	1985-1990	0.0001	0.0001	0.0001	0.0001
6	STDPCLIG	1985-1989	0.0001	0.0015	0.0001	0.0000
7	PCN	1985-1988	0.0001	0.1877	0.0001	0.0000
8	PCP	1985-1988	0.0001	0.0644	0.0001	0.0000
9	L60	1985-1988	0.0001	0.8188	0.0001	0.0000
10	T76,M76,T76	1985-1989	0.0001	0.1098	0.0157	0.0000
11	ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN,PCP,	1985-1988	0.0001	0.0001	0.0018	0.0001
12	ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN,PCP,L60	1985-1988	0.7740	0.9259	0.2215	0.0001
13	ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN,PCP,L60, L76,M76,T76	1985-1988	0.8843	0.8041	0.7561	0.0001

a/ See Table 46 for definitions of covariates.
b/ constrained by availability of data at time of analysis.

Table 78. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, using the following covariates: ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, PCP, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	22	2.91		178.31	0.0000	0.94
Year	3		0.03	17.13	0.0001	
Hardwood Stand	1		0.02	24.35	0.0001	
Year * Stand	3		0.01	5.14	0.0018	
Plot (Stand)	4		0.01	3.08	0.0169	
Month	6		0.03	6.57	0.0001	
ST5DDRT	1		0.01	14.19	0.0002	
PRWRT	1		0.01	15.55	0.0001	
PR.10RT	1		0.01	16.81	0.0001	
STDPCLIG	0		0.00	.	.	
PCN	1		0.00	1.23	0.2676	
PCP	1		0.00	2.52	0.1139	
Error	239	0.18				
Corrected Total	261	3.08				

Table 79. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, using the following covariates: ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, PCP, L60, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	23	2.91		169.91	0.0000	0.94
Year	3		0.00	0.26	0.7740	
Hardwood Stand	1		0.00	0.01	0.9259	
Year * Stand	3		0.00	1.48	0.2215	
Plot (Stand)	4		0.01	2.85	0.0247	
Month	6		0.03	6.54	0.0001	
ST5DDRT	1		0.01	14.16	0.0002	
PRWRT	1		0.01	15.48	0.0001	
PR.10RT	1		0.01	16.75	0.0001	
STDPCLIG	0		0.00	.	.	
PCN	1		0.00	1.24	0.2658	
PCP	1		0.00	2.48	0.1169	
L60	1		0.00	0.03	0.8611	
Error	238	0.18				
Corrected Total	261	3.08				

Table 80. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, using the following covariates: ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, PCP, L60, L76, M76, T76 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	26	2.91		148.91	0.0000	0.94
Year	3		0.00	0.12	0.8843	
Hardwood Stand	1		0.00	0.06	0.8041	
Year * Stand	3		0.00	0.40	0.7561	
Plot (Stand)	4		0.01	2.63	0.0353	
Month	6		0.03	6.48	0.0001	
ST5DDRT	1		0.01	14.31	0.0002	
PRWRT	1		0.01	15.27	0.0001	
PR.10RT	1		0.01	16.51	0.0001	
STDPCLIG	0		0.00	.	.	
PCN	1		0.00	1.19	0.2771	
PCP	1		0.00	2.45	0.1189	
L60	1		0.00	0.10	0.7497	
L76	1		0.00	0.00	0.9920	
M76	1		0.00	0.18	0.6676	
T76	1		0.00	0.33	0.5677	
Error	235	0.18				
Corrected Total	261	3.08				

Bulk Oak Leaf Litter (Hardwood Stands)

Table 81 presents partial results from several of the bulk oak ANACOV models tested on the hardwood stand data set. Tables 82-83 present the ANACOV tables for models 11-13. Again, SAS could not derive multiple comparisons for models 11-13, because of the nature of the variable STDPCLIG. None of the combinations of covariates tested, except for certain models containing the 76 Hz and/or 60 Hz field strengths, appeared to explain all differences among the years included in the ANACOVs (mainly 1985-1988). The same was true for the year-by-site interaction ($\alpha = 0.05$). Again, no combination of covariates explained differences among months. Though ANOVA did not detect a significant difference between the control vs. antenna hardwood stands, several individual covariates (i.e., AET, PRWRT, PR.10RT, STDPCLIG, PCN, PCP) raised the P value for differences among sites to levels higher than those derived through ANOVA. It is interesting to note, however, that addition of L60 as a covariate to the three covariates in model 11 provides a model (model 12) which appears to explain differences among both years and sites, though the year-by-site interaction remains unexplained. Further addition of the 76 Hz field strength variables to model 12 appears to explain, in addition, the year-by-site interaction (model 13).

Again, we are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models, for the same reasons discussed above with respect to bulk pine litter decomposition. Note, however, that AET also has a high P value in models 11-13 (Tables 82-83).

Table 81. Results of selected **covariance** analyses for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining from **bulk oak** leaf samples in the two **hardwood stand** subunits.

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Hardwood Stand	Y*S	Month
	(ANOVA)	1985-1990	0.0001	0.1180	0.0001	0.0000
1	AET	1985-1990	0.0001	0.2522	0.0001	0.0001
2	ATDDRT	1985-1990	0.0001	0.0012	0.0001	0.0001
3	ST5DDRT	1985-1990	0.0001	0.0714	0.0001	0.0001
4	PRWRT	1985-1990	0.0001	0.1545	0.0001	0.0001
5	PR.10RT	1985-1990	0.0001	0.7365	0.0001	0.0001
6	STDPCLIG	1985-1989	0.0001	0.8924	0.0001	0.0000
7	PCN	1985-1988	0.0001	0.6303	0.0001	0.0000
8	PCP	1985-1988	0.0001	0.6429	0.0001	0.0000
9	L60	1985-1988	0.0001	0.2793	0.0001	0.0000
10	L76,M76,T76	1985-1989	0.0001	0.2999	0.0014	0.0000
11	AET, PCN, STDPCLIG	1985-1988	0.0001	0.7226	0.0001	0.0001
12	AET, PCN, STDPCLIG, L60	1985-1988	0.1701	0.6500	0.0001	0.0001
13	AET, PCN, STDPCLIG, L60,L76,M76, T76	1985-1988	0.2495	0.8543	0.0708	0.0001

a/ See Table 46 for definitions of covariates.
b/ constrained by availability of data at time of analysis

Table 82. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, using the following covariates: AET, STDPCLIG, PCN, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	19	3.80		111.29	0.0000	0.90
Year	3		0.17	45.94	0.0001	
Hardwood Stand	1		0.00	0.13	0.7226	
Year * Stand	3		0.05	9.52	0.0001	
Plot (Stand)	4		0.01	1.05	0.3812	
Month	6		0.29	26.77	0.0001	
AET	1		0.00	0.35	0.5529	
STDPCLIG	0		0.00	.	.	
PCN	1		0.01	8.09	0.0046	
Error	241	0.43				
Corrected Total	260	4.23				

Table 83. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, using the following covariates: AET, STDPCLIG, PCN, L60, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	3.80		105.39	0.0000	0.90
Year	3		0.01	1.78	0.1701	
Hardwood Stand	1		0.00	0.21	0.6500	
Year * Stand	3		0.04	8.07	0.0001	
Plot (Stand)	4		0.01	1.03	0.3945	
Month	6		0.29	26.71	0.0001	
AET	1		0.00	0.33	0.5677	
STDPCLIG	0		0.00	.	.	
PCN	1		0.01	8.19	0.0046	
L60	1		0.00	0.21	0.6467	
Error	240	0.43				
Corrected Total	260	4.23				

Table 84. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, using the following covariates: AET, STDPCLIG, PCN, L60, L76, M76, T76 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	23	3.80		91.57	0.0000	0.90
Year	3		0.01	1.40	0.2495	
Hardwood Stand	1		0.00	0.03	0.8543	
Year * Stand	3		0.01	2.37	0.0708	
Plot (Stand)	4		0.01	0.82	0.5154	
Month	6		0.29	26.55	0.0001	
AET	1		0.00	0.37	0.5424	
STDPCLIG	0		0.00	.	.	
PCN	1		0.01	8.09	0.0048	
L60	1		0.00	0.04	0.8328	
L76	1		0.00	0.71	0.3989	
M76	1		0.00	0.02	0.8764	
T76	1		0.00	0.54	0.4615	
Error	237	0.43				
Corrected Total	260	4.23				

Bulk Maple Leaf Litter (Hardwood Stands)

Table 85 presents partial results from several of the bulk maple ANACOV models tested on the hardwood stand data set. Tables 86-88 present the ANACOV tables for models 11-13. Once again, SAS could not derive multiple comparisons for models 11-13, because of the nature of the variable STDPCLIG. None of the combinations of covariates tested, except for certain models containing the 76 Hz and 60 Hz field strength variables (e.g., model 13), appeared to explain all differences among the years included in the ANACOVs (mainly 1985-1988). The same was true for the year-by-site interaction. Again, no combination of covariates explained differences among months, but this was not considered to be a primary objective. Again, addition of L60 as a covariate to the four covariates in model 11 provides a model (model 12) which appears to explain differences among sites, and addition of the 76 Hz field strength variables to model 12 appears to explain the differences among years and the year-by-site interaction as well (model 13).

Once again, we are very concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models, for the same reasons discussed above with respect to bulk pine litter decomposition. In the cases of models 11-13, Aet and PCP both have P values greater than 0.05.

Table 85. Results of selected **covariance** analyses for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining from **bulk maple** leaf samples in the two **hardwood stand** subunits.

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Hardwood Stand	Y*S	Month
	(ANOVA)	1985-1990	0.0000	0.5535	0.0001	0.0000
1	AET	1985-1990	0.0000	0.0001	0.0001	0.0001
2	ATDDRT	1985-1990	0.0000	0.0001	0.0001	0.0001
3	ST5DDRT	1985-1990	0.0000	0.0001	0.0001	0.0001
4	PRWRT	1985-1990	0.0000	0.0001	0.0001	0.0001
5	PR.10RT	1985-1990	0.0000	0.0001	0.0001	0.0001
6	STDPCLIG	1985-1989	0.0000	0.0001	0.0001	0.0000
7	PCN	1985-1988	0.0000	0.0057	0.0001	0.0001
8	PCP	1985-1988	0.0000	0.0189	0.0002	0.0000
9	L60	1985-1988	0.0001	0.6252	0.0019	0.0000
10	L76,M76,T76	1985-1989	0.0000	0.0242	0.0016	0.0000
11	AET,PCN,PCP, STDPCLIG,	1985-1988	0.0001	0.0056	0.0001	0.0001
12	AET,PCN,PCP, STDPCLIG, L60	1985-1988	0.0009	0.8761	0.0080	0.0001
13	AET,PCN,PCP, STDPCLIG, L60,L76,M76, T76	1985-1988	0.1340	0.7685	0.2469	0.0001

a/ See Table 46 for definitions of covariates.
b/ constrained by availability of data at time of analysis

Table 86. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, using the following covariates: AET, STDPCLIG, PCN, PCP (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	20	3.21		120.00	0.0000	0.91
Year	3		0.23	87.37	0.0001	
Hardwood Stand	1		0.01	7.82	0.0056	
Year * Stand	3		0.03	7.29	0.0001	
Plot (Stand)	4		0.01	1.04	0.3869	
Month	6		0.12	15.26	0.0001	
AET	1		0.00	1.48	0.2245	
STDPCLIG	0		0.00	.	.	
PCN	1		0.01	8.73	0.0034	
PCP	1		0.00	2.10	0.1486	
Error	240	0.32				
Corrected Total	260	3.53				

Table 87. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, using the following covariates: AET, STDPCLIG, PCN, PCP, L60 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	21	3.21		113.82	0.0000	0.91
Year	3		0.02	7.19	0.0009	
Hardwood Stand	1		0.00	0.02	0.8761	
Year * Stand	3		0.02	4.03	0.0080	
Plot (Stand)	4		0.00	0.14	0.9666	
Month	6		0.12	15.20	0.0001	
AET	1		0.00	1.49	0.2240	
STDPCLIG	0		0.00	.	.	
PCN	1		0.01	8.66	0.0036	
PCP	1		0.00	2.07	0.1512	
L60	1		0.00	0.01	0.9057	
Error	239	0.32				
Corrected Total	260	3.53				

Table 88. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, using the following covariates: AET, STDPCLIG, PCN, PCP, L60, L76, M76, T76 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	24	3.21		98.58	0.0000	0.91
Year	3		0.01	2.03	0.1340	
Hardwood Stand	1		0.00	0.09	0.7685	
Year * Stand	3		0.01	1.39	0.2469	
Plot (Stand)	4		0.00	0.25	0.9099	
Month	6		0.12	14.95	0.0001	
AET	1		0.00	1.41	0.2363	
STDPCLIG	0		0.00	.	.	
PCN	1		0.01	8.39	0.0041	
PCP	1		0.00	1.71	0.1924	
L60	1		0.00	0.11	0.7442	
L76	1		0.00	0.06	0.8130	
M76	1		0.00	0.37	0.5434	
T76	1		0.00	0.16	0.6883	
Error	236	0.32				
Corrected Total	260	3.53				

Bulk Pine Needle Litter (Plantations)

Table 89 presents partial results from several of the bulk pine ANACOV models tested on the plantation data set. Tables 90-91 present the ANACOV tables for models 12-14. SAS could not derive multiple comparisons for models 12-14, because of the nature of the variable STDPCLIG. Model 8, including PR.10RT and STDPCLIG as covariates, barely explained the year-by-site interaction, but without explaining either years or plantations. The covariate combination in model 12 (ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, and PCP) provided a higher p value for the year-by-site interaction, but considered one fewer years (1985 - 1988 vs. 1985 - 1989). Adding L60 as a covariate (model 13) further raised the p value for year-by-site interaction, again without explaining years or plantations. Including the 76 Hz field strengths (model 14) appeared to explain all differences among the plantations, as well as the year-by-site interaction. No combination of covariates explained differences among months, but again this was not considered to be a primary objective, and electromagnetic field data are only available on an annual basis.

Here again, we are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models. It seems possible that they may behave largely as categorical variables in apparently explaining differences among years and sites (and year-by-site interaction), especially considering the relatively small number of years included in the analysis so far. Also, the P values achieved by all four electromagnetic field strength variables (models 13 and 14, Tables 91 and 92) are very high, raising questions about the nature of their contributions to a real explanation of year and site differences. In this regard, however, other more satisfactory covariates also have P values considerably greater than 0.05, in models 12-14 (Tables 90-92).

Table 89. Results of selected **covariance** analyses for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining from **bulk pine** needle samples in the three **plantation** subunits.

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Plantation	Y*S	Month
	(ANOVA)	1985-1990	0.0001	0.0006	0.0065	0.0000
1	AET	1985-1990	0.0001	0.0001	0.0005	0.0001
2	ATDDRT	1985-1990	0.0001	0.0001	0.0071	0.0001
3	ST5DDRT	1985-1990	0.0001	0.0001	0.0032	0.0001
4	PRWRT	1985-1990	0.0001	0.0001	0.0025	0.0001
5	PR.01RT	1985-1990	0.0001	0.0001	0.0004	0.0001
6	PR.10RT	1985-1990	0.0001	0.0001	0.0458	0.0001
7	STDPCLIG	1985-1989	0.0001	0.0001	0.0023	0.0000
8	PR.10RT, STDPCLIG	1985-1989	0.0001	0.0001	0.0589	0.0001
9	PCN	1985-1988	0.0001	0.0001	0.0161	0.0000
10	PCP	1985-1988	0.0001	0.0001	0.0308	0.0000
11	L60	1985-1988	0.0001	0.0001	0.0039	0.0000
12	ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN,PCP,	1985-1988	0.0001	0.0001	0.1126	0.0002
13	ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN,PCP,L60	1985-1988	0.0001	0.0001	0.2987	0.0002
14	ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN,PCP,L60, L76,M76,T76	1985-1988	0.0026	0.2153	0.6985	0.0002

a/ See Table 46 for definitions of covariates.
b/ constrained by availability of data at time of analysis.

Table 90. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, using the following covariates: ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, PCP, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	28	3.64		124.29	0.0000	0.90
Year	3		0.05	21.99	0.0001	
Plantation	2		0.03	14.03	0.0001	
Year * Site	6		0.01	1.73	0.1126	
Plot (Site)	6		0.01	2.17	0.0454	
Month	6		0.03	4.63	0.0002	
ST5DDRT	1		0.01	1.36	0.2445	
PRWRT	1		0.00	0.72	0.3968	
PR.10RT	1		0.00	0.36	0.5472	
STDPCLIG	0		0.00	.	.	
PCN	1		0.00	0.12	0.7332	
PCP	1		0.00	0.45	0.5032	
Error	365	0.38				
Corrected Total	393	4.02				

Table 91. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, using the following covariates: ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, PCP, L60, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	29	3.64		119.69	0.0000	0.90
Year	3		0.02	10.54	0.0001	
Plantation	2		0.03	13.85	0.0001	
Year * Site	6		0.01	1.21	0.2987	
Plot (Site)	6		0.01	2.16	0.0460	
Month	6		0.03	4.62	0.0002	
ST5DDRT	1		0.00	1.35	0.2458	
PRWRT	1		0.00	0.72	0.3980	
PR.10RT	1		0.00	0.36	0.5476	
STDPCLIG	0		0.00	.	.	
PCN	1		0.00	0.11	0.7367	
PCP	1		0.00	0.43	0.5104	
L60	1		0.00	0.05	0.8267	
Error	364	0.38				
Corrected Total	393	4.02				

Table 92. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, using the following covariates: ST5DDRT, PRWRT, PR.10RT, STDPCLIG, PCN, PCP, L60, L76, M76, T76 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	32	3.64		108.05	0.0000	0.91
Year	3		0.01	6.03	0.0026	
Plantation	2		0.00	1.54	0.2153	
Year * Site	6		0.00	0.64	0.6985	
Plot (Site)	6		0.01	2.01	0.0638	
Month	6		0.03	4.59	0.0002	
ST5DDRT	1		0.00	1.29	0.2568	
PRWRT	1		0.00	0.72	0.3982	
PR.10RT	1		0.00	0.36	0.5470	
STDPCLIG	0		0.00	.	.	
PCN	1		0.00	0.11	0.7460	
PCP	1		0.00	0.48	0.4873	
L60	1		0.00	0.00	0.9992	
L76	1		0.00	0.59	0.4410	
M76	1		0.00	0.21	0.6450	
T76	1		0.00	0.39	0.5301	
Error	361	0.38				
Corrected Total	393	4.02				

Bulk Oak Leaf Litter (Plantations)

Table 93 presents partial results from several of the bulk oak ANACOV models tested on the plantation data set. Tables 94-96 present the ANACOV tables for models 11-13. Again, SAS could not derive multiple comparisons for models 11-13, because of the nature of the variable STDPCLIG. Several of the models (numbers 8-12) explained the year-by-site interaction without explaining years or plantations. Only model 13, which included both the 76 Hz and 60 Hz field strengths, appeared to explain all differences among plantations as well as the year-by-site interaction. None of the models explained years, and as usual, no combination of covariates explained differences among months.

Again, we are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models, for the same reasons discussed above with respect to bulk pine litter decomposition. Note, however, that AET also has a high P value in models 11-13 (Tables 94-96).

Bulk Maple Leaf Litter (Plantations)

Table 97 presents partial results from several of the bulk maple ANACOV models tested on the plantation data set. Tables 98-100 present the ANACOV tables for models 11-13. In this case, none of the combinations of covariates tested were able to explain differences among years, plantations, or months, or the year-by-site interaction.

Table 93. Results of selected **covariance** analyses for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining from **bulk oak** leaf samples in the three **plantation** subunits.

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Plantation	Y*S	Month
	(ANOVA)	1985-1990	0.0001	0.7378	0.0034	0.0000
1	AET	1985-1990	0.0001	0.0001	0.0028	0.0001
2	ATDDRT	1985-1990	0.0001	0.0015	0.0037	0.0001
3	ST5DDRT	1985-1990	0.0001	0.0001	0.0036	0.0001
4	PRWRT	1985-1990	0.0001	0.0015	0.0088	0.0001
5	PR.01RT	1985-1990	0.0001	0.0001	0.0006	0.0001
6	PR.10RT	1985-1990	0.0001	0.0001	0.0034	0.0001
7	STDPCLIG	1985-1989	0.0001	0.0001	0.0343	0.0000
8	PCN	1985-1988	0.0001	0.0010	0.2011	0.0000
9	PCP	1985-1988	0.0001	0.0004	0.3313	0.0000
10	L60	1985-1988	0.0001	0.0004	0.4192	0.0000
11	AET, PCN,	1985-1988	0.0001	0.0014	0.1916	0.0001
12	AET, PCN, L60	1985-1988	0.0001	0.0296	0.5886	0.0001
13	AET, PCN, L60,L76,M76, T76	1985-1988	0.0001	0.1010	0.6157	0.0001

a/ See Table 46 for definitions of covariates.
b/ constrained by availability of data at time of analysis

Table 94. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the three plantation subunits, using the following covariates: AET, PCN, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	25	5.53		93.80	0.0000	0.86
Year	3		0.14	20.06	0.0001	
Plantation	2		0.03	6.67	0.0014	
Year * Site	6		0.02	1.46	0.1916	
Plot (Site)	6		0.01	0.58	0.7433	
Month	6		0.20	14.17	0.0001	
AET	1		0.00	0.21	0.6475	
PCN	1		0.04	17.72	0.0001	
Error	367	0.86				
Corrected Total	392	6.39				

Table 95. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, using the following covariates: AET, PCN, L60, (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	26	5.53		90.19	0.0000	0.86
Year	3		0.14	20.33	0.0001	
Plantation	2		0.02	3.56	0.0296	
Year * Site	6		0.01	0.78	0.5886	
Plot (Site)	6		0.01	0.43	0.8557	
Month	6		0.20	14.18	0.0001	
AET	1		0.00	0.17	0.6815	
PCN	1		0.04	17.54	0.0001	
L60	1		0.00	0.85	0.3576	
Error	366	0.86				
Corrected Total	392	6.39				

Table 96. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, using the following covariates: AET, PCN, L60, L76, M76, T76 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	29	5.53		80.67	0.0000	0.87
Year	3		0.14	20.19	0.0001	
Plantation	2		0.01	2.31	0.1010	
Year * Site	6		0.01	0.74	0.6157	
Plot (Site)	6		0.01	0.40	0.8799	
Month	6		0.20	14.10	0.0001	
AET	1		0.00	0.16	0.6904	
PCN	1		0.04	17.67	0.0001	
L60	1		0.00	1.33	0.2487	
L76	1		0.00	0.98	0.3222	
M76	1		0.00	0.26	0.6112	
T76	1		0.00	0.30	0.5821	
Error	363	0.86				
Corrected Total	392	6.39				

Table 97. Results of selected **covariance** analyses for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining from **bulk maple** leaf samples in the three **plantation** subunits.

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Plantation	Y*S	Month
	(ANOVA)	1985-1990	0.0000	0.3013	0.0001	0.0000
1	AET	1985-1990	0.0000	0.0001	0.0001	0.0001
2	ATDDRT	1985-1990	0.0000	0.0004	0.0001	0.0001
3	ST5DDRT	1985-1990	0.0000	0.0001	0.0001	0.0001
4	PRWRT	1985-1990	0.0000	0.0001	0.0001	0.0001
5	PR.01RT	1985-1990	0.0000	0.0001	0.0001	0.0001
6	PR.10RT	1985-1990	0.0000	0.0001	0.0001	0.0001
7	STDPCLIG	1985-1989	0.0000	0.0001	0.0001	0.0000
8	PCN	1985-1988	0.0001	0.0001	0.0002	0.0001
9	PCP	1985-1988	0.0001	0.0001	0.0001	0.0000
10	L60	1985-1988	0.0000	0.0001	0.0006	0.0000
11	AET,PCN,PCP, STDPCLIG,	1985-1988	0.0001	0.0001	0.0001	0.0001
12	AET,PCN,PCP, STDPCLIG, L60	1985-1988	0.0001	0.0001	0.0091	0.0001
13	AET,PCN,PCP, STDPCLIG, L60,L76,M76, T76	1985-1988	0.0001	0.0002	0.0002	0.0001

a/ See Table 46 for definitions of covariates.
b/ constrained by availability of data at time of analysis

Table 98. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, using the following covariates: AET, STDPCLIG, PCN, PCP (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	26	6.31		90.77	0.0000	0.87
Year	3		0.47	87.53	0.0001	
Plantation	2		0.08	15.92	0.0001	
Year * Site	6		0.07	4.68	0.0001	
Plot (Site)	6		0.06	3.95	0.0008	
Month	6		0.11	6.80	0.0001	
AET	1		0.02	9.14	0.0027	
STDPCLIG	0		0.00	.	.	
PCN	1		0.04	15.87	0.0001	
PCP	1		0.05	18.34	0.0001	
Error	364	0.97				
Corrected Total	390	7.28				

Table 99. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, using the following covariates: AET, STDPCLIG, PCN, PCP, L60 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	27	6.33		89.13	0.0000	0.87
Year	3		0.30	57.31	0.0001	
Plantation	2		0.06	10.90	0.0001	
Year * Site	6		0.05	2.89	0.0091	
Plot (Site)	6		0.05	2.92	0.0085	
Month	6		0.11	7.10	0.0001	
AET	1		0.03	10.05	0.0017	
STDPCLIG	0		0.00	.	.	
PCN	1		0.04	15.70	0.0001	
PCP	1		0.04	16.92	0.0001	
L60	1		0.02	7.09	0.0081	
Error	363	0.94				
Corrected Total	390	7.28				

Table 100. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, using the following covariates: AET, STDPCLIG, PCN, PCP, L60, L76, M76, T76 (see Table 46 for definitions).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	30	6.36		82.58	0.0000	0.87
Year	3		0.09	17.62	0.0001	
Plantation	2		0.05	8.94	0.0002	
Year * Site	6		0.07	4.53	0.0002	
Plot (Site)	6		0.04	2.90	0.0089	
Month	6		0.11	7.10	0.0001	
AET	1		0.02	9.62	0.0021	
STDPCLIG	0		0.00	.	.	
PCN	1		0.05	19.63	0.0001	
PCP	1		0.06	22.71	0.0001	
L60	1		0.04	13.85	0.0002	
L76	1		0.01	3.62	0.0579	
M76	1		0.00	0.14	0.7038	
T76	1		0.01	4.93	0.0270	
Error	360	0.92				
Corrected Total	390	7.28				

ANACOV Results - Summary

The major goals of our ANACOV analysis are tc explain as many as possible of the differences in decomposition rate detected by ANOVA 1) between the two hardwood stands and between the three plantations, and 2) among years, and especially 3) to explain any year-by-site interaction. This will be especially challenging for the plantations, because they are changing rapidly and becoming increasingly different with age.

We anticipate that explanation of all differences in decomposition rate among years for all litter sample types is probably an unrealistic goal, especially in the plantation subunits, where vegetational changes are proceeding at different rates and interacting with yearly weather differences. It is not surprising that effects model ANOVAs ranked years differently for each litter species. The annual parent litter collections probably differ somewhat in quality as decomposition substrata, even though the parent collections for each species have been taken from the same location for all years. Differences in insect defoliator activity among years, for example, have been noted, and to the extent that years rank differently in substrate quality for the three litter species, it should be expected that substrate quality would exert a similar influence on the ranking of years for dry matter mass loss for the three species.

Covariates are proving useful for explaining differences detected by ANOVA in dry matter mass loss among hardwood stands, plantations, and years. Use of covariates is an important tool for explaining the generally significant year-by-site interactions detected by ANOVA. Useful covariates so far include actual evapotranspiration (AET), total precipitation, precipitation event frequency, air and soil temperature degree days, and initial lignin content. Nevertheless, for several reasons, we expect that ANACOV will become more effective as our understanding of the decomposition process, as influenced by the ELF study area ecosystem, allows us to design more appropriate covariates.

Two approaches are being taken to improve the effectiveness of covariate analysis. Both approaches address in effect the basic nonlinearity of litter decomposition progress at the ELF study sites. First, the data collected in early November will not be included in ANOVA or ANACOV models in future reports, because of an apparent shift during October in the relationship between sample decomposition and sample mass loss. We have noticed that the early November mass loss data commonly demonstrate a slow-down in mass loss during October, especially at the site where mass loss through September was fastest. In some cases, sample mass gains occur during October. These mass loss slow-downs or mass gains appear to result in artificially similar estimates of the year-end state of sample decomposition, and in some cases, indicate a reversal of site ranking. We presume that decomposition is actually proceeding during October, but that sample mass loss due to decomposition is being masked by additions of inorganic mass and microbial biomass associated with an advanced state of decomposition. Presuming this to be the case, exclusion of the early November data from analysis should improve the effectiveness of both our ANOVA and ANACOV modeling efforts. ANOVA would provide clearer recognition of differences in mass loss rates among plantations and hardwood stands, and the effectiveness of our ANACOV models, which are largely based on the driving influence of weather variables on mass loss progress, should be substantially improved. Indeed, the correlations between weather variables (including AET) and mass loss are much poorer, and frequently non-significant, for the November-only data set vs. the May through November data set. Second, we are developing an additional set of covariates, based on monthly (and seasonal) contributions of energy and moisture to the decomposition system. This set of covariates (e.g., degree days, total precipitation, and frequency of precipitation for each month or season) should permit expression of the differential seasonal effects of energy inputs with respect to concurrent precipitation inputs.

We are concerned about the appropriateness of including

electromagnetic field strength variables in our ANACOV models. It seems possible that they may behave largely as categorical variables in apparently explaining differences among years and sites (and year-by-site interaction), especially considering the relatively small number of years included in the analysis so far. Also, the P values achieved by all four electromagnetic field strength variables (L60, L76, M76, and T76) are very high, raising questions about the nature of their contributions to a real explanation of year and site differences. In this regard, however, AET, PCN and PCP also have P values in a number of interesting models. At present, however, it remains that 76 Hz and/or 60 Hz electromagnetic field exposures contributed strongly with other more satisfactory covariates toward accounting for more differences among years, sites, and year-by-site interactions than did other groups of covariates without electromagnetic field exposure variables.

Element 2: RED PINE SEEDLING RHIZOPLANE STREPTOMYCETES

Introduction

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectomycorrhizae, and can influence mycorrhizosphere microbial population composition through production and excretion of compounds such as antibiotics, vitamins, amino acids, and hormones (Marx 1982, Keast and Tonkin 1983, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk et al. 1987, Richter et al. 1989). Streptomycetes have also been found to degrade calcium oxalate, cellulose, and lignin/lignocellulose, in both coniferous and deciduous litter systems (Graustein et al. 1977, Crawford 1978, Knutson et al. 1980, Antai and Crawford 1981, McCarthy and Broda 1984). Mycorrhizal fungi are not capable of degrading either cellulose or lignin, though many saprotrophic fungi are.

As part of the indigenous soil, rhizosphere, and rhizoplane microflora, populations of streptomycetes are not considered to undergo great population changes in stable ecosystems (Orchard 1984). Streptomycete populations functionally associated with the mycorrhizae of the planted red pine seedlings were therefore selected for inclusion in these long-term studies assessing potential impacts of ELF electromagnetic fields. As noted in the Introduction, the hypotheses to be tested are that there are no differences in either 1) the overall or seasonal levels of mycorrhizoplane streptomycete populations, or 2) the detectable presence of different identifiable strains of mycorrhizoplane streptomycetes, that cannot be explained using factors unaffected by ELF antenna operations.

The value of the red pine mycorrhiza studies being conducted by the Herbaceous Plant Cover and Tree Studies ("Trees") project is also greatly enhanced through quantitative study of the associated streptomycete populations. For instance, in cognate studies, we have found that in vitro growth rates of several common mycorrhizal fungus species are differentially affected by

certain streptomycete morphotypes isolated from the mycorrhizoplane of ELF plantation red pine seedlings (Richter et al. 1989, Paetchow 1990). Some of these same morphotypes also inhibit the growth of Armillaria spp. (Becker et al. 1990), one of which causes the only fatal disease encountered so far among the plantation red pine seedlings (Moore 1989, Bruhn et al. 1989, Smith et al. 1990).

The emphasis of this element during the 1990 sampling season continued to be the enumeration and characterization (into morphological types or morphotypes) of streptomycetes associated with the red pine mycorrhizal rhizoplane (i.e., washed mycorrhizal fine roots). As has been the case from 1985 through 1989, the mycorrhizal condition of red pine seedlings in the ground, antenna, and control site plantations was followed on a monthly basis in 1990, from May through October, by staff of the "Trees" project. Type 3 mycorrhizae continue to predominate in all three ELF study plantations, probably because they are most often caused by species of Laccaria and/or Thelephora which occur naturally both in the study area and in the nursery from which the seedlings were originally obtained. Samples of the Type 3 red pine mycorrhizae collected and identified from each of the ELF study red pine plantations were provided to this study, for analysis of streptomycete population dynamics. Detailed information on the 1990 red pine seedling mycorrhiza populations can be found in the 1990 Draft Annual Report of the "Trees" project (Element 4, Mycorrhizae Characterization and Root Growth). The total numbers of mycorrhizae per gram of sampled red pine root weight in 1990 were still lower than in 1985 through 1987, but continued to rise slightly higher than 1988 and 1989 levels. ANOVA on the six-year data set did not detect any significant differences between sites in mycorrhizae per gram of sampled root (either total or type 3), nor was the year by site interaction significant. Numbers of mycorrhizae per gram of root weight in 1990 were not significantly different from those determined for 1986 through 1989.

As in previous years, the experimental design called for

analysis of six washed root samples (for macerate plate counts) per month from each of the three ELF study site red pine plantations. In addition to comparing data among plantations and sampling dates, the streptomycete level and morphotype data obtained during the 1990 sampling season were compared to data obtained for 1985 through 1989. The capabilities of the streptomycete morphotypes recovered to degrade calcium oxalate, cellulose, and lignocellulose have been determined previously. Only one 1990 isolate per morphotype was checked, for consistency. The degradative capacities of the morphotypes have been constant through the years.

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 are excavated per month on each of the three plots comprising each plantation. Two independent composite samples were derived from two to three of the seedlings from each plot. An exception occurred with the September, 1990, control plantation root samples, when only two samples from a single plot were available for testing. The same plantation plots were sampled in 1990 as in 1984 through 1989. 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. An average of 8.5 days (ranging from 7 to 10 days) were 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.

Using flame-sterilized forceps, 0.1 g (wet weight) of washed roots was placed in 9.9 ml of sterile buffer (0.01 M phosphate buffer, pH 7.2) and homogenized in a flame-sterilized 30 ml blender. This mixture was then transferred to a sterile, screw-cap test tube. Subsequent serial dilutions were made using the same type of sterile buffer. Two larger portions of the

washed roots (about 0.5 g each) were transferred to separate pre-weighed aluminum pans and weighed; these portions were then placed in a drying oven (60°C) for determination of dry weights. There was one exception to this procedure; insufficient root material was received for all of the October samples to allow for dry weight determinations.

As in the earlier studies, all washed root samples (after preparation and appropriate serial dilution) were spread-plated onto starch casein agar (SCA) in 100 x 15 mm petri dishes. Cycloheximide (50 mg/l) and nystatin (50 mg/l) were added to the SCA to prevent fungal growth (Andrews and Kennerly 1979, Goodfellow and Dawson 1978). Three dilutions (in duplicate) were spread-plated per sample. All plates were incubated at 20°C. Total numbers of streptomycete colonies were determined after 14 days incubation.

After enumeration, individual streptomycete colonies were characterized to determine the number of morphotypes per sample. All colonies with the same characteristics (i.e., presence/absence of diffusable pigment, presence/absence of aerial mycelium, color of aerial mycelium and any diffusable pigment, and reverse colony color) were considered to represent one morphological type or strain (Keast et al. 1984). Throughout the study, several colonies per streptomycete morphotype have been maintained in pure culture for further study. In order to evaluate the streptomycetes' potential contribution to mycorrhiza development and root growth, and to confirm previous results with each streptomycete type, one isolate of each type found during 1990 was tested to evaluate degradation of calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose (Smith 1977), and lignocellulose (Sutherland 1985). Both the numbers and identity (with respect to recurrence) of distinct streptomycete morphotypes found in the 1990 samples were compared to observations from similar samples for 1984 through 1989. This allowed us to determine if some of the same types are still present after the red pine seedlings have been in the field six years or more, and to determine whether the same types are

present in all three ELF study site plantations.

Data for streptomycete levels and morphotype numbers, based on the SCA plate counts, 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). Two-way analysis of variance was used to compare sampling dates and plantations within 1990. Three-way analysis of variance was used to compare years (1985 through 1990), sampling dates (month), and plantations (Zar 1984). Wherever these analyses showed significant differences ($\alpha = 0.05$) between years, sites, or sampling dates, the Least Squares Means procedure was used to conduct multiple comparisons between years, sites and/or sampling dates (SAS, PROC GLM).

Covariates are being used to help explain differences in streptomycete levels and/or morphotype numbers among years, plantations, and sampling dates. Table 46 presented the abbreviated names and definitions of all covariates used in any of the ANACOV models included in this report. Most of the covariates tested to date are weather-related variables, due both to their effectiveness and to their presumed independence of ELF field influence. So far, soil temperature (5 cm) and precipitation-related covariates have behaved in a fashion indicative of ELF-independence ("Trees" Annual Report 1989, Element 1. Development, Installation and Operation of the Ambient Monitoring System, pages 10-62). Wherever covariance analysis detected significant differences, the results of pairwise comparisons (SAS, PROC GLM, Least Squares Means option) are presented. The capability of our experimental design to detect changes in mean values for either streptomycete levels or morphotype numbers is approximated, by using the 95 percent confidence interval for each sample mean (least squares means and standard errors, in the case of covariance analysis) to calculate the minimum detectable change (expressed as a percentage of each sample mean).

Description of Progress

Data for 1990 streptomycete levels and morphotype numbers associated with washed type 3 mycorrhizal fine roots are presented in Tables 73 and 74, as the mean and the standard error of the sample mean, for up to six samples per plantation. The larger S.E. for the 1989 and 1990 levels and types compared to some of the previous years result partially from often having data from less than six samples per plantation and date. In 1989, this was due both to problems with the June and July samples (less than six samples provided per site or insufficient sample mass provided for replicate analyses) and with bacterial or fungal contamination of several of the samples. Problems in 1990 were associated with the September and October samples (less than six samples provided per site or insufficient sample mass provided for dry mass determinations), and again with bacterial or fungal contamination of several of the samples.

The relevant ANOVA statistics for the 1990 levels and morphotype numbers are presented in Tables 75 and 76, respectively. Means, standard errors, detectable differences and the results of least squares means comparisons are presented in Tables 77 and 78, for levels and morphotype numbers, respectively. There were no significant differences during 1990 in streptomycete levels ($p = 0.7430$) or morphotype numbers ($p = 0.0840$) between sites. The fact that a significant seasonal effect was detected on morphotype numbers ($p = 0.0001$), but not on streptomycete levels ($p = 0.2123$), is probably due to the availability of October data for morphotype numbers only. October levels and morphotype numbers have typically been significantly lower than those of any other month, as indicated by three-way ANOVA (see below). Morphotype numbers declined in June, peaked in August, and then declined in September and October. The relatively large detectable difference estimates for morphotype numbers (approximately 10 to 15 percent for sites and 12 to 33 percent for months) indicates that these data are much less precise than are levels data. However, in light of the

Table 73. Levels of streptomycetes (x 10^5) isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1990.

Sampling Date	Sampling Site								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	N[c]	Mean	S.E.	N	Mean	S.E.	N
25 May 1990	4.0	0.79	5	2.8	0.78	5	2.9	0.66	6
19 June 1990	3.6	0.67	3	2.2	0.58	3	C[d]	-	0
17 July 1990	2.8	0.20	5	4.5	1.52	3	4.0	-	1
14 Aug. 1990	4.0	0.20	5	3.8	0.42	5	4.3	0.64	5
10 Sept. 1990	3.9	1.40	2	3.6	0.52	6	3.6	0.47	5
8 Oct. 1990	M[e]	-	0	M	-	0	M	-	0

a/ mean value (per gram of soil, o.d.w.)
b/ standard error of the mean
c/ up to six samples per plot, each sample representing the composited roots of 2-3 red pine seedlings
d/ missing data due to sample plate contamination
e/ missing data due to insufficient sample material provided

Table 74. Numbers of streptomycete morphotypes isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1990.

Sampling Date	Sampling Site								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	N[c]	Mean	S.E.	N	Mean	S.E.	N
25 May 1990	3.2	0.37	5	3.6	0.60	5	2.7	0.49	6
19 June 1990	2.0	0.00	3	2.7	0.33	3	[d]	-	0
17 July 1990	2.4	0.24	5	2.3	0.33	3	3.0	-	1
14 Aug. 1990	4.2	0.37	5	3.8	0.58	5	3.2	0.37	5
10 Sept. 1990	4.0	1.00	2	3.8	0.48	6	3.2	0.37	5
8 Oct. 1990	2.5	0.34	6	2.5	0.29	4	2.0	0.00	3

a/ mean value (per gram of soil, o.d.w.)
b/ standard error of the mean
c/ up to six samples per plot, each sample representing the composited roots of 2-3 red pine seedlings
d/ missing data due to sample plate contamination

Table 75. **ANOVA** table for detection of differences in **1990 levels** of streptomycetes associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	0.35		0.94	0.5171	0.20
Plantation	2		0.02	0.30	0.7430	
Plot(Plantation)	6		0.11	0.59	0.7381	
Month	4		0.19	1.52	0.2123	
Error	46	1.43				
Corrected Total	58	1.78				

Table 76. **ANOVA** table for detection of differences in numbers of streptomycete **types** associated in **1990** with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	0.59		2.94	0.0025	0.40
Plantation	2		0.08	2.59	0.0840	
Plot(Plantation)	6		0.04	0.45	0.8446	
Month	5		0.48	6.14	0.0001	
Error	58	0.90				
Corrected Total	71	1.50				

Table 77. Means, standard errors, detectable differences, and significantly different pairs of means, based on the levels model analyzed in Table 75.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Difference[d]
Plantation				G A
Ground	5.51	0.048	1.71	Ground
Antenna	5.48	0.040	1.43	Antenna
Control	5.53	0.043	1.52	Control
Month				M J J A
May	5.45	0.044	1.58	May
June	5.42	0.078	2.82	June
July	5.52	0.062	2.20	July
August	5.58	0.046	1.62	Aug
September	5.56	0.051	1.80	Sept
October				

a/ 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 ($t_{.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least squares Means Procedures

Table 78. Means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 76.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]
Plantation				G C
Ground	0.39	0.031	15.58	Ground
Antenna	0.47	0.026	10.84	Antenna
Control	0.46	0.026	11.08	Control
Month				M J J A S
May	0.47	0.031	12.93	May
June	0.33	0.054	32.07	June *
July	0.36	0.044	23.96	July
August	0.56	0.033	11.55	Aug * *
September	0.44	0.036	13.07	Sept * *
October	0.36	0.035	19.06	Oct * * *

a/ 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 ($t_{.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means Procedure

low average number of morphotypes encountered per sample (2.0 - 4.2; Table 74), loss of a single morphotype would probably still be detectable. Estimated detectable differences (using ANOVA) for streptomycete levels, among sites and sampling dates were all below 3 percent of the mean.

The seasonal patterns for levels and morphotype numbers at the ground, antenna, and control site plantations are presented in Figures 88 - 90, as $\log_{10}$-transformed data for 1985 through 1990. The seasonal patterns of levels at the three plantations in 1990 again show similar trends. Morphotype numbers for all years but 1985 also typically show a significant decrease in October. The observed differences in monthly patterns, before ANACOV, between the periods 1985-1986 and 1987-1990, may be related to the growth and maturation of the red pine seedlings during this same time period. The possibility of such relationships is being investigated.

Results of three-way ANOVA models for comparisons of streptomycete levels and morphotype numbers among years, sampling dates and plantations are presented in Tables 79 and 80, respectively. As in past years' analyses, significant differences were found among years and months with both data sets. Also in agreement with past years' analyses, no significant difference was detected in morphotype numbers among the three plantations. However, for the first time, a significant difference ($p = 0.0347$) was detected in streptomycete levels among the three plantations; levels at the control plantation are slightly lower than those at the antenna and ground plantations. Results of Least Squares Means comparison tests are presented in Tables 81 and 82, for levels and morphotype numbers, respectively. Streptomycete levels for 1985, 1986, 1989, and 1990 were not significantly different from each other, but were significantly lower than the 1987 and 1988 levels, which also were similar. As in past years' analyses, the only month with significantly different levels was October. The numbers of observed morphotypes declined from 1985 to 1986 and from 1986 to 1987. No further decline, from 1987-1989, is

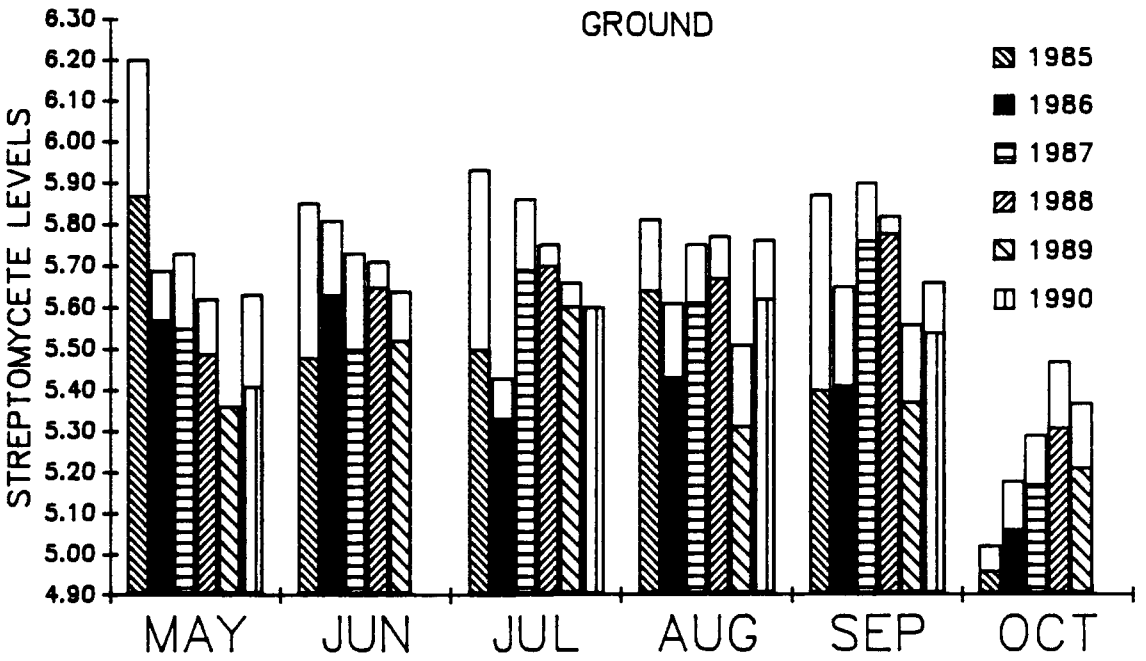
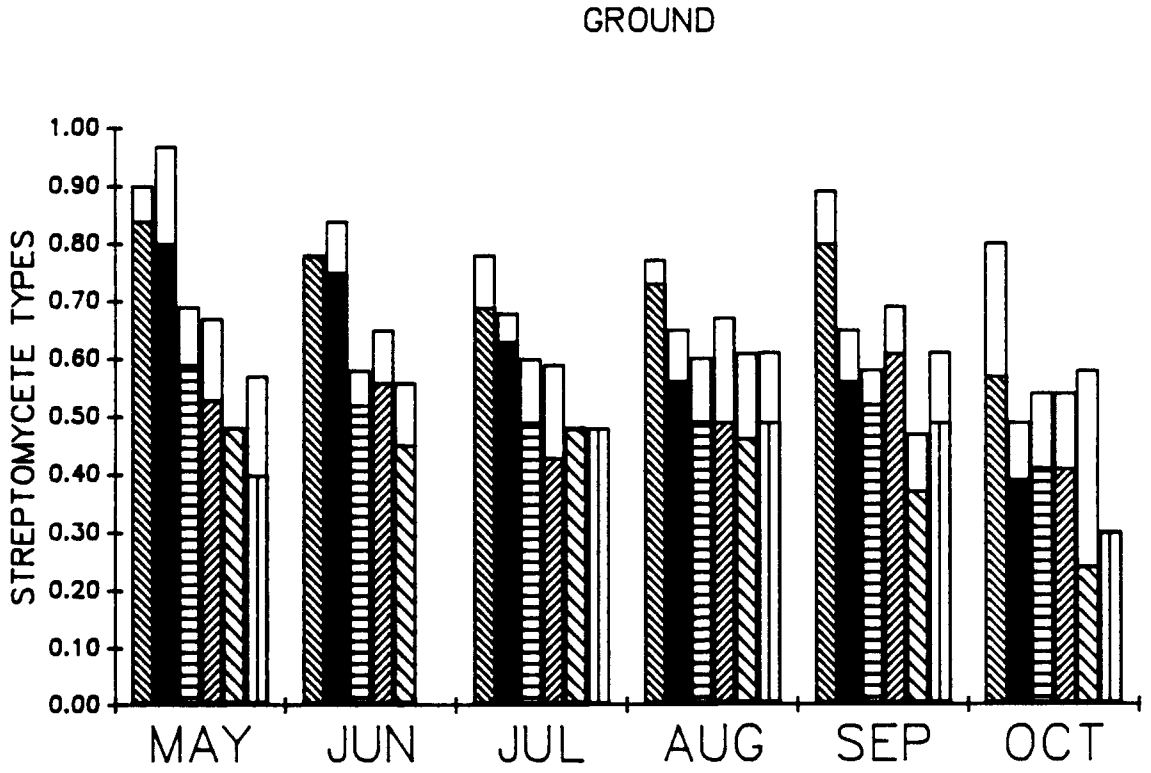


Figure 88. Seasonal patterns of streptomycete levels and morphotype numbers at the ground site plantation from 1985 through 1990. (mean ± s.e.)



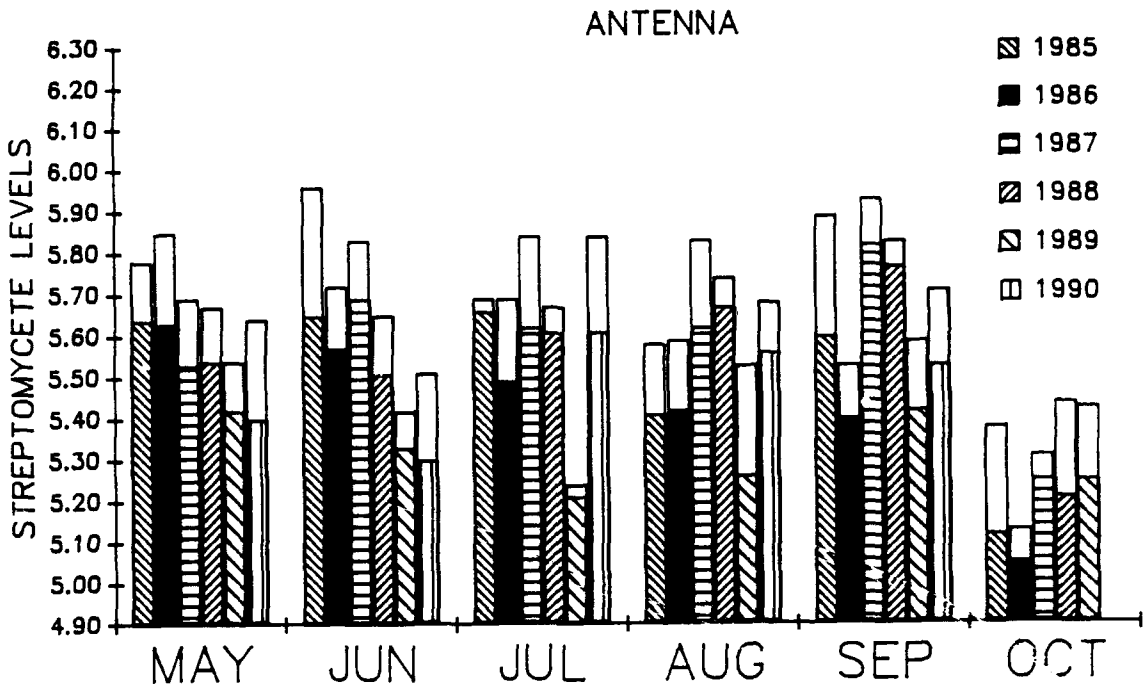
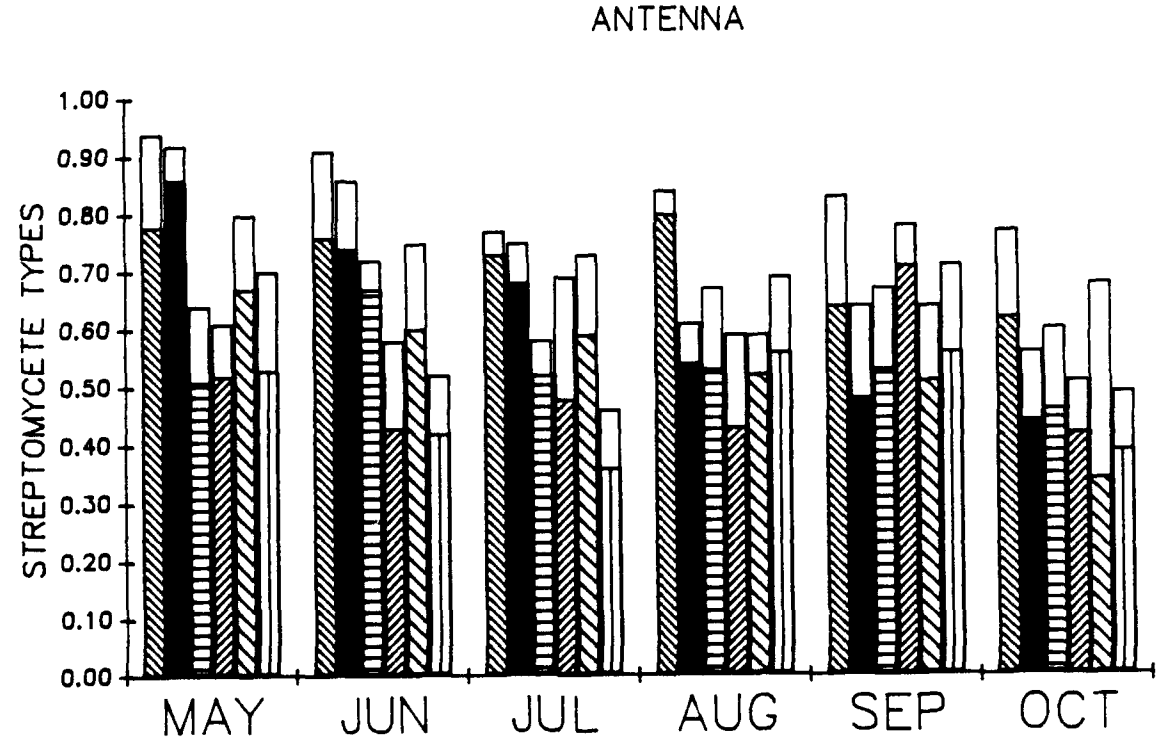


Figure 89. Seasonal patterns of streptomycete levels and morphotype numbers at the antenna site plantation from 1985 through 1990. (mean ± s.e.)



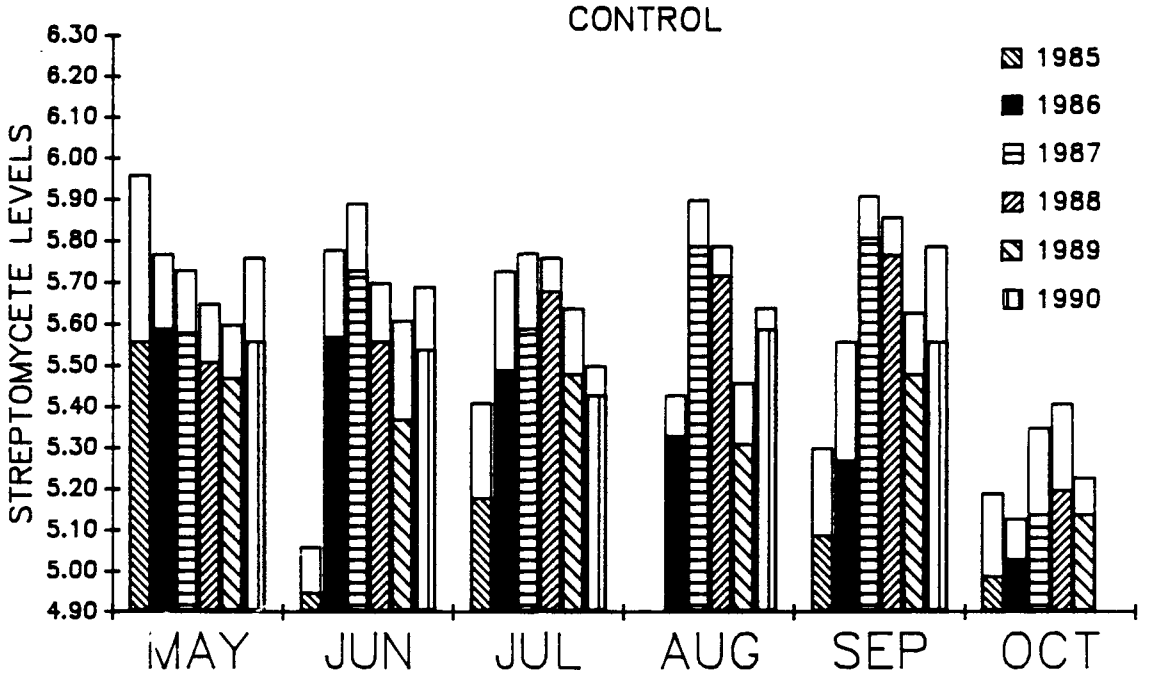


Figure 90. Seasonal patterns of streptomycete levels and morphotype numbers at the control site plantation from 1985 through 1990. (mean ± s.e.)

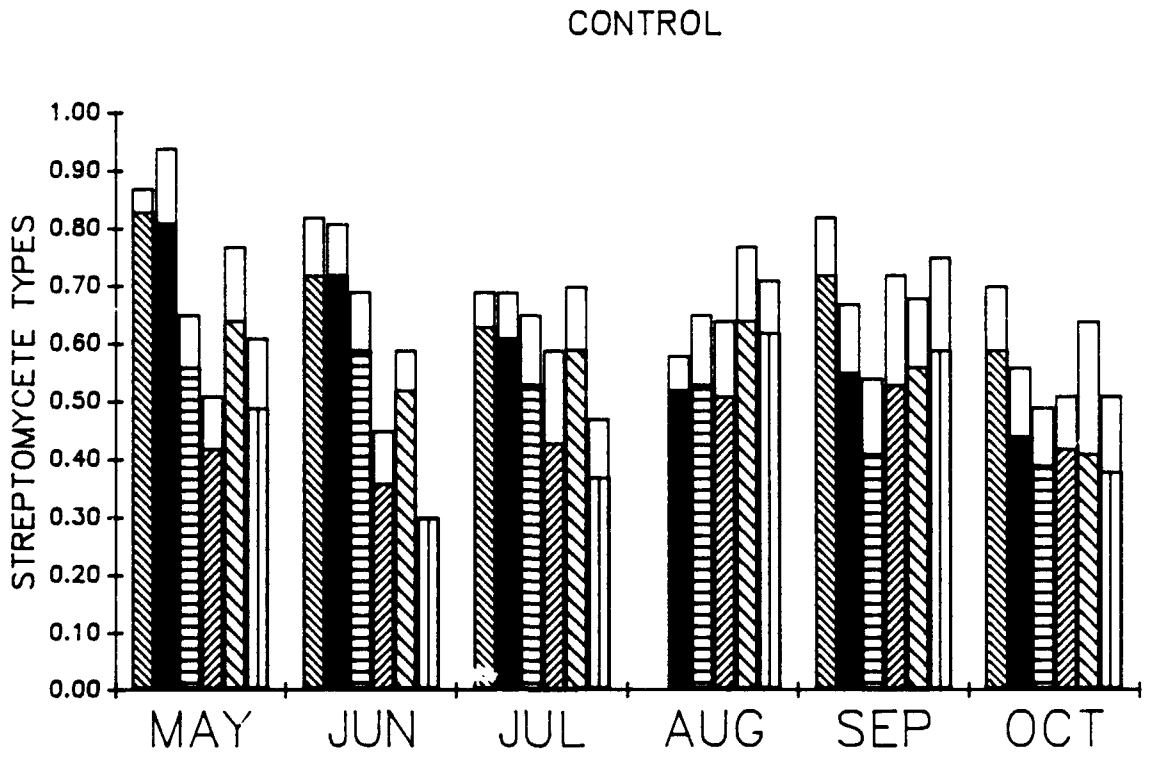


Table 79. **ANOVA** table for detection of differences in streptomycete **levels** associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month (**May - October**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	28	15.57		10.86	0.0001	0.39
Year	5		3.66	14.74	0.0001	
Year*Plantation	10		1.32	2.58	0.0048	
Plot(Plantation)	6		0.11	0.35	0.9085	
Month	5		10.43	40.74	0.0001	
Plantation	2		0.35	3.38	0.0347	
Error	482	24.67				
Corrected Total	510	40.24				

Table 80. **ANOVA** 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**), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	28	4.91		5.39	0.0001	0.23
Year	5		3.00	18.43	0.0001	
Year*Plantation	10		0.28	0.86	0.5756	
Plot(Plantation)	6		0.18	0.91	0.4900	
Month	5		1.46	8.99	0.0001	
Plantation	2		0.09	1.42	0.2416	
Error	495	16.11				
Corrected Total	523	21.03				

Table 81. Means, standard errors, detectable differences, and significantly different pairs of means, based on the levels model analyzed in Table 79.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]	
Year					5 6 7 8 9
1985	5.38	0.032	1.17	1985	
1986	5.40	0.022	0.80	1986	
1987	5.58	0.022	0.77	1987	* *
1988	5.58	0.022	0.77	1988	* *
1989	5.40	0.026	0.94	1989	* *
1990	5.45	0.030	1.08	1990	* *
Plantation					G A
Ground	5.47	0.019	0.68	Ground	
Antenna	5.49	0.018	0.64	Antenna	
Control	5.43	0.018	0.65	Control	*
Month					M J J A S
May	5.52	0.024	0.85	May	
June	5.55	0.025	0.88	June	
July	5.52	0.026	0.92	July	
August	5.52	0.024	0.85	Aug	
September	5.55	0.024	0.85	Sept	
October	5.13	0.027	1.03	Oct	* * * * *

a/ 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. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means Procedure

Table 82. Means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 80.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]
Year				5 6 7 8 9
1985	0.72	0.025	6.81	1985
1986	0.62	0.017	5.37	1986 *
1987	0.51	0.017	6.53	1987 * *
1988	0.51	0.017	6.53	1988 * *
1989	0.50	0.021	8.23	1989 * *
1990	0.46	0.022	9.37	1990 * * *
Plantation				G C
Ground	0.53	0.015	5.55	Ground
Antenna	0.57	0.014	4.81	Antenna
Control	0.56	0.014	4.90	Control
Month				M J J A S
May	0.62	0.019	6.01	May
June	0.59	0.020	6.64	June
July	0.53	0.021	7.77	July * *
August	0.56	0.019	6.65	Aug *
September	0.56	0.019	6.65	Sept *
October	0.45	0.019	8.28	Oct * * * * *

a/ 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. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means Procedure

apparent. However, morphotype numbers in 1990 were lower than those for 1987. 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. Morphotype numbers recovered in October were significantly lower than those found from May to September, and May numbers were significantly higher than those found from July to October. The detectable difference levels for this $\log_{10}$-transformed 6-year data set as a whole were approximately 1 percent for streptomycete levels, and between 5 and 10 percent for morphotype numbers.

Correlation analyses were conducted as the first step in exploring relationships of seasonal patterns of streptomycete levels and morphotype numbers with weather, other environmental, and vegetation-associated variables. Over 30 variables related to temperature, precipitation, soil moisture, actual evapotranspiration (AET), nutrient status, rhizosphere soil pH, previous forest cover, mycorrhizae levels, seedling growth and vigor, and "delay" in sample delivery to the lab were analyzed, in order to determine their potential value as covariates to explain differences detected by ANOVA among years, plantations, and months. Some of the variables having p values less than 0.05 and correlation coefficients greater than $|0.3000|$ were selected for the initial analysis of covariance (ANACOV) studies. Priority has been given to weather-related variables and "delay", which are presumed to be independent of direct ELF field influence. Temperature- and precipitation-related variables were evaluated in two basic forms: 1) as the running totals leading up to each sampling date, and 2) as totals for the 30 day period previous to each sampling date. AET was calculated based on soil moisture retentions of 300 mm for all three plantations (Thornthwaite and Mather 1957, Meentemeyer 1978). Names and definitions for all covariates used in models presented in this report have been provided in Table 46.

The results of selected ANACOV models for use with the 1985-1990 streptomycete levels and morphotype numbers data

are presented in Tables 83 and 84, respectively. For streptomycete levels (Table 83), ANACOV utilizing ATDDRT, PRWRT, PR.10RT, and mycorrhizosphere pH (Table 85) explained all differences between years ($p = 0.6929$) and plantations ($p = 0.8673$) which had been detected by ANOVA (Tables 79 and 81), without inordinately raising detectable differences (Table 86). The corresponding year-by-plantation interaction detected by ANOVA ($p = 0.0048$, Table 79) was also explained ($p = 0.2322$). However, this ANACOV did not explain the lower levels consistently detected in October.

For morphotype numbers (Table 84), ANACOV utilizing ST5DDRT, PR.10RT, and DELAY (Table 87) explained all differences between years ($p = 0.6109$) and plantations ($p = 0.1395$) which were detected by ANOVA (Tables 80 and 82), with only modest increases in detectable differences to 7 - 14 percent (Table 88). However, since the number of morphotypes observed is quite small (Table 74), loss of a single morphotype would likely be detected. Differences between sampling dates were explained, but with greatly increased detectable differences. The covariate data utilized in the models represented by Tables 85 - 88 are presented in Tables 89 - 93 (mycorrhizosphere pH), Table 94 (ATDDRT and ST5DDRT), Table 95 (PRWRT, PR.01RT, and PR.10RT), and Tables 96 - 101 (AET).

Table 83. Results of selected **covariance** analyses for detection of differences in numbers of streptomycete **levels** associated with type 3 red pine mycorrhizae (log_{10} -transformed data), among the three plantation subunits, by year and month (**May - October**).

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Plantation	Y*P	Month
1	pH	1986-1990	0.0001	0.8610	0.6470	0.0001
2	ATDDRT	1985-1990	0.0047	0.0001	0.0031	0.0001
3	PRWRT	1985-1990	0.0001	0.1221	0.0240	0.0001
4	PR.10RT	1985-1990	0.0001	0.0758	0.0016	0.0001
5	PRWRT, PR.10RT	1985-1990	0.0001	0.5094	0.0066	0.0001
6	ATDDRT, PRWRT	1985-1990	0.0612	0.0002	0.0248	0.0001
7	ATDDRT, PR.10RT	1985-1990	0.0034	0.0001	0.0016	0.0001
8	ATDDRT, PRWRT, PR.10RT	1985-1990	0.2947	0.3438	0.0068	0.0001
9	pH, ATDDRT, PRWRT, PR.10RT	1985-1990	0.6929	0.8673	0.2322	0.0001

a/ see Table 46.
b/ constrained by availability of data at time of analysis (pH: 1986-1990; ATDDRT, PRWRT, PR.01RT: 1985-1990).

Table 84. Results of selected **covariance** analyses 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**).

Model	Covariates[a]	Years Represented[b]	Significance of F			
			Year	Plantation	Y*P	Month
A1	AET	1985-1990	0.0001	0.3455	0.1918	0.0001
A2	DELAY	1987-1990	0.2001	0.0623	0.3529	0.0306
A3	AET, DELAY	1987-1990	0.3014	0.1022	0.3441	0.0441
B1	ST5DDRT	1985-1990	0.0001	0.3131	0.6567	0.0062
B2	PR.10RT	1985-1990	0.0001	0.1819	0.7121	0.0264
B3	ST5DDRT, PR.10RT	1985-1990	0.0001	0.2588	0.7683	0.0581
B4	ST5DDRT, PR.10RT, DELAY	1987-1990	0.6109	0.1395	0.5296	0.1128

a/ see Table 46.
b/ constrained by availability of data at time of analysis (AET, ST5DDRT, PR.01RT: 1985-1989; DELAY: 1987-1990).

Table 85 . Covariance analysis table far 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 **pH**, **ATDDRT**, **PRWRT**, and **PR.1RT** as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	29	14.37		11.34	0.0001	0.43
Year	4		0.10	0.56	0.6929	
Plantation	2		0.01	0.14	0.8673	
Year*Plantation	8		0.46	1.32	0.2322	
Plot(Plantation)	6		0.13	0.51	0.8028	
Month	5		4.64	21.24	0.0001	
pH	1		0.00	0.00	0.9728	
ATDDRT	1		0.11	2.50	0.0191	
PRWRT	1		1.05	24.14	0.0001	
PR.1RT	1		0.60	13.70	0.0002	
Error	430	18.79				
Corrected Total	459	33.16				

a/ pH is the pH of rhizosphere soil collected from the sampled red pine seedlings; ATDDRT is the running total number of air temperature degree days (4.4°C basis); PRWRT is the running total of rainfall for the year; PR.1RT is the running total of the number of days with precipitation events delivering at least 0.10 inch of rain.

Table 86 . Adjusted means, standard errors, detectable differences, and significantly different pairs of old means, based on the levels model analyzed in Table 85.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]
Year				6 7 8 9
1986	5.48	0.029	1.04	1986
1987	5.52	0.041	1.46	1987
1988	5.51	0.029	1.03	1988
1989	5.46	0.028	1.01	1989
1990	5.46	0.039	1.40	1990
Month				M J J A S
May	5.77	0.185	6.28	May
June	5.76	0.118	4.02	June
July	5.58	0.044	1.55	July *
August	5.44	0.055	1.98	Aug
September	5.41	0.119	4.31	Sept
October	4.94	0.166	6.59	Oct * * * * *
Plantation				G A
Ground	5.48	0.024	0.86	Ground
Antenna	5.48	0.018	0.64	Antenna
Control	5.50	0.025	0.89	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. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means procedure

Table 87. **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 **AET**, and **DELAY** as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	24	1.32		1.43	0.0909	0.09
Year	3		0.14	1.22	0.3014	
Plantation	2		0.18	2.30	0.1022	
Year*Plantation	6		0.26	1.13	0.3444	
Plot(Plantation)	6		0.24	1.02	0.4140	
Month	5		0.44	2.31	0.0441	
AET	1		0.01	0.16	0.6859	
DELAY	1		0.07	1.86	0.1738	
Error	340	13.10				
Corrected Total	364	14.42				

a/ AET is actual evapotranspiration, as defined by Thornthwaite and Mather (1957); DELAY is the elapsed time in days between excavation of red pine seedlings and delivery of mycorrhizae to the lab for streptomycete isolation.

Table 88. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the types model analyzed in Table 87.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]
Year				7 8 9
1987	0.50	0.033	12.94	1987
1988	0.51	0.022	8.45	1988
1989	0.52	0.034	12.82	1989
1990	0.46	0.032	13.63	1990
Month				M J J A S
May	0.62	0.232	73.34	May
June	0.55	0.146	52.03	June
July	0.47	0.053	22.10	July
August	0.49	0.060	24.00	Aug
September	0.48	0.138	56.35	Sept
October	0.36	0.190	103.44	Oct
Plantation				G C
Ground	0.46	0.023	9.80	Ground
Antenna	0.51	0.019	7.30	Antenna
Control	0.51	0.018	6.92	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. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Least Squares Means procedure

Table 89. Mycorrhizosphere soil pH for each streptomycete sampling date in 1986.

	Ground Unit		
	Plantation		
Sampling Date	Plot 1	Plot 2	Plot 3
29 May	4.70	5.50	5.50
23 June	5.70	5.30	5.50
21 July	5.80	5.60	5.60
18 August	5.60	5.70	4.70
23 September	4.90	4.70	4.80
22 October	5.25	5.15	5.10

Table 89. (cont)

	Antenna Unit		
	Plantation		
Sampling Date	Plot 1	Plot 2	Plot 3
29 May	5.40	5.10	5.40
23 June	5.50	4.80	5.90
21 July	4.90	4.90	4.90
18 August	5.20	5.30	5.10
23 September	4.70	4.90	5.10
22 October	5.30	5.25	4.80

Table 89. (cont)

	Control Unit		
	Plantation		
Sampling Date	Plot 1	Plot 2	Plot 3
29 May	5.00	5.20	5.40
23 June	5.20	5.50	5.20
21 July	5.10	5.00	5.80
18 August	5.10	5.30	4.90
23 September	5.00	4.70	5.00
22 October	5.00	5.30	5.15

Table 90. Mycorrhizosphere soil pH for each streptomycete sampling date in 1987.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	5.80	5.61	5.66
23 June	5.51	5.34	5.39
21 July	4.59	4.94	4.69
17 August	5.10	4.94	4.83
14 September	4.61	4.97	4.85
12 October	4.55	5.04	5.09

Table 90. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	5.46	5.41	5.49
23 June	5.27	5.27	5.29
21 July	4.84	4.84	4.57
17 August	4.46	4.27	5.12
14 September	4.69	4.95	5.35
12 October	4.74	4.74	4.41

Table 90. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	5.49	5.60	5.74
23 June	5.65	5.38	4.90
21 July	4.79	4.74	4.73
17 August	4.90	5.00	4.85
14 September	4.63	5.00	4.75
12 October	4.78	5.03	4.62

Table 91. Mycorrhizosphere soil pH for each streptomycete sampling date in 1988.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
27 May	4.28	5.28	4.62
21 June	4.84	4.84	5.09
19 July	4.56	4.56	5.05
16 August	4.62	5.62	4.59
13 September	5.21	5.21	5.27
20 October	4.62	4.62	4.81

Table 91. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
27 May	4.57	4.41	4.64
21 June	5.07	5.12	4.75
19 July	4.64	5.03	4.56
16 August	4.33	4.71	4.82
13 September	4.75	4.49	4.66
20 October	4.83	4.85	4.90

Table 91. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
27 May	4.79	4.70	4.84
21 June	5.17	4.66	4.81
19 July	4.89	5.10	5.03
16 August	4.85	4.59	5.06
13 September	5.12	4.76	4.79
20 October	4.36	4.12	4.44

Table 92. Mycorrhizosphere soil pH for each streptomycete sampling date in 1989.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
26 May	4.83	4.54	4.54
29 June	4.56	4.97	4.58
22 July	5.13	5.02	5.14
14 August	5.16	5.53	5.23
12 September	5.20	5.30	5.31
26 October	5.71	5.59	5.30

Table 92. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
26 May	4.90	4.80	4.74
29 June	4.58	4.51	4.64
22 July	5.14	4.99	4.89
14 August	5.56	5.51	5.45
12 September	5.33	5.16	5.21
26 October	5.37	5.45	5.08

Table 92. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
26 May	4.79	4.86	4.59
29 June	4.97	4.65	4.69
22 July	5.34	5.18	5.56
14 August	5.73	5.52	5.43
12 September	5.65	5.34	5.38
26 October	5.67	5.53	5.77

Table 93. Mycorrhizosphere soil pH for each streptomycete sampling date in 1990.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
25 May	4.67	4.97	4.75
19 June	5.02	5.06	5.03
17 July	4.76	4.65	4.74
14 August	4.71	4.65	4.69
10 September	4.65	4.87	4.99
8 October	4.88	4.18	5.03

Table 93. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
25 May	4.91	4.87	4.40
19 June	4.94	4.77	4.89
17 July	4.81	4.89	4.54
14 August	4.65	4.73	4.91
10 September	4.85	4.50	4.46
8 October	5.04	4.69	4.66

Table 93. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
25 May	4.78	4.75	4.71
19 June	4.63	4.80	4.68
17 July	4.66	4.89	4.41
14 August	4.79	5.00	4.80
10 September	4.51	4.76	4.62
8 October	4.94	4.91	4.51

Table 94. Values of ATDDRT, the running total of air temperature degree days (4.4°C basis), and ST5DDRT, the running total of soil temperature degree days (5 cm depth, 4.4°C basis), achieved by each sampling date in 1990.

	Sampling Date					
Site[a]	25 May	19 Jun	17 Jul	14 Aug	10 Sep	08 Oct
ATDDRT						
111	220	393	735	1081	1411	1574
112	222	464	809	1158	1492	1654
113	220	459	800	1145	1477	1639
211	228	482	837	1196	1544	1719
212	223	472	820	1174	1517	1685
213	223	472	821	1176	1516	1686
311	258	510	869	1232	1595	1780
312	262	536	910	1284	1647	1836
313	253	519	887	1255	1612	1803
ST5DDRT						
111	194	436	783	1132	1464	1678
112	190	425	759	1112	1453	1677
113	201	442	797	1155	1504	1738
211	193	443	800	1157	1495	1709
212	182	423	775	1137	1481	1686
213	205	461	810	1167	1512	1740
311	178	416	754	1089	1421	1642
312	192	442	798	1154	1504	1729
313	207	472	848	1226	1590	1838

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 95. Values of PRWRT, the running total of precipitation, PR.01RT, the running total of days with precipitation events totaling at least 0.01 inch, and PR.10RT, the running total of days with precipitation events totaling at least 0.10 inch, achieved by each sampling date in 1990.

Site[a]	Sampling Date: 25 May	19 Jun	17 Jul	14 Aug	10 Sep	08 Oct
PRWRT						
11	3.3	6.7	8.1	9.6	12.4	14.4
21	3.5	7.1	8.7	10.1	13.4	15.5
31	4.4	7.9	9.5	12.9	13.3	16.4
PR.01RT						
11	11	22	30	38	48	61
21	14	25	34	43	54	71
31	14	25	33	44	48	59
PR.1RT						
11	7	14	18	21	27	33
21	7	13	18	21	27	33
31	9	16	19	28	30	37

a/ First two digits represent plantation (11 = ground; 21 = antenna; 31 = control); third digit represents plot replicate in each plantation.

Table 96. Seasonal cumulative AET[a] for each streptomycete sampling date in 1985.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
21 May	89.0	89.0	89.0
17 June	165.7	165.7	165.1
16 July	260.4	260.4	260.4
21 August	382.3	382.3	382.3
25 September	472.6	472.6	472.6
30 October	516.8	516.8	516.8

Table 96. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
21 May	89.0	89.0	89.0
17 June	166.6	168.3	166.6
16 July	262.1	265.1	260.5
21 August	386.7	389.7	381.2
25 September	480.7	483.7	474.1
30 October	528.1	528.4	521.5

Table 96. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
21 May	98.4	98.4	98.4
17 June	177.4	179.1	179.1
16 July	266.3	268.7	268.7
21 August	375.3	378.0	378.0
25 September	462.5	468.1	465.5
30 October	506.7	515.5	509.7

a/ calculated according to Thornthwaite and Mather (1957).

Table 97. Seasonal cumulative AET[a] for each streptomycete sampling date in 1986.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	110.9	110.9	110.9
23 June	170.9	170.9	169.3
21 July	247.1	247.1	244.4
18 August	321.6	323.3	319.7
23 September	402.8	405.8	399.4
22 October	439.4	442.4	435.3

Table 97. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	106.4	108.2	108.2
23 June	163.0	165.0	166.5
21 July	236.9	238.9	240.2
18 August	311.4	312.8	314.4
23 September	393.0	394.0	396.0
22 October	429.6	430.6	432.6

Table 97. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	106.6	106.6	106.6
23 June	174.4	174.4	172.9
21 July	259.4	259.4	257.4
18 August	334.3	333.7	331.7
23 September	418.3	419.7	415.3
22 October	458.3	460.5	455.3

a/ calculated according to Thornthwaite and Mather (1957).

Table 98. Seasonal cumulative AET[a] for each streptomycete sampling date in 1987.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	116.3	116.3	116.3
23 June	202.1	204.4	204.4
21 July	315.3	318.3	318.3
17 August	410.1	413.1	413.1
14 September	483.7	486.7	486.7
12 October	525.1	528.1	528.1

Table 98. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	116.0	116.0	113.0
23 June	205.0	205	203.5
21 July	316.3	319.0	315.3
17 August	411.4	416.4	410.4
14 September	486.7	494.1	486.2
12 October	528.6	537.6	528.6

Table 98. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
29 May	126.4	126.4	118.9
23 June	211.5	213.8	205.3
21 July	324.3	332.6	315.8
17 August	424.1	436.1	412.9
14 September	501.5	515.3	488.6
12 October	542.4	558.4	529.0

a/ calculated according to Thornthwaite and Mather (1957).

Table 99. Seasonal cumulative AET[a] for each streptomycete sampling date in 1988.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
27 May	101.8	97.1	101.8
21 June	169.5	165.2	168.1
19 July	260.5	255.8	257.8
16 August	355.1	355.7	354.0
13 September	433.0	439.0	433.7
20 October	477.5	487.1	479.9

Table 99. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
27 May	102.7	104.8	105.3
21 June	172.0	173.3	174.3
19 July	262.7	263.7	264.7
16 August	362.4	363.4	364.4
13 September	445.7	446.7	446.4
20 October	493.8	492.9	490.8

Table 99. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
27 May	107.6	107.6	105.4
21 June	188.5	188.5	185.8
19 July	278.7	278.7	276.3
16 August	375.1	379.9	373.1
13 September	458.4	471.7	456.4
20 October	504.6	526.9	504.4

a/ calculated according to Thornthwaite and Mather (1957).

Table 100. Seasonal cumulative AET[a] for each streptomycete sampling date in 1989.

Sampling Date	Ground Unit / Plantation Plot 1	Plot 2	Plot 3
26 May	77.4	79.9	77.4
29 June	183.1	186.1	183.1
22 July	263.8	266.8	263.8
14 August	344.7	347.7	343.4
12 September	424.1	426.7	421.3
26 October	484.2	486.2	481.4

Table 100. (cont)

Sampling Date	Antenna Unit / Plantation Plot 1	Plot 2	Plot 3
26 May	74.4	80.1	80.1
29 June	180.4	186.4	186.4
22 July	264.6	269.2	269.2
14 August	344.2	348.2	348.7
12 September	419.4	423.8	424.8
26 October	475.9	483.2	484.2

Table 100. (cont)

Sampling Date	Control Unit / Plantation Plot 1	Plot 2	Plot 3
26 May	78.6	84.2	80.8
29 June	191.3	201.2	188.5
22 July	266.6	275.2	306.2
14 August	330.6	339.5	384.9
12 September	385.3	394.5	436.7
26 October	435.0	443.0	487.0

a/ calculated according to Thornthwaite and Mather (1957).

Table 101. Seasonal cumulative AET[a] for each streptomycete sampling date in 1990.

Sampling Date	Ground Unit / Plantation / Plot 1	Plot 2	Plot 3
25 May	89.9	85.9	85.9
19 June	163.6	166.6	164.0
17 July	257.5	264.5	261.0
14 August	348.3	353.4	350.9
10 September	423.8	425.8	423.8
8 October	477.9	477.2	475.2

Table 101. (cont)

Sampling Date	Antenna Unit / Plantation / Plot 1	Plot 2	Plot 3
25 May	86.1	86.1	86.1
19 June	167.2	167.2	167.2
17 July	268.3	266.6	266.6
14 August	362.7	358.4	358.4
10 September	440.1	434.4	434.4
8 October	494.8	489.0	489.0

Table 101. (cont)

Sampling Date	Control Unit / Plantation / Plot 1	Plot 2	Plot 3
25 May	92.3	92.3	90.3
19 June	168.6	172.4	166.6
17 July	270.9	276.9	268.9
14 August	366.5	372.0	364.5
10 September	440.8	445.8	438.8
8 October	495.2	500.2	493.2

a/ calculated according to Thornthwaite and Mather (1957).

Morphotype Distribution and Characterization

Streptomycete morphotypes isolated during the 1990 sampling season from type 3 washed mycorrhizal fine roots are presented in Table 102. In general, the same morphotypes and same incidence patterns were found during the 1990 sampling season as in 1986 through 1989. As in the past, morphotype B was detected at each plantation on each sampling date; it was usually found in multiple samples/plantation per date, often as the predominate type. Morphotypes D, J, S, T, and U were again commonly detected, as in 1987 through 1989. Morphotype F levels were similar to those found in 1989, i.e., much less frequent than found prior to 1989. Levels of morphotypes A, K, and W were increased over those found in 1989; the 1990 levels of these types were more similar to those found prior to 1989. Frequencies of isolation of morphotypes E, N and R were lower in 1990 than in 1989; however, these levels were again more similar to those found prior to 1989. Detection of morphotypes was made more difficult in 1990, due to the increased overgrowth of media plates with saprotrophic fungi and non-streptomycete bacteria. This was particularly the case with the ground plantation samples, which have had an elevated level of "contamination" in past years as well.

Other similarities were present in common morphotype incidence among those plantation site samples consisting only of mycorrhizal type 3 fine roots, i.e., 1986 - 1990. For the control plantation, the incidence pattern found in 1990 was very similar to that found in 1989, except that types A and W were more commonly found and type F less commonly found than in 1989. The incidences of types B, D, J, and S were about the same for all five years. Morphotypes B, D, and K were commonly found with the antenna plantation samples from 1986-90. In general, the overall 1990 morphotype incidence patterns were more like those found in 1987 and 1988 than in 1986 or 1989. Morphotype H, which previously has been detected commonly only in the 1989 antenna plantation samples, was again found mainly with the antenna

Table 102. Streptomycete morphotypes associated with washed mycorrhizal type 3 fine roots.

Sampling Date (1990)	Study Site[a]	N[b]	Streptomycete Morphotype																			
			A	B	C	D	E	F	G	H	J	K	N	O	P	Q	R	S	T	U	V	W
25 May	C	5		X[d]												X		X	X[c]			X[c]
	A	5		X[d]		X			X		X[c]X		X			X			X[c]			X[c]
	G	6		X[d]			X											X	X			X[c]
18 June	C	3		X[d]								X							X			
	A	3		X[c]		X[c]						X[c]				X			X			
	G	0																				
17 July	C	5		X[d]		X[c]		X				X[c]X										
	A	3		X[c]		X[c]						X										
	G	1		X								X										
14 August	C	5		X[c]X[c]X[c]X[c]								X[c]X[c]						X	X	X		X
	A	5		X[c]X[c]		X[c]						X[c]X	X					X				X[c]
	G	5		X[c]X[c]						X	X	X[c]X		X	X	X	X[c]					
10 September	C	2		X	X[c]X			X				X								X		
	A	6		X[c]X[c]X[c]X[c]X				X		X		X[c]						X[c]X[c]X			X[c]X[c]	
	G	5		X	X[d]	X	X				X		X[c]					X[c]				
8 October	C	6		X	X[c]	X	X		X		X	X[c]						X[c]				X
	A	4		X	X[c]	X						X[c]								X		
	G	3			X[c]													X[c]				

[a] C - Control Plantation; A - Antenna Plantation; G - Ground Plantation
[b] N - number of replicate samples/plantation
[c] detected in two or more of replicate samples/plantation
[d] predominant type in two or more of replicate samples/plantation

samples. There were again relatively few ground plantation sample morphotype data for the 1990 season, primarily due to contamination problems (as noted above). Morphotype B was therefore the only commonly detected type. The incidences of morphotypes A, N, and S appeared to be similar to earlier sampling seasons, while incidences of types D, J, and R were lower than those found in earlier years.

Representatives of each streptomycete type detected during the 1990 sampling season (Table 102) were tested for ability to degrade calcium oxalate, cellulose, and lignocellulose. The same results were found as in past seasons, in terms of which morphotypes could degrade one or more of these compounds, again indicating little detectable change in either morphotypes or their activities in the past four sampling seasons.

Projected Work

Analyses in 1991 will continue to deal with determination of streptomycete levels and morphotype numbers associated with washed red pine type 3 mycorrhizal fine roots. There will be no change in sampling or detection methods, or in numbers of samples analyzed per plantation. We hope that the difficulties encountered with root sample preparation during the 1989 and 1990 seasons can be avoided in 1991. However, we do not have direct control over preparation of these samples. We have communicated the need for prompt preparation and delivery to the responsible "TREES" staff; we also recognize that careful preparation of these samples is a time-consuming task. The time interval between root collection and delivery of roots for streptomycete analyses will be kept as short as feasible, and never more than 9 days.

Emphasis will continue to be placed on covariate analysis of the data in modeling environmental/biological variables affecting streptomycete population differences between plantation subunits, sampling dates, and years.

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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.
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 rhizoplane of mycorrhizae.
Mycorrhizosphere	The rhizosphere of mycorrhizae.
NESS	National Earth Satellite Service.
NOAA	National Oceanographic and Atmospheric Administration.
Nutrient Flux	In litter decomposition, the balance between the rates of nutrient movement into and out of decomposing litter.
Rhizoplane	The actual surface of plant roots, together with any closely adhering particles of soil or debris.
Rhizosphere	The narrow zone of soil subject to the influence of living roots.
Streptomycete	Members of the genus Streptomyces, a group of actinomycetes which reproduce by forming spores.